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America's Ethanol Supporters

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January 25, 2012

California Air Resources Board
1001 I Street
Sacramento, California 95812

Dear Chairwoman Nichols and Members of the Air Resources Board:

Growth Energy is the leading trade association for America's ethanol producers and supporters. Growth Energy promotes expanding the use of ethanol in gasoline, decreasing our dependence on foreign oil, and creating American jobs here at home. We are pleased to have this opportunity to provide comments at the public hearing to consider the "LEV III" amendments to the California Greenhouse Gas and Criteria Pollutant Exhaust and Evaporative Emissions Standard and Test Procedures and to the On-Board Diagnostic System Requirements for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and to the Evaporative Exhaust Requirements for Heavy Duty Vehicles.

Our comments focus on two priorities:

First, we believe that by removing incentives to produce flexible fuel vehicles (FFVs) for the model year 2016 and later years, the proposed amendments will cause automakers to cease production of FFVs, and that any greenhouse gas benefits of the Federal Renewable Fuel Standard will be lost. We recommend projecting ethanol usage factors for FFVs, so that the automakers can incorporate the projected usage into their planning decisions for the future.

Second, CARB and the EPA have long recognized that vehicle technology and the fuel employed with that technology need to work in concert as an integrated "system" so that vehicles can operate efficiently and achieve the lowest technologically emission targets. We believe that CARB did not completely examine the impact of fuel parameter changes that could enable additional engine technologies to improve efficiency and ultimately improve emissions. Specifically, we are recommending one new fuel for vehicles model year 2017 and later (in addition to legacy FFVs) with an octane rating of 94 accomplished with a 30 percent blend of ethanol (E30). This new fuel used in conjunction with new engine technologies would provide even more clean air benefits than CARB is currently proposing. CARB is obligated by the California Government Code, the California Environmental Quality Act, and the California Health and Safety Code to propose and adopt only those regulations that maximize public benefits, minimize public and private costs, and afford maximum protection to the environment in a cost-effective manner. Those requirements can only be met by reducing vehicular emissions through new fuel standards.

Attached you will find our basis and support for these recommendations, and we would urge you to consider our recommendations as you finalize your greenhouse gas and vehicle emission program. We would be happy to work with you and your staff to provide whatever information you may need as this program will have far reaching impact on both the automotive and fuel industries for years to come.

If you have any questions, please contact Chris Bliley, Growth Energy's Director of Regulatory Affairs, at 202-545-4000. Thank you in advance for your consideration.

Sincerely,

Tom Buis

Tom Buis, CEO

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Comments by Growth Energy on California Environmental Protection Agency's Advanced Clean Car Program

January 2012

Summary

The Greenhouse Gas Emission standards proposed by CARB/EPA/NHTSA[1] for cars, light trucks, and medium duty vehicles for model years 2017 through 2025 set very ambitious targets for the automotive industry. The Agencies evaluated many different technologies to improve vehicle fuel economy and reduce vehicle GHG emissions in setting these emission standards. They also considered the costs of these technologies, both vehicle cost and the overall cost to operate the new vehicles.

We have two major comments on CARB's GHG proposal. We believe these comments must be addressed by CARB and the Executive Officer before deciding what action to take on the GHG proposal because the issues that we identify directly affect the benefits and costs of the proposal.[2]

1. Without intending to do so, the GHG proposal would have the effect of eliminating any meaningful incentives for vehicle manufacturers to produce flexible fuel vehicles (FFVs) capable of operation on both gasoline and ethanol for the 2016 and later model years. FFVs are the backbone of the federal Renewable Fuel Standard (RFS), as they are expected to consume most of the ethanol that is produced to meet the RFS after the on-road fleet is all operating on E10, a blend of 90% gasoline and 10% ethanol by volume. As the largest market for transportation fuel in the United States, California has a strong interest in the federal RFS program, which is based in large part on the federal Energy Independence and Security Act of 2007, passed by Congress with the support of the California delegation. One important goal of the RFS program is to help the United States do its part to control GHG emissions. If vehicle manufacturers stop selling FFVs in California after 2016, the GHG benefits of the RFS program will be lower than currently anticipated. To address this potential problem, Growth Energy recommends that CARB and the federal government develop and permit the use of E85 "usage factors" for FFVs utilizing volumes of ethanol projected by the U.S. Energy Information Agency, so that vehicle manufacturers can decide when developing their product plans whether to provide FFVs, and to create incentives for the manufacturers to do so. In these comments, we lay out a reasonable method of projecting these usage factors. *If the GHG proposal is not modified along the lines suggested here to allow reasonable incentives for FFVs in the post-2015 timeframe, the loss of GHG benefits in this program should be allocated*

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[1] Hereafter referred to as the "Agencies."

[2] We plan to file similar comments on the EPA/NHTSA proposal because the proposal was developed jointly between the three agencies. CARB has obligations separate from the federal government under its governing statutes to consider and address the issues presented in these comments.

against CARB's 2017-2025 tailpipe GHG proposal, thereby reducing the claimed benefits of CARB's GHG proposal.

2. In addition to the current proposal, CARB and the Executive Officer need to consider an alternative approach, which would include fuel parameter changes that could enable additional engine technologies to be used to improve efficiency and reduce emissions. To its credit, CARB is proposing to change certification gasoline to include ethanol at 10% (the current CARB certification gasoline still contains MTBE, which has been banned in California since 2003) in both "Regular" fuel and "Premium" fuel. However, higher octane levels were not examined. *The Agencies' proposal requires new technology to be used on vehicles using old technology fuels.* It has long been recognized that vehicles and fuels operate as a system. To undertake significant changes and increases in the stringency of tailpipe GHG standards without a parallel and integrated examination of potential changes in the fuel used by these vehicles is inappropriate and is not permitted by CARB's governing statutes.

Growth Energy recommends that CARB put into place enforceable requirements for the gasoline marketing industry in California that will ensure the commercial availability of gasolines that have an octane value of 94, for use in optimizing the GHG performance of new vehicles certified to the proposed LEVIII emission standards. CARB's two currently proposed certification fuels are both E10 blends; one a "regular," and the other "premium," with the regular blend having an octane number of 87 (AKI) and premium having an octane number of 91 (AKI). Growth Energy's proposal would provide for a certification and in-use fuel for 2017 and later LEVIII vehicles with an octane value of 94, accomplished with E30 instead of E10. This fuel would only be intended for the LEVIII vehicles, and not the legacy fleet (2016 and earlier), although legacy FFVs could also use it if doing so was consistent with the vehicle manufacturers' instructions or recommendations to owners and approved by CARB on that basis. The non-FFV legacy fleet (i.e., LEV II, LEV I, Tier 1) would continue to operate on E10.

It is important that the increase in octane be accomplished with ethanol and not other gasoline blending components because of ethanol's many advantages relative to the other high octane blending components as explained later in this paper. Ethanol has a very high octane number relative to other gasoline hydrocarbons, has a lower carbon content than the gasoline components it generally replaces, and has many other benefits that assist in combustion to increase engine efficiency and reduce both tailpipe GHG and criteria pollutant emissions.

The use of a 94 octane E30 blend for LEV III vehicles would also provide additional GHG and PM emission reductions in California, greater than could be achieved by the current Agency proposal. We note that some vehicle manufacturers have also requested that CARB study higher octane fuels as a part of the GHG program, and have also recommended continued control of multi-substituted alkyl aromatics, since they can lead to increased HC and PM emissions. [3]

FFV Recommendations

Current California Requirement

FFVs typically have GHG emissions on E85 that are approximately 5% below the GHG emissions on E0, but this can vary between 3-6%. [4]

CARB's regulations on estimating GHG emissions from alternative fueled vehicles are found in Section 1961.1 of Title 13, California Code Of Regulations.[5] These regulations require that the GHG value used in estimating the manufacturers weighted average GHG emissions be based on gasoline, unless the manufacturer presents detailed fleet data to the Executive Officer of the fraction of use on the alternative fuel versus gasoline. In the case where detailed data is presented, the manufacturer is allowed to weigh the emissions on gasoline with the emissions on the alternative fuel (in this case, E85 for an FFV) based on the percentage of operation on each fuel. We do not know how many manufacturers have used this option so far (rather than merely using the gasoline value), but the numbers of vehicles certified under this provision is probably small.

Discussion

Automakers currently sell FFVs in California because they receive fuel economy and GHG credits for these vehicles under EPA/NHTSA credit provisions, at least through model year 2015. Automakers can receive up to 1.2 miles per gallon in fuel economy credit against the applicable NHTSA CAFÉ standards through 2015. After 2015, this credit declines by 0.2 mpg per year until it is fully phased-out in 2020. EPA's GHG emission standards between 2012 and 2015 are consistent with the NHTSA fuel economy credit.

EPA's current rules for 2016 model year FFVs, and its proposal for 2017 and later FFVs are very similar to California's. In discussing the proposed procedures for estimating emissions for FFVs for 2016 and later model years, EPA states the following[6]:

> Beginning in MY 2016, EPA ended the GHG emissions compliance incentives and adopted a methodology based on demonstrated vehicle emissions

[3] California LEVIII E10 Gasoline Certification – Alliance Fuels Group Position, Alliance of Automobile Manufacturers, September 8, 2010.
[4] "Ethanol – the primary renewable liquid fuel", Datta, Maher, Jones, and Brinker, J. Chem Technol. Biotechnol. 2011; 86:473-480
[5] Final Regulation Order, Amendments to Sections 1900 and 1961 and Adoption of New Section 1961.1, Title 13, California Code of Regulations
[6] Federal Register/ Vol. 76, No 231/Thursday, December 1, 2011/Proposed Rules, page 75019

> performance. This methodology established a default value assumption where ethanol FFVs are operated 100 percent of the time on gasoline, but allows manufacturers to use a relative E85 and gasoline vehicle emissions performance weighting based on either national average E85 and gasoline sales data, or manufacturer-specific data showing the percentage of miles that are driven on E85 vis-à-vis gasoline for that manufacturers' ethanol FFVs. EPA is not proposing any changes to this methodology for MYs 2017-2025.

Regarding current national average E85 use by FFVs, EPA states[7]:

> The data confirm that, on a national average basis for 2008, less than one percent of the ethanol FFVs used E85.

The vast majority of FFVs are sold to the general public (and not fleets that may have more control over fuel type), and it would be very difficult for manufacturers to determine the fraction of use on E85 for these vehicles. Under either current California law or the proposed EPA requirements for 2016 and later vehicles, manufacturers would have to certify FFVs on 100% gasoline, or under the EPA proposal, use some national average E85 use, which as EPA indicates is still quite low. Since FFVs have a non-zero cost, but are assumed to have zero or very near zero benefit under either California or EPA requirements, the chances of automakers providing FFVs after 2016 is also zero, or near zero. [8]

EPA expected that when they required model year 2016 FFVs to demonstrate use on E85, that this would provide incentive for automakers to optimize their FFVs on E85[9]:

> However, if a manufacturer can demonstrate that a portion of its FFVs are using an alternative fuel in use, then the FFV emissions compliance value can be calculated based on the vehicle's tested value using the alternative fuel, prorated based on the percentage of the fleet using the alternative fuel in the field….EPA believes this approach will provide an actual incentive to ensure that such fuels are used. The incentive arises since actual use of the flexible fuel typically results in lower tailpipe GHG emissions than use of gasoline and hence improves the vehicles' performance, making it more likely that its performance will improve a manufacturers' average fleetwide performance. Based on existing certification data, E85 FFV CO_2 emissions are typically about 5 percent lower on E85 than CO_2 emissions on 100 percent gasoline. Moreover, currently there is little incentive to optimize CO_2 performance for vehicles when running E85. EPA believes the above approach would provide such an incentive to manufacturers and that E85 vehicles could be optimized through engine redesign and calibration to provide additional CO_2 reductions.

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[7] Ibid.

[8] The fact that they may have a non-zero CAFÉ credit until 2020 will mean little if there is no credit under GHG requirements.

[9] Federal Register / Vol. 75. No. 88 / Friday, May 7, 2010/Rules and Regulations, 25433

Manufacturers typically utilize a four-year lead-time in designing vehicles, therefore, in 2012 most manufacturers are working with the 2016 model year.[10] While such an approach as outlined by the EPA above could provide incentive for manufacturers to optimize 2016 model year FFVs on E85, if they have no idea or guidance from the EPA (or CARB) what E85 use could be in 2016, and current use is close to zero, then it does not matter how much they optimize FFVs on E85, a larger GHG benefit times a current zero use factor is still zero.

While current E85 refueling frequencies are quite low, EPA is counting on FFVs to use a significant amount of E85 due to the Renewable Fuel Standard requirements, which expand biofuel use in the U.S. to 36 billion ethanol equivalent gallons per year by calendar year 2022. EPA projected a range of ethanol volumes in the RFS, a “low”, “mid” and “high”.[11] Figure 1.7-11 from the RFS Regulatory Impact Analysis shows necessary FFV E85 refueling rates in the future with the RFS. In 2016, FFV E85 refueling rates are between 38% and 55%, and increase to 40% to 70% by 2020.

The rates shown in Figure 1 were estimated by EPA with the 2012-2016 GHG emission standards, but without the 2017-2025 GHG emission standards. If the 2017-2025 GHG emission standards were included, the rates would be higher than shown in Figure 1.

Figure 1

[10] Assessment of Fuel Economy Technologies for Light-Duty Vehicles, National Research Council, (page 109) 2011

[11] Renewable Fuel Standard (RFS) Regulatory Impact Analysis, EPA-420-R-10-006 February 2010.

Figure 1.7-11.
Necessary FFV E85 Refueling Rates
(Given 1-in-4 Access to Fuel)

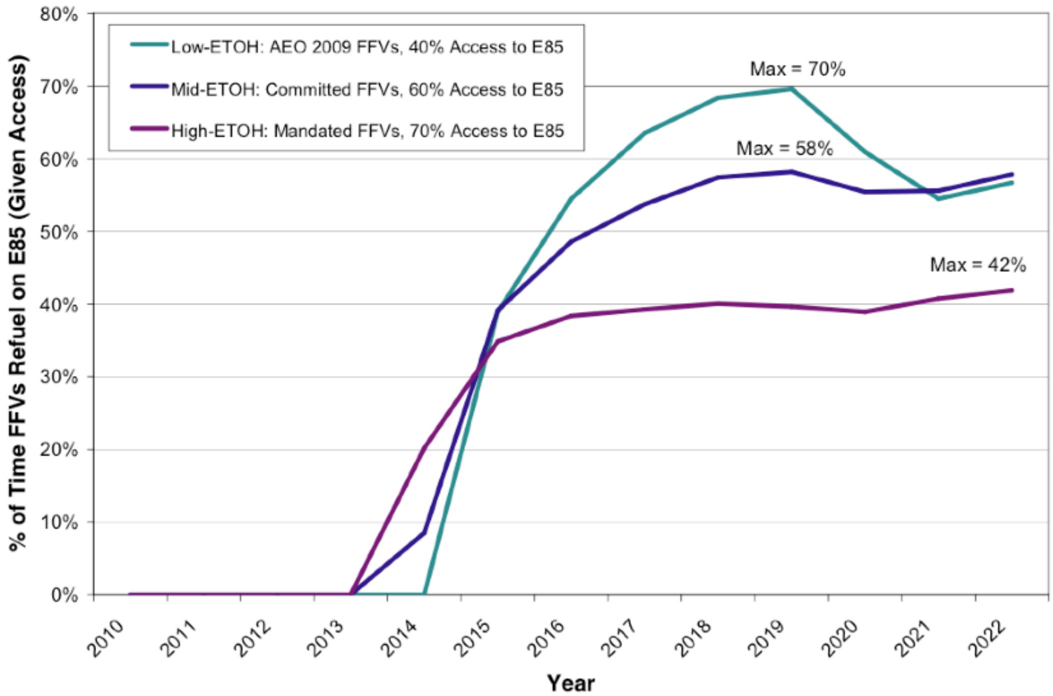


Figure 2 shows the Energy Information Agency's projection of ethanol volume in the latest forecast.[12] EIA's forecast is very close to EPA's mid level case.

[12] Annual Energy Outlook 2011, Report No. DOE/EIA-0383 (2011)

Figure 2

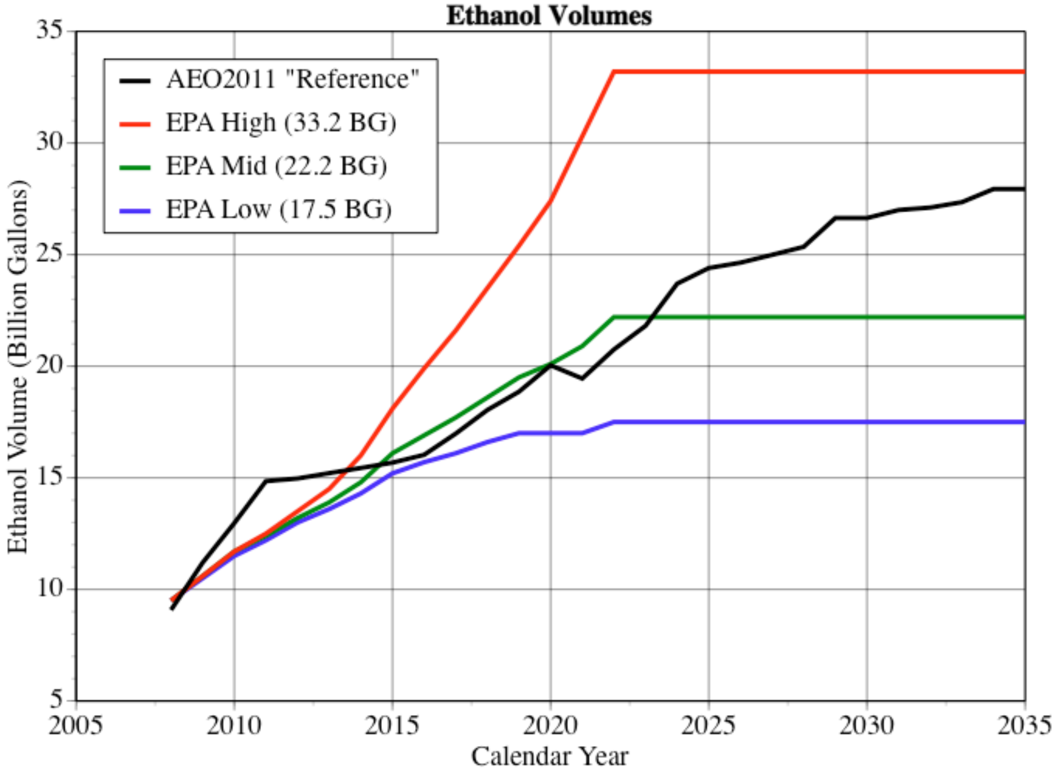
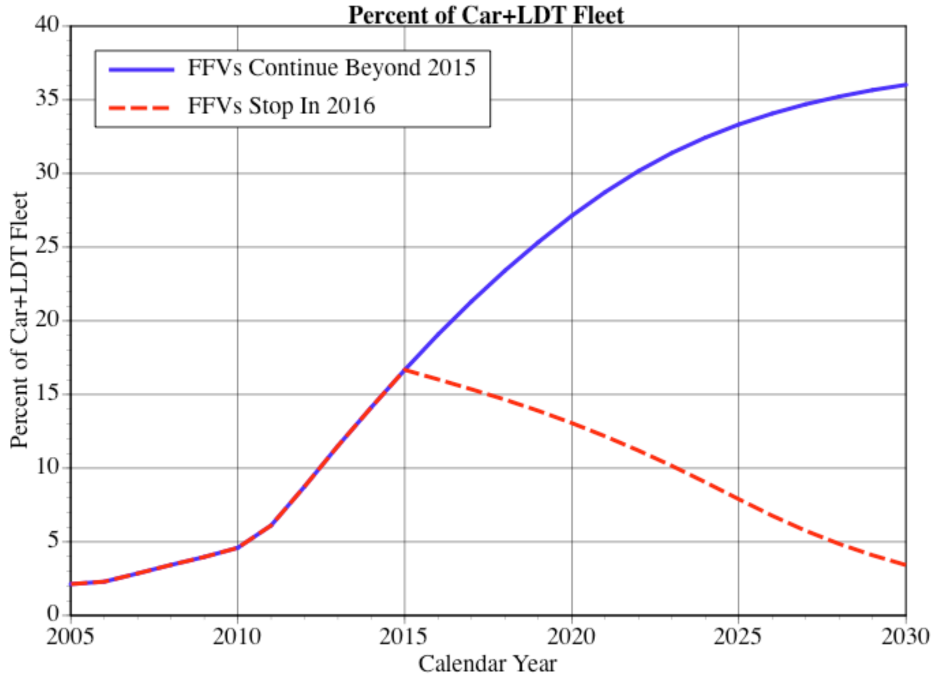


Figure 3 shows FFV fractions of the national on-road car + LDT fleet from 2010 through 2030 with two assumptions – that FFV sales would continue at about 37% from 2012 on, and that FFV sales stop in 2016. In 2020, if FFV sales continue, then 25% of the on-road fleet would be FFVs. Alternatively, if FFV sales stop in 2016, then only 12% of the fleet would be FFVs in 2020. Clearly, if FFV sales stop in 2016, it may be difficult for the FFV fleet to absorb RFS ethanol volumes.

Figure 3



EPA's RFS benefits analysis depends on E85 being consumed to claim GHG benefits under these rules. And yet, EPA is not rolling these use projections into its guidance on FFVs to the manufacturers so they can continue to build FFVs to support the RFS. Thus, EPA and CARB need to either provide guidance to the manufacturers on likely E85 use in the 2016-2025 timeframe, or they need to downgrade the GHG benefits of the RFS due to lack of availability of FFVs, and charge these benefit downgrades against their current GHG proposal.

Recommendation

We recommend that both CARB and EPA develop new default projections of E85 use based on EIA's projection of ethanol use in the U.S. through 2020. These projections should also incorporate the Agencies new fuel economy levels for 2017-2025. The projections should be provided to the auto industry so that they can make a clear determination of whether to optimize FFVs on E85 and whether to continue building FFVs after model year 2015. A further projection to calendar year 2025 can be made around calendar year 2016.

If CARB does not make this suggested change, the benefits of the proposed regulatory action will need to be adjusted, in order to ensure that the Board's estimates of costs and benefits for the regulation comport with the requirements of the California Government Code.(*See, e.g.,* Cal. Gov't Code §11346.5(a)(9), 11346.9(a)(1).) CARB would also need to explain why, consistent with its mandate to comply with the California Environmental Quality Act, it was selecting a program that did not maximize the potential environmental benefits of its regulatory efforts.

E30, 94 (AKI) Octane Certification Fuel

CARB's Proposal

CARB is proposing two new E10 certification fuels for implementation with the 2017 and later LEVIII and GHG proposals. They are a regular and premium fuel with 87 and 91 octane, respectively. Other key parameters are shown in Table 1.

Table 1. Proposed Gasoline Properties		
Property	Regular	Premium
Octane (AKI)	87-88.4	91
Sulfur (ppm)	8-11	Same
RVP (psi)	6.9-7.2	Same
Total Aromatics (vol %)	19.5-22.5	Same
MSAA's % (vol %)	13-15	Same
Ethanol (vol %)	9.75-10.25	Same

Vehicles/engines that require the use of premium fuel as a part of their manufacturers' warranty are required to use the premium fuel with 91 octane, with all the other properties being the same as regular.

CARB also examined an alternative to the proposed E10 certification fuel.

> The only alternative to the proposed certification fuel would be to leave the certification unchanged with MTBE as the oxygenate. MTBE was banned for use in California gasoline staring December 31,2003. As a result of the ban of MTBE, ethanol became the prevalent oxygenate used in California gasoline. Currently, all gasoline in California contains 10 percent ethanol and will continue to contain 10 percent ethanol for the foreseeable future.

Staff does not appear to have examined the possibility of any ethanol concentrations above E10 as part of its regulatory package. Yet, as explained below, fuels with the higher octane levels that rely on higher ethanol blends would permit the automobile industry to meet CARB's stringent GHG standards at lower costs. Those lower costs would benefit the public, insofar as they would reduce the initial purchase price of new vehicles. That omission does not comport with the California Government Code, which requires the consideration of alternatives to a proposed regulatory action that could be more or equally effective as the proposed action but less burdensome for affected parties. (*See, e.g.,* Cal. Gov't Code § 11346.5(a)(13); *see also id.* § 11346.9(a)(5) *and* Cal. Health & Safety Code S 57005.) Alternatives to more stringent vehicular emission control measures that utilize and rely on improved fuels must be considered to determine if they would be less costly to the motoring public (including but not limited to small businesses).

Growth Energy's Proposal

Growth Energy's proposal for LEVIII certification fuel is shown in Table 2. This certification fuel is essentially the same as the Alliance of Automobile Manufacturer's proposal, but with the addition of 20 volume percent more ethanol, so that octane is higher, the distillation parameters are changed, and other parameters are lower by dilution.

Table 2. Growth Energy's LEVII Certification Fuel Proposal

Property	CARB Regular	Growth Energy
Octane (AKI or FON)	87-88.4	94
Sulfur (ppm)	8-11	7-8, max.
RVP (psi)	6.9-7.2	6.2-6.8
Total Aromatics (vol %)	19.5-22.5	12-16
Multi Substituted Alkyl Aromatics % (vol %)	13-15	10, max.
Olefins	4-6	4
T50	205-215	150-190
T90	310-320	280-295
Benzene	0.6-0.8	0.4
Oxygen (wt %)	3.3-3.7	10-10.5
Ethanol (vol %)	9.75 – 10.25	29.5 – 30.5

Fuel marketers would be required to produce fuel that would be similar to this proposed fuel for LEVIII vehicles. The parameters could have latitude initially to allow flexibility. An E30 Predictive Model would be develop based on test data to allow flexibility and to ensure in-use emission reductions are being met with alternative market fuel formulas.

Other concepts of this proposal are as follows:

- Automakers would certify LEVIII vehicles only on E30, they would not be required to certify on E10. The legacy fleet would continue to operate on E10

- The state would have to modify state regulations which limits blends to either E10 or just E85

- Ramp-up of ethanol for E30 would build with the introduction of each successive model year of LEVIII vehicles. Ethanol would have to be used preferentially for E30, then for E10 in the legacy fleet.

- There may be a net positive impact on upstream GHG emissions from producing the base gasoline (normalized to gasoline volume); this would have to be evaluated

The primary advantages of implementing this type of fuel (relative to the CARB proposal) are:

- Low carbon intensity ethanol volumes ramp up slowly from calendar year 2017 as the new LEVIII vehicles using this fuel are introduced into the fleet, and continue ramping up well beyond the 2020-2022 timeframe, providing ongoing *upstream* (i.e., lifecycle) GHG reductions well into the future (through 2040) beyond the RFS.

- Currently the cellulosic projections in the RFS are not being met in part because the United States ethanol market is saturated by E10. Creating an E30 certification fuel would send a fresh market signal to the cellulosic industry that market space is being created through this new fuel standard. To meet the 36 billion gallon biofuel projection by 2022, market access for advanced (50% lifecycle emissions reduction) and cellulosic ethanol (60% lifecycle emissions reduction) must be offered a path. This proposal would provide that opportunity as well as the other benefits a higher octane standard would offer.

- Automakers should be able to use the higher octane ethanol fuel to boost engine efficiency beyond the engine efficiency obtained from the current CARB proposal (tailpipe GHG emissions would be the same as the CARB proposal), maintaining the same fuel economy and vehicle range

- Importantly, exhaust Particulate Matter (PM) emissions and carbon monoxide (CO) emissions from 2017-2025 model year vehicles would be much lower than the current ARB proposal because of increased fuel oxygen content

Other criteria pollutant emissions (exhaust and evaporative NMOG and NOx) from on-road motor vehicles should be the same as the CARB proposal, since the vehicles must meet the LEVIII emission standards. Distribution of the E30 fuel should ultimately be no more difficult than E85 distribution, which has to take place anyway because of the RFS. The slow phase-in of E30 gives time for additional low carbon intensity (i.e., cellulose and other) ethanol supplies to develop. In the interim, some of these supplies could be derived from the FFV fleet or from areas using E10 as these higher fuel consumption vehicles are turned over. [13]

Ramp-up of Low CI Ethanol, Additional GHG Reductions

For the RFS, EPA estimates that ethanol from cornstarch peaks at 15 bgy in 2014. Additional increases in ethanol volumes are projected to come from advanced ethanol and cellulosic ethanol. Advanced ethanol is required to have a 50% reduction in lifecycle GHG emissions from gasoline, and cellulosic ethanol is required to have a 60% reduction in lifecycle emissions from gasoline. These additional volumes currently are projected to go into FFVs.

[13] Areas with reformulated gasoline would see no change in emissions for the legacy fleet, because oxygen is not required for RFG in these areas.

The ethanol volumes produced above E10 level could go into the 2017 and later vehicle fleet as E30, and if there is ethanol left over, could also go into FFVs. The amount of ethanol needed for the 2017 and later model year vehicles would slowly build as these vehicles are introduced. These advanced and cellulosic volumes would increase steadily until the on-road fleet is fully turned over to 2017 and later vehicles.

Engine Efficiency

Ethanol has several properties that make it very desirable blendstock with gasoline. These were discussed in a paper referred to earlier.[14]

> The high octane of ethanol allows the use of higher compression ratios, particularly in dedicated ethanol vehicles. The high heat of vaporization produces a charge cooling effect, which is particularly effective with direct injection engines, that can again allow higher compression ratios. This effect is enhanced by the increased volume of fuel that is required to compensate for the lower energy content of ethanol. Even when a vehicle is not optimized to take advantage of some of ethanol's attributes, the higher octane and faster flame propagation speeds for ethanol result in increased efficiency (miles per BTU of energy present in the fuel used) for high ethanol blends relative to gasoline.

The paper goes on to show that there is an approximate 2% efficiency gain for E85 in 2010 FFVs on E85, which are not optimized on E85 but on E0, and some companies are able to do better than this across their portfolio.

A second study by Delphi examined changes in performance and efficiency on an engine equipped with gasoline direct injection and other control technologies at different gasoline/ethanol blend levels.[15] The study investigated methods of improving fuel consumption when fueled with E85.

> The benefit of the improved strategies for reducing the disparity between fuel consumption with gasoline and E85 is almost entirely offset on the FTP city cycle but is less effective as the demands of the driving conditions increase. At highway cruise speeds the shift schedule has no effect since the vehicles is in overdrive in all cases, only the benefits of the lower final driver ratio and the engine modifications are evident.

The paper then goes on to discuss the potential benefits of lower ethanol blends:

> It is also important to consider that many of the techniques used to improve performance on E85 would also improve fuel consumption with gasoline or lower

[14] See reference 2

[15] "Engine Efficiency Improvements Enabled by Ethanol Fuel Blends in a GDi VVA Flex Fuel Engine", Moore, Foster, and Hoyer, SAE2011-01-0900, 4/12/2011.

ethanol blends. Differences will show up more in performance and may need a shift schedule dependent on the ethanol blends torque capability. Ethanol blends from near E20 provide a good compromise, enabling most of the performance of an E85 blend with a significantly reduced energy penalty. Blends in this range would likely be able to offset the fuel density penalties with improved efficiency while providing superior performance to gasoline.

The above discussions highlight the need to focus more on the power density of ethanol (power per unit volume) rather than the energy density (heat content per unit volume). When automakers can optimize on a particular ethanol blend, they are able to take increased advantage of ethanol's power density as opposed to its energy density, thereby improving vehicle fuel economy and extending vehicle range between refills. Much additional research is taking place in this area which will be released in the coming months.

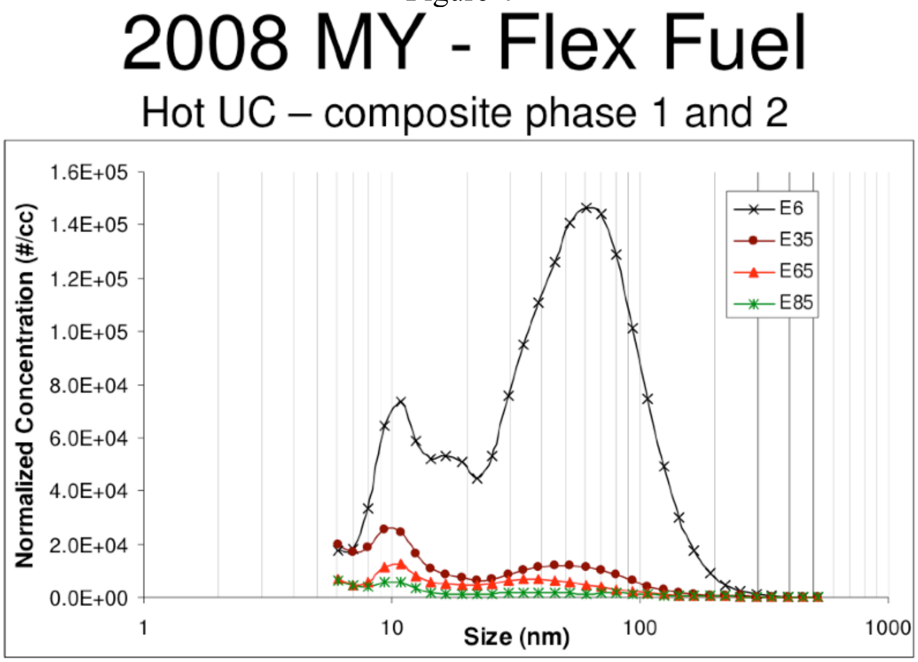
PM Emissions

Two appendices to the Technical Support Document discuss the Staff's analysis of PM emissions from both ported fuel injected (PFI) vehicles and gasoline direct injection (GDI) vehicles.[16] Staff estimates the PM emissions of both types of vehicles at approximately 4 mg/mi on either straight gasoline or E10 blends. The current PM standard is 10 mg/mi, so both types of vehicles meet the current standard. Staff proposes a 3 mg/mi PM standard for 2017-2025 vehicles, phased-in between 2017-2021. Staff further proposes a 1 mg/mi PM standard starting in 2025 and phased-in between the 2025 and 2028 model years. If the Staff were not concerned with the 4 mg/mi levels for both technologies, they would not have proposed lower PM standards, because both levels meet the current PM standard.

There are a number of studies that show that increasing ethanol reduces PM emissions from gasoline vehicles. The most notable is one by Zhang [17], the key results being shown in Figure 4. In this testing, a 2008 FFV was tested on a hot Unified Cycle on E6, E35, E65, and E85. Ethanol appears to have caused a large reduction in PM emissions (in particularly PN) from E6 to E35, with further PM reductions as ethanol concentration increased. However, the most significant PM and PN reductions are between E6 and E35.

[16] Appendix P, LEVIII PM, Technical Support Document, December 7, 2011, Appendix T, Proposed, LEVIII Mobile Source Emission Inventory, Technical Support Document, December 7, 2011.
[17] Zhang et al, "A Comparison of Total mass, Particle Size Distribution and Particle Number Emissions of Light Duty Vehicles tested at Haagen-Smit Laboratory from 2009 to 2010"

Figure 4



Ethanol Fuel	PM mg/mile	PN 10^{12} #/mile
E6	1.60	4.70
E35	N/A	0.70
E65	0.60	0.30
E85	0.27	0.14

Appendix P of the Technical Support Document contained a section where fuel effects on PM was discussed. The data presented in Appendix P, however, was only with an E6 and E10 fuel. Both fuels were "summer" fuels. A comparison was shown of PM emissions for a vehicle with wall-guided GDI, and for a PFI vehicle. The wall-guided GDI vehicle showed no difference in PM emissions, but the PFI vehicle showed 40% lower emissions on E10 than E6. Because the range of ethanol concentrations in these data are quite close together, these results can not necessarily be extrapolated to interpret potential differences between a E10 and E30 fuel. But the results imply that directionally, PM would be lower on E30 than E10 for PFI vehicles. Also, ARB believes that wall-guided GDI will give way quickly to spray-guided GDI, therefore, the ethanol results on the one wall-guided GDI are probably not indicative of trends for spray-guided GDI.

Szybist et al. also summarize recent literature for ethanol effects[18]:

[18] J. Szybist, A. Youngquist, T. Barone, J. Storey, W. Moore, M. Foster, and K. Confer, Ethanol Blends and Engine Operating Strategy Effects on Light-Duty Spark-Ignition Engine Particle Emissions, Energy and Fuels, vol. 25, pp. 4977-4985 (2011).

A number of investigations have examined the effect of ethanol content on particle emissions in vehicles. Storey et al.11 found that blends of 10 and 20% ethanol in gasoline (E10 and E20) decreased particle number emissions during vehicle drive cycles, with the 20% blend decreasing particles by about 40% during the high-load US06 vehicle drive cycle. In comparison to gasoline, He et al.12 found a 20% reduction in particle emissions with E20 but no change with E10. Khalek and Bougher13 showed that E10 increased particle emissions compared to two different gasoline formulations, both with higher volatility than the E10. This work showed the importance of the hydrocarbon fraction of the E10 blend and suggests that the heavier hydrocarbons used to control vapor pressure of E10 may also increase particulate emissions. Aakko and Nylund found that the particle mass emissions from 85% ethanol (E85) were comparable to those with gasoline in a PFI vehicle but that DI fueling with gasoline produced particle emissions that were an order of magnitude higher.

Other Emissions Impacts

LEVIII vehicles must meet very low emission standards for evaporative NMOG, exhaust NMOG, CO, and NOx, no matter what fuel they are certified on. So ultimately, there should be no difference in these emissions between an E10 fuel and an E30 fuel. A number of manufacturers offer FFVs that meet Tier 2 and LEVII emission standards on E85 and E0 now.

Increasing ethanol from E10 to E30 reduces fuel volatility, so depending on a final volatility specification, meeting evaporative requirements could be somewhat less difficult with an E30 blend. Fuel system permeation also contributes to evaporative emissions. Permeation emissions have not been studied on E30 blends, but a Coordinating Research Council study on permeation from ethanol blends between E6 and E20 found that increasing ethanol content from E10 to E20 increased diurnal permeation emissions by about 16% on five vehicles, however, one FFV that was tested experienced lower permeation emissions on E20 than E10. [19]

[19] CRC Report No. E-65-3, “Fuel Permeation From Automotive Systems: E0, E6, E10, E20, and E85”, Harold Haskew and Associates and McClement of ATL for Coordinating Research Council, December 2006.

AUTO ALLIANCE

DRIVING INNOVATION®

California LEVIII E10 Certification Gasoline - Alliance Fuels Group Position

Presented by: Bill Studzinski, GM Powertrain - Fuels Group

California Phase 3 Reformulated Gasoline (CaRFG3) E10 Certification Gasoline and Marketplace E85 Workshop

Sacramento, CA, Cal/EPA Headquarters Bldg.

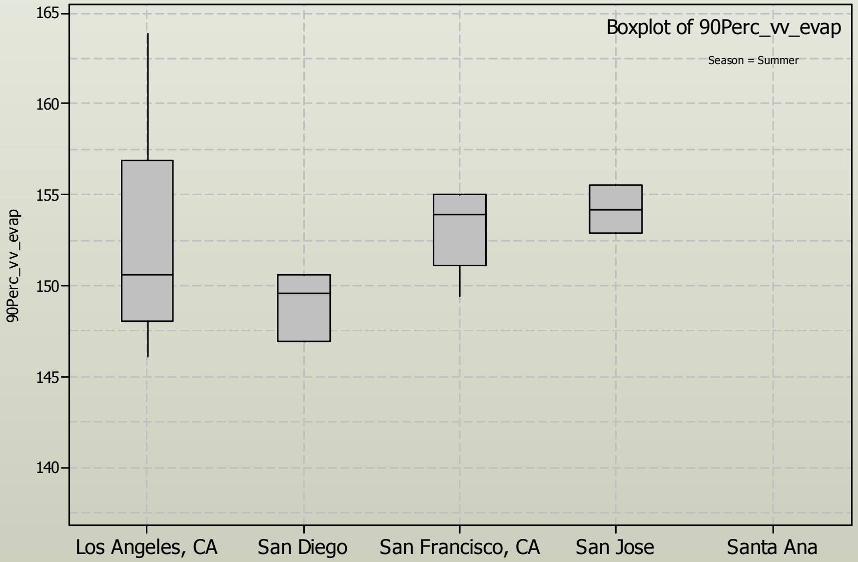
September 8, 2010

Alliance of Automobile Manufacturers

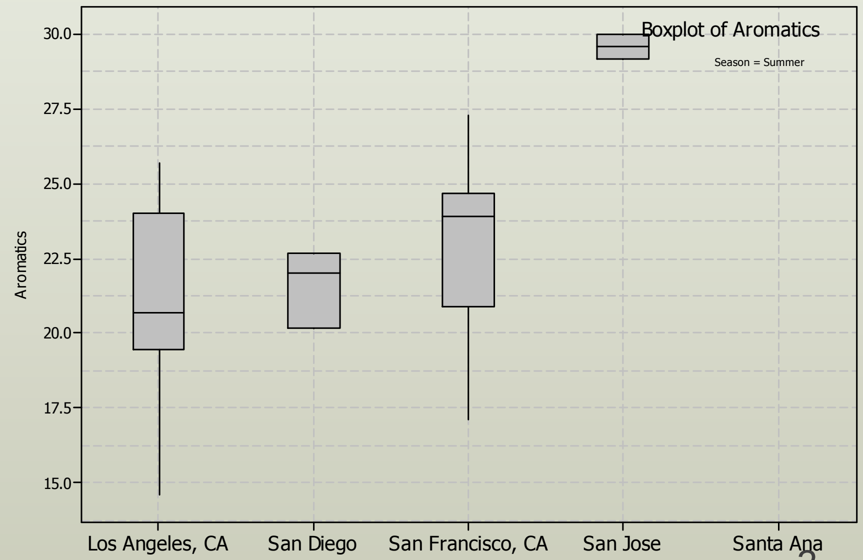
California Fuel Quality - "Past Marketplace Fuel Composition vs. Future Direction"

Alliance & SGS N. America Surveys (CY 2008 and 2009 Combined)											
Summer	(n = 37)										
	Density (kg/m3)	RVP (psi@100F)	T10 (deg. F)	T50 (deg. F)	T90 (deg. F)	Ethanol (Vol.%)	Aromatics (Vol.%)	Benzene (wt.%)	Olefins (Vol.%)	Sulfur (ppm)	Octane Sensitivity (S = RON - MON)
25tile	738	6.9	136	210	301	5.4	20.2	0.5	3.6	5	8.5
50tile	740	7.0	137	212	307	5.5	22.5	0.5	4.8	6	8.7
75tile	745	7.1	138	213	311	5.7	24.5	0.6	6.2	11	8.9

Calif. T90 (deg. C) Summer Fuels



Calif. Aromatics (vol. %) Summer Fuels

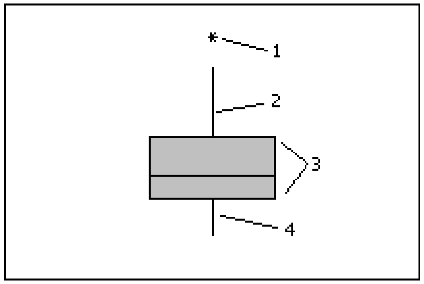


Alliance

Background – Boxplot Interpretation

A graphical summary of the distribution of a sample that shows its shape, central tendency, and variability.

The default boxplot display consists of the following:



1 **Outlier (*)** – Observation that is beyond the upper or lower whisker

2 **Upper whisker** – Extends to the maximum data point within 1.5 box heights from the top of the box

3 **Interquartile range box** – Middle 50% of the data

- Top line – Q3 (third quartile). 75% of the data are less than or equal to this value.
- Middle line – Q2 (median). 50% of the data are less than or equal to this value.
- Bottom line – Q1 (first quartile). 25% of the data are less than or equal to this value.

4 **Lower whisker** – Extends to the minimum data point within 1.5 box heights from the bottom of the box

Boxplots can help you understand your distribution. For example, the boxplot above represents hold times for customer support calls. The outlier at the upper end and longer upper whisker and upper part of the box indicate positive skewness, which makes sense because at the lower end of the distribution, no hold times can be less than zero.

Boxplots are also useful for comparing several distributions. For example, a quality engineer compares the diameter of plastic pipes produced weekly over three weeks. The boxplot below represents the results.

Alliance Proposal Summary – Relative to ARB Proposal

(yellow = differences, green = no difference)

Parameter	Units	California Cert Gasoline "Phase II"	CARB LEVIII Proposed Targets	Alliance Proposal - Ambient Standard
Octane				
RON, min.	RON	---	---	---
MON, min.	MON	---	---	---
AKI, min.	Calc.	91	91	91 , min.
Sensitivity, min	Calc.	7.5	7.5	10.0, min.
Volatility				
RVP	psi	6.7 - 7.0	6.9 - 7.2	6.70 - 6.95
RVP Evap	psi	---	---	---
RVP Altitude (1)	psi	---	---	---
IBP (2)	deg. F	---	---	---
T10	deg. F	130 - 150	---	130 - 150
T50	deg. F	200 - 210	205 - 215	195 - 205
T90	deg. F	290 - 300	310 - 320	290 - 300
FBP, max.	deg. F	390	390, max.	390, max.
Residue, max.	vol. %	2.0	2.0, max.	2.0
Driveability Index	---	---	---	Report
Chemical Composition / Other Physical				
Aromatics, max.	vol. %	22 - 25	20 - 22	18 - 22
Aromatics, Multi-substituted Alkyl	vol. %	12 - 14	---	10, max.
Olefins, max.	vol. %	4.0 - 6.0	4 - 6	4 - 6
Saturates	vol. %	---	---	Report
MTBE	vol. %	10.8 - 11.2	0.05, max.	---
Ethanol	vol. %		9.8 - 10.0	9.8 - 10.0
Total Oxygen	wt. %	---	3.5	3.5, min.
Benzene	vol. %	0.8 - 1.0	0.6 - 0.8	0.6 - 0.8
Sulfur	ppm m/m	30 - 40	8 - 11	8, max.
Lead	g/gal	0 - 0.01	0.0 - 0.01	0.0 - 0.01
Phosphorus	g/gal	0.005	0.005, max.	0.005, max.
Additives (3)			Title 13, CCR, Sec. 2257	Title 13, CCR, Sec. 2257
Copper Corrosion	---	No. 1.	No. 1	No. 1
Existent Gum, Washed, max.	mg/100ml	3.0	3.0, max.	3.0, max.
Oxidation Stability, min.	minutes	1000	1000, min.	1000, min.
Specific Gravity	---	No limit, report	---	Report
Heat of Combustion	---	No limit, report	---	Report
Carbon	wt. %	No limit, report	---	Report
Hydrogen	wt. %	No limit, report	---	Report

Evaporative Emissions – Ethanol Effects

- **The addition of 10vol% ethanol even with RVP control results in a more severe EVAP Standard because of ethanol's ability to increase permeability of vehicle fuel system elastomeric materials**

- **EVAP Standard needs a "Test Procedure Adjustment" to compensate**

  Hot Soak ("True Hot Soak") Permeation [a] – The Hot Soak emissions as defined in this report are the net increase in permeation rate following vehicle operation. We measured the mass increase in the SHED for one hour immediately following vehicle operation, and subtracted the previously measured static (or normal) permeation at the same temperature. While this is not the traditional Code of Federal Regulations (CFR) definition, we feel it is appropriate for the intent of this project.

"There was a large increase in the hot soak value with the E10 fuel compared to the E0. " (p. 22)

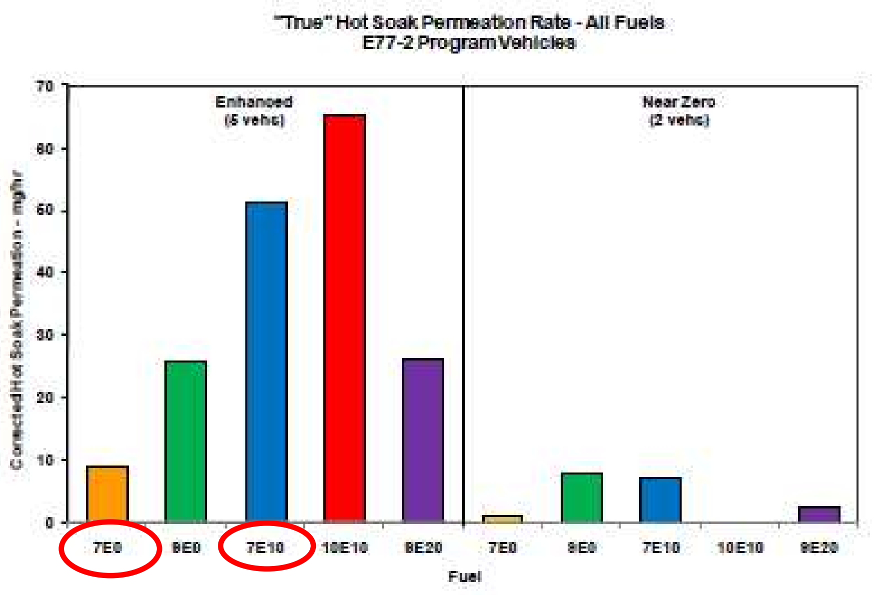


Figure 15 – True Hot Soak Permeation Comparison

Ref. (a): CRC Report No. E77-2, "Enhanced Evaporative Emissions Vehicles," Harold M. Haskew and Thomas F. Liberty, March 2010

Multi-substituted Alkyl Aromatics

- **The multi-substituted alkyl aromatics should continue to be controlled in the ARB's LEV III cert fuel to minimize variation in fuel composition effects on tailpipe emissions.**
  - As emissions regulations become more stringent, the emissions certification fuel will need to be equally controlled to ensure the measured emissions are a result of vehicle hardware and calibration effects and not spurious fuel formulation shifts.

- **A Total Aromatics limit alone in the cert fuel spec does not preclude the blending of relatively high molecular weight aromatics that can lead to increased HC and PM emissions.**
  - The proposed Distillation T90 and FBP serve to control high molecular weight HCs, but will not be exact enough.
  - Very generally, multi-substituted alkyl aromatics (MSAA) can be the building blocks of high levels of particulate matter.
    - The higher the concentration of MSAA hydrocarbons the greater likelihood of reaction between benzylic partial oxidation species of substituted aromatic fuel molecules and the 1,3-butadiene, ethylene and acetylene partial oxidation species, also known as soot precursors.

•References:

- Zhang, Hongzhi R., et. al., Univ. of Utah, "Pollutant Emissions from Gasoline Combustion. 1. Dependence of Fuel Structural Functionalities.", Environmental Science Technology., 2008, Vol. 42, pp. 5615-5621
- Kayes, David and Simone Hochgreb, MIT, "Mechanisms of Particulate Matter Formation in Spark-Ignition Engines., 2. Effect of Fuel, Oil, and Catalyst Parameters," Environmental Sci. Tech., 1999, Vol. 33, pp. 3968 – 3977
- Baral, Bivek and Robert Raine, Univ. of Auckland, "Performance and Emission of a Spark Ignition Engine Running on Gasoline Adulterated with Kerosene.", SAE 2009-28-0014

Alliance Proposal - California LEVIII E10 Cert Fuel Specification

Parameter	Units	ASTM Test Method (in CFR)	Alternative Test Method List	Alliance Proposal - Ambient Standard
Octane				
RON, min.	RON	D2699		---
MON, min.	MON	D2700		---
AKI, min.	Calc.	(R+M)/2		**91 , min.**
Sensitivity, min	Calc.	RON - MON		**10.0, min.**
Volatility				
RVP	psi	D 3231	D5190, D5191, or D5482	**6.70 - 6.95**
RVP Evap	psi	D 3231	D5190, D5191, or D5482	---
RVP Altitude [1]	psi	D 3231	D5190, D5191, or D5482	---
IBP [2]	deg. F	D86		---
T10	deg. F	D86		**130 - 150**
T50	deg. F	D86		**195 - 205**
T90	deg. F	D86		**290 - 300**
FBP, max.	deg. F	D86		**390, max.**
Residue, max.	vol. %	D86		**2.0**
Driveability Index	---	D4814		**Report**
Chemical Composition / Other Physical				
Aromatics, max.	vol. %	D1319		**18 - 22**
Aromatics, Multi-substituted Alkyl	vol. %	DHA single column cap GC' (Johansen, 1992)		**10, max.**
Olefins, max.	vol. %	D1319		**4 - 6**
Saturates	vol. %	D1319		**Report**
MTBE	vol. %	---		---
Ethanol	vol. %	D4815		**9.8 - 10.0**
Total Oxygen	wt. %			**3.5, min.**
Benzene	vol. %	---	D3606, D5580	**0.6 - 0.8**
Sulfur	ppm m/m	D3120	D2622, D3120, or D5453	**8, max.**
Lead	g/gal	D3237	D3227 or D5059	**0.0 - 0.01**
Phosphorus	g/gal	D3231		**0.005, max.**
Additives [3]				**Note 5**
Copper Corrosion	---	---	D130	**No. 1**
Existent Gum, Washed, max.	mg/100ml	---	D381	**3.0, max.**
Oxidation Stability, min.	minutes	---	D525	**1000, min.**
Specific Gravity	---	---		**Report**
Heat of Combustion	---	---	D240, D4809	**Report**
Carbon	wt. %	---		**Report**
Hydrogen	wt. %	---		**Report**

The Alliance of Automobile Manufacturers Thanks the Air Resources Board for their consideration!

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Back-up Material

Octane Sensitivity – Ethanol Effects

- For the LEVIII Cert Fuel, the octane sensitivity value should be set higher (10, min.)
  - Fuel Survey Data show the California marketplace Octane Sensitivity (50th Percentile) is nominally already 9 when ethanol is at 5.5v% (Slide 2)
  - Ethanol's Sensitivity is 19 and ethanol concentration is moving from 5.5v% to 10 v%.

Octane Sensitivity of Pure Hydrocarbons [d]

Hydrocarbon	Type	RON	MON	Sensitivity
Isooctane[a]	Paraffin	100	100	0
Isopentane[a]	Paraffin	92	90	2
Neohexane [a] (2,2-DiM-butane)	Paraffin	92	93	-1
2-M-2-Pentene[a]	Olefin	98	83	15
2,3-DiM-2-Pentene[a]	Olefin	98	80	18
Toluene[a]	Aromatic	120	104	16
1-M-3-E-Benzene[a]	Aromatic	112	100	12
Ethanol[b]	Oxygenate	109	90	19
Methanol[b]	Oxygenate	109	89	20

Notes:
(a)API Research Project 45, "Summary of Data on the Knock Ratings of Hydrocarbons", Technical Data on Fuel by J.W. Rose and J.R. Cooper, 7th Ed., The British National Committee, World Energy Conf., 1977.
(b)Automotive Fuels Reference Book, Keith Owen & Trevor Coley, 1995, p. 591
(c)Values reported are for pure hydrocarbons, not blending numbers, which are reported higher. Octane numbers for ethanol verified by GM Fuels Group using standard CFR engine with modifications to carburetor fixed jet and intake air heater to stay within prescribed requirements of ASTMD2699 & D2700.

Ethanol-The Primary Renewable Liquid Fuel

Rathin Datta

Chief Scientific Officer

Coskata, Inc.

International Fuel Ethanol Workshop and Expo

June 2011

Indianapolis

Perspective paper by Rathin Datta, Mark Maher, Coleman Jones, and Richard Brinker
J. Chemical Technology and Biotechnology, 2011,
86: 473-480, Society of Chemical Industry

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Primary topics

1. Renewable biomass feedstocks that are efficiently and easily available are highly oxygenated

2. Ethanol is the primary renewable liquid transportation fuel with a long history of very good performance

3. Ethanol can be produced with high yields and efficiency with some conversion technologies – particularly the “Hybrid” of gasification with bioconversion – that have developed to the commercial implementation stage

4. Longer chain alcohols, lipids or hydrocarbons cannot be derived from renewable carbon sources with equivalent yields

5. Large quantities of renewable and sustainable biomass feedstocks to produce ethanol are available in the US and many other parts of the world

- ***Thus ethanol is and should continue to be the major renewable liquid fuel.***

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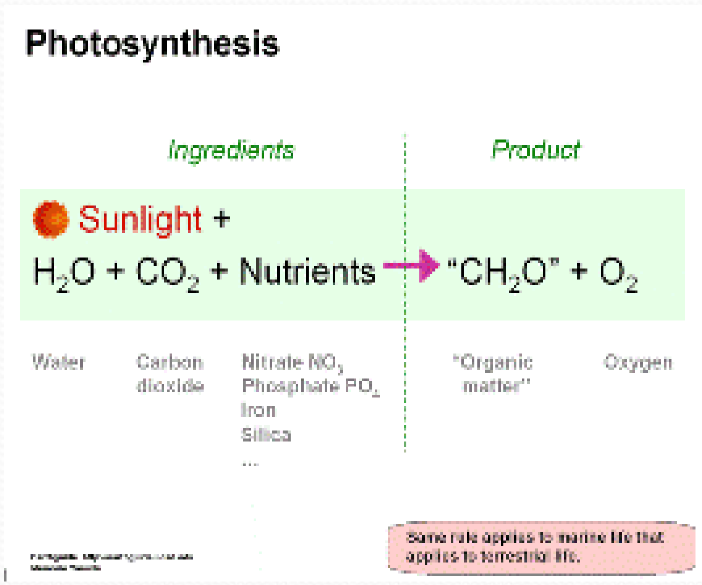
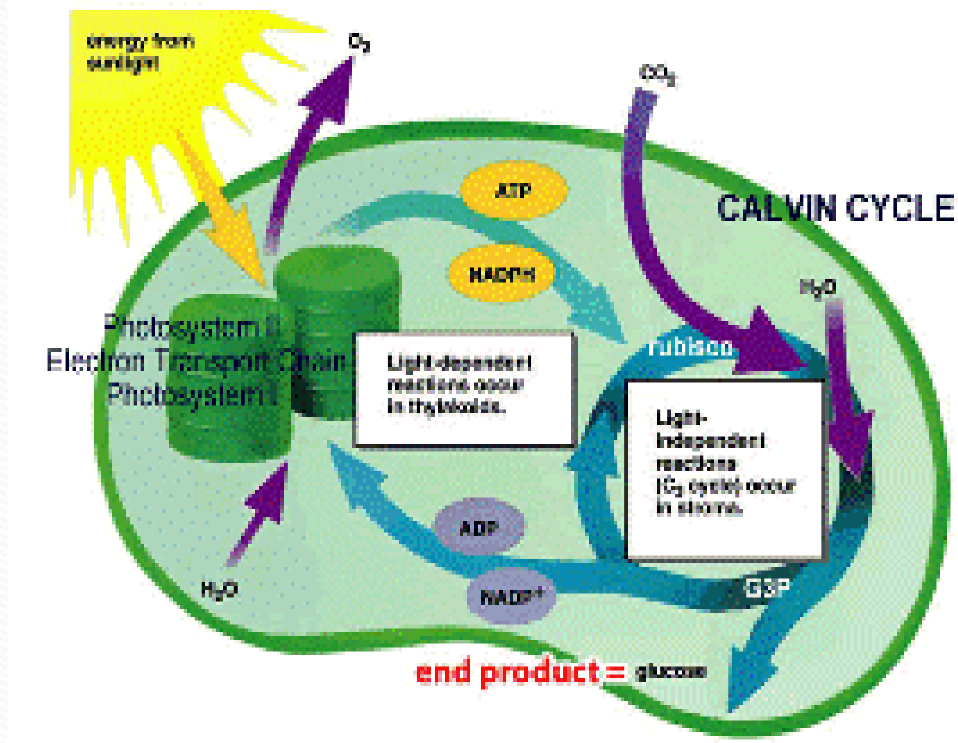
Photosynthesis and biomass composition

- CO_2 is fixed in nature in a complex but well balanced system – the primary composition of “photosynthate” – “CH_2O”





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High yielding biomass composition

- **Typical high yielding biomass composition – C $H_{1.45}$ $O_{0.65}$**
  (Biomass Feedstock Composition and Property Database – U.S. DOE, www.afdc.energy.gov/biomass/progs/search)
  - Irrespective of Species
  - Sustainable yields – 3 to 6 Tons/acre

Biomass feedstock	C (% mass)	H (% mass)	O (% mass)	Composition CHO
Hybrid Poplar	49.8	6.1	41.5	$CH_{1.47}O_{0.63}$
Black Locust	49.9	6.1	41.6	$CH_{1.47}O_{0.63}$
Eucalyptus	49.9	5.9	42.5	$CH_{1.42}O_{0.64}$
Monterey Pine	50.2	6.0	42.1	$CH_{1.44}O_{0.64}$
Corn Stover	46.7	5.5	40.6	$CH_{1.41}O_{0.65}$
Sugarcane bagasse	47.6	5.7	41.4	$CH_{1.44}O_{0.65}$
Switchgrass	48.0	5.7	40.0	$CH_{1.43}O_{0.63}$

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Production of More Reduced Feedstock - Oils, Fats, Hydrocarbons – Loss of Yield

- This is fundamental and governed by laws of electron balances and Thermodynamics
  - Independent of species or production systems – terrestrial or aquatic plants or algae
  - More "photosynthate" "CH_2O" units required per molecule –
    - e.g. 14 $CH_2O \rightarrow C_9H_{19}COOH + 4\ CO_2 + 4\ H_2O$
      - (theoretical yield 41%; actual is lower 20 -30%)

- Typical vegetable oils produced annual crops or plantations
  - 0.2 to 1 ton/acre/yr

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The Winning Strategy

- Hence, based on the fundamentals of photosynthesis and laws of thermodynamics, the biomass feedstocks that are and will be efficiently available are highly oxygenated and are lignocellulosic materials.

- ***For liquid fuel or chemical production from this feedstock, the winning strategy is to produce a product that has proven and widespread use, with the highest yield using the entire feedstock***

  – and that is ethanol.

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Performance as liquid transportation fuel

- Long history of use as a liquid transportation fuel
  - Henry Ford – 1908 in the original Model T
  - Has been blended with gasoline (ranging from 3% to 85%) in many countries for decades
- Suitable for "spark ignition "Otto" cycle engines
  - 80% of the vehicles run on this type of engine
  - About 650 million worldwide
- The automobile manufacturers have successfully adapted their technology to handle ethanol gasoline blends
- In the US
  - E 10 vehicles started in the 1970s
  - In the 1990s the industry began to develop E85 (blend of 70 to 85% ethanol in gasoline)
  - Currently all vehicles are E10
  - About 9 million are E85 and that number is growing rapidly

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Ethanol's properties: Lower emissions, higher engine efficiency

Comparative properties between ethanol and gasoline

- Some of these properties lead to less emissions and increase in engine efficiency
- Numerous studies on emissions have been conducted
  - Reduction of carbon monoxide, VOC, SO2
  - References on "Ethanol Fact Book" - Ethanol Fact Book, Clean Fuels Development Coalition, www.cleanfuelsdc.org, 60p. (2010).

Fuel	Density, gm/ml	Oxygen content m/m	Boiling Point C	Vapor pressure at 37.8C, kPa	Heat of Vaporization J/g	Water Solubility	Research Octane (RON)	Motor Octane (MON)	Conductivity μS/cm
Ethanol	0.7893	0.347	78.5	16	0.92	Miscible	108	92	6
Gasoline	0.72-0.78	0	25-225	35-110	0.36	Negligible	90-98	82-90	1E-8

Higher engine efficiency can be achieved

- Ethanol's properties
  - High octane number leads to higher compression ratios
  - High heat of vaporization also allows higher compression
  - Faster flame propagation
- High ethanol containing blends (E85) actually give higher engine efficiency
- Recent EPA certification data (2010 vehicles) with E85
  - Average 2 % increase in engine efficiency
  - For GM cars – average 3.2 % increase

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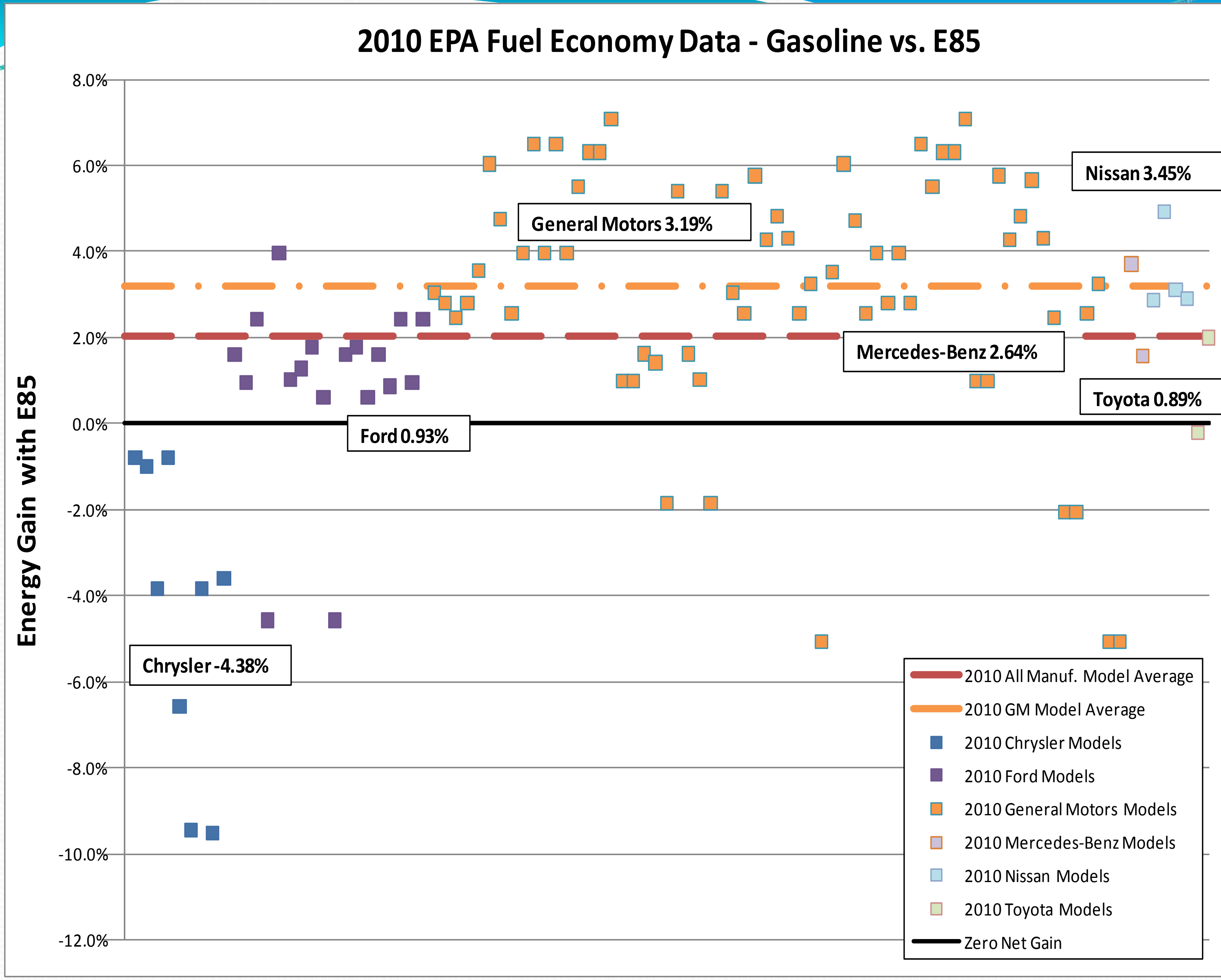
2010 EPA Fuel Economy Data - Gasoline vs. E85
Energy Gain with E85
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-4.0%
-6.0%
-8.0%
-10.0%
-12.0%
General Motors 3.19%
Nissan 3.45%
Mercedes-Benz 2.64%
Toyota 0.89%
Ford 0.93%
Chrysler -4.38%
2010 All Manuf. Model Average
2010 GM Model Average
2010 Chrysler Models
2010 Ford Models
2010 General Motors Models
2010 Mercedes-Benz Models
2010 Nissan Models
2010 Toyota Models
Zero Net Gain

Transition to Electricity – Ethanol fits very well

- Lot of popular interest and news on this subject
- Recent high level study and report by the National Research Council has been published to put this subject in appropriate technical, feasibility, timing and commercial context

    National Research Council, NRC report, ISBN: 0-309-14851-0, 70 p. (2010)

- The report has looked at various rates of penetration from the 'Maximum Practical' to a 'Realistic' rate considering the high cost of batteries, modest gasoline savings, limited availability of places to plug in, competition from other vehicles, consumer resistance to plugging in virtually every day and continuing government support for several decades.
- Regarding the effect on oil consumption the report concludes

    "PHEVs will have little impact on oil consumption before 2030 because there will not be enough of them in the fleet. More substantial reductions could be achieved by 2050 but will reduce oil consumption only slightly more than can be achieved by just the hybrid vehicles (HEVs)".

- Hence, liquid fuels will be required and will be the primary fuel for decades while this transition takes place.
- ***Ethanol as a renewable liquid fuel would be a very good fit***

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Key points established

- Based on the fundamentals of photosynthesis and laws of thermodynamics, the biomass feedstocks that are and will be efficiently available are highly oxygenated and are lignocellulosic materials.
- Ethanol is the primary renewable liquid transportation fuel with a long history of very good performance
- Ethanol fits very well into the future of combination of electricity and renewable liquid fuel for transportation

- ***The winning strategy is to produce ethanol, a product that has proven and widespread use, with the highest yield using the entire feedstock***

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Conversion technology, yield and efficiency

- **Ethanol, butanol, hydrocarbons – the yield issue**
  - Butanol or other reduced hydrocarbon production from biomass
  - A lot of recent discussions on these more reduced, so called “Drop In” products.
  - The yields are governed by the same laws of electron balances and thermodynamics and would thus be considerably lower than that of ethanol.
  - None of these “Drop In”s have the proven record of widespread use in automobile transportation

Comparative yields of ethanol vs. other reduced products

Product	Chemical Equation	Theoretical Yield (w%)	Typical Yields Achieved	Comments
Ethanol	3”CH_2O” → $C_2H_5OH + CO_2$	51%	46 to 50%	90 to 98% of theoretical yields achieved in industrial carbohydrate fermentations
n-Butanol or iso-Butanol	6”CH_2O”→ $C_4H_9OH + 2\ CO_2 + H_2O$	41%	23 to 25%	55 to 60% of theoretical yields achieved in industrial scale ABE fermentations (11)
Octane C8-Hydrocarbon	13 “CH_2O” → $C_8H_{20} + 5CO_2 + 3H_2O$	29.7	N.A.	Wide ranging mix of hydrocarbons and oxygenates are produced in catalytic processes – not practiced industrially

Conversion technology paths for ethanol

1. The **Biochemical path** uses enzymes to convert pretreated lignocellulosic biomass materials into sugars which can then be fermented into ethanol.
2. The **Thermochemical path,** a biomass feedstock is gasified to produce syngas (carbon monoxide, hydrogen and carbon dioxide) which is then converted into ethanol by a chemical reaction utilizing chemical catalysis.
3. The **Hybrid path** combines both the thermochemical and biochemical elements, gasification is used to convert a biomass feedstock into syngas, microorganisms ferment the syngas into ethanol, and the ethanol is then separated from water to produce fuel grade ethanol.
   - converts all the components of the biomass feedstock to the syngas mixture of CO, H_2 and CO_2 with > 75% efficiency
   - specific anaerobic organisms can convert these to ethanol with >95% theoretical yield.
   - the heat generated in the gasification process provides a portion of the process energy for drying and distillation.

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Conversion technology comparison

	Biochemical (pretreat +enzyme +fermentation)	Thermochemical (gasification +catalysis)	Hybrid (Gasification +fermentation)
Ethanol synthesis technology	Enzymes and Microorganisms	Metal Catalyst	Microorganisms
Feedstock flexibility	**No**	**Yes**	**Yes**
Significant feedstock pre-treatment reqd.	**Yes**	**No**	**No**
Low pressure process	**Yes**	**No**	**Yes**
Selectively produces ethanol	**Yes**	**No**	**Yes**
Yield (gal/dry ton)	72-90*	74-86*	>100[#]

*Yield estimates from DOE's FY2007 State of Technology reports. Low end of range represents 2007 status based on NREL bench scale data and high end represents 2012 NREL targets.
Source Coskata, Inc.

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The "Hybrid" path – progress to commercialization

- **Three companies - Ineos BIO, Coskata, Lanzatech**

Moving from development to demonstration to commercial project

- **INEOS Bio** announced the commercial project in Indian River County in Florida to convert renewable biomass to ethanol using their process that follows the "Hybrid" technology path. This joint venture project between INEOS Bio and NPE Florida is targeted to produce about 30 million liters/year of ethanol
- **Coskata technology progress**
  - In the four years since its inception, Coskata has advanced the technology from the bench to the pilot scale at its Warrenville, Illinois, facility to the demonstration scale in its "Lighthouse" facility in Pennsylvania
  - The Lighthouse facility successfully started up in the third quarter of 2009 and has since generated over 2000 hours of operating data, including hundreds of hours at steady-state operations.
  - The operating results from Lighthouse is validating the base case economic forecasts for its full scale commercial plant.

Coskata commercial project - Flagship

- **Location SE US**
  - **55 million GPY capacity**
  - **Woody biomass feedstock**

Further economic analysis has shown that this facility will produce fuel-grade ethanol at a very competitive cost point.

Project, when completed and operational ,will:

- Contribute meaningfully to the volume of cellulosic biofuel mandated by the current Renewable Fuel Standard;
- Provide cash flow sufficient to service the debt associated with the Project and allow Coskata to continue to invest in optimizing its technology platform;
- Generate an attractive return on capital employed, and therefore a sustainable return to stakeholders;
- Provide the basis for technology licensing, such that the production capacity for cellulosic ethanol can be expanded in the marketplace as rapidly as possible; and
- Validate a commercial-scale process for producing ethanol as a renewable transportation fuel that is environmentally sustainable
  - From non-food and ag crops
  - Reduces lifecycle greenhouse gas emissions
  - Vastly reduces requirements for scarce resources such as water.

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Key points established

- Based on the fundamentals of photosynthesis and laws of thermodynamics, the biomass feedstocks that are and will be efficiently available are highly oxygenated and are lignocellulosic materials.
- Ethanol is the primary renewable liquid transportation fuel with a long history of very good performance
- Other "Drop in" products will not have the yield advantages of ethanol and do not have the long history performance and usage
- Ethanol fits very well into the future of combination of electricity and renewable liquid fuel for transportation
- The "Hybrid" Technology path provides many advantages
  - Use of all the feedstock components
  - Feedstock flexibility
  - High yield
  - High process efficiency
  - Attractive economics
- This technology is moving to commercialization

Large quantities of renewable and sustainable biomass feedstocks to produce ethanol are available or can become available in the US and many other parts of the world

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Large and sustainable feedstock supply

- **The "Billion Ton Report – 2005**

  The Technical Feasibility of a Billion-Ton Annual Supply, Report of a joint study sponsored by the U.S. Department of Energy and U.S. Department of Agriculture (2005). www.osti.gov/bridge

  - **Primary conclusions**
  - U S is capable of producing a sustainable supply of biomass sufficient to displace 30 percent or more of the country's present petroleum consumption
  - Over 1.3 billion dry tons per year of biomass potential — about 368 million dry tons of sustainably removable biomass could be produced on forestlands, and about 998 million dry tons could come from agricultural lands".

- **Follow up report – Sandia National Laboratory 2009**

  West, T. et al, Feasibility, Economics and Environmental Impact of Producing 90 Billion Gallons of Ethanol per Year by 2030, Report by the Sandia National Laboratory, SAND 2009 – 3076J (2009).

\- **Primary conclusions**

  - No theoretical barriers to reaching large volumes (~90 billion gallons/year) of ethanol production.
  - Practical barriers need to be overcome:
    - Sustained effort will be needed to achieve large production goals.
    - Sustained technology improvement in feedstock development and conversion technology is critical.
    - Other practical considerations, such as capital availability and cost, are also significant.
    - Sensitivity analysis - feasible for cellulosic ethanol to be cost competitive with gasoline at oil prices above approximately $90/barrel.
    - Improvements in conversion yield and significant decreases in feedstock and capital costs can make cellulosic ethanol more cost-competitive at lower oil rices

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The Southeastern Forest Industry Experience

Actual experience from the past 70 years in the southeastern US helps to further support the fact that an efficient and sustainable biomass supply can be developed and maintained to support large increased usage.

- **The forest industry evolved over the past 100 years**
  - Early to mid 1900s - Supply of solid wood – lumber and timber for construction
  - From 1920 to 2000 – development and maturation of pulp and paper industry
  - Continuous evolution and improvement of forest management practice
  - Continuous improvement in harvesting technologies
- **Some key achievements**
  - Pulpwood production quadrupled from 1953 to 2006 – from 44 to 177 million tons/yr
  - The volume of standing timber increased 80% - from 60 to 108 billion cu ft
  - The total area of forest land remained stable since the 1970s ~ 214 million acres
  - The land ownership has also remained stable – 89% privately owned
    - 22 percent by the forest industry
    - 21 percent by farmers
    - 12 percent by other corporations
    - 45 percent by other individuals

Conclusions: Ethanol-The Primary Renewable Liquid Fuel

- Based on the fundamentals of photosynthesis and laws of thermodynamics, the biomass feedstocks that are and will be efficiently available are highly oxygenated and are lignocellulosic materials.
- Ethanol is the primary renewable liquid transportation fuel with a long history of very good performance
- Other "Drop in" products will not have the yield advantages of ethanol and do not have the long history performance and usage
- Ethanol fits very well into the future of combination of electricity and renewable liquid fuel for transportation
- Among the conversion technologies:

  The "Hybrid" Technology path provides many advantages
  - **Use of all the feedstock components**
  - **Feedstock flexibility**
  - **High yield**
  - **High process efficiency**
  - **Attractive economics**

  This technology is moving to commercialization
- Large quantities of renewable and sustainable biomass feedstocks to produce ethanol are available or can become available in the US and many other parts of the world
  - Actual experience from the past 70 years in the southeastern US helps to further support the fact that an efficient and sustainable biomass supply can be developed and maintained to support large increased usage.

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ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 85, 86, and 600

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Parts 523, 531, 533, 536, and 537

[EPA–HQ–OAR–2010–0799; FRL–9495–2; NHTSA–2010–0131]

RIN 2060–AQ54; RIN 2127–AK79

2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards

AGENCY: Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA).

ACTION: Proposed rule.

SUMMARY: EPA and NHTSA, on behalf of the Department of Transportation, are issuing this joint proposal to further reduce greenhouse gas emissions and improve fuel economy for light-duty vehicles for model years 2017–2025. This proposal extends the National Program beyond the greenhouse gas and corporate average fuel economy standards set for model years 2012–2016. On May 21, 2010, President Obama issued a Presidential Memorandum requesting that NHTSA and EPA develop through notice and comment rulemaking a coordinated National Program to reduce greenhouse gas emissions of light-duty vehicles for model years 2017–2025. This proposal, consistent with the President's request, responds to the country's critical need to address global climate change and to reduce oil consumption. NHTSA is proposing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, and EPA is proposing greenhouse gas emissions standards under the Clean Air Act. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, and represent a continued harmonized and consistent National Program. Under the National Program for model years 2017–2025, automobile manufacturers would be able to continue building a single light-duty national fleet that satisfies all requirements under both programs while ensuring that consumers still have a full range of vehicle choices. EPA is also proposing a minor change to the regulations applicable to MY 2012–2016, with respect to air conditioner performance and measurement of nitrous oxides.

DATES: *Comments:* Comments must be received on or before January 30, 2012. Under the Paperwork Reduction Act, comments on the information collection provisions must be received by the Office of Management and Budget (OMB) on or before January 3, 2012. See the **SUPPLEMENTARY INFORMATION** section on ''Public Participation'' for more information about written comments.

Public Hearings: NHTSA and EPA will jointly hold three public hearings on the following dates: January 17, 2012, in Detroit, Michigan; January 19, 2012 in Philadelphia, Pennsylvania; and January 24, 2012, in San Francisco, California. EPA and NHTSA will announce the addresses for each hearing location in a supplemental **Federal Register** Notice. The agencies will accept comments to the rulemaking documents, and NHTSA will also accept comments to the Draft Environmental Impact Statement (EIS) at these hearings and to Docket No. NHTSA–2011–0056. The hearings will start at 10 a.m. local time and continue until everyone has had a chance to speak. See the **SUPPLEMENTARY INFORMATION** section on ''Public Participation.'' for more information about the public hearings.

ADDRESSES: Submit your comments, identified by Docket ID No. EPA–HQ–OAR–2010–0799 and/or NHTSA–2010–0131, by one of the following methods:

Online: www.regulations.gov: Follow the on-line instructions for submitting comments.

Email: a-and-r-Docket@epa.gov

Fax: EPA: (202) 566–9744; NHTSA: (202) 493–2251.

Mail:

EPA: Environmental Protection Agency, EPA Docket Center (EPA/DC), Air and Radiation Docket, Mail Code 28221T, 1200 Pennsylvania Avenue NW., Washington, DC 20460, Attention Docket ID No. EPA–HQ–OAR–2010–0799. In addition, please mail a copy of your comments on the information collection provisions to the Office of Information and Regulatory Affairs, Office of Management and Budget (OMB), Attn: Desk Officer for EPA, 725 17th St., NW., Washington, DC 20503.

NHTSA: Docket Management Facility, M–30, U.S. Department of Transportation, West Building, Ground Floor, Rm. W12–140, 1200 New Jersey Avenue SE, Washington, DC 20590.

Hand Delivery:

EPA: Docket Center, (EPA/DC) EPA West, Room B102, 1301 Constitution Ave. NW., Washington, DC, Attention Docket ID No. EPA–HQ–OAR–2010–0799. Such deliveries are only accepted during the Docket's normal hours of operation, and special arrangements should be made for deliveries of boxed information.

NHTSA: West Building, Ground Floor, Rm. W12–140, 1200 New Jersey Avenue SE, Washington, DC 20590, between 9 a.m. and 4 p.m. Eastern Time, Monday through Friday, except Federal Holidays.

Instructions: Direct your comments to Docket ID No. EPA–HQ–OAR–2010–0799 and/or NHTSA–2010–0131. See the **SUPPLEMENTARY INFORMATION** section on ''Public Participation'' for more information about submitting written comments.

Docket: All documents in the dockets are listed in the *http://www.regulations.gov* index. Although listed in the index, some information is not publicly available, *e.g.,* confidential business information (CBI) or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available in hard copy in EPA's docket, and electronically in NHTSA's online docket. Publicly available docket materials are available either electronically in *www.regulations.gov* or in hard copy at the following locations: EPA: EPA Docket Center, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave. NW., Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744. NHTSA: Docket Management Facility, M–30, U.S. Department of Transportation, West Building, Ground Floor, Rm. W12–140, 1200 New Jersey Avenue SE., Washington, DC 20590. The Docket Management Facility is open between 9 a.m. and 5 p.m. Eastern Time, Monday through Friday, except Federal holidays.

FOR FURTHER INFORMATION CONTACT: *EPA:* Christopher Lieske, Office of Transportation and Air Quality, Assessment and Standards Division, Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; telephone number: (734) 214–4584; fax number: (734) 214–4816; email address: *lieske.christopher@epa.gov*, or contact the Assessment and Standards Division; email address: *otaqpublicweb@epa.gov*. *NHTSA:* Rebecca Yoon, Office of the Chief Counsel, National Highway Traffic Safety Administration, 1200 New Jersey

Avenue SE., Washington, DC 20590. Telephone: (202) 366–2992.

SUPPLEMENTARY INFORMATION:

A. Does this action apply to me?

This action affects companies that manufacture or sell new light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles, as defined under EPA's CAA regulations,[1] and passenger automobiles (passenger cars) and non-passenger automobiles (light trucks) as defined under NHTSA's CAFE regulations.[2] Regulated categories and entities include:

Category	NAICS Codes[A]	Examples of Potentially Regulated Entities
Industry	336111 336112	Motor Vehicle Manufacturers
Industry	811111 811112 811198 423110	Commercial Importers of Vehicles and Vehicle Components
Industry	335312 336312 336399 811198	Alternative Fuel Vehicle Converters

[A] North American Industry Classification System (NAICS)

This list is not intended to be exhaustive, but rather provides a guide regarding entities likely to be regulated by this action. To determine whether particular activities may be regulated by this action, you should carefully examine the regulations. You may direct questions regarding the applicability of this action to the person listed in **FOR FURTHER INFORMATION CONTACT**.

B. Public Participation

NHTSA and EPA request comment on all aspects of this joint proposed rule. This section describes how you can participate in this process.

How do I prepare and submit comments?

In this joint proposal, there are many issues common to both EPA's and NHTSA's proposals. For the convenience of all parties, comments submitted to the EPA docket will be considered comments submitted to the NHTSA docket, and vice versa. An exception is that comments submitted to the NHTSA docket on NHTSA's Draft Environmental Impact Statement (EIS) will not be considered submitted to the EPA docket. Therefore, the public only needs to submit comments to either one of the two agency dockets, although they may submit comments to both if they so choose. Comments that are submitted for consideration by one agency should be identified as such, and comments that are submitted for consideration by both agencies should be identified as such. Absent such identification, each agency will exercise its best judgment to determine whether a comment is submitted on its proposal.

Further instructions for submitting comments to either the EPA or NHTSA docket are described below.

EPA: Direct your comments to Docket ID No EPA–HQ–OAR–2010–0799. EPA's policy is that all comments received will be included in the public docket without change and may be made available online at *http://www.regulations.gov*, including any personal information provided, unless

[1] ''Light-duty vehicle,'' ''light-duty truck,'' and ''medium-duty passenger vehicle'' are defined in 40 CFR 86.1803–01. Generally, the term ''light-duty vehicle'' means a passenger car, the term ''light-duty truck'' means a pick-up truck, sport-utility vehicle, or minivan of up to 8,500 lbs gross vehicle weight rating, and ''medium-duty passenger vehicle'' means a sport-utility vehicle or passenger van from 8,500 to 10,000 lbs gross vehicle weight rating. Medium-duty passenger vehicles do not include pick-up trucks.

[2] ''Passenger car'' and ''light truck'' are defined in 49 CFR part 523.

the comment includes information claimed to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through *http://www.regulations.gov* or email. The *http://www.regulations.gov* Web site is an ''anonymous access'' system, which means EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an email comment directly to EPA without going through *http://www.regulations.gov* your email address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses. For additional information about EPA's public docket visit the EPA Docket Center homepage at *http://www.epa.gov/epahome/dockets.htm.*

NHTSA: Your comments must be written and in English. To ensure that your comments are correctly filed in the Docket, please include the Docket number NHTSA–2010–0131 in your comments. Your comments must not be more than 15 pages long.[3] NHTSA established this limit to encourage you to write your primary comments in a concise fashion. However, you may attach necessary additional documents to your comments, and there is no limit on the length of the attachments. If you are submitting comments electronically as a PDF (Adobe) file, we ask that the documents submitted be scanned using the Optical Character Recognition (OCR) process, thus allowing the agencies to search and copy certain portions of your submissions.[4] Please note that pursuant to the Data Quality Act, in order for the substantive data to be relied upon and used by the agency, it must meet the information quality standards set forth in the OMB and Department of Transportation (DOT) Data Quality Act guidelines. Accordingly, we encourage you to consult the guidelines in preparing your comments. OMB's guidelines may be accessed at *http://www.whitehouse.gov/omb/fedreg/reproducible.html.* DOT's guidelines may be accessed at *http://www.dot.gov/dataquality.htm.*

Tips for Preparing Your Comments

When submitting comments, please remember to:

Identify the rulemaking by docket number and other identifying information (subject heading, **Federal Register** date and page number).

Explain why you agree or disagree, suggest alternatives, and substitute language for your requested changes.

Describe any assumptions and provide any technical information and/or data that you used.

If you estimate potential costs or burdens, explain how you arrived at your estimate in sufficient detail to allow for it to be reproduced.

Provide specific examples to illustrate your concerns, and suggest alternatives.

Explain your views as clearly as possible, avoiding the use of profanity or personal threats.

Make sure to submit your comments by the comment period deadline identified in the DATES section above.

How can I be sure that my comments were received?

NHTSA: If you submit your comments by mail and wish Docket Management to notify you upon its receipt of your comments, enclose a self-addressed, stamped postcard in the envelope containing your comments. Upon receiving your comments, Docket Management will return the postcard by mail.

How do I submit confidential business information?

Any confidential business information (CBI) submitted to one of the agencies will also be available to the other agency. However, as with all public comments, any CBI information only needs to be submitted to either one of the agencies' dockets and it will be available to the other. Following are specific instructions for submitting CBI to either agency.

EPA: Do not submit CBI to EPA through *http://www.regulations.gov* or email. Clearly mark the part or all of the information that you claim to be CBI. For CBI information in a disk or CD ROM that you mail to EPA, mark the outside of the disk or CD ROM as CBI and then identify electronically within the disk or CD ROM the specific information that is claimed as CBI. In addition to one complete version of the comment that includes information claimed as CBI, a copy of the comment that does not contain the information claimed as CBI must be submitted for inclusion in the public docket. Information so marked will not be disclosed except in accordance with procedures set forth in 40 CFR Part 2.

NHTSA: If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Chief Counsel, NHTSA, at the address given above under **FOR FURTHER INFORMATION CONTACT.** When you send a comment containing confidential business information, you should include a cover letter setting forth the information specified in our confidential business information regulation.[5]

In addition, you should submit a copy from which you have deleted the claimed confidential business information to the Docket by one of the methods set forth above.

Will the agencies consider late comments?

NHTSA and EPA will consider all comments received before the close of business on the comment closing date indicated above under DATES. To the extent practicable, we will also consider comments received after that date. If interested persons believe that any information that the agencies place in the docket after the issuance of the NPRM affects their comments, they may submit comments after the closing date concerning how the agencies should consider that information for the final rule. However, the agencies' ability to consider any such late comments in this rulemaking will be limited due to the time frame for issuing a final rule.

If a comment is received too late for us to practicably consider in developing a final rule, we will consider that comment as an informal suggestion for future rulemaking action.

How can I read the comments submitted by other people?

You may read the materials placed in the docket for this document (*e.g.,* the comments submitted in response to this document by other interested persons) at any time by going to *http://www.regulations.gov*. Follow the online instructions for accessing the dockets. You may also read the materials at the EPA Docket Center or NHTSA Docket

[3] See 49 CFR 553.21.

[4] Optical character recognition (OCR) is the process of converting an image of text, such as a scanned paper document or electronic fax file, into computer-editable text.

[5] See 49 CFR part 512.

Management Facility by going to the street addresses given above under **ADDRESSES**.

How do I participate in the public hearings?

NHTSA and EPA will jointly host three public hearings on the dates and locations described in the DATES section above. At all hearings, both agencies will accept comments on the rulemaking, and NHTSA will also accept comments on the EIS.

If you would like to present testimony at the public hearings, we ask that you notify the EPA and NHTSA contact persons listed under **FOR FURTHER INFORMATION CONTACT** at least ten days before the hearing. Once EPA and NHTSA learn how many people have registered to speak at the public hearing, we will allocate an appropriate amount of time to each participant, allowing time for lunch and necessary breaks throughout the day. For planning purposes, each speaker should anticipate speaking for approximately ten minutes, although we may need to adjust the time for each speaker if there is a large turnout. We suggest that you bring copies of your statement or other material for the EPA and NHTSA panels. It would also be helpful if you send us a copy of your statement or other materials before the hearing. To accommodate as many speakers as possible, we prefer that speakers not use technological aids (*e.g.,* audio-visuals, computer slideshows). However, if you plan to do so, you must notify the contact persons in the **FOR FURTHER INFORMATION CONTACT** section above. You also must make arrangements to provide your presentation or any other aids to NHTSA and EPA in advance of the hearing in order to facilitate set-up. In addition, we will reserve a block of time for anyone else in the audience who wants to give testimony. The agencies will assume that comments made at the hearings are directed to the NPRM unless commenters specifically reference NHTSA's EIS in oral or written testimony.

The hearing will be held at a site accessible to individuals with disabilities. Individuals who require accommodations such as sign language interpreters should contact the persons listed under **FOR FURTHER INFORMATION CONTACT** section above no later than ten days before the date of the hearing.

NHTSA and EPA will conduct the hearing informally, and technical rules of evidence will not apply. We will arrange for a written transcript of the hearing and keep the official record of the hearing open for 30 days to allow you to submit supplementary information. You may make arrangements for copies of the transcript directly with the court reporter.

Table of Contents

I. Overview of Joint EPA/NHTSA Proposed 2017–2025 National Program

Executive Summary

EPA and NHTSA are each announcing proposed rules that call for strong and coordinated Federal greenhouse gas and fuel economy standards for passenger cars, light-duty trucks, and medium-duty passenger vehicles (hereafter light-duty vehicles or LDVs). Together, these vehicle categories, which include passenger cars, sport utility vehicles, crossover utility vehicles, minivans, and pickup trucks, among others, are presently responsible for approximately 60 percent of all U.S. transportation-related greenhouse gas (GHG) emissions and fuel consumption. This proposal would extend the National Program of Federal light-duty vehicle GHG emissions and corporate average fuel economy (CAFE) standards to model years (MYs) 2017–2025. This proposed coordinated program would achieve important reductions in GHG emissions and fuel consumption from the light-duty vehicle part of the transportation sector, based on technologies that either are commercially available or that the agencies project will be commercially available in the rulemaking timeframe and that can be incorporated at a reasonable cost. Higher initial vehicle costs will be more than offset by significant fuel savings for consumers over the lives of the vehicles covered by this rulemaking.

This proposal builds on the success of the first phase of the National Program to regulate fuel economy and GHG emissions from U.S. light-duty vehicles, which established strong and coordinated standards for model years (MY) 2012–2016. As with the first phase of the National Program, collaboration with California Air Resources Board (CARB) and with automobile manufacturers and other stakeholders has been a key element in developing the agencies' proposed rules. Continuing the National Program would ensure that all manufacturers can build a single fleet of U.S. vehicles that would satisfy all requirements under both programs as well as under California's program, helping to reduce costs and regulatory complexity while providing significant energy security and environmental benefits.

Combined with the standards already in effect for MYs 2012–2016, as well as the MY 2011 CAFE standards, the proposed standards would result in MY 2025 light-duty vehicles with nearly double the fuel economy, and approximately one-half of the GHG emissions compared to MY 2010 vehicles—representing the most significant federal action ever taken to reduce GHG emissions and improve fuel economy in the U.S. EPA is proposing standards that are projected to require, on an average industry fleet wide basis, 163 grams/mile of carbon dioxide (CO_2) in model year 2025, which is equivalent to 54.5 mpg if this level were achieved solely through improvements in fuel efficiency.[6] Consistent with its statutory authority, NHTSA is proposing passenger car and light truck standards for MYs 2017–2025 in two phases. The first phase, from MYs 2017–2021, includes proposed standards that are projected to require, on an average industry fleet wide basis, 40.9 mpg in MY 2021. The second phase of the CAFE program, from MYs 2022–2025, represents conditional[7] proposed standards that are projected to require, on an average industry fleet wide basis, 49.6 mpg in model year 2025. Both the EPA and NHTSA standards are projected to be achieved through a range of technologies, including improvements in air conditioning efficiency, which reduces both GHG emissions and fuel consumption; the EPA standards also are projected to be achieved with the use of air conditioning refrigerants with a lower global warming potential (GWP), which reduce GHGs (*i.e.,* hydrofluorocarbons) but do not improve fuel economy. The agencies are proposing separate standards for passenger cars and trucks, based on a vehicle's size or ''footprint.'' For the MYs 2022–2025 standards, EPA and NHTSA are proposing a comprehensive mid-term evaluation and agency decision-making process, given both the long time frame and NHTSA's obligation to conduct a separate rulemaking in order to establish final standards for vehicles for those model years.

From a societal standpoint, this second phase of the National Program is projected to save approximately 4 billion barrels of oil and 2 billion metric tons of GHG emissions over the lifetimes of those vehicles sold in MY 2017–2025. The agencies estimate that fuel savings will far outweigh higher vehicle costs, and that the net benefits to society of the MYs 2017–2025 National Program will be in the range of $311 billion to $421 billion (7 and 3 percent discount rates, respectively) over the lifetimes of those vehicles sold in MY 2017–2025.

These proposed standards would have significant savings for consumers at the pump. Higher costs for new vehicle technology will add, on average, about $2000 for consumers who buy a new vehicle in MY 2025. Those consumers who drive their MY 2025 vehicle for its entire lifetime will save, on average, $5200 to $6600 (7 and 3 percent discount rates, respectively) in fuel savings, for a net lifetime savings of $3000 to $4400. For those consumers who purchase their new MY 2025 vehicle with cash, the discounted fuel savings will offset the higher vehicle cost in less than 4 years, and fuel savings will continue for as long as the consumer owns the vehicle. Those consumers that buy a new vehicle with a typical 5-year loan will benefit from an average monthly cash flow savings of about $12 during the loan period, or about $140 per year, on average. So the consumer would benefit beginning at the time of purchase, since the increased monthly fuel savings would more than offset the higher monthly payment due to the higher incremental vehicle cost.

The agencies have designed the proposed standards to preserve consumer choice—that is, the proposed standards should not affect consumers' opportunity to purchase the size of vehicle with the performance, utility and safety features that meets their needs. The standards are based on a vehicle's size, or footprint—that is, consistent with their general performance and utility needs, larger vehicles have numerically less stringent fuel economy/GHG emissions targets and smaller vehicles have more stringent fuel economy/GHG emissions targets, although since the standards are fleet average standards, no specific vehicle *must* meet a target. Thus, consumers will be able to continue to choose from the same mix of vehicles that are currently in the marketplace.

The agencies' believe there is a wide range of technologies available for manufacturers to consider in reducing GHG emissions and improving fuel economy. The proposals allow for long-term planning by manufacturers and suppliers for the continued development and deployment across their fleets of fuel saving and emissions-reducing technologies. The agencies believe that advances in gasoline engines and transmissions will continue for the foreseeable future, and that there will be continual improvement in other technologies, including vehicle weight reduction, lower tire rolling resistance, improvements in vehicle aerodynamics, diesel engines, and more efficient vehicle accessories. The agencies also expect to see increased electrification of the fleet through the expanded production of stop/start, hybrid, plug-in hybrid and electric vehicles. Finally, the agencies expect that vehicle air conditioners will continue to improve by becoming more efficient and by increasing the use of alternative refrigerants. Many of these technologies are already available today, and manufacturers will be able to meet the standards through significant efficiency improvements in these technologies, as well as a significant penetration of these and other technologies across the fleet. Auto manufacturers may also introduce new technologies that we have not considered for this rulemaking analysis, which could make possible alternative, more cost-effective paths to compliance.

A. Introduction

1. Continuation of the National Program

EPA and NHTSA are each announcing proposed rules that call for strong and coordinated Federal greenhouse gas and fuel economy standards for passenger cars, light-duty trucks, and medium-duty passenger vehicles (hereafter light-duty vehicles or LDVs). Together, these vehicle categories, which include passenger cars, sport utility vehicles, crossover utility vehicles, minivans, and pickup trucks, are presently responsible for approximately 60 percent of all U.S. transportation-related greenhouse gas emissions and fuel consumption. The proposal would extend the National Program of Federal light-duty vehicle greenhouse gas (GHG) emissions and corporate average fuel economy (CAFE) standards to model years (MYs) 2017–2025. The coordinated program being proposed would achieve important reductions of greenhouse gas (GHG) emissions and fuel consumption from the light-duty vehicle part of the

[6] Real-world CO_2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower than the CO_2 and CAFE compliance values discussed here. The reference to CO_2 here refers to CO_2 equivalent reductions, as this included some degree of reductions in greenhouse gases other than CO_2, as one part of the air conditioning related reductions.

[7] By ''conditional,'' NHTSA means to say that the proposed standards for MYs 2022–2025 represent the agency's current best estimate of what levels of stringency would be maximum feasible in those model years, but in order for the standards for those model years to be legally binding a subsequent rulemaking must be undertaken by the agency at a later time. *See* Section IV for more information.

transportation sector, based on technologies that either are commercially available or that the agencies project will be commercially available in the rulemaking timeframe and that can be incorporated at a reasonable cost.

In working together to develop the next round of standards for MYs 2017–2025, NHTSA and EPA are building on the success of the first phase of the National Program to regulate fuel economy and GHG emissions from U.S. light-duty vehicles, which established the strong and coordinated standards for model years (MY) 2012–2016. As for the MYs 2012–2016 rulemaking, collaboration with California Air Resources Board (CARB) and with industry and other stakeholders has been a key element in developing the agencies' proposed rules. Continuing the National Program would ensure that all manufacturers can build a single fleet of U.S. vehicles that would satisfy all requirements under both programs as well as under California's program, helping to reduce costs and regulatory complexity while providing significant energy security and environmental benefits.

The agencies have been developing the basis for these joint proposed standards almost since the conclusion of the rulemaking establishing the first phase of the National Program. After much research and deliberation by the agencies, along with CARB and other stakeholders, President Obama announced plans for these proposed rules on July 29, 2011 and NHTSA and EPA issued a Supplemental Notice of Intent (NOI) outlining the agencies' plans for proposing the MY 2017–2025 standards and program.[8] This July NOI built upon the extensive analysis conducted by the agencies over the past year, including an initial technical assessment report and NOI issued in September 2010, and a supplemental NOI issued in December 2010 (discussed further below). The State of California and thirteen auto manufacturers representing over 90 percent of U.S. vehicle sales provided letters of support for the program concurrent with the Supplemental NOI.[9] The United Auto Workers (UAW) also supported the announcement,[10] as well as many consumer and environmental groups. As envisioned in the Presidential announcement and Supplemental NOI, this proposal sets forth proposed MYs 2017–2025 standards as well as detailed supporting analysis for those standards and regulatory alternatives for public review and comment. The program that the agencies are proposing will spur the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will, in turn, spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment. Consistent with Executive Order 13563, this proposal was developed with early consultation with stakeholders, employs flexible regulatory approaches to reduce burdens, maintains freedom of choice for the public, and helps to harmonize federal and state regulations.

As described below, NHTSA and EPA are proposing a continuation of the National Program that the agencies believe represents the appropriate levels of fuel economy and GHG emissions standards for model years 2017–2025, given the technologies that the agencies anticipate will be available for use on these vehicles and the agencies' understanding of the cost and manufacturers' ability to apply these technologies during that time frame, and consideration of other relevant factors. Under this joint rulemaking, EPA is proposing GHG emissions standards under the Clean Air Act (CAA), and NHTSA is proposing CAFE standards under EPCA, as amended by the Energy Independence and Security Act of 2007 (EISA). This joint rulemaking proposal reflects a carefully coordinated and harmonized approach to implementing these two statutes, in accordance with all substantive and procedural requirements imposed by law.[11]

The proposed approach allows for long-term planning by manufacturers and suppliers for the continued development and deployment across their fleets of fuel saving and emissions-reducing technologies. NHTSA's and EPA's technology assessment indicates there is a wide range of technologies available for manufacturers to consider in reducing GHG emissions and improving fuel economy. The agencies believe that advances in gasoline engines and transmissions will continue for the foreseeable future, which is a view that is supported in the literature and amongst the vehicle manufacturers and suppliers.[12] The agencies also believe that there will be continual improvement in other technologies including reductions in vehicle weight, lower tire rolling resistance, improvements in vehicle aerodynamics, diesel engines, and more efficient vehicle accessories. The agencies also expect to see increased electrification of the fleet through the expanded production of stop/start, hybrid, plug-in hybrid and electric vehicles.[13] Finally, the agencies expect that vehicle air conditioners will continue to improve by becoming more efficient and by increasing the use of alternative refrigerants. Many of these technologies are already available today, and EPA's and NHTSA's assessments are that manufacturers will be able to meet the standards through significant efficiency improvements in these technologies as well as a significant penetration of these and other technologies across the fleet. We project that these potential compliance pathways for manufacturers will result in significant benefits to consumers and to society, as quantified below. Manufacturers may also introduce new technologies that we have not considered for this rulemaking analysis, which could make possible alternative, more cost-effective paths to compliance.

As discussed further below, as with the standards for MYs 2012–2016, the agencies believe that the proposed standards would continue to preserve consumer choice, that is, the proposed standards should not affect consumers' opportunity to purchase the size of vehicle that meets their needs. NHTSA and EPA are proposing to continue standards based on vehicle footprint, where smaller vehicles have relatively more stringent standards, and larger vehicles have less stringent standards, so there should not be a significant effect on the relative availability of different size vehicles in the fleet.

[8] 76 FR 48758 (August 9, 2011).

[9] Commitment letters are available at *http://www.epa.gov/otaq/climate/regulations.htm* and at *http://www.nhtsa.gov/fuel-economy* (last accessed Aug. 24, 2011).

[10] The UAW's support was expressed in a statement on July 29, 2011, which can be found at *http://www.uaw.org/articles/uaw-supports-administration-proposal-light-duty-vehicle-cafe-and-greenhouse-gas-emissions-r* (last accessed September 19, 2011).

[11] For NHTSA, this includes the requirements of the National Environmental Policy Act (NEPA).

[12] There are a number of competing gasoline engine technologies, with one in particular that the agencies project will be common beyond 2016. This is the gasoline direct injection and downsized engines equipped with turbochargers and cooled exhaust gas recirculation, which has performance characteristics similar to that of larger, less efficient engines. Paired with these engines, the agencies project that advanced transmissions (such as automatic and dual clutch transmissions with eight forward speeds) and higher efficiency gearboxes will provide significant improvements. Transmissions with eight or more speeds can be found in the fleet today in very limited production, and while they are expected to penetrate further by 2016, we anticipate that by 2025 these will be the dominant transmissions in new vehicle sales.

[13] For example, while today less than three percent of annual vehicle sales are strong hybrids, plug-in hybrids and all electric vehicles, by 2025 we estimate these technologies could represent nearly 15 percent of new sales.

Additionally, as with the standards for MYs 2012–2016, the agencies believe that the proposed standards should not have a negative effect on vehicle safety, as it relates to vehicle footprint and mass as described in Section II.C and II.G below, respectively.

We note that as part of this rulemaking, given the long time frame at issue in setting standards for MY 2022–2025 light-duty vehicles, the agencies are discussing a comprehensive mid-term evaluation and agency decision-making process. NHTSA has a statutory obligation to conduct a separate de novo rulemaking in order to establish final standards for vehicles for the 2022–2025 model years and would conduct the mid-term evaluation as part of that rulemaking, and EPA is proposing regulations that address the mid-term evaluation. The mid-term evaluation will assess the appropriateness of the MY 2022–2025 standards considered in this rulemaking, based on an updated assessment of all the factors considered in setting the standards and the impacts of those factors on the manufacturers' ability to comply. NHTSA and EPA fully expect to conduct this mid-term evaluation in coordination with the California Air Resources Board, given our interest in a maintaining a National Program to address GHGs and fuel economy. Further discussion of the mid-term evaluation is found later in this section, as well as in Sections III and IV.

Based on the agencies' analysis, the National Program standards being proposed are currently projected to reduce GHGs by approximately 2 billion metric tons and save 4 billion barrels of oil over the lifetime of MYs 2017–2025 vehicles relative to the MY 2016 standard curves [14] already in place. The average cost for a MY 2025 vehicle to meet the standards is estimated to be about $2,000 compared to a vehicle that would meet the level of the MY 2016 standards in MY 2025. However, fuel savings for consumers are expected to more than offset the higher vehicle costs. The typical driver would save a total of $5,200 to $6,600 (7 percent and 3 percent discount rate, respectively) in fuel costs over the lifetime of a MY 2025 vehicle and, even after accounting for the higher vehicle cost, consumers would save a net $3,000 to $4,400 (7 percent and 3 percent discount rate, respectively) over the vehicle's lifetime. Further, consumers who buy new vehicles with cash would save enough in lower fuel costs after less than 4 years (at either 7 percent or 3 percent discount rate) of owning a MY 2025 vehicle to offset the higher upfront vehicle costs, while consumers who buy with a 5-year loan would save more each month on fuel than the increased amount they would spend on the higher monthly loan payment, beginning in the first month of ownership.

Continuing the National Program has both energy security and climate change benefits. Climate change is widely viewed as a significant long-term threat to the global environment. EPA has found that elevated atmospheric concentrations of six greenhouse gases—carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perflurocarbons, and sulfur hexafluoride—taken in combination endanger both the public health and the public welfare of current and future generations. EPA further found that the combined emissions of these greenhouse gases from new motor vehicles and new motor vehicle engines contribute to the greenhouse gas air pollution that endangers public health and welfare. 74 FR 66496 (Dec. 15, 2009). As summarized in EPA's Endangerment and Cause or Contribute Findings under Section 202(a) of the Clear Air Act, anthropogenic emissions of GHGs are very likely (90 to 99 percent probability) the cause of most of the observed global warming over the last 50 years.[15] Mobile sources emitted 31 percent of all U.S. GHGs in 2007 (transportation sources, which do not include certain off-highway sources, account for 28 percent) and have been the fastest-growing source of U.S. GHGs since 1990.[16] Mobile sources addressed in the endangerment and contribution findings under CAA section 202(a)—light-duty vehicles, heavy-duty trucks, buses, and motorcycles—accounted for 23 percent of all U.S. GHG in 2007.[17] Light-duty vehicles emit CO_2, methane, nitrous oxide, and hydrofluorocarbons and are responsible for nearly 60 percent of all mobile source GHGs and over 70 percent of Section 202(a) mobile source GHGs. For light-duty vehicles in 2007, CO_2 emissions represent about 94 percent of all greenhouse emissions (including HFCs), and the CO_2 emissions measured over the EPA tests used for fuel economy compliance represent about 90 percent of total light-duty vehicle GHG emissions.[18 19]

Improving our energy and national security by reducing our dependence on foreign oil has been a national objective since the first oil price shocks in the 1970s. Net petroleum imports accounted for approximately 51 percent of U.S. petroleum consumption in 2009.[20] World crude oil production is highly concentrated, exacerbating the risks of supply disruptions and price shocks as the recent unrest in North Africa and the Persian Gulf highlights. Recent tight global oil markets led to prices over $100 per barrel, with gasoline reaching as high as $4 per gallon in many parts of the U.S., causing financial hardship for many families and businesses. The export of U.S. assets for oil imports continues to be an important component of the historically unprecedented U.S. trade deficits. Transportation accounted for about 71 percent of U.S. petroleum consumption in 2009.[21] Light-duty vehicles account for about 60 percent of transportation oil use, which means that they alone account for about 40 percent of all U.S. oil consumption.

The automotive market is becoming increasingly global. The U.S. auto companies and U.S. suppliers produce and sell automobiles and automotive components around the world, and foreign auto companies produce and sell in the U.S. As a result, the industry has become increasingly competitive. Staying at the cutting edge of automotive technology while maintaining profitability and consumer acceptance has become increasingly important for the sustainability of auto companies. The proposed standards cover model years 2017–2025 for passenger cars and light-duty trucks sold in the United States. Many other countries and regions around the world have in place fuel economy or CO_2

[14] The calculation of GHG reductions and oil savings is relative to a future in which the MY 2016 standards remain in place for MYs 2017–2025 and manufacturers comply on average at those levels.

[15] 74 FR 66,496,–66,518, December 18, 2009; ''Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act'' Docket: EPA–HQ–OAR–2009–0472–11292, *http://epa.gov/climatechange/endangerment.html*.

[16] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007. EPA 430–R–09–004. Available at *http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf*.

[17] U.S. EPA. 2009 Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC. pp. 180–194. Available at *http://epa.gov/climatechange/endangerment/downloads/Endangerment%20TSD.pdf*.

[18] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007. EPA 430–R–09–004. Available at *http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf*.

[19] U.S. Environmental Protection Agency. RIA, Chapter 2.

[20] Energy Information Administration, ''How dependent are we on foreign oil?'' *Available at http://www.eia.gov/energy_in_brief/foreign_oil_dependence.cfm* (last accessed August 28, 2011).

[21] Energy Information Administration, Annual Energy Outlook 2011, ''Oil/Liquids.'' *Available at http://www.eia.gov/forecasts/aeo/MT_liquidfuels.cfm* (last accessed August 28, 2011).

emission standards for light-duty vehicles. In addition, the European Union is currently discussing more stringent CO_2 standards for 2020, and the Japanese government has recently issued a draft proposal for new fuel efficiency standards for 2020. The overall trend is clear—globally many of the major economic countries are increasing the stringency of their fuel economy or CO_2 emission standards for light-duty vehicles. When considering this common trend, the proposed CAFE and CO_2 standards for MY 2017–2025 may offer some advantages for U.S.-based automotive companies and suppliers. In order to comply with the proposed standards, U.S. firms will need to invest significant research and development dollars and capital in order to develop and produce the technologies needed to reduce CO_2 emissions and improve fuel economy. Companies have limited budgets for research and development programs. As automakers seek greater commonality across the vehicles they produce for the domestic and foreign markets, improving fuel economy and reducing GHGs in U.S. vehicles should have spillovers to foreign production, and vice versa, thus yielding the ability to amortize investment in research and production over a broader product and geographic spectrum. To the extent that the technologies needed to meet the standards contained in this proposal can also be used to comply with the fuel economy and CO_2 standards in other countries, this can help U.S. firms in the global automotive market, as the U.S. firms will be able to focus their available research and development funds on a common set of technologies that can be used both domestically as well as internationally.

2. Additional Background on the National Program

Following the successful adoption of a National Program of federal standards for greenhouse gas emissions (GHG) and fuel economy standards for model years (MY) 2012–2016 light duty vehicles, President Obama issued a Memorandum on May 21, 2010 requesting that the National Highway Traffic Safety Administration (NHTSA), on behalf of the Department of Transportation, and the Environmental Protection Agency (EPA) work together to develop a national program for model years 2017–2025. Specifically, he requested that the agencies develop ''* * * *a coordinated national program under the CAA [Clean Air Act] and the EISA [Energy Independence and Security Act of 2007] to improve fuel efficiency and to reduce greenhouse gas emissions of passenger cars and light-duty trucks of model years 2017–2025.''*[22] The President recognized that our country could take a leadership role in addressing the global challenges of improving energy security and reducing greenhouse gas pollution, stating that *''America has the opportunity to lead the world in the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment.''*

The Presidential Memorandum stated ''*The program should also seek to achieve substantial annual progress in reducing transportation sector greenhouse gas emissions and fossil fuel consumption, consistent with my Administration's overall energy and climate security goals, through the increased domestic production and use of existing, advanced, and emerging technologies, and should strengthen the industry and enhance job creation in the United States.''* Among other things, the agencies were tasked with researching and then developing standards for MYs 2017 through 2025 that would be appropriate and consistent with EPA's and NHTSA's respective statutory authorities, in order to continue to guide the automotive sector along the road to reducing its fuel consumption and GHG emissions, thereby ensuring corresponding energy security and environmental benefits. During the public comment period for the MY 2012–2016 proposed rulemaking, many stakeholders, including automakers, encouraged NHTSA and EPA to begin working toward standards for MY 2017 and beyond in order to maintain a single nationwide program. Several major automobile manufacturers and CARB sent letters to EPA and NHTSA in support of a MYs 2017 to 2025 rulemaking initiative as outlined in the President's May 21, 2010 announcement.[23]

The President's memo requested that the agencies, ''work with the State of California to develop by September 1, 2010, a technical assessment to inform the rulemaking process * * *.'' As a first step in responding to the President's request, the agencies collaborated with CARB to prepare an Interim Joint Technical Assessment Report (TAR) to inform the rulemaking process and provide an initial technical assessment for that work. NHTSA, EPA, and CARB issued the joint Technical Assessment Report consistent with Section 2(a) of the Presidential Memorandum.[24] In developing the technical assessment, EPA, NHTSA, and CARB held numerous meetings with a wide variety of stakeholders including the automobile original equipment manufacturers (OEMs), automotive suppliers, non-governmental organizations, states and local governments, infrastructure providers, and labor unions. The Interim Joint TAR provided an overview of key stakeholder input, addressed other topics noted in the Presidential memorandum, and EPA's and NHTSA's initial assessment of benefits and costs of a range of stringencies of future standards.

In accordance with the Presidential Memorandum, NHTSA and EPA also issued a joint Notice of Intent to Issue a Proposed Rulemaking (NOI).[25] The September 2010 NOI highlighted the results of the analyses contained in the Interim Joint TAR, provided an overview of key program design elements, and announced plans for initiating the joint rulemaking to improve the fuel efficiency and reduce the GHG emissions of passenger cars and light-duty trucks built in MYs 2017–2025. The agencies requested comments on the September NOI and accompanying Interim Joint TAR.

The Interim Joint TAR contained an initial fleet-wide analysis of improvements in overall average GHG emissions and equivalent fuel economy

[22] The Presidential Memorandum is found at: *http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards*. For the reader's reference, the President also requested the Administrators of EPA and NHTSA to issue joint rules under the CAA and EISA to establish fuel efficiency and greenhouse gas emissions standards for commercial medium-and heavy-duty on-highway vehicles and work trucks beginning with the 2014 model year. The agencies recently promulgated final GHG and fuel efficiency standards for heavy duty vehicles and engines for MYs 2014–2018. 76 FR 57106 (September 15, 2011).

[23] These letters of support in response to the May 21, 2010 Presidential Memorandum are available at *http://www.epa.gov/otaq/climate/regulations.htm#prez* and *http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Stakeholder+Commitment+Letters* (last accessed August 28, 2011).

[24] This Interim Joint Technical Assessment Report (TAR) is available at *http://www.epa.gov/otaq/climate/regulations/ldv-ghg-tar.pdf* and *http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017+CAFE–GHG_Interim_TAR2.pdf.*Section 2(a) of the Presidential Memorandum requested that EPA and NHTSA ''Work with the State of California to develop by September 1, 2010, a technical assessment to inform the rulemaking process, reflecting input from an array of stakeholders on relevant factors, including viable technologies, costs, benefits, lead time to develop and deploy new and emerging technologies, incentives and other flexibilities to encourage development and deployment of new and emerging technologies, impacts on jobs and the automotive manufacturing base in the United States, and infrastructure for advanced vehicle technologies.''

[25] 75 FR 62739, October 13, 2010.

levels. For purposes of an initial assessment, this range was intended to represent a reasonably broad range of stringency increases for potential future GHG emissions standards, and was also consistent with the increases suggested by CARB in its letter of commitment in response to the President's memorandum.[26 27] The TAR evaluated a range of potential stringency scenarios through model year 2025, representing a 3, 4, 5, and 6 percent per year estimated decrease in GHG levels from a model year 2016 fleet-wide average of 250 gram/mile (g/mi). Thus, the model year 2025 scenarios analyzed in the Interim Joint TAR ranged from 190 g/mi on an estimated fleet-wide average (calculated to be equivalent to 47 miles per gallon, mpg, if all improvements were made with fuel economy-improving technologies) under the 3 percent per year reduction scenario, to 143 g/mi on an estimated fleet-wide average (calculated to be equivalent to 62 mpg, if all improvements were made with fuel economy-improving technologies) under the 6 percent per year scenario.[28] For each of these scenarios, the TAR also evaluated four pre-defined "technological pathways" by which these levels could be attained. These pathways were meant to represent ways that the industry as a whole could increase fuel economy and reduce greenhouse gas emissions, and did not represent ways that individual manufacturers would be required to or necessarily would employ in responding to future standards. Each defined technology pathway emphasized a different mix of advanced technologies, by assuming various degrees of penetration of advanced gasoline technologies, mass reduction, hybrid electric vehicles (HEVs), plug-in hybrids (PHEVs), and electric vehicles (EVs).

Manufacturers and others commented extensively on the NOI and Interim Joint TAR on a variety of topics, including the stringency of the standards, program design elements, the effect of potential standards on vehicle safety, and the TAR's discussion of technology costs, effectiveness, and feasibility. In response, the agencies and CARB spent the next several months continuing to gather information from the industry and others in response to the agencies' initial analytical efforts. To aid the public's understanding of some of the key issues facing the agencies in developing the proposed rule, EPA and NHTSA also issued a follow-on Supplemental NOI in November 2010.[29] The Supplemental NOI highlighted many of the key comments the agencies received in response to the September NOI and Interim Joint TAR, and summarized some of the key themes from the comments and the additional stakeholder meetings. We note, as highlighted in the November Supplemental NOI, that there continued to be widespread stakeholder support for continuing the National Program for improved fuel economy and greenhouse gas standards for model years 2017–2025. The November Supplemental NOI also provided an overview of many of the key technical analyses the agencies planned in support the proposed rule.

After issuing the November 2010 Supplemental NOI, EPA, NHTSA and CARB continued studies on technology cost and effectiveness and more in-depth and comprehensive analysis of the issues. In addition to this work, the agencies continued meeting with stakeholders, including with manufacturers, manufacturer organizations, automotive suppliers, a labor union, environmental groups, consumer interest groups, and investment organizations. As discussed above, on July 29, 2011 President Obama announced plans for these proposed rules and NHTSA and EPA issued a Supplemental Notice of Intent (NOI) outlining the agencies' plans for proposing the MY 2017–2025 standards and program.

3. California's Greenhouse Gas Program

In 2004, the California Air Resources Board (CARB) approved standards for new light-duty vehicles, regulating the emission of CO_2 and other GHGs. Thirteen states and the District of Columbia, comprising approximately 40 percent of the light-duty vehicle market, adopted California's standards. On June 30, 2009, EPA granted California's request for a waiver of preemption under the CAA with respect to these standards.[30] The granting of the waiver permits California and the other states to proceed with implementing the California emission standards for MYs 2009–2016. After EPA and NHTSA issued their MYs 2012–2016 standards, CARB revised its program such that compliance with the EPA greenhouse gas standards will be deemed to be compliance with California's GHG standards.[31] This facilitates the National Program by allowing manufacturers to meet all of the standards with a single national fleet.

As requested by the President and in the interest of maximizing regulatory harmonization, NHTSA and EPA have worked closely with CARB throughout the development of this proposal to develop a common technical basis. CARB is releasing a proposal for MY 2017–2025 GHG emissions standards which are consistent with the standards being proposed by EPA and NHTSA. CARB recognizes the benefit for the country of continuing the National Program and plans an approach similar to the one taken for MYs 2012–2016. CARB has committed to propose to revise its GHG emissions standards for MY 2017 and later such that compliance with EPA GHG emissions standards shall be deemed compliance with the California GHG emissions standards, as long as EPA's final GHG standards are substantially as described in the July 2011 Supplemental NOI.[32]

4. Stakeholder Engagement

On July 29, 2010, President Obama announced the support of thirteen major automakers to pursue the next phase in the Administration's national vehicle program, increasing fuel economy and reducing GHG emissions for passenger cars and light trucks built in MYs 2017–2025.[33] The President was joined by Ford, GM, Chrysler, BMW, Honda, Hyundai, Jaguar/Land Rover, Kia, Mazda, Mitsubishi, Nissan, Toyota and Volvo, which together account for over 90 percent of all vehicles sold in the United States. The California Air Resources Board (CARB), the United Auto Workers (UAW) and a number of

[26] 75 FR at 62744–45.

[27] Statement of the California Air Resources Board Regarding Future Passenger Vehicle Greenhouse Gas Emissions Standards, California Air Resources Board, May 21, 2010. Available at: *http://www.epa.gov/otaq/climate/regulations.htm.*

[28] These levels correspond to on-road values of 37 to 50 mpg, respectively, recognizing that on-road fuel economy tends to be about 20 percent worse than calculated mpg values based on the CAFE test cycle. We note, however, that because these mpg values are translated from CO_2e values that include reductions in hydrofluorocarbon (HFC) leakage due to use of advanced refrigerants and leakage improvements, therefore these numbers are not as representative of either CAFE test cycle or real-world mpg.

[29] 75 FR 76337, December 8, 2010.

[30] 74 FR 32744 (July 8, 2009). See also *Chamber of Commerce* v. *EPA,* 642 F.3d 192 (DC Cir. 2011) (dismissing petitions for review challenging EPA's grant of the waiver).

[31] See "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles as approved by OAL," March 29, 2010. *Available at http://www.arb.ca.gov/regact/2010/ghgpv10/oaltp.pdf* (last accessed August 28, 2011).

[32] See State of California July 28, 2011 letter available at: *http://www.epa.gov/otaq/climate/regulations.htm.*

[33] The President's remarks are available at *http://www.whitehouse.gov/the-press-office/2011/07/29/remarks-president-fuel-efficiency-standards*; see also *http://www.nhtsa.gov/fuel-economy* for more information from the agency about the announcement.

environmental and consumer groups, also announced their support.

On the same day as the President's announcement, the agencies released a second SNOI (published in the **Federal Register** on August 9, 2011) generally describing the joint proposal that the EPA and NHTSA expected to issue to establish the National Program for model years 2017–2025, and which is set forth in this NPRM. The agencies explained that the proposal would be developed based on extensive technical analyses, an examination of the factors required under their respective statutes and discussions with and input from individual motor vehicle manufacturers and other stakeholders. The input of stakeholders, which is encouraged by Executive Order 13563, has been invaluable to the agencies in developing today's NPRM.

For background, as discussed above, after publishing the Supplemental NOI on December 8, 2010 (the December 8 SNOI), NHTSA, EPA and CARB continued studies and conducted more in-depth and comprehensive rulemaking analyses related to technology cost and effectiveness, technological feasibility, reasonable timing for manufacturers to implement technologies, and economic factors, and other relevant considerations. In addition to this ongoing and more in-depth work, the agencies continued meeting with stakeholders and received additional input and feedback to help inform the rulemaking. Meetings were held with and relevant information was obtained from manufacturers, manufacturer organizations, suppliers, a labor union, environmental groups, consumer interest groups, and investment organizations.

This section summarizes NHTSA and EPA stakeholder engagement between December 2010 and July 29, 2011, the date on which President Obama announced the agencies' plans for proposing standards for MY2017–2025, and the support of thirteen major automakers and other stakeholders for these plans.[34] Information that the agencies presented to stakeholders is posted in the docket and referenced in multiple places in this section.

The agencies' engagement with the large and diverse group of stakeholders described above between December 2010 and July 29, 2011 shared the single aim of ensuring that the agencies possessed the most complete and comprehensive set of information possible to inform the proposed rulemaking.

Throughout this period, the stakeholders repeated many of the broad concerns and suggestions described in the TAR, NOI, and December 8 SNOI. For example, stakeholders uniformly expressed interest in maintaining a harmonized and coordinated national program that would be supported by CARB and allow auto makers to build one fleet and preserve consumer choice. The stakeholders also raised concerns about potential stringency levels, consumer acceptance of some advanced technologies and the potential structure of compliance flexibilities available under EPCA (as amended by EISA) and the CAA. In addition, most of the stakeholders wanted to discuss issues concerning technology availability, cost and effectiveness and economic practicability. The auto manufacturers, in particular, sought to provide the agencies with a better understanding of their respective strategies (and associated costs) for improving fuel economy while satisfying consumer demand in the coming years. Additionally, some stakeholders expressed concern about potential safety impacts associated with the standards, consumer costs and consumer acceptance, and potential disparate treatment of cars and trucks. Some stakeholders also stressed the importance of investing in infrastructure to support more widespread deployment of alternative vehicles and fuels. Many stakeholders also asked the agencies to acknowledge prevailing economic uncertainties in developing proposed standards. In addition, many stakeholders discussed the number of years to be covered by the program and what they considered to be important features of a mid-term review of any standards set or proposed for MY 2022–2025. In all of these meetings, NHTSA and EPA sought additional data and information from the stakeholders that would allow them to refine their initial analyses and determine proposed standards that are consistent with the agencies' respective statutory and regulatory requirements. The general issues raised by those stakeholders are addressed in the sections of this NPRM discussing the topics to which the issues pertain (*e.g.,* the form of the standards, technology cost and effectiveness, safety impacts, impact on U.S. vehicle sales and other economic considerations, costs and benefits).

The first stage of the meetings occurred between December 2010 and June 20, 2011. These meetings covered topics that were generally similar to the meetings that were held prior to the publication of the December 8 Supplemental NOI and that were summarized in the Supplemental NOI. The manufacturers provided the agencies with additional information related to their product plans for vehicle models and fuel efficiency improving technologies and associated cost estimates. Detailed product plans generally extend only five or six model years into the future. Manufacturers also provided estimates of the amount of improvement in CAFE and CO_2 emissions they could reasonably achieve in model MYs 2017–2025; feedback on the shape of MY 2012–2016 regulatory stringency curves and curve cut points, regulatory program flexibilities; recommendations for and on the structure of one or more mid-term reviews of the later model year standards; estimates of the cost, effectiveness and availability of some fuel efficiency improving technologies; and feedback on some of the cost and effectiveness assumptions used in the TAR analysis. In addition, manufacturers provided input on manufacturer experience with consumer acceptance of some advanced technologies and raised concerns over consumer acceptance if higher penetration of these technologies were needed in the future, consumer's willingness to pay for improved fuel economy, and ideas on enablers and incentives that would increase consumer acceptance. Many manufacturers stated that technology is available to significantly improve fuel economy and CO_2 emissions; however, they maintained that the biggest challenges relate to the cost of the technologies, consumer willingness to pay and consumer acceptance.

During this first phase NHTSA and EPA continued to meet with other stakeholders, who provided their own perspectives on issues of importance to them. They also provided data to the extent available to them. Information obtained from stakeholders during this phase is contained in the docket.

The second stage of meetings occurred between June 21, 2011 and July 14, 2011, during which time EPA, NHTSA, CARB and several White House Offices kicked-off an intensive series of meetings, primarily with manufacturers, to share tentative regulatory concepts developed by EPA, NHTSA and CARB, which included concept stringency curves and program flexibilities based on the analyses completed by the agencies as of June 21,[35] and requested

[34] NHTSA has prepared a list of stakeholder meeting dates and participants, found in a memorandum to the docket, titled ''2017–2025 CAFE Stakeholders Meetings List,'' at NHTSA–2010–0131.

[35] The agencies consider a range of standards that may satisfy applicable legal criteria, taking into account the complete record before them . The

feedback.[36] In particular, the agencies requested that the manufacturers provide detailed and reliable information on how they might comply with the concepts and, if they projected they could not comply, information supporting their belief that they would be unable to comply. Additionally, EPA and NHTSA sought detailed input from the manufacturers regarding potential changes to the concept stringency levels and program flexibilities available under EPA's and NHTSA's respective authority that might facilitate compliance. In addition, manufacturers provided input related to consumer acceptance and adoption of some advanced technologies and program costs based on their independent assessments or information previously submitted to the agencies.

In these second stage meetings, the agencies received considerable input from the manufacturers. The agencies carefully considered the manufacturer information along with information from the agencies' independent analyses. The agencies used all available information to refine their assessment of the range of program concept stringencies and provisions that the agencies determined were consistent with their statutory mandates.

The third stage of meetings occurred between July 15, 2011 and July 28, 2011. During this time period the agencies continued to refine concept stringencies and compliance flexibilities based on further consideration of the information available to them. They also met with approximately 13 manufacturers who expressed ongoing interest in engaging with the agencies.[37]

Throughout all three stages, EPA and NHTSA continued to engage other stakeholders to ensure that the agencies were obtaining the most comprehensive and reliable information possible to guide the agencies in developing proposed standards for MY 2017–2025. Many of these stakeholders reiterated comments previously presented to the agencies. For instance, environmental organizations consistently stated that stringent standards are technically achievable and critical to important national interests, such as improving energy independence, reducing climate change, and enabling the domestic automobile industry to remain competitive in the global market. Labor interests stressed the need to carefully consider economic impacts and the opportunity to create and support new jobs, and consumer advocates emphasized the economic and practical benefits to consumers of improved fuel economy and the need to preserve consumer choice. In addition, a number of stakeholders stated that the standards under development should not have an adverse impact on safety.

On July 29, 2011, EPA and NHTSA the agencies issued a new SNOI with concept stringency curves and program provisions based on refined analyses and further consideration of the record before the agencies. The agencies have received letters of support for the concepts laid out in the SNOI from BMW, Chrysler, Ford, General Motors, Global Automakers, Honda, Hyundai, Jaguar Land Rover, Kia, Mazda, Mitsubishi, Nissan, Toyota, Volvo and CARB. Numerous other stakeholders, including labor, environmental and consumer groups, have expressed their support for the agencies' plans to move forward.

The agencies have considered all of this stakeholder input in developing this proposal, and look forward to continuing the productive dialogue through the comment period following this proposal.

B. Summary of the Proposed 2017–2025 National Program

1. Joint Analytical Approach

This proposed rulemaking continues the collaborative analytical effort between NHTSA and EPA, which began with the MYs 2012–2016 rulemaking. NHTSA and EPA have worked together, and in close coordination with CARB, on nearly every aspect of the technical analysis supporting these joint proposed rules. The results of this collaboration are reflected in the elements of the respective NHTSA and EPA proposed rules, as well as in the analytical work contained in the Draft Joint NHTSA and EPA Technical Support Document (Joint TSD). The agencies have continued to develop and refine supporting analyses since issuing the NOI and Interim Joint TAR last September. The Joint TSD, in particular, describes important details of the analytical work that are common, as well as highlighting any key differences in approach. The joint analyses include the build-up of the baseline and reference fleets, the derivation of the shape of the footprint-based attribute curves that define the agencies' respective standards, a detailed description of the estimated costs and effectiveness of the technologies that are available to vehicle manufacturers, the economic inputs used to calculate the costs and benefits of the proposed rules, a description of air conditioner and other off-cycle technologies, and the agencies' assessment of the effects of the proposed standards on vehicle safety. This comprehensive joint analytical approach has provided a sound and consistent technical basis for both agencies in developing their proposed standards, which are summarized in the sections below.

2. Level of the Standards

EPA and NHTSA are each proposing two separate sets of standards, each under its respective statutory authorities. Both the proposed CO_2 and CAFE standards for passenger cars and light trucks would be footprint-based, similar to the standards currently in effect through model year 2016, and would become more stringent on average in each model year from 2017 through 2025. The basis for measuring performance relative to standards would continue to be based predominantly on the EPA city and highway test cycles (2-cycle test). However, EPA is proposing optional air conditioning and off-cycle credits for the GHG program and adjustments to calculated fuel economy for the CAFE programs that would be based on test procedures other than the 2-cycle tests.

EPA is proposing standards that are projected to require, on an average industry fleet wide basis, 163 grams/mile of CO_2 in model year 2025. This is projected to be achieved through improvements in fuel efficiency with some additional reductions achieved through reductions in non-CO_2 GHG emissions from reduced AC system leakage and the use of lower global warming potential (GWP) refrigerants. The level of 163 grams/mile CO_2 would be equivalent on a mpg basis to 54.5 mpg, if this level was achieved solely through improvements in fuel efficiency.[38]

For passenger cars, the CO_2 compliance values associated with the footprint curves would be reduced on average by 5 percent per year from the model year 2016 projected passenger car industry-wide compliance level through model year 2025. In recognition of manufacturers' unique challenges in improving the fuel economy and GHG emissions of full-size pickup trucks as we transition from the MY 2016

initial concepts shared with stakeholders were within the range the agencies were considering, based on the information then available to the agencies.

[36] ''Agency Materials Provided to Manufacturers'' Memo to docket NHTSA–2010–0131.

[37] ''Agency Materials Provided to Manufacturers'' Memo to docket NHTSA–2010–0131.

[38] Real-world CO_2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower than the CO2 and CAFE values discussed here. The reference to CO_2 here refers to CO_2 equivalent reductions, as this included some degree of reductions in greenhouse gases other than CO_2, as one part of the AC related reductions.

standards to MY 2017 and later, while preserving the utility (*e.g.,* towing and payload capabilities) of those vehicles, EPA is proposing a lower annual rate of improvement for light-duty trucks in the early years of the program. For light-duty trucks, the proposed average annual rate of CO_2 emissions reduction in model years 2017 through 2021 is 3.5 percent per year. EPA is also proposing to change the slopes of the CO_2-footprint curves for light-duty trucks from those in the 2012–2016 rule, in a manner that effectively means that the annual rate of improvement for smaller light-duty trucks in model years 2017 through 2021 would be higher than 3.5 percent, and the annual rate of improvement for larger light-duty trucks over the same time period would be lower than 3.5 percent. For model years 2022 through 2025, EPA is proposing an average annual rate of CO_2 emissions reduction for light-duty trucks of 5 percent per year.

NHTSA is proposing two phases of passenger car and light truck standards in this NPRM. The first phase runs from MYs 2017–2021, with proposed standards that are projected to require, on an average industry fleet wide basis, 40.9 mpg in MY 2021. For passenger cars, the annual increase in the stringency of the target curves between model years 2017 to 2021 is expected to average 4.1 percent. In recognition of manufacturers' unique challenges in improving the fuel economy and GHG emissions of full-size pickup trucks as we transition from the MY 2016 standards to MY 2017 and later, while preserving the utility (*e.g.,* towing and payload capabilities) of those vehicles, NHTSA is also proposing a slower annual rate of improvement for light trucks in the first phase of the program. For light trucks, the proposed annual increase in the stringency of the target curves in model years 2017 through 2021 would be 2.9 percent per year on average. NHTSA is proposing to change the slopes of the fuel economy footprint curves for light trucks from those in the MYs 2012–2016 final rule, which would effectively make the annual rate of improvement for smaller light trucks in MYs 2017–2021 higher than 2.9 percent, and the annual rate of improvement for larger light trucks over that time period lower than 2.9 percent.

The second phase of the CAFE program runs from MYs 2022–2025 and represents conditional [39] proposed standards that are projected to require, on an average industry fleet wide basis, 49.6 mpg in model year 2025. For passenger cars, the annual increase in the stringency of the target curves between model years 2022 and 2025 is expected to average 4.3 percent, and for light trucks, the annual increase during those model years is expected to average 4.7 percent. For the first time, NHTSA is proposing to increase the stringency of standards by the amount (in mpg terms) that industry is expected to improve air conditioning system efficiency, and EPA is proposing, under EPCA, to allow manufacturers to include air conditioning system efficiency improvements in the calculation of fuel economy for CAFE compliance. NHTSA notes that the proposed rates of increase in stringency for CAFE standards are lower than EPA's proposed rates of increase in stringency for GHG standards. As in the MYs 2012–2016 rulemaking, this is for purposes of harmonization and in reflection of several statutory constraints in EPCA/EISA. As a primary example, NHTSA's proposed standards, unlike EPA's, do not reflect the inclusion of air conditioning system refrigerant and leakage improvements, but EPA's proposed standards would allow consideration of such A/C refrigerant improvements which reduce GHGs but do not affect fuel economy.

As with the MYs 2012–2016 standards, NHTSA and EPA's proposed MYs 2017–2025 passenger car and light truck standards are expressed as mathematical functions depending on vehicle footprint.[40] Footprint is one measure of vehicle size, and is determined by multiplying the vehicle's wheelbase by the vehicle's average track width. The standards that must be met by each manufacturer's fleet would be determined by computing the production-weighted average of the targets applicable to each of the manufacturer's fleet of passenger cars and light trucks.[41] Under these footprint-based standards, the average levels required of individual manufacturers will depend, as noted above, on the mix and volume of vehicles the manufacturer produces. The values in the tables below reflect the agencies' projection of the corresponding average fleet levels that will result from these attribute-based curves given the agencies' current assumptions about the mix of vehicles that will be sold in the model years covered by the proposed standards.

As shown in Table I–1, NHTSA's fleet-wide required CAFE levels for passenger cars under the proposed standards are estimated to increase from 40.0 to 56.0 mpg between MY 2017 and MY 2025. Fleet-wide required CAFE levels for light trucks, in turn, are estimated to increase from 29.4 to 40.3 mpg. For the reader's reference, Table I–1 also provides the estimated average fleet-wide required levels for the combined car and truck fleets, culminating in an estimated overall fleet average required CAFE level of 49.6 mpg in MY 2025. Considering these combined car and truck increases, the proposed standards together represent approximately a 4.0 percent annual rate of increase,[42] on average, relative to the MY 2016 required CAFE levels.

[39] By ''conditional,'' NHTSA means to say that the proposed standards for MYs 2022–2025 represent the agency's current best estimate of what levels of stringency would be maximum feasible in those model years, but in order for the standards for those model years to be legally reviewable a subsequent rulemaking must be undertaken by the agency at a later time. See Section IV for more information.

[40] NHTSA is required to set attribute-based CAFE standards for passenger cars and light trucks. 49 U.S.C. 32902(b)(3).

[41] For CAFE calculations, a harmonic average is used.

[42] This estimated average percentage increase includes the effect of changes in standard stringency and changes in the forecast fleet sales mix.

Table I-1 Estimated Average Required Fleet-Wide Fuel Economy (mpg) under Proposed Footprint-Based CAFE Standards

	2016 base	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars	37.8	40.0	41.4	43.0	44.7	46.6	48.8	51.0	53.5	56.0
Light Trucks	28.8	29.4	30.0	30.6	31.2	33.3	34.9	36.6	38.5	40.3
Combined Cars & Trucks	34.1	35.3	36.4	37.5	38.8	40.9	42.9	45.0	47.3	49.6

The estimated average required mpg levels for cars and trucks under the proposed standards shown in Table I–1 above include the use of A/C efficiency improvements, as discussed above, but do not reflect a number of proposed flexibilities and credits that manufacturers could use for compliance that NHTSA cannot consider in establishing standards based on EPCA/EISA constraints. These flexibilities would cause the actual achieved fuel economy to be lower than the required levels in the table above. The flexibilities and credits that NHTSA cannot consider include the ability of manufacturers to pay civil penalties rather than achieving required CAFE levels, the ability to use FFV credits, the ability to count electric vehicles for compliance, the operation of plug-in hybrid electric vehicles on electricity for compliance prior to MY 2020, and the ability to transfer and carry-forward credits. When accounting for these flexibilities and credits, NHTSA estimates that the proposed CAFE standards would lead to the following average achieved fuel economy levels, based on the projections of what each manufacturer's fleet will comprise in each year of the program: [43]

[43] The proposed CAFE program includes incentives for full size pick-up trucks that have mild HEV or strong HEV systems, and for full size pick-up trucks that have fuel economy performance that is better than the target curve by more than proposed levels. To receive these incentives, manufacturers must produce vehicles with these technologies or performance levels at volumes that meet or exceed proposed penetration levels (percentage of full size pick-up truck volume). This incentive is described in detail in Section IV.1. The NHTSA estimates in Table I–2 do not account for the reduction in estimated average achieved fleet-wide CAFE fuel economy that would occur if manufacturers use this incentive. NHTSA has conducted a sensitivity study that estimates the effects for manufacturers' potential use of this flexibility in Chapter X of the PRIA.

Table I-2 Estimated Average Achieved Fleet-Wide Fuel Economy (mpg) under Proposed Footprint-Based CAFE Standards

	2016 base	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars	37.5	38.8	40.6	42.7	44.6	46.1	47.2	48.8	50.5	52.7
Light Trucks	28.2	29.0	30.1	31.8	33.0	34.8	35.5	36.3	37.4	38.6
Combined Cars & Trucks	33.4	34.5	36.0	38.0	39.7	41.4	42.4	43.7	45.2	47.0

NHTSA is also required by EISA to set a minimum fuel economy standard for domestically manufactured passenger cars in addition to the attribute-based passenger car standard. The minimum standard ''shall be the greater of (A) 27.5 miles per gallon; or (B) 92 percent of the average fuel economy projected by the Secretary for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year * * *,'' and applies to each manufacturer's fleet of domestically manufactured passenger cars (*i.e.,* like the other CAFE standards, it represents a fleet average requirement, not a requirement for each individual vehicle within the fleet).

Based on NHTSA's current market forecast, the agency's estimates of these proposed minimum standards for domestic passenger cars for MYs 2017–2025 are presented below in Table I–3.

Table I-3 Estimated Minimum Standard for Domestically Manufactured Passenger Cars (mpg)

2017	2018	2019	2020	2021	2022	2023	2024	2025
36.8	38.1	39.6	41.1	42.9	44.9	47.0	49.2	51.5

EPA is proposing GHG emissions standards, and Table I–4 provides estimates of the projected overall fleet-wide CO_2 emission compliance target levels. The values reflected in Table I–4 are those that correspond to the manufacturers' projected CO_2 compliance target levels from the car and truck footprint curves, but do not account for EPA's projection of how manufactures will implement two of the proposed incentive programs (advanced technology vehicle multipliers, and hybrid and performance-based incentives for full-size pickup trucks). EPA's projection of fleet-wide emissions levels that do reflect these incentives is shown in Table I–5 below.

[44] The projected fleet compliance levels for 2016 are different for trucks and the fleet than were projected in the 2012–2016 rule. Our assessment for this proposal is based on a predicted 2016 truck value of 297 and a projected combined car and truck value of 252 g/mi. That is because the standards are footprint based and the fleet projections, hence the footprint distributions, change slightly with each update of our projections, as described below. In addition, the actual fleet compliance levels for any model year will not be known until the end of that model year based on actual vehicle sales.

Table I-4 Projected Fleet-Wide CO_2 Compliance Targets under the Proposed Footprint-Based CO_2 Standards (g/mi)

	2016 base	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars	225	213	202	192	182	173	165	158	151	144
Light Trucks	298	295	285	277	270	250	237	225	214	203
Combined Cars and Trucks	250[44]	243	232	223	213	200	190	181	172	163

As shown in Table I–4, projected fleet-wide CO_2 emission compliance targets for cars increase in stringency from 213 to 144 g/mi between MY 2017 and MY 2025. Similarly, projected fleet-wide CO_2 equivalent emission compliance targets for trucks increase in stringency from 295 to 203 g/mi. As shown, the overall fleet average CO_2 level targets are projected to increase in stringency from 243 g/mi in MY 2017 to 163 g/mi in MY 2025, which is equivalent to 54.5 mpg if all reductions were made with fuel economy improvements.

EPA anticipates that manufacturers would take advantage of proposed program credits and incentives, such as car/truck credit transfers, air conditioning credits, off-cycle credits, advanced technology vehicle multipliers, and hybrid and performance-based incentives for full size pick-up trucks. Two of these flexibility provisions—advanced technology vehicle multipliers and the full size pick-up hybrid/performance incentives—are expected to have an impact on the fleet-wide emissions levels that manufacturers will actually achieve. Therefore, Table I–5 shows EPA's projection of the achieved emission levels of the fleet for MY 2017 through 2025. The differences between the emissions levels shown in Tables I–4 and I–5 reflect the impact on stringency due to the advanced technology vehicle multipliers and the full size pick-up hybrid/performance incentives, but do not reflect car-truck trading, air conditioning credits, or off-cycle credits, because, while those credit provisions should help reduce manufacturers' costs of the program, EPA believes that they will result in real-world emission reductions that will not affect the achieved level of emission reductions. These estimates are more fully discussed in III.B

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Table I-5 Projected Fleet-Wide Achieved CO_2-equivalent Emission Levels under the Proposed Footprint-Based CO_2 Standards (g/mi)[45]

	2016 base	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars	225	215	205	194	184	174	165	158	151	144
Light Trucks	298	295	285	278	271	251	238	226	214	204
Combined Cars and Trucks	250[46]	245	234	224	214	201	190	181	172	163.6

A more detailed description of how the agencies arrived at the year by year progression of the stringency of the proposed standards can be found in Sections III and IV of this preamble.

Both agencies also considered other alternative standards as part of their respective Regulatory Impact Analyses that span a reasonable range of alternative stringencies both more and less stringent than the standards being proposed. EPA's and NHTSA's analyses of these regulatory alternatives (and explanation of why we are proposing the standards proposed and not the regulatory alternatives) are contained in Sections III and IV of this preamble, respectively, as well as in EPA's DRIA and NHTSA's PRIA.

3. Form of the Standards

As noted, NHTSA and EPA are proposing to continue attribute-based standards for passenger cars and light trucks, as required by EISA and as allowed by the CAA, and continue to use vehicle footprint as the attribute. Footprint is defined as a vehicle's wheelbase multiplied by its track width—in other words, the area enclosed by the points at which the wheels meet the ground. NHTSA and EPA adopted an attribute-based approach based on vehicle footprint for MYs 2012–2016 light-duty vehicle standards.[47] The agencies continue to believe that footprint is the most appropriate attribute on which to base the proposed standards, as discussed later in this notice and in Chapter 2 of the Joint TSD.

Under the footprint-based standards, the curve defines a GHG or fuel economy performance target for each separate car or truck footprint. Using the curves, each manufacturer thus will have a GHG and CAFE average standard that is unique to each of its fleets, depending on the footprints and production volumes of the vehicle models produced by that manufacturer. A manufacturer will have separate footprint-based standards for cars and for trucks. The curves are mostly sloped, so that generally, larger vehicles (*i.e.,* vehicles with larger footprints) will be subject to less stringent targets (*i.e.,* higher CO_2 grams/mile targets and lower CAFE mpg targets) than smaller vehicles. This is because, generally speaking, smaller vehicles are more capable of achieving lower levels of CO_2 and higher levels of fuel economy than larger vehicles. Although a manufacturer's fleet average standards could be estimated throughout the model year based on projected production volume of its vehicle fleet, the standards to which the manufacturer must comply will be based on its final model year production figures. A manufacturer's calculation of its fleet average standards as well as its fleets' average performance at the end of the model year will thus be based on the production-weighted average target and performance of each model in its fleet.[48]

While the concept is the same, the proposed curve shapes for MYs 2017–2025 are somewhat different from the MYs 2012–2016 footprint curves. The passenger car curves are similar in shape to the car curves for MYs 2012–2016. However, the agencies are proposing more significant changes to the light trucks curves for MYs 2017–2025 compared to the light truck curves for MYs 2012–2016. The agencies are proposing changes to the light-truck curve to increase the slope and to

[45] Electric vehicles are assumed at 0 gram/mile in this analysis.

[46] The projected fleet compliance levels for 2016 are different for the fleet than were projected in the 2012–2016 rule. Our assessment for this proposal is based on a predicted 2016 truck value of 297 and a projected combined car and truck value of 252 g/mi. That is because the standards are footprint based and the fleet projections, hence the footprint distributions, change slightly with each update of our projections, as described below. In addition, the actual fleet compliance levels for any model year will not be known until the end of that model year based on actual vehicle sales.

[47] NHTSA also uses the footprint attribute in its Reformed CAFE program for light trucks for model years 2008–2011 and passenger car CAFE standards for MY 2011.

[48] As in the MYs 2012–2016 rule, a manufacturer may have some models that exceed their target, and some that are below their target. Compliance with a fleet average standard is determined by comparing the fleet average standard (based on the sales weighted average of the target levels for each model) with fleet average performance (based on the sales weighted average of the performance for each model).

extend the large-footprint cutpoint over time to larger footprints, which we believe represent an appropriate balance of both technical and policy issues, as discussed in Section II.C below and Chapter 2 of the draft Joint TSD.

NHTSA is proposing the attribute curves below for assigning a fuel economy target level to an individual car or truck's footprint value, for model years 2017 through 2025. These mpg values will be production weighted to determine each manufacturer's fleet average standard for cars and trucks. Although the general model of the target curve equation is the same for each vehicle category and each year, the parameters of the curve equation differ for cars and trucks. Each parameter also changes on a model year basis, resulting in the yearly increases in stringency. Figure I–1 below illustrates the passenger car CAFE standard curves for model years 2017 through 2025 while Figure I–2 below illustrates the light truck CAFE standard curves for model years 2017 through 2025.

EPA is proposing the attribute curves shown in Figure I–3 and Figure I–4 below for assigning a CO_2 target level to an individual vehicle's footprint value, for model years 2017 through 2025. These CO_2 values would be production weighted to determine each manufacturer's fleet average standard for cars and trucks. As with the CAFE curves, the general form of the equation is the same for each vehicle category and each year, but the parameters of the equation differ for cars and trucks. Again, each parameter also changes on a model year basis, resulting in the yearly increases in stringency. Figure I–3 below illustrates the CO_2 car standard curves for model years 2017 through 2025 while Figure I–4 shows the CO_2 truck standard curves for model years 2017–2025.

Figure I-1 CAFE Target Curves for Passenger Cars

Figure I-2 CAFE Target Curves for Light Trucks

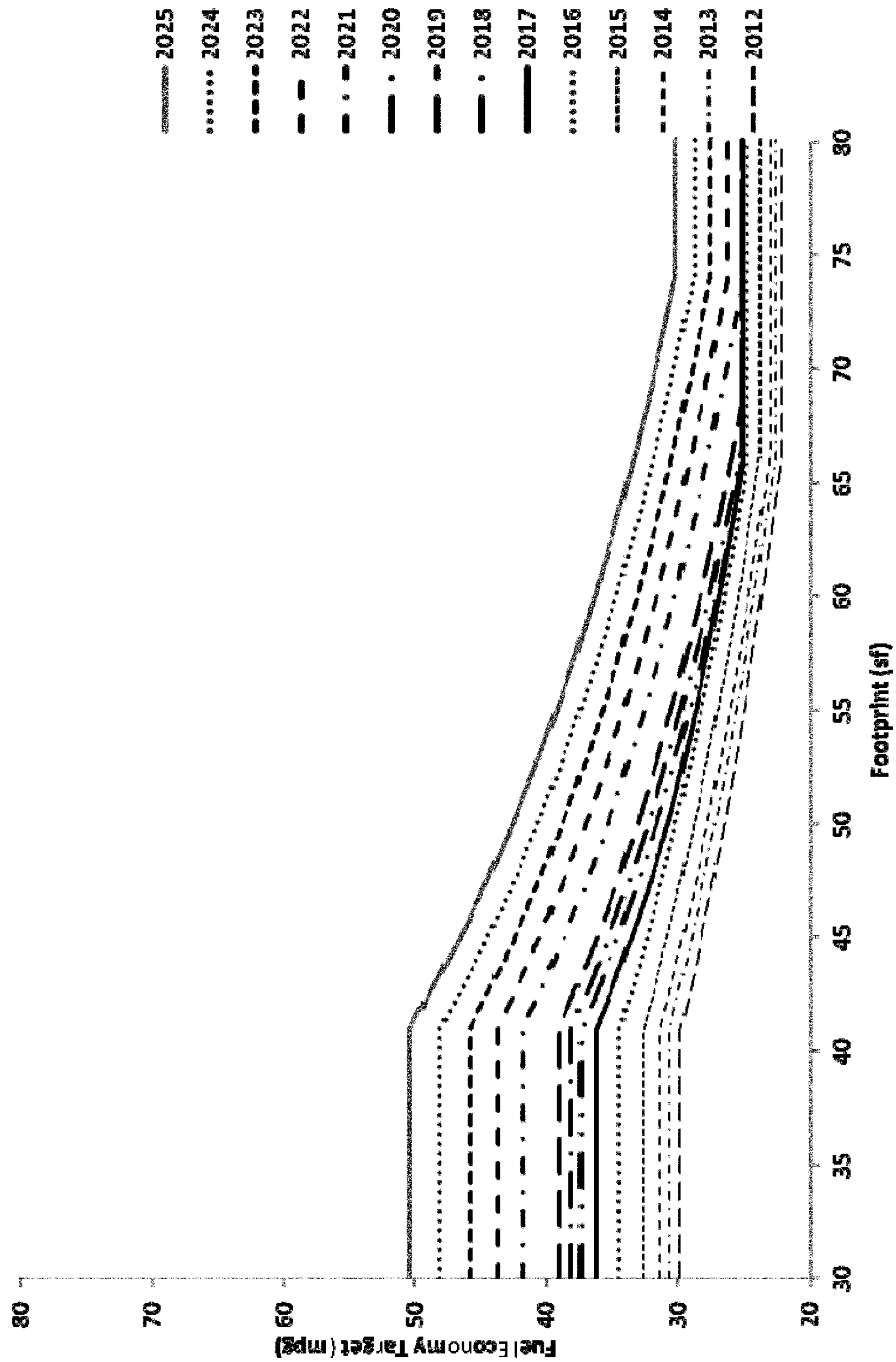


Figure I-3 CO2 (g/mile) Car Standards Curves

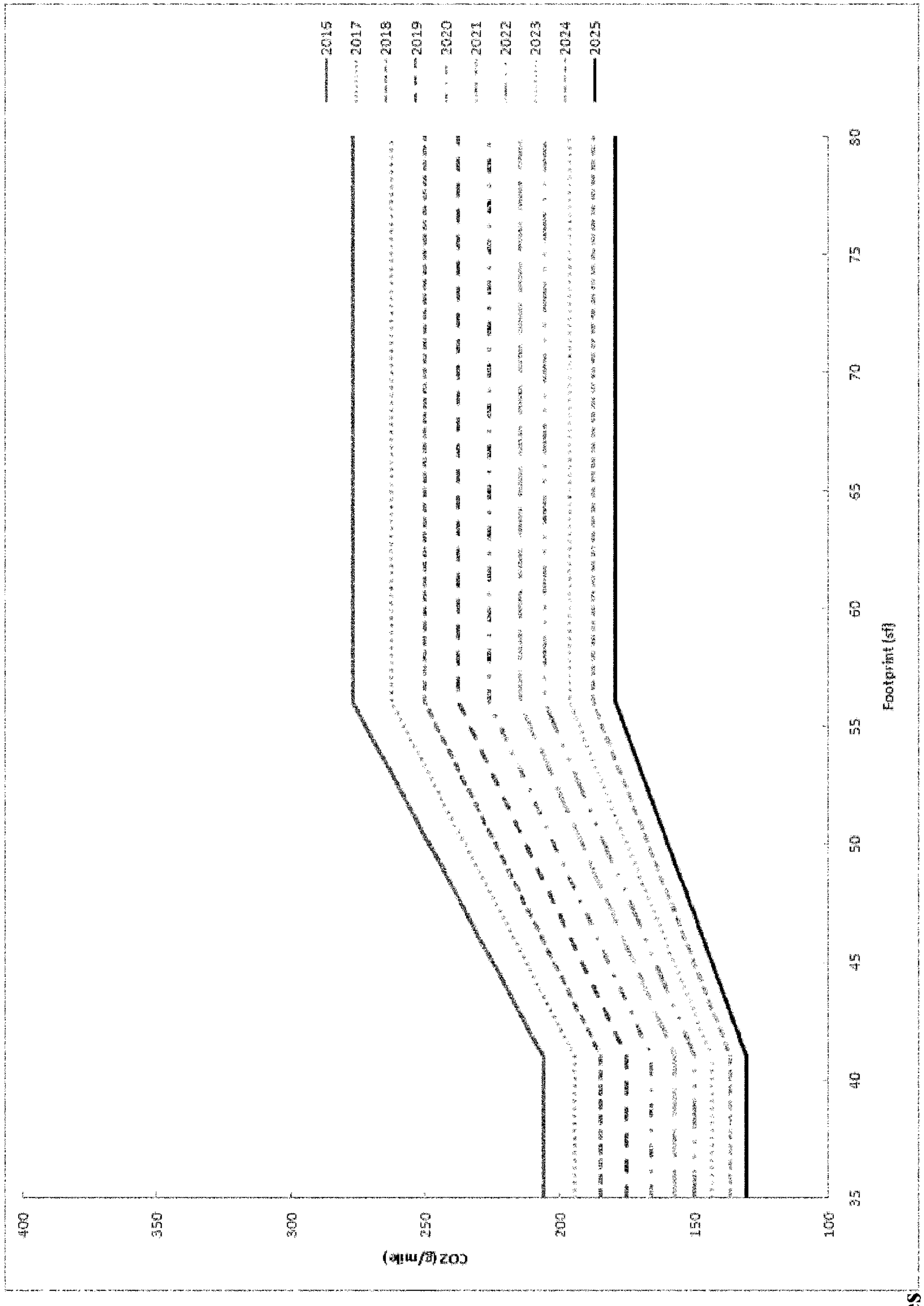
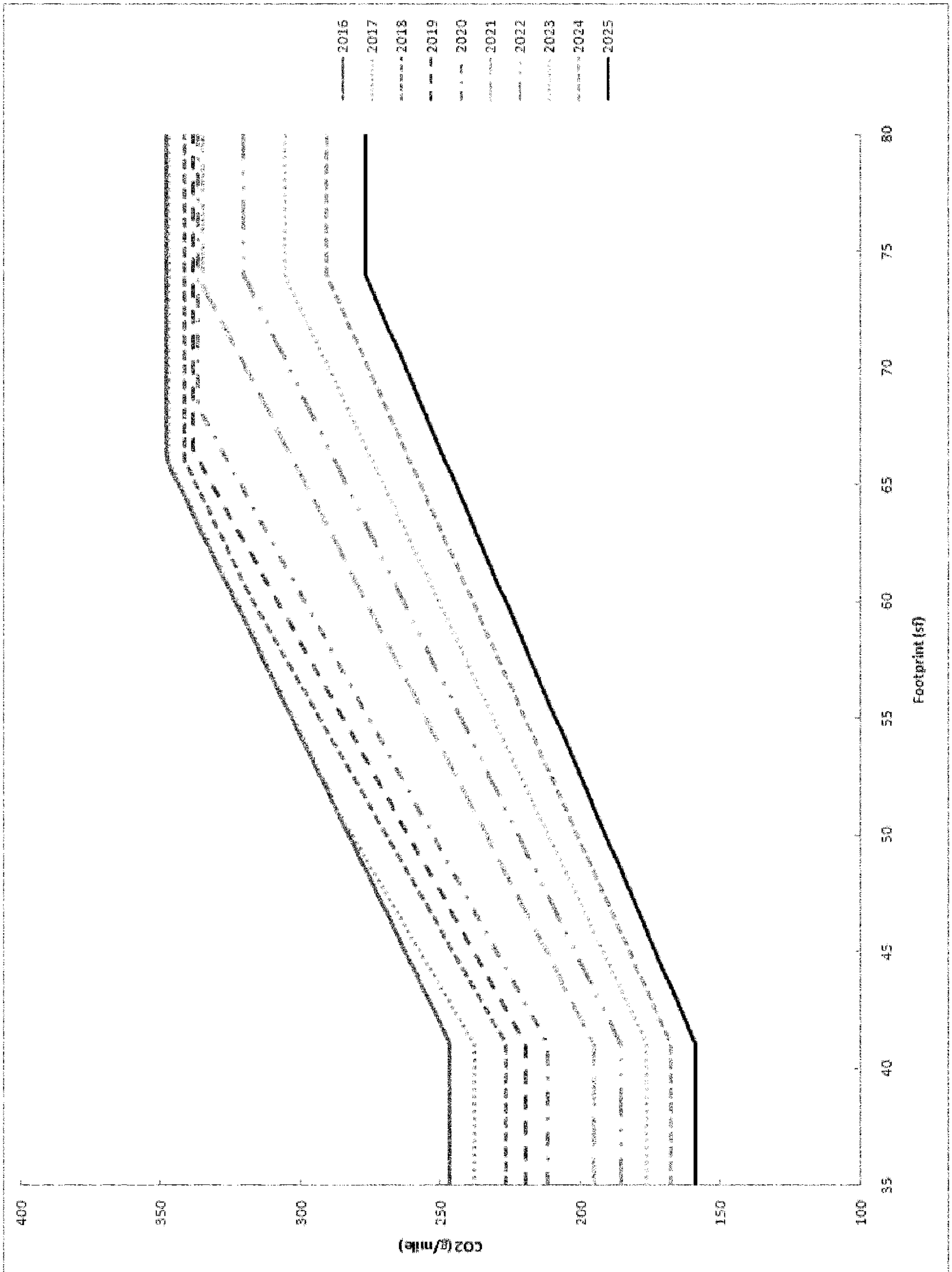


Figure I-4 CO2 (g/mile) Truck Standard Curves



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NHTSA and EPA are proposing to use the same vehicle category definitions for determining which vehicles are subject to the car curve standards versus the truck curve standards as were used for MYs 2012–2016 standards. As in the MYs 2012–2016 rulemaking, a vehicle classified as a car under the NHTSA CAFE program will also be classified as a car under the EPA GHG program, and likewise for trucks.[49] This approach of using CAFE definitions allows the CO_2 standards and the CAFE standards to continue to be harmonized across all vehicles for the National Program.

As just explained, generally speaking, a smaller footprint vehicle will tend to have higher fuel economy and lower CO_2 emissions relative to a larger footprint vehicle when both have the same level of fuel efficiency improvement technology. Since the

[49] See 49 CFR 523 for NHTSA's definitions for passenger car and light truck under the CAFE program.

proposed standards apply to a manufacturer's overall fleet, not to an individual vehicle, if a manufacturer's fleet is dominated by small footprint vehicles, then that fleet will have a higher fuel economy requirement and a lower CO_2 requirement than a manufacturer whose fleet is dominated by large footprint vehicles. Compared to the non-attribute based CAFE standards in place prior to MY 2011, the proposed standards more evenly distribute the compliance burdens of the standards among different manufacturers, based on their respective product offerings. With this footprint-based standard approach, EPA and NHTSA continue to believe that the rules will not create significant incentives to produce vehicles of particular sizes, and thus there should be no significant effect on the relative availability of different vehicle sizes in the fleet due to the proposed standards, which will help to maintain consumer choice during the rulemaking timeframe. Consumers should still be able to purchase the size of vehicle that meets their needs. Table I–6 helps to illustrate the varying CO_2 emissions and fuel economy targets under the proposed standards that different vehicle sizes will have, although we emphasize again that these targets are not actual standards—the proposed standards are manufacturer-specific, rather than vehicle-specific.

Table I-6 Model Year 2025 CO_2 and Fuel Economy Targets for Various MY 2008 Vehicle Types

Vehicle Type	Example Models	Example Model Footprint (sq. ft.)	CO_2 Emissions Target (g/mi)[a]	Fuel Economy Target (mpg)[b]
Example Passenger Cars				
Compact car	Honda Fit	40	131	61.1
Midsize car	Ford Fusion	46	147	54.9
Fullsize car	Chrysler 300	53	170	48.0
Example Light-duty Trucks				
Small SUV	4WD Ford Escape	44	170	47.5
Midsize crossover	Nissan Murano	49	188	43.4
Minivan	Toyota Sienna	55	209	39.2
Large pickup truck	Chevy Silverado	67	252	33.0

[a, b] Real-world CO_2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower than the CO_2 and fuel economy target values presented here.

4. Program Flexibilities for Achieving Compliance

a. CO_2/CAFE Credits Generated Based on Fleet Average Over-Compliance

The MYs 2012–2016 rules contain several provisions which provide flexibility to manufacturers in meeting standards, many of which the agencies are not proposing to change for MYs 2017 and later. For example, the agencies are proposing to continue allowing manufacturers to generate credits for over-compliance with the CO_2 and CAFE standards.[50] Under the agencies' footprint-based approach to the standards, a manufacturer's ultimate compliance obligations are determined at the end of each model year, when production of the model year is complete. Since the fleet average standards that apply to a manufacturer's car and truck fleets are based on the applicable footprint-based curves, a production volume-weighted fleet average requirement will be calculated for each averaging set (cars and trucks) based on the mix and volumes of the models manufactured for sale by the manufacturer. If a manufacturer's car and/or truck fleet achieves a fleet average CO_2/CAFE level better than the car and/or truck standards, then the manufacturer generates credits. Conversely, if the fleet average CO_2/CAFE level does not meet the standard, the fleet would incur debits (also referred to as a shortfall). As in the MY 2011 CAFE program under EPCA/EISA, and also in MYs 2012–2016 for the light-duty vehicle GHG and CAFE program, a manufacturer whose fleet generates credits in a given model year would have several options for using those credits, including credit carry-back, credit carry-forward, credit transfers, and credit trading.

Credit ''carry-back'' means that manufacturers are able to use credits to offset a deficit that had accrued in a prior model year, while credit ''carry-forward'' means that manufacturers can bank credits and use them toward compliance in future model years. EPCA, as amended by EISA, requires NHTSA to allow manufacturers to carry-back credits for up to three model years, and to carry-forward credits for up to five model years. EPA's MYs 2012–2016 light duty vehicle GHG program includes the same limitations and EPA is proposing to continue this limitation in the MY 2017–2025 program. To facilitate the transition to the increasingly more stringent standards, EPA is proposing under its CAA authority a one-time CO_2 carry-forward beyond 5 years, such that any credits generated from MY 2010 through 2016 will be able to be used any time through MY 2021. This provision would not apply to early credits generated in MY 2009. NHTSA's program will continue the 5-year carry-forward and 3-year carry-back, as required by statute.

Credit ''transfer'' means the ability of manufacturers to move credits from their passenger car fleet to their light truck fleet, or vice versa. EISA required NHTSA to establish by regulation a CAFE credits transferring program, now codified at 49 CFR part 536, to allow a manufacturer to transfer credits between its car and truck fleets to achieve compliance with the standards. For example, credits earned by over-compliance with a manufacturer's car fleet average standard could be used to offset debits incurred due to that manufacturer's not meeting the truck fleet average standard in a given year. However, EISA imposed a cap on the amount by which a manufacturer could raise its CAFE through transferred credits: 1 mpg for MYs 2011–2013; 1.5 mpg for MYs 2014–2017; and 2 mpg for MYs 2018 and beyond.[51] Under section 202(a) of the CAA, in contrast, there is no statutory limitation on car-truck credit transfers, and EPA's GHG program allows unlimited credit transfers across a manufacturer's car-truck fleet to meet the GHG standard. This is based on the expectation that this flexibility will facilitate setting appropriate GHG standards that manufacturers' can comply with in the lead time provided, and will allow the required GHG emissions reductions to be achieved in the most cost effective way. Therefore, EPA did not constrain the magnitude of allowable car-truck credit transfers,[52] as doing so would reduce the flexibility for lead time, and would increase costs with no corresponding environmental benefit. EISA also prohibits the use of transferred credits to meet the minimum domestic passenger car fleet CAFE standard.[53] These statutory limits will necessarily continue to apply to the determination of compliance with the CAFE standards.

Credit ''trading'' means the ability of manufacturers to sell credits to, or purchase credits from, one another. EISA allowed NHTSA to establish by regulation a CAFE credit trading program, also now codified at 49 CFR Part 536, to allow credits to be traded between vehicle manufacturers. EPA also allows credit trading in the light-duty vehicle GHG program. These sorts of exchanges between averaging sets are typically allowed under EPA's current mobile source emission credit programs (as well as EPA's and NHTSA's recently promulgated GHG and fuel efficiency standards for heavy-duty vehicles and engines). EISA also prohibits manufacturers from using traded credits to meet the minimum domestic passenger car CAFE standard.[54]

b. Air Conditioning Improvement Credits/Fuel Economy Value Increases

Air conditioning (A/C) systems contribute to GHG emissions in two ways. Hydrofluorocarbon (HFC) refrigerants, which are powerful GHGs, can leak from the A/C system (direct A/C emissions). In addition, operation of the A/C system places an additional load on the engine which increases fuel consumption and thus results in additional CO_2 tailpipe emissions (indirect A/C related emissions). In the MYs 2012–2016 program, EPA allows manufacturers to generate credits by reducing either or both types of GHG emissions related to A/C systems. The expected generation of A/C credits is accounted for in setting the level of the overall CO_2 standard. For the current proposal, as with the MYs 2012–2016 program, manufacturers will be able to generate CO_2-equivalent credits to use in complying with the CO_2 standards for improvements in air conditioning (A/C) systems, both for efficiency improvements (reduces tailpipe CO_2 and improves fuel consumption) and for leakage reduction or alternative, lower GWP (global warming potential) refrigerant use (reduces hydrofluorocarbon (HFC) emissions). EPA is proposing that the maximum A/C credit available for cars is 18.8 grams/mile CO_2 and for trucks is 24.4 grams/mile CO_2. The proposed test methods used to calculate these direct and indirect A/C credits are very similar to those of the MYs 2012–2016 program, though EPA is seeking comment on a revised idle test as well as a new test procedure.

For the first time in the current proposal, the agencies are proposing provisions that would account for improvements in air conditioner efficiency in the CAFE program. Improving A/C efficiency leads to real-world fuel economy benefits, because as explained above, A/C operation

[50] This credit flexibility is required by EPCA/EISA, see 49 U.S.C. 32903, and allowed by the CAA.

[51] 49 U.S.C. 32903(g)(3).

[52] EPA's proposed program will continue to adjust car and truck credits by vehicle miles traveled (VMT), as in the MY 2012–2016 program.

[53] 49 U.S.C. 32903(g)(4).

[54] 49 U.S.C. 32903(f)(2).

represents an additional load on the engine, so more efficient A/C operation imposes less of a load and allows the vehicle to go farther on a gallon of gas. Under EPCA, EPA has authority to adopt procedures to measure fuel economy and calculate CAFE. Under this authority EPA is proposing that manufacturers could generate fuel consumption improvement values for purposes of CAFE compliance based on air conditioning system efficiency improvements for cars and trucks. This increase in fuel economy would be allowed up to a maximum based on 0.000563 gallon/mile for cars and 0.000810 gallon/mile for trucks. This is equivalent to the A/C efficiency CO_2 credit allowed by EPA under the GHG program. The same methods would be used in the CAFE program to calculate the values for air conditioning efficiency improvements for cars and trucks as are used in EPA's GHG program. NHTSA is including in its proposed passenger car and light truck CAFE standards an increase in stringency in each model year from 2017–2025 by the amount industry is expected to improve air conditioning system efficiency in those years, in a manner consistent with EPA's GHG standards. EPA is not proposing to allow generation of fuel consumption improvement values for CAFE purposes, nor is NHTSA proposing to increase stringency of the CAFE standard, for the use of A/C systems that reduce leakage or employ alternative, lower GWP refrigerant, because those changes do not improve fuel economy.

c. Off-cycle Credits/Fuel Economy Value Increases

For MYs 2012–2016, EPA provided an option for manufacturers to generate credits for employing new and innovative technologies that achieve CO_2 reductions that are not reflected on current test procedures. EPA noted in the MYs 2012–2016 rulemaking that examples of such ''off-cycle'' technologies might include solar panels on hybrids, adaptive cruise control, and active aerodynamics, among other technologies. See generally 75 FR at 25438–39. EPA's current program allows off-cycle credits to be generated through MY 2016.

EPA is proposing that manufacturers may continue to use off-cycle credits for MY 2017 and later for the GHG program. As with A/C efficiency, improving efficiency through the use of off-cycle technologies leads to real-world fuel economy benefits and allows the vehicle to go farther on a gallon of gas. Thus, under its EPCA authority EPA is proposing to allow manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of off-cycle technologies. Increases in fuel economy under the CAFE program based on off-cycle technology will be equivalent to the off-cycle credit allowed by EPA under the GHG program, and these amounts will be determined using the same procedures and test methods as are used in EPA's GHG program. For the reasons discussed in sections III and IV of this proposal, the ability to generate off-cycle credits and increases in fuel economy for use in compliance will not affect or change the level of the GHG or CAFE standards proposed by each agency.

Many automakers indicated that they had a strong interest in pursuing off-cycle technologies, and encouraged the agencies to refine and simplify the evaluation process to provide more certainty as to the types of technologies the agencies would approve for credit generation. For 2017 and later, EPA is proposing to expand and streamline the MYs 2012–2016 off-cycle credit provisions, including an approach by which the agencies would provide specified amounts of credit and fuel consumption improvement values for a subset of off-cycle technologies whose benefits are readily quantifiable. EPA is proposing a list of technologies and credit values, where sufficient data is available, that manufacturers could use without going through an advance approval process that would otherwise be required to generate credits. EPA believes that our assessment of off-cycle technologies and associated credit values on this proposed list is conservative, and automakers may apply for additional off-cycle credits beyond the minimum credit value if they have sufficient supporting data. Further, manufacturers may also apply for off-cycle technologies beyond those listed, again, if they have sufficient data.

In addition, EPA is providing additional detail on the process and timing for the credit/fuel consumption improvement values application and approval process. EPA is proposing a timeline for the approval process, including a 60-day EPA decision process from the time a manufacturer submits a complete application. EPA is also proposing a detailed, common, step-by-step process, including a specification of the data that manufacturers must submit. For off-cycle technologies that are both not covered by the pre-approved off-cycle credit/fuel consumption improvement values list and that are not quantifiable based on the 5-cycle test cycle option provided in the 2012–2016 rulemaking, EPA is proposing to retain the public comment process from the MYs 2012–2016 rule.

d. Incentives for Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Fuel Cell Vehicles

To facilitate market penetration of the most advanced vehicle technologies as rapidly as possible, EPA is proposing an incentive multiplier for compliance purposes for all electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) sold in MYs 2017 through 2021. This multiplier approach means that each EV/PHEV/FCV would count as more than one vehicle in the manufacturer's compliance calculation. EPA is proposing that EVs and FCVs start with a multiplier value of 2.0 in MY 2017, phasing down to a value of 1.5 in MY 2021. PHEVs would start at a multiplier value of 1.6 in MY 2017 and phase down to a value of 1.3 in MY 2021.[55] The multiplier would be 1.0 for MYs 2022–2025.

NHTSA currently interprets EPCA and EISA as precluding the agency from offering additional incentives for EVs, FCVs and PHEVs, except as specified by statute,[56] and thus is not proposing incentive multipliers comparable to the EPA incentive multipliers described above.

For EVs, PHEVs and FCVs, EPA is proposing to set a value of 0 g/mile for the tailpipe compliance value for EVs, PHEVs (electricity usage) and FCVs for MY 2017–2021, with no limit on the quantity of vehicles eligible for 0 g/mi tailpipe emissions accounting. For MY 2022–2025, EPA is proposing that 0 g/mi only be allowed up to a per-company cumulative sales cap, tiered as follows: 1) 600,000 vehicles for companies that sell 300,000 EV/PHEV/FCVs in MYs 2019–2021; 2) 200,000 vehicles for all other manufacturers. EPA believes the industry-wide impact of such a tiered cap will be approximately 2 million vehicles. EPA

[55] The multipliers for EV/FCV would be: 2017–2019—2.0, 2020—1.75, 2021—1.5; for PHEV: 2017–2019—1.6, 2020—1.45, 2021—1.3.

[56] Because 49 U.S.C. 32904(a)(2)(B) expressly requires EPA to calculate the fuel economy of electric vehicles using the Petroleum Equivalency Factor developed by DOE, which contains an incentive for electric operation already, and because 49 U.S.C. 32905(a) expressly requires EPA to calculate the fuel economy of FCVs using a specified incentive, NHTSA believes that Congress' having provided clear incentives for these technologies in the CAFE program suggests that additional incentives beyond those would not be consistent with Congress' intent. Similarly, because the fuel economy of PHEVs' electric operation must also be calculated using DOE's PEF, the incentive for electric operation appears to already be inherent in the statutory structure.

proposes to phase-in the change in compliance value, from 0 grams per mile to net upstream accounting, for any manufacturer that exceeds its cumulative production cap for EV/PHEV/FCVs. EPA proposes that, starting with MY 2022, the compliance value for EVs, FCVs, and the electric portion of PHEVs in excess of individual automaker cumulative production caps would be based on net upstream accounting.

For EVs and other dedicated alternative fuel vehicles, EPA is proposing to calculate fuel economy for the CAFE program using the same methodology as in the MYs 2012–2016 rulemaking, which aligns with EPCA/EISA statutory requirements. For liquid alternative fuels, this methodology generally counts 15 percent of the volume of fuel used in determine the mpg-equivalent fuel economy. For gaseous alternative fuels, the methodology generally determines a gasoline equivalent mpg based on the energy content of the gaseous fuel consumed, and then adjusts the fuel consumption by effectively only counting 15 percent of the actual energy consumed. For electricity, the methodology generally determines a gasoline equivalent mpg by measuring the electrical energy consumed, and then using a petroleum equivalency factor (PEF) to convert to an mpg-equivalent value. The PEF for electricity includes an adjustment that effectively only counts 15 percent of the actual energy consumed. Counting 15 percent of the volume or energy provides an incentive for alternative fuels in the CAFE program.

The methodology that EPA is proposing for dual fueled vehicles under the GHG program and to calculate fuel economy for the CAFE program is discussed below in subsection I.B.7.a.

e. Incentives for ''Game Changing'' Technologies Performance for Full-Size Pickup Truck Including Hybridization

The agencies recognize that the standards under consideration for MYs 2017–2025 will be challenging for large trucks, including full size pickup trucks. In order to incentivize the penetration into the marketplace of ''game changing'' technologies for these pickups, including their hybridization, EPA is proposing a CO_2 credit in the GHG program and an equivalent fuel consumption improvement value in the CAFE program for manufacturers that employ significant quantities of hybridization on full size pickup trucks, by including a per-vehicle CO_2 credit and fuel consumption improvement value available for mild and strong hybrid electric vehicles (HEVs). EPA would provide the incentive for the GHG program under EPA's CAA authority and the incentive for the CAFE program under EPA's EPCA authority. EPA's GHG and NHTSA's CAFE proposed standards are set at levels that take into account this flexibility as an incentive for the introduction of advanced technology. This provides the opportunity to begin to transform the most challenging category of vehicles in terms of the penetration of advanced technologies, which, if successful at incentivizing these ''game changing technologies,'' should allow additional opportunities to successfully achieve the higher levels of truck stringencies in MYs 2022–2025.

EPA is proposing that access to this credit and fuel consumption improvement value be conditioned on a minimum penetration of the technology in a manufacturer's full size pickup truck fleet, and is proposing criteria for a full size pickup truck (*e.g.,* minimum bed size and minimum towing or payload capability). EPA is proposing that mild HEV pickup trucks would be eligible for a per vehicle credit of 10 g/mi [57] during MYs 2017–2021 if the technology is used on a minimum percentage of a company's full size pickups, beginning with at least 30% of a company's full size pickup production in 2017 and ramping up to at least 80% in MY 2021. Strong HEV pickup trucks would be eligible for a 20 g/mi per [58] vehicle credit during MYs 2017–2025 if the technology is used on at least 10% of the company's full size pickups. These volume thresholds are being proposed in order to encourage rapid penetration of these technologies in this vehicle segment. EPA and NHTSA are proposing specific definitions of mild and strong HEV pickup trucks.

Because there are other technologies besides mild and strong hybrids which can significantly reduce GHG emissions and fuel consumption in pickup trucks, EPA is also proposing a performance-based incentive CO_2 emissions credit and equivalent fuel consumption improvement value for full size pickup trucks that achieve a significant CO_2 reduction below/fuel economy improvement above the applicable target. This would be available for vehicles achieving significant CO_2 reductions/fuel economy improvements through the use of technologies other than hybrid drive systems. EPA is proposing that eligible pickup trucks achieving 15 percent below their applicable CO_2 target would receive a 10 g/mi credit, and those achieving 20 percent below their target would receive a 20 g/mi credit. The 10 g/mi performance-based credit would be available for MYs 2017 to 2021 and a vehicle meeting the requirements would receive the credit until MY 2021 unless its CO_2 level increases. The 20 g/mi performance-based credit would be available for a maximum of 5 years within the model years of 2017 to 2025, provided the CO_2 level does not increase for those vehicles earning the credit. The credits would begin in the model year of the eligible vehicle's introduction, and could not extend past MY 2021 for the 10 g/mi credit and MY 2025 for the 20 g/mi credit.

To avoid double-counting, the same vehicle would not receive credit under both the HEV and the performance based approaches.

5. Mid-Term Evaluation

Given the long time frame at issue in setting standards for MYs 2022–2025, and given NHTSA's obligation to conduct a separate rulemaking in order to establish final standards for vehicles for those model years, EPA and NHTSA are proposing a comprehensive mid-term evaluation and agency decision-making process. As part of this undertaking, both NHTSA and EPA will develop and compile up-to-date information for the evaluation, through a collaborative, robust and transparent process, including public notice and comment. The evaluation will be based on (1) a holistic assessment of all of the factors considered by the agencies in setting standards, including those set forth in the rule and other relevant factors, and (2) the expected impact of those factors on the manufacturers' ability to comply, without placing decisive weight on any particular factor or projection. The comprehensive evaluation process will lead to final agency action by both agencies.

Consistent with the agencies' commitment to maintaining a single national framework for regulation of vehicle emissions and fuel economy, the agencies fully expect to conduct the mid-term evaluation in close coordination with the California Air Resources Board (CARB). Moreover, the agencies fully expect that any adjustments to the GHG standards will be made with the participation of CARB and in a manner that ensures continued harmonization of state and federal vehicle standards.

Further discussion of the mid-term evaluation can be found in section III and IV of the proposal.

[57] 0.001125 gallon/mile.

[58] 0.00225 gallon/mile.

6. Coordinated Compliance

The MYs 2012–2016 final rules established detailed and comprehensive regulatory provisions for compliance and enforcement under the GHG and CAFE programs. These provisions remain in place for model years beyond MY 2016 without additional action by the agencies and EPA and NHTSA are not proposing any significant modifications to them. In the MYs 2012–2016 final rule, NHTSA and EPA established a program that recognizes, and replicates as closely as possible, the compliance protocols associated with the existing CAA Tier 2 vehicle emission standards, and with earlier model year CAFE standards. The certification, testing, reporting, and associated compliance activities established for the GHG program closely track those in previously existing programs and are thus familiar to manufacturers. EPA already oversees testing, collects and processes test data, and performs calculations to determine compliance with both CAFE and CAA standards. Under this coordinated approach, the compliance mechanisms for both programs are consistent and non-duplicative. EPA also applies the CAA authorities applicable to its separate in-use requirements in this program.

The compliance approach allows manufacturers to satisfy the GHG program requirements in the same general way they comply with previously existing applicable CAA and CAFE requirements. Manufacturers will demonstrate compliance on a fleet-average basis at the end of each model year, allowing model-level testing to continue throughout the year as is the current practice for CAFE determinations. The compliance program design includes a single set of manufacturer reporting requirements and relies on a single set of underlying data. This approach still allows each agency to assess compliance with its respective program under its respective statutory authority. The program also addresses EPA enforcement in cases of noncompliance.

7. Additional Program Elements

a. Treatment of Compressed Natural Gas (CNG), Plug-in Hybrid Electric Vehicles (PHEVs), and Flexible Fuel Vehicles (FFVs)

EPA is proposing that CO_2 compliance values for plug-in hybrid electric vehicles (PHEVs) and bi-fuel compressed natural gas (CNG) vehicles will be based on estimated use of the alternative fuels, recognizing that, once a consumer has paid several thousand dollars to be able to use a fuel that is considerably cheaper than gasoline, it is very likely that the consumer will seek to use the cheaper fuel as much as possible. Accordingly, for CO_2 emissions compliance, EPA is proposing to use the Society of Automotive Engineers ''utility factor'' methodology (based on vehicle range on the alternative fuel and typical daily travel mileage) to determine the assumed percentage of operation on gasoline and percentage of operation on the alternative fuel for both PHEVs and bi-fuel CNG vehicles, along with the CO_2 emissions test values on the alternative fuel and gasoline.

EPA is proposing to account for E85 use by flexible fueled vehicles (FFVs) as in the existing MY 2016 and later program, based on actual usage of E85 which represents a real-world reduction attributed to alternative fuels. Unlike PHEV and bi-fuel CNG vehicles, there is not a significant cost differential between an FFV and a conventional gasoline vehicle and historically consumers have only fueled these vehicles with E85 a very small percentage of the time.

In the CAFE program for MYs 2017–2019, the fuel economy of dual fuel vehicles will be determined in the same manner as specified in the MY 2012–2016 rule, and as defined by EISA. Beginning in MY 2020, EISA does not specify how to measure the fuel economy of dual fuel vehicles, and EPA is proposing under its EPCA authority to use the ''utility factor'' methodology for PHEV and CNG vehicles described above to determine how to proportion the fuel economy when operating on gasoline or diesel fuel and the fuel economy when operating on the alternative fuel. For FFVs, EPA is proposing to use the same methodology as it uses for the GHG program to determine how to proportion the fuel economy, which would be based on actual usage of E85. EPA is proposing to continue to use Petroleum Equivalency Factors and the 0.15 divisor used in the MY 2012–2016 rule for the alternative fuels, however with no cap on the amount of fuel economy increase allowed. This issue is discussed further in Section III.B.10.

b. Exclusion of Emergency and Police Vehicles

Under EPCA, manufacturers are allowed to exclude emergency vehicles from their CAFE fleet[59] and all manufacturers have historically done so. In the MYs 2012–2016 program, EPA's GHG program applies to these vehicles. However, after further consideration of this issue, EPA is proposing the same type of exclusion provision for these vehicles for MY 2012 and later because of the unique features of vehicles designed specifically for law enforcement and emergency purposes, which have the effect of raising their GHG emissions and calling into question the ability of manufacturers to sufficiently reduce the emissions from these vehicles without compromising necessary vehicle features or dropping vehicles from their fleets.

c. Small Businesses and Small Volume Manufacturers

EPA is proposing provisions to address two categories of smaller manufacturers. The first category is small businesses as defined by the Small Business Administration (SBA). For vehicle manufacturers, SBA's definition of small business is any firm with less than 1,000 employees. As with the MYs 2012–2016 program, EPA is proposing to continue to exempt small businesses from the GHG standards, for any company that meets the SBA's definition of a small business. EPA believes this exemption is appropriate given the unique challenges small businesses would face in meeting the GHG standards, and since these businesses make up less than 0.1% of total U.S. vehicle sales, and there is no significant impact on emission reductions.

EPA's proposal also addresses small volume manufacturers, with U.S. annual sales of less than 5,000 vehicles. Under the MYs 2012–2016 program, these small volume manufacturers are eligible for an exemption from the CO_2 standards. EPA is proposing to bring small volume manufacturers into the CO_2 program for the first time starting in MY 2017, and allow them to petition EPA for alternative standards.

EPCA provides NHTSA with the authority to exempt from the generally applicable CAFE standards manufacturers that produce fewer than 10,000 passenger cars worldwide in the model year each of the two years prior to the year in which they seek an exemption.[60] If NHTSA exempts a manufacturer, it must establish an alternate standard for that manufacturer for that model year, at the level that the agency decides is maximum feasible for that manufacturer. The exemption and alternative standard apply only if the exempted manufacturer also produces fewer than 10,000 passenger cars

[59] 49 U.S.C. 32902(e).

[60] 49 U.S.C. 32902(d). Implementing regulations may be found in 49 CFR part 525.

worldwide in the year for which the exemption was granted.

Further, the Temporary Lead-time Allowance Alternative Standards (TLAAS) provisions included in EPA's MYs 2012–2016 program for manufacturers with MY 2009 U.S. sales of less than 400,000 vehicles ends after MY 2015 for most eligible manufacturers.[61] EPA is not proposing to extend or otherwise replace the TLAAS provisions for the proposed MYs 2017–2025 program. However, EPA is inviting comment on whether this or some other form of flexibility is warranted for lower volume, limited line manufacturers, as further discussed in Section III.B.8. With the exception of the small businesses and small volume manufacturers discussed above, the proposed MYs 2017–2025 standards would apply to all manufacturers.

C. Summary of Costs and Benefits for the Proposed National Program

This section summarizes the projected costs and benefits of the proposed CAFE and GHG emissions standards. These projections helped inform the agencies' choices among the alternatives considered and provide further confirmation that the proposed standards are appropriate under their respective statutory authorities. The costs and benefits projected by NHTSA to result from these CAFE standards are presented first, followed by those from EPA's analysis of the GHG emissions standards. The agencies recognize that there are uncertainties regarding the benefit and cost values presented in this proposal. Some benefits and costs are not quantified. The value of other benefits and costs could be too low or too high.

For several reasons, the estimates for costs and benefits presented by NHTSA and EPA, while consistent, are not directly comparable, and thus should not be expected to be identical. Most important, NHTSA and EPA's standards would require slightly different fuel efficiency improvements. EPA's proposed GHG standard is more stringent in part due to its assumptions about manufacturers' use of air conditioning leakage credits, which result from reductions in air conditioning-related emissions of HFCs. NHTSA is proposing standards at levels of stringency that assume improvements in the efficiency of air conditioning systems, but that do not account for reductions in HFCs, which are not related to fuel economy or energy conservation. In addition, the CAFE and GHG standards offer somewhat different program flexibilities and provisions, and the agencies' analyses differ in their accounting for these flexibilities (examples include the treatment of EVs, dual-fueled vehicles, and civil penalties), primarily because NHTSA is statutorily prohibited from considering some flexibilities when establishing CAFE standards,[62] while EPA is not. These differences contribute to differences in the agencies' respective estimates of costs and benefits resulting from the new standards. Nevertheless, it is important to note that NHTSA and EPA have harmonized the programs as much as possible, and this proposal to continue the National Program would result in significant cost and other advantages for the automobile industry by allowing them to manufacture one fleet of vehicles across the U.S., rather than comply with potentially multiple state standards that may occur in the absence of the National Program.

In summary, the projected costs and benefits presented by NHTSA and EPA are not directly comparable, because the levels being proposed by EPA include air conditioning-related improvements in HFC reductions, and because of the projection by EPA of complete compliance with the proposed GHG standards, whereas NHTSA projects some manufacturers will pay civil penalties as part of their compliance strategy, as allowed by EPCA. It should also be expected that overall EPA's estimates of GHG reductions and fuel savings achieved by the proposed GHG standards will be slightly higher than those projected by NHTSA only for the CAFE standards because of the same reasons described above. For the same reasons, EPA's estimates of manufacturers' costs for complying with the proposed passenger car and light truck GHG standards are slightly higher than NHTSA's estimates for complying with the proposed CAFE standards.

1. Summary of Costs and Benefits for the Proposed NHTSA CAFE Standards

In reading the following section, we note that tables are identified as reflecting ''estimated required'' values and ''estimated achieved'' values. When establishing standards, EPCA allows NHTSA to only consider the fuel economy of dual-fuel vehicles (for example, FFVs and PHEVs) when operating on gasoline, and prohibits NHTSA from considering the use of dedicated alternative fuel vehicle credits (including for example EVs), credit carry-forward and carry-back, and credit transfer and trading. NHTSA's primary analysis of costs, fuel savings, and related benefits from imposing higher CAFE standards does not include them. However, EPCA does not prohibit NHTSA from considering the fact that manufacturers may pay civil penalties rather than comply with CAFE standards, and NHTSA's primary analysis accounts for some manufacturers' tendency to do so. The primary analysis is generally identified in tables throughout this document by the term ''*estimated required* CAFE levels.''

To illustrate the effects of the flexibilities and technologies that NHTSA is prohibited from including in its primary analysis, NHTSA performed a supplemental analysis of these effects on benefits and costs of the proposed CAFE standards that helps to demonstrate the real-world impacts. As an example of one of the effects, including the use of FFV credits reduces estimated per-vehicle compliance costs of the program, but does not significantly change the projected fuel savings and CO_2 reductions, because FFV credits reduce the fuel economy levels that manufacturers achieve not only under the proposed standards, but also under the baseline MY 2016 CAFE standards. As another example, including the operation of PHEV vehicles on both electricity and gasoline, and the expected use of EVs for compliance may raise the fuel economy levels that manufacturers achieve under the proposed standards. The supplemental analysis is generally identified in tables throughout this document by the term ''*estimated achieved* CAFE levels.''

Thus, NHTSA's primary analysis shows the estimates the agency considered for purposes of establishing new CAFE standards, and its supplemental analysis including manufacturer use of flexibilities and advanced technologies currently reflects the agency's best estimate of the potential real-world effects of the proposed CAFE standards.

Without accounting for the compliance flexibilities and advanced technologies that NHTSA is prohibited from considering when determining the maximum feasible level of new CAFE standards, since manufacturers' decisions to use those flexibilities and technologies are voluntary, NHTSA estimates that the required fuel economy increases would lead to fuel savings totaling 173 billion gallons throughout the lives of vehicles sold in MYs 2017–2025. At a 3 percent discount rate, the present value of the economic benefits resulting from those fuel

[61] TLAAS ends after MY 2016 for manufacturers with MY 2009 U.S. sales of less than 50,000 vehicles.

[62] *See* 49 U.S.C. 32902(h).

savings is $451 billion; at a 7 percent private discount rate, the present value of the economic benefits resulting from those fuel savings is $358 billion.

The agency further estimates that these new CAFE standards would lead to corresponding reductions in CO_2 emissions totaling 1.8 billion metric tons during the lives of vehicles sold in MYs 2017–2025. The present value of the economic benefits from avoiding those emissions is $49 billion, based on a global social cost of carbon value of $22 per metric ton (in 2010, and growing thereafter).[63] It is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to increases in average fuel economy and CO_2 reductions. The two agencies standards together comprise the National Program, and this discussion of the costs and benefits of NHTSA's CAFE standards does not change the fact that both the CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program. All costs are in 2009 dollars.

Table I-7 NHTSA's Estimated MYs 2017-2025 Costs, Benefits, and Net Benefits ($Billion) under the CAFE Standards (Estimated Required)

	3% discount rate		7% discount rate	
	Lifetime present value	Annualized value	Lifetime present value	Annualized value
Costs	157	6.3	157	8.5
Benefits	515	31.8	419	36.3
Net benefits	358	25.5	262	27.8

[63] NHTSA also estimated the benefits associated with three more estimates of a one ton GHG reduction in 2009 ($5, $36, and $67), which will likewise grow thereafter. *See* Section II for a more detailed discussion of the social cost of carbon.

[64] The ''Earlier'' column shows benefits that NHTSA forecasts manufacturers will implement in model years prior to 2017 that are in response to the proposed MY 2017–2025 standards. The CAFE model forecasts that manufactures will implement some technologies, and achieve benefits during vehicle redesigns that occur prior to MY 2017 in order to comply with MY 2017 and later standards in a cost effective manner.

Table I-8 NHTSA's Estimated Fuel Saved (Billion Gallons and Barrels) and CO_2 Emissions Avoided (mmt) under the CAFE Standards (Estimated Required)

		Earlier[64]	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Passenger Cars	Fuel (billion gallons)	3	2	5	7	9	11	13	15	17	19	104
	Fuel (billion barrels)	0.09	0.06	0.12	0.17	0.22	0.27	0.31	0.36	0.42	0.46	2.47
	CO_2 (mmt)	41	26	52	76	100	122	139	158	184	202	1100
Light Trucks	Fuel (billion gallons)	0	0	2	5	6	9	10	11	12	13	69
	Fuel (billion barrels)	0.01	0.01	0.05	0.11	0.15	0.21	0.24	0.27	0.29	0.32	1.65
	CO_2 (mmt)	4	5	22	49	65	93	108	118	129	141	734
Combined	Fuel (billion gallons)	4	3	7	12	16	20	23	26	30	33	173
	Fuel (billion barrels)	0.10	0.07	0.16	0.28	0.37	0.48	0.55	0.62	0.71	0.78	4.13
	CO_2 (mmt)	45	31	74	124	165	215	246	276	313	343	1834

[64] The "Earlier" column shows benefits that NHTSA forecasts manufacturers will implement in model years prior to 2017 that are in response to the proposed MY 2017-2025 standards. The CAFE model forecasts that manufactures will implement some technologies, and achieve benefits during vehicle redesigns that occur prior to MY 2017 in order to comply with MY 2017 and later standards in a cost effective manner.

Considering manufacturers' ability to employ compliance flexibilities and advanced technologies for meeting the standards, NHTSA estimates the following for fuel savings and avoided CO_2 emissions, assuming FFV credits would be used toward both the baseline and final standards:

Table I-9 NHTSA's Estimated Fuel Saved (Billion Gallons and Barrels) and CO_2 Emissions Avoided (mmt) under the CAFE Standards (Estimated Achieved)

		Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Passenger Cars	Fuel (billion gallons)	4	2	4	6	9	10	12	14	17	20	98
	Fuel (billion barrels)	0.09	0.05	0.10	0.15	0.21	0.25	0.29	0.34	0.40	0.47	2.34
	CO_2 (mmt)	41	23	43	69	93	111	128	151	177	204	1040
Light Trucks	Fuel (billion gallons)	0	1	2	4	6	8	9	10	11	13	65
	Fuel (billion barrels)	0.01	0.02	0.05	0.10	0.14	0.19	0.22	0.24	0.27	0.30	1.54
	CO_2 (mmt)	4	7	22	47	64	89	100	109	123	138	702
Combined	Fuel (billion gallons)	4	3	6	11	14	19	21	24	28	32	163
	Fuel (billion barrels)	0.10	0.07	0.14	0.25	0.34	0.44	0.50	0.58	0.67	0.77	3.88
	CO_2 (mmt)	45	31	65	116	157	200	227	260	300	341	1742

NHTSA estimates that the fuel economy increases resulting from the proposed standards would produce other benefits both to drivers (*e.g.,* reduced time spent refueling) and to the U.S. as a whole (*e.g.,* reductions in the costs of petroleum imports *beyond* the direct savings from reduced oil purchases),[65] as well as some disbenefits (*e.g.,* increased traffic congestion) caused by drivers' tendency to travel more when the cost of driving declines (as it does when fuel economy increases). NHTSA has estimated the total monetary value to society of these benefits and disbenefits, and estimates that the proposed standards will produce significant net benefits to society. Using a 3 percent discount rate, NHTSA estimates that the present value of these benefits would total more than $515 billion over the lives of the vehicles sold during MYs 2017–2025; using a 7 percent discount rate, more than $419 billion. More discussion regarding monetized benefits can be found in Section IV of this notice and in NHTSA's PRIA. Note that the benefit calculation in the following tables includes the benefits of reducing CO_2 emissions,[66] but not the benefits of reducing other GHG emissions.

[65] We note, of course, that reducing the amount of fuel purchased also reduces tax revenue for the Federal and state/local governments. NHTSA discusses this issue in more detail in Chapter VIII of the PRIA.

[66] CO_2 benefits for purposes of these tables are calculated using the $22/ton SCC values. Note that the net present value of reduced GHG emissions is calculated differently from other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency.

Table I-10 NHTSA's Discounted Benefits ($Billion) under the CAFE Standards Using a 3 and 7 Percent Discount Rate

(Estimated Required)

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
3% discount rate											
Passenger cars	11	7	14	21	27	34	39	45	53	59	310
Light trucks	1	1	6	13	18	26	30	33	37	40	206
Combined	12	8	20	34	45	60	69	78	90	100	515
7% discount rate											
Passenger cars	9	6	12	17	22	28	32	37	44	49	254
Light trucks	1	1	5	10	14	21	24	27	30	33	165
Combined	9	7	16	27	37	49	56	64	73	81	419

Considering manufacturers' ability to employ compliance flexibilities and advanced technologies for meeting the standards, NHTSA estimates the present value of these benefits would be reduced as follows:

Table I-11 NHTSA's Discounted Benefits ($Billion) under the CAFE Standards Using a 3 and 7 Percent Discount Rate

(Estimated Achieved)

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
3% discount rate											
Passenger cars	10	6	12	19	26	31	36	43	51	60	293
Light trucks	1	2	6	12	17	24	28	30	35	39	195
Combined	11	8	17	31	43	55	63	74	86	99	488
7% discount rate											
Passenger cars	8	5	9	15	21	25	29	35	42	49	240
Light trucks	1	2	5	10	14	20	22	24	28	32	157
Combined	9	7	14	25	35	45	52	60	70	81	397

NHTSA attributes most of these benefits (about $451 billion at a 3 percent discount rate, or about $358 billion at a 7 percent discount rate, excluding consideration of compliance flexibilities and advanced technologies for meeting the standards) to reductions in fuel consumption, valuing fuel (for societal purposes) at the future pre-tax prices projected in the Energy Information Administration's (EIA) reference case forecast from the Annual Energy Outlook (AEO) 2011. NHTSA's PRIA accompanying this proposal presents a detailed analysis of specific benefits of the rule.

Table I-12 Summary of NHTSA's Fuel Savings and CO_2 Emissions Reduction under the CAFE Standards (Estimated Required)

	Amount	3% discount rate	7% discount rate
Fuel savings	173	451	358
CO_2 emissions reductions	1,834	49	49

NHTSA estimates that the increases in technology application necessary to achieve the projected improvements in fuel economy will entail considerable monetary outlays. The agency estimates that the incremental costs for achieving the proposed CAFE standards—that is, outlays by vehicle manufacturers over and above those required to comply with the MY 2016 CAFE standards—will total about $157 billion (*i.e.,* during MYs 2017–2025).

Table I-13 NHTSA's Incremental Technology Outlays ($Billion) under the CAFE Standards (Estimated Required)

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Passenger cars	4	2	5	7	9	12	14	17	22	23	113
Light trucks	0	0	1	2	4	5	6	7	8	9	44
Combined	4	3	6	9	13	17	20	24	30	32	157

However, NHTSA estimates that manufacturers employing compliance flexibilities and advanced technologies to meet the standards could significantly reduce these outlays:

Table I-14 NHTSA's Incremental Technology Outlays ($Billion) under the CAFE Standards (Estimated Achieved)

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Passenger cars	1	1	3	5	8	10	12	16	19	22	98
Light trucks	0	0	1	2	3	4	5	6	6	8	35
Combined	1	2	4	7	11	15	17	21	25	30	133

NHTSA projects that manufacturers will recover most or all of these additional costs through higher selling prices for new cars and light trucks. To allow manufacturers to recover these increased outlays (and, to a much less extent, the civil penalties that some manufacturers are expected to pay for non-compliance), the agency estimates that the standards would lead to increase in average new vehicle prices ranging from $161 per vehicle in MY 2017 to $1876 per vehicle in MY 2025:

Table I-15 NHTSA's Incremental Increases in Average New Vehicle Costs ($) under the CAFE Standards (Estimated Required)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger cars	228	467	652	885	1,108	1,259	1,536	1,927	2,023
Light trucks	44	187	427	688	965	1,102	1,284	1,428	1,578
Combined	161	365	572	815	1,058	1,205	1,450	1,760	1,876

And as before, NHTSA estimates that manufacturers employing compliance flexibilities and advanced technologies to meet the standards could significantly reduce these increases.

Table I-16 NHTSA's Incremental Increases in Average New Vehicle Costs ($) under the CAFE Standards (Estimated Achieved)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger cars	141	320	529	767	977	1,122	1,424	1,688	1,926
Light trucks	57	178	359	524	755	863	976	1,141	1,348
Combined	110	268	468	681	899	1,032	1,271	1,505	1,735

NHTSA estimates, therefore, that the total benefits of these proposed CAFE standards will be more than 2.5 times the magnitude of the corresponding costs. As a consequence, the proposed CAFE standards would produce net benefits of $358 billion at a 3 percent discount rate (with compliance flexibilities, $355 billion), or $262 billion at a 7 percent discount rate (with compliance flexibilities, $264 billion), over the useful lives of the vehicles sold during MYs 2017–2025.

2. Summary of Costs and Benefits for the Proposed EPA GHG Standards

EPA has analyzed in detail the costs and benefits of the proposed GHG standards. Table I–17 shows EPA's estimated lifetime discounted cost, fuel savings, and benefits for all vehicles projected to be sold in model years 2017–2025. The benefits include impacts such as climate-related economic benefits from reducing emissions of CO_2 (but not other GHGs), reductions in energy security externalities caused by U.S. petroleum consumption and imports, the value of certain health benefits, the value of additional driving attributed to the rebound effect, the value of reduced refueling time needed to fill up a more fuel efficient vehicle. The analysis also includes economic impacts stemming from additional vehicle use, such as the economic damages caused by accidents, congestion and noise. Note that benefits depend on estimated values for the social cost of carbon (SCC), as described in Section III.H.

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Table I-17 EPA's Estimated 2017-2025 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits assuming the 3% discount rate SCC Value[a,b] (Billions of 2009 dollars)

Lifetime Present Value[c] – 3% Discount Rate	
Program Costs	$140
Fuel Savings	$444
Benefits	$117
Net Benefits[d]	$421
Annualized Value[e] – 3% Discount Rate	
Annualized costs	$6.43
Annualized fuel savings	$20.3
Annualized benefits	$5.36
Net benefits	$19.3
Lifetime Present Value[c] - 7% Discount Rate	
Program Costs	$138
Fuel Savings	$347
Benefits	$101
Net Benefits[d]	$311
Annualized Value[e] – 7% Discount Rate	
Annualized costs	$10.6
Annualized fuel savings	$26.7
Annualized benefits	$6.35
Net benefits	$22.4

Notes:

[a] The agencies estimated the benefits associated with four different values of a one ton CO_2 reduction (model average at 2.5% discount rate, 3%, and 5%; 95th percentile at 3%), which each increase over time. For the purposes of this overview presentation of estimated costs and benefits, however, we are showing the benefits associated with the marginal value deemed to be central by the interagency working group on this topic: the model average at 3% discount rate, in 2009 dollars. Section III.H provides a complete list of values for the 4 estimates.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

[c] Present value is the total, aggregated amount that a series of monetized costs or benefits that occur over time is worth in a given year. For this analysis, lifetime present values are calculated for the first year of each model year for MYs 2017-2025 (in year 2009 dollar terms). The lifetime present values shown here are the present values of each MY in its first year summed across MYs.

[d] Net benefits reflect the fuel savings plus benefits minus costs.

[e] The annualized value is the constant annual value through a given time period (the lifetime of each MY in this analysis) whose summed present value equals the present value from which it was derived. Annualized SCC values are calculated using the same rate as that used to determine the SCC value while all other costs and benefits are annualized at either 3% or 7%.

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Table I–18 shows EPA's estimated lifetime fuel savings and CO_2 equivalent emission reductions for all vehicles sold in the model years 2017–2025. The values in Table I–18 are projected lifetime totals for each model year and are not discounted. As documented in EPA's draft RIA, the potential credit transfer between cars and trucks may change the distribution of the fuel savings and GHG emission impacts between cars and trucks. As discussed above with respect to NHTSA's CAFE standards, it is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to increases in average fuel economy and reductions in CO_2 emissions. The two agencies' standards together comprise the National Program, and this discussion of costs and benefits of EPA's proposed GHG standards does not change the fact that both the proposed CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program. In general though, in addition to the added GHG benefit of HFC reductions from the EPA program, the fuel savings benefit are also somewhat higher than that from CAFE, primarily because of the possibility of paying civil penalties in lieu of applying technology in NHTSA's program, which is required by EPCA.

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Table I-18 EPA's Estimated 2017-2025 Model Year Lifetime Fuel Saved and GHG Emissions Avoided

		2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Total
Cars	Fuel (billion gallons)	1	3	6	8	11	13	16	19	21	99
	Fuel (billion barrels)	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.5	2.4
	CO_2 EQ (mmt)	17	44	71	101	131	160	186	213	241	1,163
Light Trucks	Fuel (billion gallons)	1	2	3	4	7	9	11	13	15	66
	Fuel (billion barrels)	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	1.6
	CO_2 EQ (mmt)	12	26	38	51	88	113	136	159	181	805
Combined	Fuel (billion gallons)	2	6	9	12	18	23	27	32	37	165
	Fuel (billion barrels)	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	3.9
	CO_2 EQ (mmt)	29	70	108	151	220	273	322	372	422	1,967

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Table I–19 shows EPA's estimated lifetime discounted benefits for all vehicles sold in model years 2017–2025. Although EPA estimated the benefits associated with four different values of a one ton GHG reduction ($5, $22 $36, $67 in CY 2010 and in 2009 dollars), for the purposes of this overview presentation of estimated benefits EPA is showing the benefits associated with one of these marginal values, $22 per ton of CO_2, in 2009 dollars and 2010 emissions. Table I–19 presents benefits based on the $22 value. Section III.H presents the four marginal values used to estimate monetized benefits of GHG reductions and Section III.H presents the program benefits using each of the four marginal values, which represent only a partial accounting of total benefits due to omitted climate change impacts and other factors that are not readily monetized. The values in the table are discounted values for each model year of vehicles throughout their projected lifetimes. The benefits include all benefits considered by EPA such as GHG reductions, PM benefits, energy security and other externalities such as reduced refueling time and accidents, congestion and noise. The lifetime discounted benefits are shown for one of four different social cost of carbon (SCC) values considered by EPA. The values in Table I–19 do not include costs associated with new technology required to meet the GHG standard and they do not include the fuel savings expected from that technology.

Table I-19 EPA's Estimated 2017-2025 Model Year Lifetime Discounted Benefits Assuming the \$22/ton SCC Value[a,b,c,d] (billions of 2009 dollars)

Discount Rate	Model Year									
	2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum of Present Values
3%	\$1.62	\$3.85	\$6.02	\$8.51	\$12.7	\$16.1	\$19.3	\$22.8	\$26.2	\$117
7%	\$1.39	\$3.31	\$5.19	\$7.34	\$11.0	\$14.0	\$16.8	\$19.8	\$22.7	\$101

[a] The benefits include all benefits considered by EPA savings in refueling time, climate-related economic benefits from reducing emissions of CO_2 (but not other GHGs), economic benefits from reducing emissions of PM and other air pollutants that contribute to its formation, and reductions in energy security externalities caused by U.S. petroleum consumption and imports. The analysis also includes disbenefits stemming from additional vehicle use, such as the economic damages caused by accidents, congestion and noise.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this proposed rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses. Also, as noted in Section III.H, SCC increases over time. The \$22/ton (2009\$) value applies to 2010 emissions and grows larger over time.

[d] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.

Table I–20 shows EPA's estimated lifetime fuel savings, lifetime CO_2 emission reductions, and the monetized net present values of those fuel savings and CO_2 emission reductions. The fuel savings and CO_2 emission reductions are projected lifetime values for all vehicles sold in the model years 2017–2025. The estimated fuel savings in billions of gallons and the GHG reductions in million metric tons of CO_2 shown in Table I–20 are totals for the nine model years throughout their projected lifetime and are not discounted. The monetized values shown in Table I–20 are the summed values of the discounted monetized fuel savings and monetized CO_2 reductions for the model years 2017–2025 vehicles throughout their lifetimes. The monetized values in Table I–20 reflect both a 3 percent and a 7 percent discount rate as noted.

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Table I-20 EPA's Estimated 2017-2025 Model Year Lifetime Fuel Savings, CO_2 Emission Reductions, and Discounted Monetized SCC Benefits using the $22/ton SCC Value (monetized values in 2009 dollars)

	Amount	$ value (billions)
Fuel savings (3% discount rate)	165 billion gallons (3.9 billion barrels)	$444
Fuel savings (7% discount rate)	165 billion gallons (3.9 billion barrels)	$347
CO_2e emission reductions (CO_2 portion valued assuming $22/ton CO_2 in 2010)	1,967 MMT CO_2e	$46.4[a,b]

[a] $46.4 billion for 1,743 MMT of reduced CO_2 emissions. As noted in Section III.H, the $22/ton (2009$) value applies to 2010 emissions and grows larger over time. Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this proposed rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 GHG emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[b] Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

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Table I–21 shows EPA's estimated incremental and total technology outlays for cars and trucks for each of the model years 2017–2025. The technology outlays shown in Table I–21 are for the industry as a whole and do not account for fuel savings associated with the program. Table I–22 shows EPA's estimated incremental cost increase of the average new vehicle for each model year 2017–2025. The values shown are incremental to a baseline vehicle and are not cumulative. In other words, the estimated increase for 2017 model year cars is $194 relative to a 2017 model year car meeting the MY 2016 standards. The estimated increase for a 2018 model year car is $353 relative to a 2018 model year car meeting the MY 2016 standards (not $194 plus $353).

Table I-21 EPA's Estimated Incremental Technology Outlays Associated with the Proposed Standards (billions of 2009 dollars)

		2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum of Present Values
3% discount rate	Cars	$1.91	$3.45	$4.71	$6.04	$7.43	$12.3	$16.1	$20.0	$22.1	$94.1
	Trucks	$0.32	$1.11	$1.68	$2.30	$4.28	$6.74	$8.55	$10.26	$11.0	$46.2
	Combined	$2.27	$4.59	$6.41	$8.34	$11.7	$19.1	$24.7	$30.3	$33.1	$140
7% discount rate	Cars	$1.88	$3.38	$4.63	$5.92	$7.29	$12.1	$15.8	$19.7	$21.7	$92.4
	Trucks	$0.31	$1.09	$1.65	$2.26	$4.20	$6.62	$8.39	$10.07	$10.8	$45.4
	Combined	$2.22	$4.50	$6.29	$8.19	$11.5	$18.7	$24.2	$29.7	$32.5	$138

Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years

Table I-22 EPA's Estimated Incremental Increase in Average New Vehicle Cost Relative to the Reference Case[a] (2009 dollars per unit)

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY
Cars	$194	$353	$479	$595	$718	$1,165	$1,492	$1,806	$1,942
Trucks	$55	$198	$305	$417	$764	$1,200	$1,525	$1,834	$1,954
Combined	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946

[a] The reference case assumes the 2016MY standards continue indefinitely.

D. Background and Comparison of NHTSA and EPA Statutory Authority

This section provides the agencies' respective statutory authorities under which CAFE and GHG standards are established.

1. NHTSA Statutory Authority

NHTSA establishes CAFE standards for passenger cars and light trucks for each model year under EPCA, as amended by EISA. EPCA mandates a motor vehicle fuel economy regulatory program to meet the various facets of the need to conserve energy, including the environmental and foreign policy implications of petroleum use by motor vehicles. EPCA allocates the responsibility for implementing the program between NHTSA and EPA as follows: NHTSA sets CAFE standards for passenger cars and light trucks; EPA establishes the procedures for testing, tests vehicles, collects and analyzes manufacturers' data, and calculates the individual and average fuel economy of each manufacturer's passenger cars and light trucks; and NHTSA enforces the standards based on EPA's calculations.

a. Standard Setting

We have summarized below the most important aspects of standard setting under EPCA, as amended by EISA. For each future model year, EPCA requires that NHTSA establish separate passenger car and light truck standards at ''the maximum feasible average fuel economy level that it decides the manufacturers can achieve in that model year,'' based on the agency's consideration of four statutory factors: technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy. EPCA does not define these terms or specify what weight to give each concern in balancing them; thus, NHTSA defines them and determines the appropriate weighting that leads to the maximum feasible standards given the circumstances in each CAFE standard rulemaking.[67] For MYs 2011–2020, EPCA further requires that separate standards for passenger cars and for light trucks be set at levels high enough to ensure that the CAFE of the industry-wide combined fleet of new passenger cars and light trucks reaches at least 35 mpg not later than MY 2020. For model years after 2020, standards need simply be set at the maximum feasible level.

Because EPCA states that standards must be set for ''* * * automobiles manufactured by manufacturers,'' and because Congress provided specific direction on how small-volume manufacturers could obtain exemptions from the passenger car standards, NHTSA has long interpreted its authority as pertaining to setting standards for the industry as a whole. Prior to this NPRM, some manufacturers raised with NHTSA the possibility of NHTSA and EPA setting alternate standards for part of the industry that met certain (relatively low) sales volume criteria—specifically, that separate standards be set so that ''intermediate-size,'' limited-line manufacturers do not have to meet the same levels of stringency that larger manufacturers have to meet until several years later. NHTSA seeks comment on whether or how EPCA, as amended by EISA, could be interpreted to allow such alternate standards for certain parts of the industry.

i. Factors That Must Be Considered in Deciding the Appropriate Stringency of CAFE Standards

(1) Technological Feasibility

''Technological feasibility'' refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established. Thus, the agency is not limited in determining the level of new standards to technology that is already being commercially applied at the time of the rulemaking, a consideration which is particularly relevant for a rulemaking with a timeframe as long as the present one. For this rulemaking, NHTSA has considered all types of technologies that improve real-world fuel economy, including air-conditioner efficiency, due to EPA's proposal to allow generation of fuel consumption improvement values for CAFE purposes based on improvements to air-conditioner efficiency that improves fuel efficiency.

(2) Economic Practicability

''Economic practicability'' refers to whether a standard is one ''within the financial capability of the industry, but not so stringent as to'' lead to ''adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice.''[68] The agency has explained in the past that this factor can be especially important during rulemakings in which the automobile industry is facing significantly adverse economic conditions (with corresponding risks to jobs). Consumer acceptability is also an element of economic practicability, one which is particularly difficult to gauge during times of uncertain fuel prices.[69] In a rulemaking such as the present one, looking out into the more distant future, economic practicability is a way to consider the uncertainty surrounding future market conditions and consumer demand for fuel economy in addition to other vehicle attributes. In an attempt to ensure the economic practicability of attribute-based standards, NHTSA considers a variety of factors, including the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology, the specific fleet mixes of different manufacturers, and assumptions about the cost of the standards to consumers and consumers' valuation of fuel economy, among other things.

It is important to note, however, that the law does not preclude a CAFE standard that poses considerable challenges to any individual manufacturer. The Conference Report for EPCA, as enacted in 1975, makes clear, and the case law affirms, ''a determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy.''[70] Instead, NHTSA is compelled ''to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers.''[71] The law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole. Thus, while a particular CAFE standard may pose difficulties for one manufacturer, it may also present opportunities for another. NHTSA has long held that the CAFE program is not necessarily intended to maintain the competitive positioning of each particular company. Rather, it is intended to enhance the fuel economy of the vehicle fleet on American roads, while protecting motor vehicle safety and being mindful of the risk to the overall United States economy.

(3) The Effect of Other Motor Vehicle Standards of the Government on Fuel Economy

''The effect of other motor vehicle standards of the Government on fuel economy,'' involves an analysis of the effects of compliance with emission,

[67] *See Center for Biological Diversity* v. *NHTSA,* 538 F.3d. 1172, 1195 (9th Cir. 2008) (''The EPCA clearly requires the agency to consider these four factors, but it gives NHTSA discretion to decide how to balance the statutory factors—as long as NHTSA's balancing does not undermine the fundamental purpose of the EPCA: energy conservation.'').

[68] 67 FR 77015, 77021 (Dec. 16, 2002).

[69] *See, e.g., Center for Auto Safety* v. *NHTSA (CAS),* 793 F.2d 1322 (D.C. Cir. 1986) (Administrator's consideration of market demand as component of economic practicability found to be reasonable); *Public Citizen* v. *NHTSA,* 848 F.2d 256 (Congress established broad guidelines in the fuel economy statute; agency's decision to set lower standard was a reasonable accommodation of conflicting policies).

[70] *CEI–I,* 793 F.2d 1322, 1352 (D.C. Cir. 1986).

[71] *Id.*

safety, noise, or damageability standards on fuel economy capability and thus on average fuel economy. In previous CAFE rulemakings, the agency has said that pursuant to this provision, it considers the adverse effects of other motor vehicle standards on fuel economy. It said so because, from the CAFE program's earliest years [72] until present, the effects of such compliance on fuel economy capability over the history of the CAFE program have been negative ones. For example, safety standards that have the effect of increasing vehicle weight lower vehicle fuel economy capability and thus decrease the level of average fuel economy that the agency can determine to be feasible.

In the wake of *Massachusetts* v. *EPA* and of EPA's endangerment finding, granting of a waiver to California for its motor vehicle GHG standards, and its own establishment of GHG standards, NHTSA is confronted with the issue of how to treat those standards under EPCA/EISA, such as in the context of the ''other motor vehicle standards'' provision. To the extent the GHG standards result in increases in fuel economy, they would do so almost exclusively as a result of inducing manufacturers to install the same types of technologies used by manufacturers in complying with the CAFE standards.

Comment is requested on whether and in what way the effects of the California and EPA standards should be considered under EPCA/EISA, *e.g.,* under the ''other motor vehicle standards'' provision, consistent with NHTSA's independent obligation under EPCA/EISA to issue CAFE standards. The agency has already considered EPA's proposal and the harmonization benefits of the National Program in developing its own proposal.

(4) The Need of the United States To Conserve Energy

''The need of the United States to conserve energy'' means ''the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum.'' [73] Environmental implications principally include reductions in emissions of carbon dioxide and criteria pollutants and air toxics. Prime examples of foreign policy implications are energy independence and security concerns.

[72] 42 FR 63184, 63188 (Dec. 15, 1977). *See also* 42 FR 33534, 33537 (Jun. 30, 1977).

[73] 42 FR 63184, 63188 (1977).

(5) Fuel Prices and the Value of Saving Fuel

Projected future fuel prices are a critical input into the preliminary economic analysis of alternative CAFE standards, because they determine the value of fuel savings both to new vehicle buyers and to society, which is related to the consumer cost (or rather, benefit) of our need for large quantities of petroleum. In this rule, NHTSA relies on fuel price projections from the U.S. Energy Information Administration's (EIA) most recent Annual Energy Outlook (AEO) for this analysis. Federal government agencies generally use EIA's projections in their assessments of future energy-related policies.

(6) Petroleum Consumption and Import Externalities

U.S. consumption and imports of petroleum products impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) Higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to provide a response option should a disruption in commercial oil supplies threaten the U.S. economy, to allow the United States to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and to provide a national defense fuel reserve. Higher U.S. imports of crude oil or refined petroleum products increase the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above the resource costs of producing them. Conversely, reducing U.S. imports of crude petroleum or refined fuels or reducing fuel consumption can reduce these external costs.

(7) Air Pollutant Emissions

While reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of various pollutants, additional vehicle use associated with the rebound effect [74] from higher fuel economy will increase emissions of these pollutants. Thus, the net effect of stricter CAFE standards on emissions of each pollutant depends on the relative magnitudes of its reduced emissions in fuel refining and distribution, and increases in its emissions from vehicle use. Fuel savings from stricter CAFE standards also result in lower emissions of CO_2, the main greenhouse gas emitted as a result of refining, distribution, and use of transportation fuels. Reducing fuel consumption reduces carbon dioxide emissions directly, because the primary source of transportation-related CO_2 emissions is fuel combustion in internal combustion engines.

[74] The ''rebound effect'' refers to the tendency of drivers to drive their vehicles more as the cost of doing so goes down, as when fuel economy improves.

NHTSA has considered environmental issues, both within the context of EPCA and the National Environmental Policy Act, in making decisions about the setting of standards from the earliest days of the CAFE program. As courts of appeal have noted in three decisions stretching over the last 20 years,[75] NHTSA defined the ''need of the Nation to conserve energy'' in the late 1970s as including ''the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum.'' [76] In 1988, NHTSA included climate change concepts in its CAFE notices and prepared its first environmental assessment addressing that subject.[77] It cited concerns about climate change as one of its reasons for limiting the extent of its reduction of the CAFE standard for MY 1989 passenger cars.[78] Since then, NHTSA has considered the benefits of reducing tailpipe carbon dioxide emissions in its fuel economy rulemakings pursuant to the statutory requirement to consider the nation's need to conserve energy by reducing fuel consumption.

ii. Other Factors Considered by NHTSA

NHTSA considers the potential for adverse safety consequences when establishing CAFE standards. This practice is recognized approvingly in case law.[79] Under the universal or ''flat''

[75] *Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, 1325 n. 12 (D.C. Cir. 1986); *Public Citizen* v. *NHTSA,* 848 F.2d 256, 262–3 n. 27 (D.C. Cir. 1988) (noting that ''NHTSA itself has interpreted the factors it must consider in setting CAFE standards as including environmental effects''); and *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172 (9th Cir. 2007).

[76] 42 FR 63184, 63188 (Dec. 15, 1977) (emphasis added).

[77] 53 FR 33080, 33096 (Aug. 29, 1988).

[78] 53 FR 39275, 39302 (Oct. 6, 1988).

[79] As the United States Court of Appeals pointed out in upholding NHTSA's exercise of judgment in

CAFE standards that NHTSA was previously authorized to establish, the primary risk to safety came from the possibility that manufacturers would respond to higher standards by building smaller, less safe vehicles in order to ''balance out'' the larger, safer vehicles that the public generally preferred to buy. Under the attribute-based standards being proposed in this action, that risk is reduced because building smaller vehicles tends to raise a manufacturer's overall CAFE obligation, rather than only raising its fleet average CAFE. However, even under attribute-based standards, there is still risk that manufacturers will rely on down-weighting to improve their fuel economy (for a given vehicle at a given footprint target) in ways that may reduce safety.[80]

iii. Factors That NHTSA Is Statutorily Prohibited From Considering in Setting Standards

EPCA provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several EPCA provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance. Specifically, in determining the maximum feasible level of fuel economy for passenger cars and light trucks, NHTSA cannot consider the fuel economy benefits of ''dedicated'' alternative fuel vehicles (like battery electric vehicles or natural gas vehicles), must consider dual-fueled automobiles to be operated only on gasoline or diesel fuel, and may not consider the ability of manufacturers to use, trade, or transfer credits.[81] This provision limits, to some extent, the fuel economy levels that NHTSA can find to be ''maximum feasible''—if NHTSA cannot consider the fuel economy of electric vehicles, for example, NHTSA cannot set a standards predicated on manufacturers' usage of electric vehicles to meet the standards.

iv. Weighing and Balancing of Factors

NHTSA has broad discretion in balancing the above factors in determining the average fuel economy level that the manufacturers can achieve. Congress ''specifically delegated the process of setting * * * fuel economy standards with *broad* guidelines concerning the factors that the agency must consider.'' [82] The breadth of those guidelines, the absence of any statutorily prescribed formula for balancing the factors, the fact that the relative weight to be given to the various factors may change from rulemaking to rulemaking as the underlying facts change, and the fact that the factors may often be conflicting with respect to whether they militate toward higher or lower standards give NHTSA discretion to decide what weight to give each of the competing policies and concerns and then determine how to balance them—''as long as NHTSA's balancing does not undermine the fundamental purpose of the EPCA: energy conservation,'' [83] and as long as that balancing reasonably accommodates ''conflicting policies that were committed to the agency's care by the statute.'' [84] Thus, EPCA does not mandate that any particular number be adopted when NHTSA determines the level of CAFE standards.

v. Other Requirements Related to Standard Setting

The standards for passenger cars and for light trucks must increase ratably each year through MY 2020.[85] This statutory requirement is interpreted, in combination with the requirement to set the standards for each model year at the level determined to be the maximum feasible level that manufacturers can achieve for that model year, to mean that the annual increases should not be disproportionately large or small in relation to each other.[86] Standards after 2020 must simply be set at the maximum feasible level.[87]

The standards for passenger cars and light trucks must also be based on one or more vehicle attributes, like size or weight, which correlate with fuel economy and must be expressed in terms of a mathematical function.[88] Fuel economy targets are set for individual vehicles and increase as the attribute decreases and vice versa. For example, footprint-based standards assign higher fuel economy targets to smaller-footprint vehicles and lower ones to larger footprint-vehicles. The fleetwide average fuel economy that a particular manufacturer is required to achieve depends on the footprint mix of its fleet, *i.e.,* the proportion of the fleet that is small-, medium-, or large-footprint.

This approach can be used to require virtually all manufacturers to increase significantly the fuel economy of a broad range of both passenger cars and light trucks, *i.e.,* the manufacturer must improve the fuel economy of all the vehicles in its fleet. Further, this approach can do so without creating an incentive for manufacturers to make small vehicles smaller or large vehicles larger, with attendant implications for safety.

b. Test Procedures for Measuring Fuel Economy

EPCA provides EPA with the responsibility for establishing procedures to measure fuel economy and to calculate CAFE. Current test procedures measure the effects of nearly all fuel saving technologies. EPA is considering revising the procedures for measuring fuel economy and calculating average fuel economy for the CAFE program, however, to account for four impacts on fuel economy not currently included in these procedures—increases in fuel economy because of increases in efficiency of the air conditioning system; increases in fuel economy because of technology improvements that achieve ''off-cycle'' benefits; incentives for use of certain hybrid technologies in a significant percentage of pickup trucks; and incentives for achieving fuel economy levels in a significant percentage pickup trucks that exceeds the target curve by specified amounts, in the form of increased values assigned for fuel economy. NHTSA has taken these proposed changes into account in determining the proposed fuel economy standards. These changes would be the same as program elements that are part of EPA's greenhouse gas performance

setting the 1987–1989 passenger car standards, ''NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program.'' *Competitive Enterprise Institute* v. *NHTSA (CEI I),* 901 F.2d 107, 120 at n.11 (D.C. Cir. 1990).

[80] For example, by reducing the mass of the smallest vehicles rather than the largest, or by reducing vehicle overhang outside the space measured as ''footprint,'' which results in less crush space.

[81] 49 U.S.C. 32902(h). We note, as discussed in greater detail in Section IV, that NHTSA interprets 32902(h) as reflecting Congress' intent that statutorily-mandated compliance flexibilities remain flexibilities. When a compliance flexibility is not statutorily mandated, therefore, or when it ceases to be available under the statute, we interpret 32902(h) as no longer binding the agency's determination of the maximum feasible levels of fuel economy. For example, when the manufacturing incentive for dual-fueled automobiles under 49 U.S.C. 32905 and 32906 expires in MY 2019, there is no longer a flexibility left to protect per 32902(h), so NHTSA considers the calculated fuel economy of plug-in hybrid electric vehicles for purposes of determining the maximum feasible standards in MYs 2020 and beyond.

[82] *Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, at 1341 (D.C. Cir. 1986).

[83] *CBD* v. *NHTSA,* 538 F.3d at 1195 (9th Cir. 2008).

[84] *Id.*

[85] 49 U.S.C. 32902(b)(2)(C).

[86] *See* 74 FR 14196, 14375–76 (Mar. 30, 2009).

[87] 49 U.S.C. 32902(b)(2)(B).

[88] 49 U.S.C. 32902(b)(3).

standards, discussed in Section III.B.10. As discussed below, these three elements would be implemented in the same manner as in the EPA's greenhouse gas program—a vehicle manufacturer would have the option to generate these fuel economy values for vehicle models that meet the criteria for these elements and to use these values in calculating their fleet average fuel economy. This proposed revision to CAFE calculation is discussed in more detail in Sections III and IV below.

c. Enforcement and Compliance Flexibility

NHTSA determines compliance with the CAFE standards based on measurements of automobile manufacturers' CAFE from EPA. If a manufacturer's passenger car or light truck CAFE level exceeds the applicable standard for that model year, the manufacturer earns credits for over-compliance. The amount of credit earned is determined by multiplying the number of tenths of a mpg by which a manufacturer exceeds a standard for a particular category of automobiles by the total volume of automobiles of that category manufactured by the manufacturer for a given model year. As discussed in more detail in Section IV.I, credits can be carried forward for 5 model years or back for 3, and can also be transferred between a manufacturer's fleets or traded to another manufacturer.

If a manufacturer's passenger car or light truck CAFE level does not meet the applicable standard for that model year, NHTSA notifies the manufacturer. The manufacturer may use ''banked'' credits to make up the shortfall, but if there are no (or not enough) credits available, then the manufacturer has the option to submit a ''carry back plan'' to NHTSA. A carry back plan describes what the manufacturer plans to do in the following three model years to earn enough credits to make up for the shortfall through future over-compliance. NHTSA must examine and determine whether to approve the plan.

In the event that a manufacturer does not comply with a CAFE standard, even after the consideration of credits, EPCA provides for the assessing of civil penalties.[89] The Act specifies a precise formula for determining the amount of civil penalties for such a noncompliance. The penalty, as adjusted for inflation by law, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year multiplied by the total volume of those vehicles in the affected fleet (*i.e.,* import or domestic passenger car, or light truck), manufactured for that model year. The amount of the penalty may not be reduced except under the unusual or extreme circumstances specified in the statute, which have never been exercised by NHTSA in the history of the CAFE program.

Unlike the National Traffic and Motor Vehicle Safety Act, EPCA does not provide for recall and remedy in the event of a noncompliance. The presence of recall and remedy provisions[90] in the Safety Act and their absence in EPCA is believed to arise from the difference in the application of the safety standards and CAFE standards. A safety standard applies to individual vehicles; that is, each vehicle must possess the requisite equipment or feature that must provide the requisite type and level of performance. If a vehicle does not, it is noncompliant. Typically, a vehicle does not entirely lack an item or equipment or feature. Instead, the equipment or features fails to perform adequately. Recalling the vehicle to repair or replace the noncompliant equipment or feature can usually be readily accomplished.

In contrast, a CAFE standard applies to a manufacturer's entire fleet for a model year. It does not require that a particular individual vehicle be equipped with any particular equipment or feature or meet a particular level of fuel economy. It does require that the manufacturer's fleet, as a whole, comply. Further, although under the attribute-based approach to setting CAFE standards fuel economy targets are established for individual vehicles based on their footprints, the individual vehicles are not required to meet or exceed those targets. However, as a practical matter, if a manufacturer chooses to design some vehicles that fall below their target levels of fuel economy, it will need to design other vehicles that exceed their targets if the manufacturer's overall fleet average is to meet the applicable standard.

Thus, under EPCA, there is no such thing as a noncompliant vehicle, only a noncompliant fleet. No particular vehicle in a noncompliant fleet is any more, or less, noncompliant than any other vehicle in the fleet.

2. EPA Statutory Authority

Title II of the Clean Air Act (CAA) provides for comprehensive regulation of mobile sources, authorizing EPA to regulate emissions of air pollutants from all mobile source categories. Pursuant to these sweeping grants of authority, EPA considers such issues as technology effectiveness, its cost (both per vehicle, per manufacturer, and per consumer), the lead time necessary to implement the technology, and based on this the feasibility and practicability of potential standards; the impacts of potential standards on emissions reductions of both GHGs and non-GHGs; the impacts of standards on oil conservation and energy security; the impacts of standards on fuel savings by consumers; the impacts of standards on the auto industry; other energy impacts; as well as other relevant factors such as impacts on safety

Pursuant to Title II of the Clean Air Act, EPA has taken a comprehensive, integrated approach to mobile source emission control that has produced benefits well in excess of the costs of regulation. In developing the Title II program, the Agency's historic, initial focus was on personal vehicles since that category represented the largest source of mobile source emissions. Over time, EPA has established stringent emissions standards for large truck and other heavy-duty engines, nonroad engines, and marine and locomotive engines, as well. The Agency's initial focus on personal vehicles has resulted in significant control of emissions from these vehicles, and also led to technology transfer to the other mobile source categories that made possible the stringent standards for these other categories.

As a result of Title II requirements, new cars and SUVs sold today have emissions levels of hydrocarbons, oxides of nitrogen, and carbon monoxide that are 98–99% lower than new vehicles sold in the 1960s, on a per mile basis. Similarly, standards established for heavy-duty highway and nonroad sources require emissions rate reductions on the order of 90% or more for particulate matter and oxides of nitrogen. Overall ambient levels of automotive-related pollutants are lower now than in 1970, even as economic growth and vehicle miles traveled have nearly tripled. These programs have resulted in millions of tons of pollution reduction and major reductions in pollution-related deaths (estimated in the tens of thousands per year) and illnesses. The net societal benefits of the mobile source programs are large. In its annual reports on federal regulations, the Office of Management and Budget reports that many of EPA's mobile source emissions standards typically have projected benefit-to-cost ratios of 5:1 to 10:1 or more. Follow-up studies show that long-term compliance costs to the industry are typically lower than the

[89] EPCA does not provide authority for seeking to enjoin violations of the CAFE standards.

[90] 49 U.S.C. 30120, Remedies for defects and noncompliance.

cost projected by EPA at the time of regulation, which result in even more favorable real world benefit-to-cost ratios.[91] Pollution reductions attributable to Title II mobile source controls are critical components to attainment of primary National Ambient Air Quality Standards, significantly reducing the national inventory and ambient concentrations of criteria pollutants, especially PM2.5 and ozone. See *e.g.* 69 FR 38958, 38967–68 (June 29, 2004) (controls on non-road diesel engines expected to reduce entire national inventory of PM2.5 by 3.3% (86,000 tons) by 2020). Title II controls have also made enormous reductions in air toxics emitted by mobile sources. For example, as a result of EPA's 2007 mobile source air toxics standards, the cancer risk attributable to total mobile source air toxics will be reduced by 30% in 2030 and the risk from mobile source benzene (a leukemogen) will be reduced by 37% in 2030. (reflecting reductions of over three hundred thousand tons of mobile source air toxic emissions) 72 FR 8428, 8430 (Feb. 26, 2007).

Title II emission standards have also stimulated the development of a much broader set of advanced automotive technologies, such as on-board computers and fuel injection systems, which are the building blocks of today's automotive designs and have yielded not only lower pollutant emissions, but improved vehicle performance, reliability, and durability.

This proposal implements a specific provision from Title II, section 202(a).[92] Section 202(a)(1) of the Clean Air Act (CAA) states that ''the Administrator shall by regulation prescribe (and from time to time revise) * * * standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles * * *, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.'' If EPA makes the appropriate endangerment and cause or contribute findings, then section 202(a) authorizes EPA to issue standards applicable to emissions of those pollutants.

Any standards under CAA section 202(a)(1) ''shall be applicable to such vehicles * * * for their useful life.'' Emission standards set by the EPA under CAA section 202(a)(1) are technology-based, as the levels chosen must be premised on a finding of technological feasibility. Thus, standards promulgated under CAA section 202(a) are to take effect only ''after providing such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period'' (section 202 (a)(2); see also *NRDC* v. *EPA,* 655 F. 2d 318, 322 (DC Cir. 1981)). EPA is afforded considerable discretion under section 202(a) when assessing issues of technical feasibility and availability of lead time to implement new technology. Such determinations are ''subject to the restraints of reasonableness'', which ''does not open the door to 'crystal ball' inquiry.'' *NRDC,* 655 F. 2d at 328, quoting *International Harvester Co.* v. *Ruckelshaus,* 478 F. 2d 615, 629 (DC Cir. 1973). However, ''EPA is not obliged to provide detailed solutions to every engineering problem posed in the perfection of the trap-oxidizer. In the absence of theoretical objections to the technology, the agency need only identify the major steps necessary for development of the device, and give plausible reasons for its belief that the industry will be able to solve those problems in the time remaining. The EPA is not required to rebut all speculation that unspecified factors may hinder 'real world' emission control.'' NRDC, 655 F. 2d at 333–34. In developing such technology-based standards, EPA has the discretion to consider different standards for appropriate groupings of vehicles (''class or classes of new motor vehicles''), or a single standard for a larger grouping of motor vehicles (NRDC, 655 F. 2d at 338).

Although standards under CAA section 202(a)(1) are technology-based, they are not based exclusively on technological capability. EPA has the discretion to consider and weigh various factors along with technological feasibility, such as the cost of compliance (see section 202(a) (2)), lead time necessary for compliance (section 202(a)(2)), safety (see *NRDC,* 655 F. 2d at 336 n. 31) and other impacts on consumers,[93] and energy impacts associated with use of the technology. See *George E. Warren Corp.* v. *EPA,* 159 F.3d 616, 623–624 (DC Cir. 1998) (ordinarily permissible for EPA to consider factors not specifically enumerated in the Act).

In addition, EPA has clear authority to set standards under CAA section 202(a) that are technology forcing when EPA considers that to be appropriate, but is not required to do so (as compared to standards set under provisions such as section 202(a)(3) and section 213(a)(3)). EPA has interpreted a similar statutory provision, CAA section 231, as follows:

> While the statutory language of section 231 is not identical to other provisions in title II of the CAA that direct EPA to establish technology-based standards for various types of engines, EPA interprets its authority under section 231 to be somewhat similar to those provisions that require us to identify a reasonable balance of specified emissions reduction, cost, safety, noise, and other factors. See, *e.g., Husqvarna AB* v. *EPA,* 254 F.3d 195 (DC Cir. 2001) (upholding EPA's promulgation of technology-based standards for small non-road engines under section 213(a)(3) of the CAA). However, EPA is not compelled under section 231 to obtain the ''greatest degree of emission reduction achievable'' as per sections 213 and 202 of the CAA, and so EPA does not interpret the Act as requiring the agency to give subordinate status to factors such as cost, safety, and noise in determining what standards are reasonable for aircraft engines. Rather, EPA has greater flexibility under section 231 in determining what standard is most reasonable for aircraft engines, and is not required to achieve a ''technology forcing'' result.[94]

This interpretation was upheld as reasonable in *NACAA* v. *EPA,* (489 F.3d 1221, 1230 (DC Cir. 2007)). CAA section 202(a) does not specify the degree of weight to apply to each factor, and EPA accordingly has discretion in choosing an appropriate balance among factors. See *Sierra Club* v. *EPA,* 325 F.3d 374, 378 (DC Cir. 2003) (even where a provision is technology-forcing, the provision ''does not resolve how the Administrator should weigh all [the statutory] factors in the process of finding the 'greatest emission reduction achievable' ''). Also see *Husqvarna AB* v. *EPA,* 254 F. 3d 195, 200 (DC Cir. 2001) (great discretion to balance statutory factors in considering level of technology-based standard, and statutory requirement ''to [give appropriate] consideration to the cost of applying * * * technology'' does not mandate a specific method of cost analysis); see also *Hercules Inc.* v. *EPA,* 598 F. 2d 91, 106 (DC Cir. 1978) (''In reviewing a numerical standard we must ask whether the agency's numbers are within a zone of reasonableness, not

[91] OMB, 2011. 2011 Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities. Office of Information and Regulatory Affairs. June. *http://www.whitehouse.gov/sites/default/files/omb/inforeg/2011_cb/2011_cba_report.pdf.* Web site accessed on October 11, 2011.

[92] 42 U.S.C. 7521 (a)

[93] Since its earliest Title II regulations, EPA has considered the safety of pollution control technologies. See 45 Fed. Reg. 14,496, 14,503 (1980). (''EPA would not require a particulate control technology that was known to involve serious safety problems. If during the development of the trap-oxidizer safety problems are discovered, EPA would reconsider the control requirements implemented by this rulemaking'').

[94] 70 FR 69664, 69676, November 17, 2005.

whether its numbers are precisely right''); *Permian Basin Area Rate Cases,* 390 U.S. 747, 797 (1968) (same); *Federal Power Commission* v. *Conway Corp.,* 426 U.S. 271, 278 (1976) (same); *Exxon Mobil Gas Marketing Co.* v. *FERC,* 297 F. 3d 1071, 1084 (DC Cir. 2002) (same).

a. EPA's Testing Authority

Under section 203 of the CAA, sales of vehicles are prohibited unless the vehicle is covered by a certificate of conformity. EPA issues certificates of conformity pursuant to section 206 of the Act, based on (necessarily) pre-sale testing conducted either by EPA or by the manufacturer. The Federal Test Procedure (FTP or ''city'' test) and the Highway Fuel Economy Test (HFET or ''highway'' test) are used for this purpose. Compliance with standards is required not only at certification but throughout a vehicle's useful life, so that testing requirements may continue post-certification. Useful life standards may apply an adjustment factor to account for vehicle emission control deterioration or variability in use (section 206(a)).

Pursuant to EPCA, EPA is required to measure fuel economy for each model and to calculate each manufacturer's average fuel economy.[95] EPA uses the same tests—the FTP and HFET—for fuel economy testing. EPA established the FTP for emissions measurement in the early 1970s. In 1976, in response to the Energy Policy and Conservation Act (EPCA) statute, EPA extended the use of the FTP to fuel economy measurement and added the HFET.[96] The provisions in the 1976 regulation, effective with the 1977 model year, established procedures to calculate fuel economy values both for labeling and for CAFE purposes. Under EPCA, EPA is required to use these procedures (or procedures which yield comparable results) for measuring fuel economy for cars for CAFE purposes, but not for labeling purposes.[97] EPCA does not pose this restriction on CAFE test procedures for light trucks, but EPA does use the FTP and HFET for this purpose. EPA determines fuel economy by measuring the amount of CO_2 and all other carbon compounds (*e.g.* total hydrocarbons (THC) and carbon monoxide (CO)), and then, by mass balance, calculating the amount of fuel consumed. EPA's proposed changes to the procedures for measuring fuel economy and calculating average fuel economy are discussed in section III.B.10.

b. EPA Enforcement Authority

Section 207 of the CAA grants EPA broad authority to require manufacturers to remedy vehicles if EPA determines there are a substantial number of noncomplying vehicles. In addition, section 205 of the CAA authorizes EPA to assess penalties of up to $37,500 per vehicle for violations of various prohibited acts specified in the CAA. In determining the appropriate penalty, EPA must consider a variety of factors such as the gravity of the violation, the economic impact of the violation, the violator's history of compliance, and ''such other matters as justice may require.'' Unlike EPCA, the CAA does not authorize vehicle manufacturers to pay fines in lieu of meeting emission standards.

c. Compliance

EPA oversees testing, collects and processes test data, and performs calculations to determine compliance with both CAA and CAFE standards. CAA standards apply not only at the time of certification but also throughout the vehicle's useful life, and EPA is accordingly is proposing in-use standards as well as standards based on testing performed at time of production. See section II*I.E.* Both the CAA and EPCA provide for penalties should manufacturers fail to comply with their fleet average standards, but, unlike EPCA, there is no option for manufacturers to pay fines in lieu of compliance with the standards. Under the CAA, penalties are typically determined on a vehicle-specific basis by determining the number of a manufacturer's highest emitting vehicles that cause the fleet average standard violation. Penalties under Title II of the CAA are capped at $25,000 per day of violation and apply on a per vehicle basis. CAA section 205 (a).

d. Test Procedures

EPA establishes the test procedures under which compliance with both the CAA GHG standards and the EPCA fuel economy standards are measured. EPA's testing authority under the CAA is flexible, but testing for fuel economy for passenger cars is by statute is limited to the Federal Test procedure (FTP) or test procedures which provide results which are equivalent to the FTP. 49 USC section 32904 and section III.B, below. EPA developed and established the FTP in the early 1970s and, after enactment of EPCA in 1976, added the Highway Fuel Economy Test to be used in conjunction with the FTP for fuel economy testing. EPA has also developed tests with additional cycles (the so-called 5-cycle test) which test is used for purposes of fuel economy labeling and is also used in the EPA program for extending off-cycle credits under both the light-duty and (along with NHTSA) heavy-duty vehicle GHG programs. See 75 FR at 25439; 76 FR at 57252. In this rule, EPA is proposing to retain the FTP and HFET for purposes of testing the fleetwide average standards, and is further proposing modifications to the N2O measurement test procedures and the A/C CO_2 efficiency test procedures EPA initially adopted in the 2012–2016 rule.

3. Comparing the Agencies' Authority

As the above discussion makes clear, there are both important differences between the statutes under which each agency is acting as well as several important areas of similarity. One important difference is that EPA's authority addresses various GHGs, while NHTSA's authority addresses fuel economy as measured under specified test procedures and calculated by EPA. This difference is reflected in this rulemaking in the scope of the two standards: EPA's proposal takes into account reductions of direct air conditioning emissions, as well as proposed standards for methane and N_2O, but NHTSA's does not, because these things do not relate to fuel economy. A second important difference is that EPA is proposing certain compliance flexibilities, such as the multiplier for advanced technology vehicles, and takes those flexibilities into account in its technical analysis and modeling supporting its proposal. EPCA specifies a number of particular compliance flexibilities for CAFE, and expressly prohibits NHTSA from considering the impacts of those statutory compliance flexibilities in setting the CAFE standard so that the manufacturers' election to avail themselves of the permitted flexibilities remains strictly voluntary.[98] The Clean Air Act, on the other hand, contains no such prohibition. These considerations result in some differences in the technical analysis and modeling used to support EPA's and NHTSA's proposed standards.

Another important area where the two agencies' authorities are similar but not identical involves the transfer of credits between a single firm's car and truck fleets. EISA revised EPCA to allow for such credit transfers, but placed a cap on the amount of CAFE credits which can be transferred between the car and

[95] See 49 U.S.C. 32904(c).

[96] See 41 FR 38674 (Sept. 10, 1976), which is codified at 40 CFR part 600.

[97] See 49 U.S.C. 32904(c).

[98] 49 U.S.C. 32902(h).

truck fleets. 49 U.S.C. 32903(g)(3). Under CAA section 202(a), EPA is proposing to continue to allow CO_2 credit transfers between a single manufacturer's car and truck fleets, with no corresponding limits on such transfers. In general, the EISA limit on CAFE credit transfers is not expected to have the practical effect of limiting the amount of CO_2 emission credits manufacturers may be able to transfer under the CAA program, recognizing that manufacturers must comply with both the proposed CAFE standards and the proposed EPA standards. However, it is possible that in some specific circumstances the EPCA limit on CAFE credit transfers could constrain the ability of a manufacturer to achieve cost savings through unlimited use of GHG emissions credit transfers under the CAA program.

These differences, however, do not change the fact that in many critical ways the two agencies are charged with addressing the same basic issue of reducing GHG emissions and improving fuel economy. The agencies are looking at the same set of control technologies (with the exception of the air conditioning leakage-related technologies). The standards set by each agency will drive the kind and degree of penetration of this set of technologies across the vehicle fleet. As a result, each agency is trying to answer the same basic question—what kind and degree of technology penetration is necessary to achieve the agencies' objectives in the rulemaking time frame, given the agencies' respective statutory authorities?

In making the determination of what standards are appropriate under the CAA and EPCA, each agency is to exercise its judgment and balance many similar factors. NHTSA's factors are provided by EPCA: technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy. EPA has the discretion under the CAA to consider many related factors, such as the availability of technologies, the appropriate lead time for introduction of technology, and based on this the feasibility and practicability of their standards; the impacts of their standards on emissions reductions (of both GHGs and non-GHGs); the impacts of their standards on oil conservation; the impacts of their standards on fuel savings by consumers; the impacts of their standards on the auto industry; as well as other relevant factors such as impacts on safety. Conceptually, therefore, each agency is considering and balancing many of the same concerns, and each agency is making a decision that at its core is answering the same basic question of what kind and degree of technology penetration is it appropriate to call for in light of all of the relevant factors in a given rulemaking, for the model years concerned. Finally, each agency has the authority to take into consideration impacts of the standards of the other agency. EPCA calls for NHTSA to take into consideration the effects of EPA's emissions standards on fuel economy capability (see 49 U.S.C. 32902 (f)), and EPA has the discretion to take into consideration NHTSA's CAFE standards in determining appropriate action under section 202(a). This is consistent with the Supreme Court's statement that EPA's mandate to protect public health and welfare is wholly independent from NHTSA's mandate to promote energy efficiency, but there is no reason to think the two agencies cannot both administer their obligations and yet avoid inconsistency. *Massachusetts* v. *EPA,* 549 U.S. 497, 532 (2007).

In this context, it is in the Nation's interest for the two agencies to continue to work together in developing their respective proposed standards, and they have done so. For example, the agencies have committed considerable effort to develop a joint Technical Support Document that provides a technical basis underlying each agency's analyses. The agencies also have worked closely together in developing and reviewing their respective modeling, to develop the best analysis and to promote technical consistency. The agencies have developed a common set of attribute-based curves that each agency supports as appropriate both technically and from a policy perspective. The agencies have also worked closely to ensure that their respective programs will work in a coordinated fashion, and will provide regulatory compatibility that allows auto manufacturers to build a single national light-duty fleet that would comply with both the GHG and the CAFE standards. The resulting overall close coordination of the proposed GHG and CAFE standards should not be surprising, however, as each agency is using a jointly developed technical basis to address the closely intertwined challenges of energy security and climate change.

As set out in detail in Sections III and IV of this notice, both EPA and NHTSA believe the agencies' proposals are fully justified under their respective statutory criteria. The proposed standards are feasible in each model year within the lead time provided, based on the agencies' projected increased use of various technologies which in most cases are already in commercial application in the fleet to varying degrees. Detailed modeling of the technologies that could be employed by each manufacturer supports this initial conclusion. The agencies also carefully assessed the costs of the proposed rules, both for the industry as a whole and per manufacturer, as well as the costs per vehicle, and consider these costs to be reasonable during the rulemaking time frame and recoverable (from fuel savings). The agencies recognize the significant increase in the application of technology that the proposed standards would require across a high percentage of vehicles, which will require the manufacturers to devote considerable engineering and development resources before 2017 laying the critical foundation for the widespread deployment of upgraded technology across a high percentage of the 2017–2025 fleet. This clearly will be challenging for automotive manufacturers and their suppliers, especially in the current economic climate, and given the stringency of the recently-established MYs 2012–2016 standards. However, based on all of the analyses performed by the agencies, our judgment is that it is a challenge that can reasonably be met.

The agencies also evaluated the impacts of these standards with respect to the expected reductions in GHGs and oil consumption and, found them to be very significant in magnitude. The agencies considered other factors such as the impacts on noise, energy, and vehicular congestion. The impact on safety was also given careful consideration. Moreover, the agencies quantified the various costs and benefits of the proposed standards, to the extent practicable. The agencies' analyses to date indicate that the overall quantified benefits of the proposed standards far outweigh the projected costs. All of these factors support the reasonableness of the proposed standards. See section III (proposed GHG standards) and section IV (proposed CAFE standards) for a detailed discussion of each agency's basis for its selection of its proposed standards.

The fact that the benefits are estimated to considerably exceed their costs supports the view that the proposed standards represent an appropriate balance of the relevant statutory factors. In drawing this conclusion, the agencies acknowledge the uncertainties and limitations of the analyses. For example, the analysis of the benefits is highly dependent on the estimated price of fuel projected out many years into the future. There is also significant uncertainty in the potential range of values that could be assigned to the social cost of carbon. There are a variety of impacts that the agencies are unable to quantify, such as non-market damages, extreme weather, socially contingent effects, or the potential for longer-term catastrophic events, or the impact on consumer choice. The cost-benefit analyses are one of the important things the agencies consider in making a judgment as to the appropriate standards to propose under their respective statutes. Consideration of the results of the cost-benefit analyses by the agencies, however, includes careful consideration of the limitations discussed above.

II. Joint Technical Work Completed for This Proposal

A. Introduction

In this section, NHTSA and EPA discuss several aspects of their joint technical analyses. These analyses are common to the development of each agency's standards. Specifically we discuss: the development of the vehicle market forecast used by each agency for assessing costs, benefits, and effects, the development of the attribute-based standard curve shapes, the technologies the agencies evaluated and their costs and effectiveness, the economic assumptions the agencies included in their analyses, a description of the air conditioning and off-cycle technology (credit) programs, as well as the effects of the proposed standards on vehicle safety. The Joint Technical Support Document (TSD) discusses the agencies' joint technical work in more detail.

The agencies have based today's proposal on a very significant body of data and analysis that we believe is the best information currently available on the full range of technical and other inputs utilized in our respective analyses. As noted in various places throughout this preamble, the draft Joint TSD, the NHTSA preliminary RIA, and the EPA draft RIA, we expect new information will become available between the proposal and final rulemaking. This new information will come from a range of sources: some is based on work the agencies have underway (*e.g.,* work on technology costs and effectiveness, potentially updating our baseline year from model year 2008 to model year 2010); other sources are those we expect to be released by others (*e.g.,* the Energy Information Agency's Annual Energy Outlook, which is published each year, and the most recent available version of which we expect to use for the final rule); and other information that will likely come from the public comment process. The agencies intend to evaluate all such new information as it becomes available, and where appropriate to update their analysis based on such information for purposes of the final rule. In addition, the agencies may make new information and/or analyses available in the agencies' respective public dockets for this rulemaking prior to the final rule, where that is appropriate, in order to facilitate public comment. We encourage all stakeholders to periodically check the two agencies' dockets between the proposal and final rules for any potential new docket submissions from the agencies.

B. Developing the Future Fleet for Assessing Costs, Benefits, and Effects

1. Why did the agencies establish a baseline and reference vehicle fleet?

In order to calculate the impacts of the EPA and NHTSA regulations, it is necessary to estimate the composition of the future vehicle fleet absent these regulations, to provide a reference point relative to which costs, benefits, and effects of the regulations are assessed. As in the 2012–2016 light duty vehicle rulemaking, EPA and NHTSA have developed this comparison fleet in two parts. The first step was to develop a baseline fleet based on model year 2008 data. This baseline includes vehicle sales volumes, GHG/fuel economy performance, and contains a listing of the base technologies on every 2008 vehicle sold. The second step was to project that baseline fleet volume into model years 2017–2025. The vehicle volumes projected out to MY 2025 is referred to as the reference fleet volumes. The third step was to modify that MY 2017–2025 reference fleet such that it reflects technology manufacturers could apply if MY 2016 standards are extended without change through MY 2025.[99] Each agency used its modeling system to develop a modified or final reference fleet, or adjusted baseline, for use in its analysis of regulatory alternatives, as discussed below and in Chapter 1 of the EPA draft RIA. All of the agencies' estimates of emission reductions, fuel economy improvements, costs, and societal impacts are developed in relation to the respective reference fleets. This section discusses the first two steps, development of the baseline fleet and the reference fleet.

EPA and NHTSA used a transparent approach to developing the baseline and reference fleets, largely working from publicly available data. Because both input and output sheets from our modeling are public, stakeholders can verify and check EPA's and NHTSA's modeling, and perform their own analyses with these datasets.[100]

2. How Did the Agencies Develop the Baseline Vehicle Fleet?

NHTSA and EPA developed a baseline fleet comprised of model year 2008 data gathered from EPA's emission and fuel economy database. This baseline fleet was originally developed by EPA and NHTSA for the 2012–2016 final rule, and was updated for this proposal.[101] The new fleet has the model year 2008 vehicle's volumes and attributes along with the addition of projected volumes from 2017 to 2025. It also has some expanded footprint data for pickup trucks that was needed for a more detailed analysis of the truck curve.

In this proposed rulemaking, the agencies are again choosing to use model year 2008 vehicle data to be the basis of the baseline fleet, but for different reasons than in the 2012–2016 final rule. Model year 2008 is now the most recent model year for which the industry had normal sales. Model year 2009 data is available, but the agencies believe that model year was disrupted by the economic downturn and the bankruptcies of both General Motors and Chrysler resulting in a significant reduction in the number of vehicles sold by both companies and the industry as a whole. These abnormalities led the agencies to conclude that 2009 data was not representative for projecting the future fleet. Model Year 2010 data was not complete because not all manufacturers have yet submitted it to EPA, and was thus not available in time for it to be used for this proposal. Therefore, the agencies chose to use model year 2008 again as the baseline since it was the latest complete representative and transparent data set available. However, the agencies will consider using Model Year 2010 for the final rule, based on availability and an

[99] EPA's MY 2016 GHG standards under the CAA continue into the future until they are changed. While NHTSA must actively promulgate standards in order for CAFE standards to extend past MY 2016, the agency has, as in all recent CAFE rulemakings, defined a no-action (i.e., baseline) regulatory alternative as an indefinite extension of the last-promulgated CAFE standards for purposes of the main analysis of the standards in this preamble.

[100] EPA's Omega Model and input sheets are available at *http://www.epa.gov/oms/climate/models.htm*; DOT/NHTSA's CAFE Compliance and Effects Modeling System (commonly known as the ''Volpe Model'') and input and output sheets are available at *http://www.nhtsa.gov/fuel-economy*.

[101] Further discussion of the development of the 2008 baseline fleet for the MY2012–2016 rule can be found at 75 Fed. Reg. 25324, 25349 (May 7, 2010).

analysis of the data representativeness. To the extent the MY 2010 data becomes available during the comment period the agencies will place a copy of this data in our respective dockets. We request comments on the relative merits of using MY 2008 and MY 2010 data, and whether one provides a better foundation than the other for purposes of using such data as the foundation for a market forecast extending through MY 2025.

The baseline fleet reflects all fuel economy technologies in use on MY 2008 light duty vehicles. The 2008 emission and fuel economy database included data on vehicle production volume, fuel economy, engine size, number of engine cylinders, transmission type, fuel type, etc., however it did not contain complete information on technologies. Thus, the agencies relied on publicly available data like the more complete technology descriptions from Ward's Automotive Group.[102] In a few instances when required vehicle information (such as vehicle footprint) was not available from these two sources, the agencies obtained this information from publicly accessible internet sites such as Motortrend.com and Edmunds.com.[103] A description of all of the technologies used in modeling the 2008 vehicle fleet and how it was constructed are available in Chapter 1 of the Joint Draft TSD.

Footprint data for the baseline fleet came mainly from internet searches, though detailed information about the pickup truck footprints with volumes was not available online. Where this information was lacking, the agencies used manufacturer product plan data for 2008 model year to find out the correct number footprint and distribution of footprints. The footprint data for pickup trucks was expanded from the original data used in the previous rulemaking. The agencies obtained this footprint data from MY 2008 product plans submitted by the various manufacturers, which can be made public at this time because by now all MY 2008 vehicle models are already in production, which makes footprint data about them essentially public information. A description of exactly how the agencies obtained all the footprints is available in Chapter 1 of the TSD.

3. How Did the Agencies Develop the Projected MY 2017–2025 Vehicle Reference Fleet?

As in the 2012–2016 light duty vehicle rulemaking, EPA and NHTSA have based the projection of total car and total light truck sales for MYs 2017–2025 on projections made by the Department of Energy's Energy Information Administration (EIA). See 75 FR at 25349. EIA publishes a mid-term projection of national energy use called the Annual Energy Outlook (AEO). This projection utilizes a number of technical and econometric models which are designed to reflect both economic and regulatory conditions expected to exist in the future. In support of its projection of fuel use by light-duty vehicles, EIA projects sales of new cars and light trucks. EIA published its Early Annual Energy Outlook for 2011 in December 2010. EIA released updated data to NHTSA in February (Interim AEO). The final release of AEO for 2011 came out in May 2011, but by that time EPA/NHTSA had already prepared modeling runs for potential 2017–2025 standards using the interim data release to NHTSA. EPA and NHTSA are using the interim data release for this proposal, but intend to use the newest version of AEO available for the FRM.

The agencies used the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate the future relative market shares of passenger cars and light trucks. However, NEMS methodology includes shifting vehicle sales volume, starting after 2007, away from fleets with lower fuel economy (the light-truck fleet) towards vehicles with higher fuel economies (the passenger car fleet) in order to facilitate projected compliance with CAFE and GHG standards. Because we use our market projection as a baseline relative to which we measure the effects of new standards, and we attempt to estimate the industry's ability to comply with new standards without changing product mix (*i.e.,* we analyze the effects of the proposed rules assuming manufacturers will not change fleet composition as a compliance strategy, as opposed to changes that might happen due to market forces), the Interim AEO 2011-projected shift in passenger car market share as a result of required fuel economy improvements creates a circularity. Therefore, for the current analysis, the agencies developed a new projection of passenger car and light truck sales shares by running scenarios from the Interim AEO 2011 reference case that first deactivate the above-mentioned sales-volume shifting methodology and then hold post-2017 CAFE standards constant at MY 2016 levels. As discussed in Chapter 1 of the agencies' joint Technical Support Document, incorporating these changes reduced the NEMS-projected passenger car share of the light vehicle market by an average of about 5% during 2017–2025.

In the AEO 2011 Interim data, EIA projects that total light-duty vehicle sales will gradually recover from their currently depressed levels by around 2013. In 2017, car sales are projected to be 8.4 million (53 percent) and truck sales are projected to be 7.3 million (47 percent). Although the total level of sales of 15.8 million units is similar to pre-2008 levels, the fraction of car sales is projected to be higher than that existing in the 2000–2007 timeframe. This projection reflects the impact of assumed higher fuel prices. Sales projections of cars and trucks for future model years can be found in Chapter 1 of the joint TSD.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have been changing and are expected to continue to change. Manufacturers are introducing more crossover utility vehicles (CUVs), which offer much of the utility of sport utility vehicles (SUVs) but use more car-like designs. The AEO 2011 report does not, however, distinguish such changes within the car and truck classes. In order to reflect these changes in fleet makeup, EPA and NHTSA used CSM Worldwide (CSM) as they did in the 2012–2016 rulemaking analysis. EPA and NHTSA believe that CSM is the best source available for a long range forecast for 2017–2025, though when EPA and NHTSA contacted several forecasting firms none of them offered comparably-detailed forecasting for that time frame. NHTSA and EPA decided to use the forecast from CSM for several reasons presented in the Joint TSD chapter I.

The long range forecast from CSM Worldwide is a custom forecast covering the years 2017–2025 which the agencies purchased from CSM in December of 2009. CSM provides quarterly sales forecasts for the automotive industry, and updates their data on the industry quarter. For the public's reference, a copy of CSM's long range forecast has been placed in the docket for this rulemaking.[104] EPA and NHTSA hope to purchase and use an updated forecast,

[102] Note that WardsAuto.com is a fee-based service, but all information is public to subscribers.

[103] Motortrend.com and Edmunds.com are free, no-fee internet sites.

[104] The CSM Sales Forecast Excel file (''CSM North America Sales Forecasts 2017–2025 for the Docket'') is available in the docket (Docket EPA–HQ–OAR–2010–0799).

whether from CSM or other appropriate sources, before the final rulemaking. To the extent that such a forecast becomes available during the comment period the agencies will place a copy in our respective dockets.

The next step was to project the CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment onto the total sales estimates of AEO 2011. Table II–1 and Table II–2 show the resulting projections for the reference 2025 model year and compare these to actual sales that occurred in the baseline 2008 model year. Both tables show sales using the traditional definition of cars and light trucks.

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Table II-1 Annual Sales of Light-Duty Vehicles by Manufacturer in 2008 and Estimated for 2025

	Cars		Light Trucks		Total	
	2008 MY	2025 MY	2008 MY	2025 MY	2008 MY	2025 MY
Aston Martin	1,370	1,182	0	0	1,370	1,182
BMW	291,796	405,256	61,324	145,409	353,120	550,665
Chrysler/Fiat	703,158	436,479	956,792	331,762	1,659,950	768,241
Daimler	208,195	340,719	79,135	101,067	287,330	441,786
Ferrari	1,450	7,658	0	0	1,450	7,658
Ford	956,699	1,540,109	814,194	684,476	1,770,893	2,224,586
Geely/Volvo	65,649	101,107	32,748	42,588	98,397	143,696
GM	1,587,391	1,673,936	1,507,797	1,524,008	3,095,188	3,197,943
Honda	1,006,639	1,340,321	505,140	557,697	1,511,779	1,898,018
Hyundai	337,869	677,250	53,158	168,136	391,027	845,386
Kia	221,980	362,783	59,472	97,653	281,452	460,436
Lotus	252	316	0	0	252	316
Mazda	246,661	306,804	55,885	61,368	302,546	368,172
Mitsubishi	85,358	73,305	15,371	36,387	100,729	109,692
Nissan	717,869	1,014,775	305,546	426,454	1,023,415	1,441,229
Porsche	18,909	40,696	18,797	11,219	37,706	51,915
Spyker/Saab	21,706	23,130	4,250	3,475	25,956	26,605

Subaru	116,035	256,970	82,546	74,722	198,581	331,692
Suzuki	79,339	103,154	35,319	21,374	114,658	124,528
Tata/JLR	9,596	65,418	55,584	56,805	65,180	122,223
Tesla	800	31,974	0	0	800	31,974
Toyota	1,260,364	2,108,053	951,136	1,210,016	2,211,500	3,318,069
Volkswagen	291,483	630,163	26,999	154,284	318,482	784,447
Total	8,230,568	11,541,560	5,621,193	5,708,899	13,851,761	17,250,459

Table II-2 Annual Sales of Light-Duty Vehicles by Market Segment in 2008 and Estimated for 2025

Cars			Light Trucks		
	2008 MY	2025 MY		2008 MY	2025 MY
Full-Size Car	829,896	245,355	Full-Size Pickup	1,332,335	1,002,806
Luxury Car	1,048,341	1,637,410	Mid-Size Pickup	452,013	431,272
Mid-Size Car	2,103,108	2,713,078	Full-Size Van	33,384	88,572
Mini Car	617,902	1,606,114	Mid-Size Van	719,529	839,452
Small Car	1,912,736	2,826,190	Mid-Size MAV*	110,353	548,457
Specialty Car	469,324	808,183	Small MAV	231,265	239,065
			Full-Size SUV*	559,160	46,978
			Mid-Size SUV	436,080	338,849

			Small SUV	196,424	71,827
			Full-Size CUV*	264,717	671,665
			Mid-Size CUV	923,165	1,259,483
			Small CUV	1,612,029	1,875,703
Total Sales**	6,981,307	9,836,330		6,870,454	7,414,129

* MAV – Multi-Activity Vehicle, or a vehicle with a tall roof and elevated seating positions such as a Mazda5SUV

– Sport Utility Vehicle, CUV – Crossover Utility Vehicle

**Total Sales are based on the classic Car/Truck definition.

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As mentioned previously, NHTSA has changed the definition of a truck for 2011 model year and beyond. The new definition has moved some 2 wheel drive SUVs and CUVs to the car category. Table II–3 shows the different volumes for car and trucks based on the new and old NHTSA definition. The table shows the difference in 2008, 2021, and 2025 to give a feel for how the change in definition changes the car/truck split.

Table II-3 New and Old Car and Truck definition in 2008, 2016, 2021, and 2025

Vehicle Type	2008	2016	2021	2025
Old Cars Definition	6,981,307	8,576,717	8,911,173	9,836,330
New Cars Definition	8,230,568	7,618,459	10,505,165	11,541,560
Old Truck Definition	6,870,454	10,140,463	7,277,894	7,414,129
New Truck Definition	5,621,193	6,054,713	5,683,902	5,708,899

The CSM forecast provides estimates of car and truck sales by segment and by manufacturer separately. The forecast was broken up into two tables. One table with manufacturer volumes by year and the other with vehicle segments percentages by year. Table II–4 and Table II–5 are examples of the data received from CSM. The task of estimating future sales using these tables is complex. We used the same methodology as in the previous rulemaking. A detailed description of how the projection process was done is found in Chapter 1 of the TSD.

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Table II-4 CSM Manufacturer Volumes in 2016, 2021, and 2025

	2016	2021	2025
BMW	328,220	325,231	317,178
Chrysler/Fiat	391,165	346,960	316,043
Daimler	298,676	272,049	271,539
Ford*	971,617	893,528	858,215
Subaru	205,486	185,281	181,062
General Motors	1,309,246	1,192,641	1,135,305
Honda	1,088,449	993,318	984,401
Hyundai	429,926	389,368	377,500
Kia	234,246	213,252	205,473
Mazda	215,117	200,003	199,193
Mitsubishi	47,414	42,693	42,227
Spyker/Saab	6	6	6
Tesla	800	800	800
Aston Martin	1,370	1,370	1,370
Lotus	252	252	252
Porsche	12	12	12
Nissan	803,177	729,723	707,361
Suzuki	88,142	81,042	76,873
Tata/JLR	58,594	53,143	52,069
Toyota	1,751,661	1,576,499	1,564,975
Volkswagen	578,420	530,378	494,596

*Ford volumes include Volvo in this table.

Table II-5 CSM Segment Percentages in 2016, 2021, and 2025

	2016	2021	2025
Full-Size CUV	3.66%	8.34%	9.06%
Full-Size Pickup	19.39%	15.42%	13.53%
Full-Size SUV	3.27%	0.90%	0.63%
Full-Size Van	0.92%	1.29%	1.19%
Mid-Size CUV	19.29%	16.88%	16.99%
Mid-Size MAV	1.63%	5.93%	7.40%
Mid-Size Pickup	4.67%	5.74%	5.82%
Mid-Size SUV	2.28%	4.73%	4.57%
Mid-Size Van	11.80%	11.63%	11.32%
Small CUV	30.67%	25.06%	25.30%
Small MAV	0.88%	2.98%	3.22%
Small Pickup	0.00%	0.00%	0.00%
Small SUV	1.53%	1.12%	0.97%

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The overall result was a projection of car and truck sales for model years 2017–2025—the reference fleet—which matched the total sales projections of the AEO forecast and the manufacturer and segment splits of the CSM forecast. These sales splits are shown in Table II–6 below.

Table II-6 Car and Truck Volumes and Split Based on NHTSA New Truck Definition

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car Volume*	10,140	9,988	9,905	9,996	10,292	10,505	10,736	10,968	11,258	11,542
Truck Volume*	6,054	5,819	5,671	5,583	5,604	5,684	5,704	5,687	5,676	5,709
Car Split	62.6%	63.2%	63.6%	64.2%	64.7%	64.9%	65.3%	65.9%	66.5%	66.9%
Truck Split	37.4%	36.8%	36.4%	35.8%	35.3%	35.1%	34.7%	34.1%	33.5%	33.1%

*in thousands

Given publicly- and commercially-available sources that can be made equally transparent to all reviewers, the forecast described above represents the agencies' best technical judgment regarding the likely composition direction of the fleet. EPA and NHTSA recognize that it is impossible to predict with certainty how manufacturers' product offerings and sales volumes will evolve through MY 2025 under baseline conditions—that is, without further changes in standards after MY 2016. The agencies have not developed alternative market forecasts to examine corresponding sensitivity of analytical results discussed below, and have not varied the market forecast when conducting probabilistic uncertainty analysis discussed in NHTSA's preliminary Regulatory Impact Analysis. The agencies invite comment regarding alternative methods or projections to inform forecasts of the future fleet at the level of specificity and technical completeness required by the agencies' respective modeling systems.

The final step in the construction of the final reference fleet involves applying additional technology to individual vehicle models—that is, technology beyond that already present in MY 2008—reflecting already-promulgated standards through MY 2016, and reflecting the assumption that MY 2016 standards would apply through MY 2025. A description of the agencies' modeling work to develop their respective final reference (or adjusted baseline) fleets appear below in Sections III and IV of this preamble.

C. Development of Attribute-Based Curve Shapes

1. Why are standards attribute-based and defined by a mathematical function?

As in the MYs 2012–2016 CAFE/GHG rules, and as NHTSA did in the MY 2011 CAFE rule, NHTSA and EPA are proposing to set attribute-based CAFE and CO_2 standards that are defined by a mathematical function. EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy, and be expressed in the form of a mathematical function.[105] The CAA has no such requirement, although such an approach is permissible under section 202 (a) and EPA has used the attribute-based approach in issuing standards under analogous provisions of the CAA (*e.g.,* criteria pollutant standards for non-road diesel engines using engine size as the attribute,[106] in the recent GHG standards for heavy duty pickups and vans using a work factor attribute,[107] and in the MYs 2012–2016 GHG rule itself which used vehicle footprint as the attribute). Public comments on the MYs 2012–2016 rulemaking widely supported attribute-based standards for both agencies' standards.

Under an attribute-based standard, every vehicle model has a performance target (fuel economy and CO_2 emissions for CAFE and CO_2 emissions standards, respectively), the level of which depends on the vehicle's attribute (for this proposal, footprint, as discussed below). Each manufacturers' fleet average standard is determined by the production-weighted[108] average (for CAFE, harmonic average) of those targets.

The agencies believe that an attribute-based standard is preferable to a single-industry-wide average standard in the context of CAFE and CO_2 standards for several reasons. First, if the shape is chosen properly, every manufacturer is more likely to be required to continue adding more fuel efficient technology each year across their fleet, because the stringency of the compliance obligation will depend on the particular product mix of each manufacturer. Therefore a maximum feasible attribute-based standard will tend to require greater fuel savings and CO_2 emissions reductions overall than would a maximum feasible flat standard (that is, a single mpg or CO_2 level applicable to every manufacturer).

Second, depending on the attribute, attribute-based standards reduce the incentive for manufacturers to respond to CAFE and CO_2 standards in ways harmful to safety.[109] Because each vehicle model has its own target (based on the attribute chosen), properly fitted attribute-based standards provide little, if any, incentive to build smaller vehicles simply to meet a fleet-wide average, because the smaller vehicles will be subject to more stringent compliance targets.[110]

Third, attribute-based standards provide a more equitable regulatory framework for different vehicle manufacturers.[111] A single industry-wide average standard imposes disproportionate cost burdens and compliance difficulties on the manufacturers that need to change their product plans to meet the standards, and puts no obligation on those manufacturers that have no need to change their plans. As discussed above, attribute-based standards help to spread the regulatory cost burden for fuel economy more broadly across all of the vehicle manufacturers within the industry.

Fourth, attribute-based standards better respect economic conditions and consumer choice, as compared to single-value standards. A flat, or single value standard, encourages a certain vehicle size fleet mix by creating incentives for manufacturers to use vehicle downsizing as a compliance strategy. Under a footprint-based standard, manufacturers are required to invest in technologies that improve the fuel economy of the vehicles they sell rather than shifting the product mix, because reducing the size of the vehicle is generally a less viable compliance strategy given that smaller vehicles have more stringent regulatory targets.

2. What attribute are the agencies proposing to use, and why?

As in the MYs 2012–2016 CAFE/GHG rules, and as NHTSA did in the MY 2011 CAFE rule, NHTSA and EPA are proposing to set CAFE and CO_2 standards that are based on vehicle footprint, which has an observable correlation to fuel economy and emissions. There are several policy and technical reasons why NHTSA and EPA believe that footprint is the most appropriate attribute on which to base the standards, even though some other vehicle attributes (notably curb weight) are better correlated to fuel economy and emissions.

First, in the agencies' judgment, from the standpoint of vehicle safety, it is important that the CAFE and CO_2 standards be set in a way that does not encourage manufacturers to respond by selling vehicles that are in any way less safe. While NHTSA's research of historical crash data also indicates that reductions in vehicle mass that are accompanied by reductions in vehicle footprint tend to compromise vehicle safety, footprint-based standards provide an incentive to use advanced lightweight materials and structures that would be discouraged by weight-based

[105] 49 U.S.C. 32902(a)(3)(A).

[106] 69 FR 38958 (June 29, 2004).

[107] 76 FR 57106, 57162–64, (Sept. 15, 2011).

[108] Production for sale in the United States.

[109] The 2002 NAS Report described at length and quantified the potential safety problem with average fuel economy standards that specify a single numerical requirement for the entire industry. See 2002 NAS Report at 5, finding 12. Ensuing analyses, including by NHTSA, support the fundamental conclusion that standards structured to minimize incentives to downsize all but the largest vehicles will tend to produce better safety outcomes than flat standards.

[110] Assuming that the attribute is related to vehicle size.

[111] *Id.* at 4–5, finding 10.

standards, because manufacturers can use them to improve a vehicle's fuel economy and CO_2 emissions without their use necessarily resulting in a change in the vehicle's fuel economy and emissions targets.

Further, although we recognize that weight is better correlated with fuel economy and CO_2 emissions than is footprint, we continue to believe that there is less risk of ''gaming'' (changing the attribute(s) to achieve a more favorable target) by increasing footprint under footprint-based standards than by increasing vehicle mass under weight-based standards—it is relatively easy for a manufacturer to add enough weight to a vehicle to decrease its applicable fuel economy target a significant amount, as compared to increasing vehicle footprint. We also continue to agree with concerns raised in 2008 by some commenters on the MY 2011 CAFE rulemaking that there would be greater potential for gaming under multi-attribute standards, such as those that also depend on weight, torque, power, towing capability, and/or off-road capability. The agencies agree with the assessment first presented in NHTSA's MY 2011 CAFE final rule [112] that the possibility of gaming is lowest with footprint-based standards, as opposed to weight-based or multi-attribute-based standards. Specifically, standards that incorporate weight, torque, power, towing capability, and/or off-road capability in addition to footprint would not only be more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they could make it less certain that the future fleet would actually achieve the average fuel economy and CO_2 reduction levels projected by the agencies.

The agencies recognize that based on economic and consumer demand factors that are external to this rule, the distribution of footprints in the future may be different (either smaller or larger) than what is projected in this rule. However, the agencies continue to believe that there will not be significant shifts in this distribution as a direct consequence of this proposed rule. The agencies also recognize that some international attribute-based standards use attributes other than footprint and that there could be benefits for a number of manufacturers if there was greater international harmonization of fuel economy and GHG standards for light-duty vehicles, but this is largely a question of how stringent standards are and how they are tested and enforced. It is entirely possible that footprint-based and weight-based systems can coexist internationally and not present an undue burden for manufacturers if they are carefully crafted. Different countries or regions may find different attributes appropriate for basing standards, depending on the particular challenges they face—from fuel prices, to family size and land use, to safety concerns, to fleet composition and consumer preference, to other environmental challenges besides climate change. The agencies anticipate working more closely with other countries and regions in the future to consider how to address these issues in a way that least burdens manufacturers while respecting each country's need to meet its own particular challenges.

The agencies continue to find that footprint is the most appropriate attribute upon which to base the proposed standards, but recognizing strong public interest in this issue, we seek comment on whether the agencies should consider setting standards for the final rule based on another attribute or another combination of attributes. If commenters suggest that the agencies should consider another attribute or another combination of attributes, the agencies specifically request that the commenters address the concerns raised in the paragraphs above regarding the use of other attributes, and explain how standards should be developed using the other attribute(s) in a way that contributes more to fuel savings and CO_2 reductions than the footprint-based standards, without compromising safety.

3. What mathematical functions have the agencies previously used, and why?

a. NHTSA in MY 2008 and MY 2011 CAFE (constrained logistic)

For the MY 2011 CAFE rule, NHTSA estimated fuel economy levels after normalization for differences in technology, but did not make adjustments to reflect other vehicle attributes (*e.g.,* power-to-weight ratios).[113] Starting with the technology adjusted passenger car and light truck fleets, NHTSA used minimum absolute deviation (MAD) regression without sales weighting to fit a logistic form as a starting point to develop mathematical functions defining the standards. NHTSA then identified footprints at which to apply minimum and maximum values (rather than letting the standards extend without limit) and transposed these functions vertically (*i.e.,* on a gpm basis, uniformly downward) to produce the promulgated standards. In the preceding rule, for MYs 2008–2011 light truck standards, NHTSA examined a range of potential functional forms, and concluded that, compared to other considered forms, the constrained logistic form provided the expected and appropriate trend (decreasing fuel economy as footprint increases), but avoided creating ''kinks'' the agency was concerned would provide distortionary incentives for vehicles with neighboring footprints.[114]

b. MYs 2012–2016 Light Duty GHG/CAFE (constrained/piecewise linear)

For the MYs 2012–2016 rules, NHTSA and EPA re-evaluated potential methods for specifying mathematical functions to define fuel economy and GHG standards. The agencies concluded that the constrained logistic form, if applied to post-MY 2011 standards, would likely contain a steep mid-section that would provide undue incentive to increase the footprint of midsize passenger cars.[115] The agencies judged that a range of methods to fit the curves would be reasonable, and used a minimum absolute deviation (MAD) regression without sales weighting on a technology-adjusted car and light truck fleet to fit a linear equation. This equation was used as a starting point to develop mathematical functions defining the standards as discussed above. The agencies then identified footprints at which to apply minimum and maximum values (rather than letting the standards extend without limit) and transposed these constrained/piecewise linear functions vertically (*i.e.,* on a gpm or CO_2 basis, uniformly downward) to produce the fleetwide fuel economy and CO_2 emission levels for cars and light trucks described in the final rule.[116]

4. How have the agencies changed the mathematical functions for the proposed MYs 2017–2025 standards, and why?

By requiring NHTSA to set CAFE standards that are attribute-based and defined by a mathematical function, Congress appears to have wanted the post-EISA standards to be data-driven—a mathematical function defining the standards, in order to be ''attribute-based,'' should reflect the observed relationship in the data between the

[112] *See* 74 FR at 14359 (Mar. 30, 2009).

[113] *See* 74 FR 14196, 14363–14370 (Mar. 30, 2009) for NHTSA discussion of curve fitting in the MY 2011 CAFE final rule.

[114] *See* 71 FR 17556, 17609–17613 (Apr. 6, 2006) for NHTSA discussion of ''kinks'' in the MYs 2008–2011 light truck CAFE final rule (there described as ''edge effects''). A ''kink,'' as used here, is a portion of the curve where a small change in footprint results in a disproportionally large change in stringency.

[115] 75 FR at 25362.

[116] *See generally* 74 FR at 49491–96; 75 FR at 25357–62.

attribute chosen and fuel economy.[117] EPA is also proposing to set attribute-based CO_2 standards defined by similar mathematical functions, for the reasonable technical and policy grounds discussed below and in section II of the preamble to the proposed rule, and which supports a harmonization with the CAFE standards.

The relationship between fuel economy (and GHG emissions) and footprint, though directionally clear (*i.e.,* fuel economy tends to decrease and CO_2 emissions tend to increase with increasing footprint), is theoretically vague and quantitatively uncertain; in other words, not so precise as to *a priori* yield only a single possible curve.[118] There is thus a range of legitimate options open to the agencies in developing curve shapes. The agencies may of course consider statutory objectives in choosing among the many reasonable alternatives. For example, curve shapes that might have some theoretical basis could lead to perverse outcomes contrary to the intent of the statutes to conserve energy and protect human health and the environment.[119] Thus, the decision of how to set the target curves cannot always be just about most ''clearly'' using a mathematical function to define the relationship between fuel economy and the attribute; it often has to have a normative aspect, where the agencies adjust the function that would define the relationship in order to avoid perverse results, improve equity of burden across manufacturers, preserve consumer choice, etc. This is true both for the decisions that guide the mathematical function defining the sloped portion of the target curves, and for the separate decisions that guide the agencies' choice of ''cutpoints'' (if any) that define the fuel economy/CO_2 levels and footprints at each end of the curves where the curves become flat. Data informs these decisions, but how the agencies define and interpret the relevant data, and then the choice of methodology for fitting a curve to the data, must include a consideration of both technical data and policy goals.

The next sections examine the policy concerns that the agencies considered in developing the proposed target curves that define the proposed MYs 2017–2025 CAFE and CO_2 standards, new technical work (expanding on similar analyses performed by NHTSA when the agency proposed MY 2011–2015 standards, and by both agencies during consideration of options for MY 2012–2016 CAFE and GHG standards) that was completed in the process of reexamining potential mathematical functions, how the agencies have defined the data, and how the agencies explored statistical curve-fitting methodologies in order to arrive at proposed curves.

5. What are the agencies proposing for the MYs 2017–2025 curves?

The proposed mathematical functions for the proposed MYs 2017–2025 standards are somewhat changed from the functions for the MYs 2012–2016 standards, in response to comments received from stakeholders and in order to address technical concerns and policy goals that the agencies judge more significant in this 9-year rulemaking than in the prior one, which only included 5 years. This section discusses the methodology the agencies selected as, at this time, best addressing those technical concerns and policy goals, given the various technical inputs to the agencies' current analyses. Below the agencies discuss how the agencies determined the cutpoints and the flat portions of the MYs 2017–2025 target curves. We also note that both of these sections address only how the target curves were fit to fuel consumption and CO_2 emission values determined using the city and highway test procedures, and that in determining respective regulatory alternatives, the agencies made further adjustments to the resultant curves in order to account for adjustments for improvements to mobile air conditioners.

Thus, recognizing that there are many reasonable statistical methods for fitting curves to data points that define vehicles in terms of footprint and fuel economy, the agencies have chosen for this proposed rule to fit curves using an ordinary least-squares formulation, on sales-weighted data, using a fleet that has had technology applied, and after adjusting the data for the effects of weight-to-footprint, as described below. This represents a departure from the statistical approach for fitting the curves in MYs 2012–2016, as explained in the next section. The agencies considered a wide variety of reasonable statistical methods in order to better understand the range of uncertainty regarding the relationship between fuel consumption (the inverse of fuel economy), CO_2 emission rates, and footprint, thereby providing a range within which decisions about standards would be potentially supportable.

a. What concerns were the agencies looking to address that led them to change from the approach used for the MYs 2012–2016 curves?

During the year and a half since the MYs 2012–2016 final rule was issued, NHTSA and EPA have received a number of comments from stakeholders on how curves should be fitted to the passenger car and light truck fleets. Some limited-line manufacturers have argued that curves should generally be flatter in order to avoid discouraging small vehicles, because steeper curves tend to result in more stringent targets for smaller vehicles. Most full-line manufacturers have argued that a passenger car curve similar in slope to the MY 2016 passenger car curve would be appropriate for future model years, but that the light truck curve should be revised to be less difficult for manufacturers selling the largest full-size pickup trucks. These manufacturers argued that the MY 2016 light truck curve was not ''physics-based,'' and that in order for future tightening of standards to be feasible for full-line manufacturers, the truck curve for later model years should be steeper and extended further (*i.e.,* made less stringent) into the larger footprints. The agencies do not agree that the MY 2016 light truck curve was somehow deficient in lacking a ''physics basis,'' or that it was somehow overly stringent for manufacturers selling large pickups—manufacturers making these arguments presented no ''physics-based'' model to explain how fuel economy should depend on footprint.[120] The same manufacturers indicated that they believed that the light truck standard should be somewhat steeper after MY 2016, primarily because, after more than ten years of progressive increases in the stringency of applicable CAFE standards, large pickups would be less capable of achieving further

[117] A mathematical function can be defined, of course, that has nothing to do with the relationship between fuel economy and the chosen attribute—the most basic example is an industry-wide standard defined as the mathematical function *average required fuel economy = X,* where X is the single mpg level set by the agency. Yet a standard that is simply defined as a mathematical function that is not tied to the attribute(s) would not meet the requirement of EISA.

[118] In fact, numerous manufacturers have confidentially shared with the agencies what they describe as ''physics based'' curves, with each OEM showing significantly different shapes, and footprint relationships. The sheer variety of curves shown to the agencies further confirm the lack of an underlying principle of ''fundamental physics'' driving the relationship between CO_2 emission or fuel consumption and footprint, and the lack of an underlying principle to dictate any outcome of the agencies' establishment of footprint-based standards.

[119] For example, if the agencies set weight-based standards defined by a steep function, the standards might encourage manufacturers to keep adding weight to their vehicles to obtain less stringent targets.

[120] See footnote 118.

improvements without compromising load carrying and towing capacity.

In developing the curve shapes for this proposed rule, the agencies were aware of the current and prior technical concerns raised by OEMs concerning the effects of the stringency on individual manufacturers and their ability to meet the standards with available technologies, while producing vehicles at a cost that allowed them to recover the additional costs of the technologies being applied. Although we continue to believe that the methodology for fitting curves for the MY2012–2016 standards was technically sound, we recognize manufacturers' technical concerns regarding their abilities to comply with a similarly shallow curve after MY2016 given the anticipated mix of light trucks in MYs 2017–2025. As in the MYs 2012–2016 rules, the agencies considered these concerns in the analysis of potential curve shapes. The agencies also considered safety concerns which could be raised by curve shapes creating an incentive for vehicle downsizing, as well as the potential loss to consumer welfare should vehicle upsizing be unduly disincentivized. In addition, the agencies sought to improve the balance of compliance burdens among manufacturers. Among the technical concerns and resultant policy trade-offs the agencies considered were the following:

Flatter standards (*i.e.,* curves) increase the risk that both the weight and size of vehicles will be reduced, compromising highway safety.

Flatter standards potentially impact the utility of vehicles by providing an incentive for vehicle downsizing.

Steeper footprint-based standards may incentivize vehicle upsizing, thus increasing the risk that fuel economy and greenhouse gas reduction benefits will be less than expected.

Given the same industry-wide average required fuel economy or CO_2 standard, flatter standards tend to place greater compliance burdens on full-line manufacturers.

Given the same industry-wide average required fuel economy or CO_2 standard, steeper standards tend to place greater compliance burdens on limited-line manufacturers (depending of course, on which vehicles are being produced).

If cutpoints are adopted, given the same industry-wide average required fuel economy, moving small-vehicle cutpoints to the left (*i.e.,* up in terms of fuel economy, down in terms of CO_2 emissions) discourages the introduction of small vehicles, and reduces the incentive to downsize small vehicles in ways that would compromise highway safety.

If cutpoints are adopted, given the same industry-wide average required fuel economy, moving large-vehicle cutpoints to the right (*i.e.,* down in terms of fuel economy, up in terms of CO_2 emissions) better accommodates the unique design requirements of larger vehicles—especially large pickups—and extends the size range over which downsizing is discouraged.

All of these were policy goals that required trade-offs, and in determining the curves they also required balance against the comments from the OEMs discussed in the introduction to this section. Ultimately, the agencies do not agree that the MY 2017 target curves for this proposal, on a relative basis, should be made significantly flatter than the MY 2016 curve,[121] as we believe that this would undo some of the safety-related incentives and balancing of compliance burdens among manufacturers—effects that attribute-based standards are intended to provide.

Nonetheless, the agencies recognize full-line OEM concerns and have tentatively concluded that further increases in the stringency of the light truck standards will be more feasible if the light truck curve is made steeper than the MY 2016 truck curve and the right (large footprint) cut-point is extended over time to larger footprints. This conclusion is supported by the agencies' technical analyses of regulatory alternatives defined using the curves developed in the manner described below.

b. What methodologies and data did the agencies consider in developing the 2017–2025 curves?

In considering how to address the various policy concerns discussed in the previous sections, the agencies revisited the data and performed a number of analyses using different combinations of the various statistical methods, weighting schemes, adjustments to the data and the addition of technologies to make the fleets less technologically heterogeneous. As discussed above, in the agencies' judgment, there is no single ''correct'' way to estimate the relationship between CO_2 or fuel consumption and footprint—rather, each statistical result is based on the underlying assumptions about the particular functional form, weightings and error structures embodied in the representational approach. These assumptions are the subject of the following discussion. This process of performing many analyses using combinations of statistical methods generates many possible outcomes, each embodying different potentially reasonable combinations of assumptions and each thus reflective of the data as viewed through a particular lens. The choice of a standard developed by a given combination of these statistical methods is consequently a decision based upon the agencies' determination of how, given the policy objectives for this rulemaking and the agencies' MY 2008-based forecast of the market through MY 2025, to appropriately reflect the current understanding of the evolution of automotive technology and costs, the future prospects for the vehicle market, and thereby establish curves (*i.e.,* standards) for cars and light trucks.

c. What information did the agencies use to estimate a relationship between fuel economy, CO_2 and footprint?

For each fleet, the agencies began with the MY 2008-based market forecast developed to support this proposal (*i.e.,* the baseline fleet), with vehicles' fuel economy levels and technological characteristics at MY 2008 levels.[122] The development, scope, and content of this market forecast is discussed in detail in Chapter 1 of the joint Technical Support Document supporting this rulemaking.

d. What adjustments did the agencies evaluate?

The agencies believe one possible approach is to fit curves to the minimally adjusted data shown above (the approach still includes sales mix adjustments, which influence results of sales-weighted regressions), much as DOT did when it first began evaluating potential attribute-based standards in 2003.[123] However, the agencies have found, as in prior rulemakings, that the data are so widely spread (*i.e.,* when graphed, they fall in a loose ''cloud'' rather than tightly around an obvious line) that they indicate a relationship between footprint and CO_2 and fuel consumption that is real but not particularly strong. Therefore, as discussed below, the agencies also explored possible adjustments that could help to explain and/or reduce the ambiguity of this relationship, or could help to produce policy outcomes the agencies judged to be more desirable.

[121] While ''significantly'' flatter is subjective, the year over year change in curve shapes is discussed in greater detail in Section 0 and Chapter 2 of the joint TSD.

[122] While the agencies jointly conducted this analysis, the coefficients ultimately used in the slope setting analysis are from the CAFE model.

[123] 68 FR 74920–74926.

i. Adjustment to reflect differences in technology

As in prior rulemakings, the agencies consider technology differences between vehicle models to be a significant factor producing uncertainty regarding the relationship between CO_2/fuel consumption and footprint. Noting that attribute-based standards are intended to encourage the application of additional technology to improve fuel efficiency and reduce CO_2 emissions, the agencies, in addition to considering approaches based on the unadjusted engineering characteristics of MY 2008 vehicle models, therefore also considered approaches in which, as for previous rulemakings, technology is added to vehicles for purposes of the curve fitting analysis in order to produce fleets that are less varied in technology content.

The agencies adjusted the baseline fleet for technology by adding all technologies considered, except for the most advanced high-BMEP (brake mean effective pressure) gasoline engines, diesel engines, strong HEVs, PHEVs, EVs, and FCVs. The agencies included 15 percent mass reduction on all vehicles.

ii. Adjustments reflecting differences in performance and ''density''

For the reasons discussed above regarding revisiting the shapes of the curves, the agencies considered adjustments for other differences between vehicle models (*i.e.,* inflating or deflating the fuel economy of each vehicle model based on the extent to which one of the vehicle's attributes, such as power, is higher or lower than average). Previously, NHTSA had rejected such adjustments because they imply that a multi-attribute standard may be necessary, and the agencies judged multi-attribute standard to be more subject to gaming than a footprint-only standard.[124] [125] Having considered this issue again for purposes of this rulemaking, NHTSA and EPA conclude the need to accommodate in the target curves the challenges faced by manufacturers of large pickups currently outweighs these prior concerns. Therefore, the agencies also evaluated curve fitting approaches through which fuel consumption and CO_2 levels were adjusted with respect to weight-to-footprint alone, and in combination with power-to-weight. While the agencies examined these adjustments for purposes of fitting curves, the agencies are not proposing a multi-attribute standard; the proposed fuel economy and CO_2 targets for each vehicle are still functions of footprint alone. No adjustment would be used in the compliance process.

The agencies also examined some differences between the technology-adjusted car and truck fleets in order to better understand the relationship between footprint and CO_2/fuel consumption in the agencies' MY 2008 based forecast. The agencies investigated the relationship between HP/WT and footprint in the agencies' MY2008-based market forecast. On a sales weighted basis, cars tend to become proportionally more powerful as they get larger. In contrast, there is a minimally positive relationship between HP/WT and footprint for light trucks, indicating that light trucks become only slightly more powerful as they get larger.

This analysis, presented in chapter 2.4.1.2 of the agencies' joint TSD, indicated that vehicle performance (power-to-weight ratio) and ''density'' (curb weight divided by footprint) are both correlated to fuel consumption (and CO_2 emission rate), and that these vehicle attributes are also both related to vehicle footprint. Based on these relationships, the agencies explored adjusting the fuel economy and CO_2 emission rates of individual vehicle models based on deviations from ''expected'' performance or weight/footprint at a given footprint; the agencies inflated fuel economy levels of vehicle models with higher performance and/or weight/footprint than the average of the fleet would indicate at that footprint, and deflated fuel economy levels with lower performance and/or weight. Previously, NHTSA had rejected such adjustments because they imply that a multi-attribute standard may be necessary, and the agency judged multi-attribute standard to be more subject to gaming than a footprint-only standard.[126] [127] While the agencies considered this technique for purposes of fitting curves, the agencies are not proposing a multi-attribute standard, as the proposed fuel economy and CO_2 targets for each vehicle are still functions of footprint alone. No adjustment would be used in the compliance process.

The agencies seek comment on the appropriateness of the adjustments as described in Chapter 2 of the joint TSD, particularly regarding whether these adjustments suggest that standards should be defined in terms of other attributes in addition to footprint, and whether they may encourage changes other than encouraging the application of technology to improve fuel economy and reduce CO_2 emissions. The agencies also seek comment regarding whether these adjustments effectively ''lock in'' through MY 2025 relationships that were observed in MY 2008.

e. What statistical methods did the agencies evaluate?

The above approaches resulted in three data sets each for (a) vehicles without added technology and (b) vehicles with technology added to reduce technology differences, any of which may provide a reasonable basis for fitting mathematical functions upon which to base the slope of the standard curves: (1) Vehicles without any further adjustments; (2) vehicles with adjustments reflecting differences in ''density'' (weight/footprint); and (3) vehicles with adjustments reflecting differences in ''density,'' and adjustments reflecting differences in performance (power/weight). Using these data sets, the agencies tested a range of regression methodologies, each judged to be possibly reasonable for application to at least some of these data sets.

i. Regression Approach

In the MYs 2012–2016 final rules, the agencies employed a robust regression approach (minimum absolute deviation, or MAD), rather than an ordinary least squares (OLS) regression.[128] MAD is generally applied to mitigate the effect of outliers in a dataset, and thus was employed in that rulemaking as part of our interest in attempting to best represent the underlying technology. NHTSA had used OLS in early development of attribute-based CAFE

[124] For example, in comments on NHTSA's 2008 NPRM regarding MY 2011–2015 CAFE standards, Porsche recommended that standards be defined in terms of a ''Summed Weighted Attribute'', wherein the fuel economy target would calculated as follows: *target = f(SWA),* where target is the fuel economy target applicable to a given vehicle model and *SWA = footprint + torque* $^{1/1.5}$ + *weight* $^{1/2.5}$. (NHTSA–2008–0089–0174). While the standards the agencies are proposing for MY 2017–2025 are not multi-attributes, that is the target is only a function of footprint, we are proposing curve shapes that were developed considering more than one attribute.

[125] 74 FR 14359.

[126] For example, in comments on NHTSA's 2008 NPRM regarding MY 2011–2015 CAFE standards, Porsche recommended that standards be defined in terms of a ''Summed Weighted Attribute'', wherein the fuel economy target would calculated as follows: *target = f(SWA),* where *target* is the fuel economy target applicable to a given vehicle model and *SWA = footprint + torque* $^{1/1.5}$ + *weight* $^{1/2.5}$. (NHTSA–2008–0089–0174). While the standards the agencies are proposing for MY 2017–2025 are not multi-attribute standards, that is the target is only a function of footprint, we are proposing curve shapes that were developed considering more than one attribute.

[127] 74 FR 14359.

[128] See 75 FR at 25359.

standards, but NHTSA (and then NHTSA and EPA) subsequently chose MAD instead of OLS for both the MY 2011 and the MYs 2012–2016 rulemakings. These decisions on regression technique were made both because OLS gives additional emphasis to outliers [129] and because the MAD approach helped achieve the agencies' policy goals with regard to curve slope in those rulemakings.[130] In the interest of taking a fresh look at appropriate regression methodologies as promised in the 2012–2016 light duty rulemaking, in developing this proposal, the agencies gave full consideration to both OLS and MAD. The OLS representation, as described, uses squared errors, while MAD employs absolute errors and thus weights outliers less.

As noted, one of the reasons stated for choosing MAD over least square regression in the MYs 2012–2016 rulemaking was that MAD reduced the weight placed on outliers in the data. However, the agencies have further considered whether it is appropriate to classify these vehicles as outliers. Unlike in traditional datasets, these vehicles' performance is not mischaracterized due to errors in their measurement, a common reason for outlier classification. Being certification data, the chances of large measurement errors should be near zero, particularly towards high CO_2 or fuel consumption. Thus, they can only be outliers in the sense that the vehicle designs are unlike those of other vehicles. These outlier vehicles may include performance vehicles, vehicles with high ground clearance, 4WD, or boxy designs. Given that these are equally legitimate on-road vehicle designs, the agencies concluded that it would appropriate to reconsider the treatment of these vehicles in the regression techniques.

Based on these considerations as well as the adjustments discussed above, the agencies concluded it was not meaningful to run MAD regressions on gpm data that had already been adjusted in the manner described above. Normalizing already reduced the variation in the data, and brought outliers towards average values. This was the intended effect, so the agencies deemed it unnecessary to apply an additional remedy to resolve an issue that had already been addressed, but we seek comment on the use of robust regression techniques under such circumstances.

ii. Sales Weighting

Likewise, the agencies reconsidered employing sales-weighting to represent the data. As explained below, the decision to sales weight or not is ultimately based upon a choice about how to represent the data, and not by an underlying statistical concern. Sales weighting is used if the decision is made to treat each (mass produced) unit sold as a unique physical observation. Doing so thereby changes the extent to which different vehicle model types are emphasized as compared to a non-sales weighted regression. For example, while total General Motors Silverado (332,000) and Ford F–150 (322,000) sales differ by less than 10,000 in MY 2021 market forecast, 62 F–150s models and 38 Silverado models are reported in the agencies baselines. Without sales-weighting, the F–150 models, because there are more of them, are given 63 percent more weight in the regression despite comprising a similar portion of the marketplace and a relatively homogenous set of vehicle technologies.

The agencies did not use sales weighting in the 2012–2016 rulemaking analysis of the curve shapes. A decision to not perform sales weighting reflects judgment that each vehicle model provides an equal amount of information concerning the underlying relationship between footprint and fuel economy. Sales-weighted regression gives the highest sales vehicle model types vastly more emphasis than the lowest-sales vehicle model types thus driving the regression toward the sales-weighted fleet norm. For unweighted regression, vehicle sales do not matter. The agencies note that the light truck market forecast shows MY 2025 sales of 218,000 units for Toyota's 2WD Sienna, and shows 66 model configurations with MY 2025 sales of fewer than 100 units. Similarly, the agencies' market forecast shows MY 2025 sales of 267,000 for the Toyota Prius, and shows 40 model configurations with MY2025 sales of fewer than 100 units. Sales-weighted analysis would give the Toyota Sienna and Prius more than a thousand times the consideration of many vehicle model configurations. Sales-weighted analysis would, therefore, cause a large number of vehicle model configurations to be virtually ignored in the regressions.[131]

However, the agencies did note in the MYs 2012–2016 final rules that, ''sales weighted regression would allow the difference between other vehicle attributes to be reflected in the analysis, and also would reflect consumer demand.'' [132] In reexamining the sales-weighting for this analysis, the agencies note that there are low-volume model types account for many of the passenger car model types (50 percent of passenger car model types account for 3.3 percent of sales), and it is unclear whether the engineering characteristics of these model types should equally determine the standard for the remainder of the market.

In the interest of taking a fresh look at appropriate methodologies as promised in the last final rule, in developing this proposal, the agencies gave full consideration to both sales-weighted and unweighted regressions.

iii. Analyses Performed

We performed regressions describing the relationship between a vehicle's CO_2/fuel consumption and its footprint, in terms of various combinations of factors: initial (raw) fleets with no technology, versus after technology is applied; sales-weighted versus non-sales weighted; and with and without two sets of normalizing factors applied to the observations. The agencies excluded diesels and dedicated AFVs because the agencies anticipate that advanced gasoline-fueled vehicles are likely to be dominant through MY 2025, based both on our own assessment of potential standards (see Sections III and IV below) as well as our discussions with large number of automotive companies and suppliers.

Thus, the basic OLS regression on the initial data (with no technology applied) and no sales-weighting represents one perspective on the relation between footprint and fuel economy. Adding sales weighting changes the interpretation to include the influence of sales volumes, and thus steps away from representing vehicle technology alone. Likewise, MAD is an attempt to reduce the impact of outliers, but reducing the impact of outliers might perhaps be less representative of technical relationships between the variables, although that relationship may change over time in reality. Each combination of methods and data reflects a perspective, and the regression results simply reflect that perspective in a simple quantifiable manner, expressed as the coefficients determining the line through the average (for OLS) or the median (for MAD) of the data. It is left to policy makers to determine an appropriate perspective and to interpret the consequences of the various alternatives.

We invite comments on the application of the weights as described

[129] *Id.* at 25362–63.

[130] *Id.* at 25363.

[131] 75 FR at 25362 and n. 64.

[132] 75 FR at 25632/3.

above, and the implications for interpreting the relationship between fuel efficiency (or CO_2) and footprint.

f. What results did the agencies obtain, which methodology did the agencies choose for this proposal, and why is it reasonable?

Both agencies analyzed the same statistical approaches. For regressions against data including technology normalization, NHTSA used the CAFE modeling system, and EPA used EPA's OMEGA model. The agencies obtained similar regression results, and have based today's joint proposal on those obtained by NHTSA. The draft Joint TSD Chapter 2 contains a large set of illustrative of figures which show the range of curves determined by the possible combinations of regression technique, with and without sales weighting, with and without the application of technology, and with various adjustments to the gpm variable prior to running a regression.

The choice among the alternatives presented in the draft Joint TSD Chapter 2 was to use the OLS formulation, on sales-weighted data, using a fleet that has had technology applied, and after adjusting the data for the effect of weight-to-footprint, as described above. The agencies believe that this represents a technically reasonable approach for purposes of developing target curves to define the proposed standards, and that it represents a reasonable trade-off among various considerations balancing statistical, technical, and policy matters, which include the statistical representativeness of the curves considered and the steepness of the curve chosen. The agencies judge the application of technology prior to curve fitting to provide a reasonable means—one consistent with the rule's objective of encouraging manufacturers to add technology in order to increase fuel economy—of reducing variation in the data and thereby helping to estimate a relationship between fuel consumption/ CO_2 and footprint.

Similarly, for the agencies' current MY 2008-based market-forecast and the agencies' current estimates of future technology effectiveness, the inclusion of the weight-to-footprint data adjustment prior to running the regression also helps to improve the fit of the curves by reducing the variation in the data, and the agencies believe that the benefits of this adjustment for this proposed rule likely outweigh the potential that resultant curves might somehow encourage reduced load carrying capability or vehicle performance (note that the we are not suggesting that we believe these adjustments will reduce load carrying capability or vehicle performance). In addition to reducing the variability, the truck curve is also steepened, and the car curve flattened compared to curves fitted to sales weighted data that do not include these normalizations. The agencies agree with manufacturers of full-size pick-up trucks that in order to maintain towing and hauling utility, the engines on pick-up trucks must be more powerful, than their low "density" nature would statistically suggest based on the agencies' current MY2008-based market forecast and the agencies' current estimates of the effectiveness of different fuel-saving technologies. Therefore, it may be more equitable (*i.e.,* in terms of relative compliance challenges faced by different light truck manufacturers) to adjust the slope of the curve defining fuel economy and CO_2 targets.

As described above, however, other approaches are also technically reasonable, and also represent a way of expressing the underlying relationships. The agencies plan to revisit the analysis for the final rule, after updating the underlying market forecast and estimates of technology effectiveness, and based on relevant public comments received. In addition, the agencies intend to update the technology cost estimates, which could alter the NPRM analysis results and consequently alter the balance of the trade-offs being weighed to determine the final curves.

g. Implications of the proposed slope compared to MY 2012–2016

The proposed slope has several implications relative to the MY 2016 curves, with the majority of changes on the truck curve. With the agencies' current MY2008-based market forecast and the agencies' current estimates of technology effectiveness, the combination of sales weighting and WT/FP normalization produced a car curve slope similar to that finalized in the MY 2012–2016 final rulemaking (4.7 g/mile in MY 2016, vs. 4.5 g/mile proposed in MY 2017). By contrast, the truck curve is steeper in MY 2017 than in MY 2016 (4.0 g/mile in MY 2016 vs. 4.9 g/mile in MY 2017). As discussed previously, a steeper slope relaxes the stringency of targets for larger vehicles relative to those for smaller vehicles, thereby shifting relative compliance burdens among manufacturers based on their respective product mix.

6. Once the agencies determined the appropriate slope for the sloped part, how did the agencies determine the rest of the mathematical function?

The agencies continue to believe that without a limit at the smallest footprints, the function—whether logistic or linear—can reach values that would be unfairly burdensome for a manufacturer that elects to focus on the market for small vehicles; depending on the underlying data, an unconstrained form could result in stringency levels that are technologically infeasible and/ or economically impracticable for those manufacturers that may elect to focus on the smallest vehicles. On the other side of the function, without a limit at the largest footprints, the function may provide no floor on required fuel economy. Also, the safety considerations that support the provision of a disincentive for downsizing as a compliance strategy apply weakly, if at all, to the very largest vehicles. Limiting the function's value for the largest vehicles thus leads to a function with an inherent absolute minimum level of performance, while remaining consistent with safety considerations.

Just as for slope, in determining the appropriate footprint and fuel economy values for the "cutpoints," the places along the curve where the sloped portion becomes flat, the agencies took a fresh look for purposes of this proposal, taking into account the updated market forecast and new assumptions about the availability of technologies. The next two sections discuss the agencies' approach to cutpoints for the passenger car and light truck curves separately, as the policy considerations for each vary somewhat.

a. Cutpoints for PC curve

The passenger car fleet upon which the agencies have based the target curves for MYs 2017–2025 is derived from MY 2008 data, as discussed above. In MY 2008, passenger car footprints ranged from 36.7 square feet, the Lotus Exige 5, to 69.3 square feet, the Daimler Maybach 62. In that fleet, several manufacturers offer small, sporty coupes below 41 square feet, such as the BMW Z4 and Mini, Honda S2000, Mazda MX–5 Miata, Porsche Carrera and 911, and Volkswagen New Beetle. Because such vehicles represent a small portion (less than 10 percent) of the passenger car market, yet often have performance, utility, and/or structural characteristics that could make it technologically infeasible and/or economically impracticable for manufacturers focusing on such vehicles to achieve the very challenging average requirements that could apply in the absence of a constraint, EPA and NHTSA are again proposing to cut off the sloped portion of the passenger car function at 41 square feet, consistent with the MYs 2012–2016 rulemaking. The agencies recognize that for manufacturers who make small vehicles in this size range, putting the cutpoint at 41 square feet creates some incentive to downsize (*i.e.,* further reduce the size, and/or increase the production of models currently smaller than 41 square feet) to make it easier to meet the target. Putting the cutpoint here may also create the incentive for manufacturers who do not currently offer such models to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars smaller than 41 square feet—most consumers likely have some minimum expectation about interior volume, among other things. The agencies thus believe that the number of consumers who will want vehicles smaller than 41 square feet (regardless of how they are priced) is small, and that the incentive to downsize to less than 41 square feet in response to this proposal, if present, will be at best minimal. On the other hand, the agencies note that some manufacturers are introducing mini cars not reflected in the agencies MY 2008-based market forecast, such as the Fiat 500, to the U.S. market, and that the footprint at which the curve is limited may affect the incentive for manufacturers to do so.

Above 56 square feet, the only passenger car models present in the MY 2008 fleet were four luxury vehicles with extremely low sales volumes—the Bentley Arnage and three versions of the Rolls Royce Phantom. As in the MYs 2012–2016 rulemaking, NHTSA and EPA therefore are proposing again to cut off the sloped portion of the passenger car function at 56 square feet.

While meeting with manufacturers prior to issuing the proposal, the agencies received comments from some manufacturers that, combined with slope and overall stringency, using 41 square feet as the footprint at which to cap the target for small cars would result in unduly challenging targets for small cars. The agencies do not agree. No specific vehicle need meet its target (because standards apply to fleet average performance), and maintaining a sloped function toward the smaller end of the passenger car market is important to discourage unsafe downsizing, the agencies are thus proposing to again ''cut off'' the passenger car curve at 41 square feet, notwithstanding these comments.

The agencies seek comment on setting cutpoints for the MYs 2017–2025 passenger car curves at 41 square feet and 56 square feet.

b. Cutpoints for LT curve

The light truck fleet upon which the agencies have based the target curves for MYs 2017–2025, like the passenger car fleet, is derived from MY 2008 data, as discussed in Section 2.4 above. In MY 2008, light truck footprints ranged from 41.0 square feet, the Jeep Wrangler, to 77.5 square feet, the Toyota Tundra. For consistency with the curve for passenger cars, the agencies are proposing to cut off the sloped portion of the light truck function at the same footprint, 41 square feet, although we recognize that no light trucks are currently offered below 41 square feet. With regard to the upper cutpoint, the agencies heard from a number of manufacturers during the discussions leading up to this proposal that the location of the cutpoint in the MYs 2012–2016 rules, 66 square feet, meant that the same standard applied to all light trucks with footprints of 66 square feet or greater, and that in fact the targets for the largest light trucks in the later years of that rulemaking were extremely challenging. Those manufacturers requested that the agencies extend the cutpoint to a larger footprint, to reduce targets for the largest light trucks which represent a significant percentage of those manufacturers light truck sales. At the same time, in re-examining the light truck fleet data, the agencies concluded that aggregating pickup truck models in the MYs 2012–2016 rule had led the agencies to underestimate the impact of the different pickup truck model configurations above 66 square feet on manufacturers' fleet average fuel economy and CO_2 levels (as discussed immediately below). In disaggregating the pickup truck model data, the impact of setting the cutpoint at 66 square feet after model year 2016 became clearer to the agencies.

In the agencies' view, there is legitimate basis for these comments. The agencies' market forecast includes about 24 vehicle configurations above 74 square feet with a total volume of about 50,000 vehicles or less during any MY in the 2017–2025 time frame. While a relatively small portion of the overall truck fleet, for some manufacturers, these vehicles are non-trivial portion of sales. As noted above, the very largest light trucks have significant load-carrying and towing capabilities that make it particularly challenging for manufacturers to add fuel economy-improving/CO_2-reducing technologies in a way that maintains the full functionality of those capabilities.

Considering manufacturer CBI and our estimates of the impact of the 66 square foot cutpoint for future model years, the agencies have initially determined to adopt curves that transition to a different cut point. While noting that no specific vehicle need meet its target (because standards apply to fleet average performance), we believe that the information provided to us by manufacturers and our own analysis supports the gradual extension of the cutpoint for large light trucks in this proposal from 66 square feet in MY 2016 out to a larger footprint square feet before MY 2025.

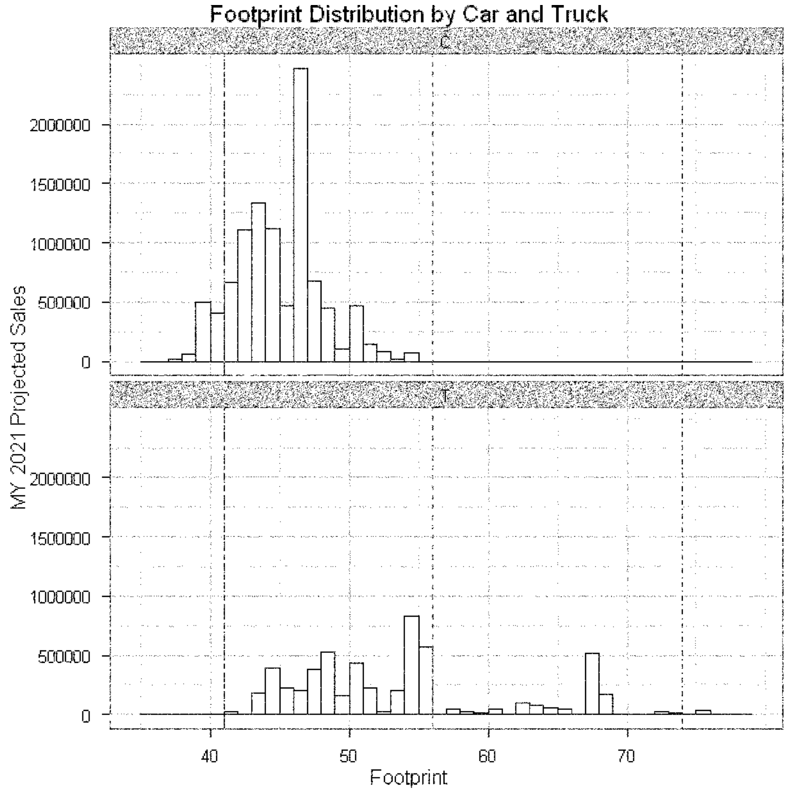

Figure II-1 Footprint Distribution by Car and Truck*

*Proposed truck cutpoints for MY 2025 shown in red, car cutpoints shown in green

The agencies are proposing to phase in the higher cutpoint for the truck curve in order to avoid any backsliding from the MY 2016 standard. A target that is feasible in one model year should never become less feasible in a subsequent model year—manufacturers should have no reason to remove fuel economy-improving/CO_2-reducing technology from a vehicle once it has been applied. Put another way, the agencies are proposing to not allow ''curve crossing'' from one model year to the next. In proposing MYs 2011–2015 CAFE standards and promulgating MY 2011 standards, NHTSA proposed and requested comment on avoiding curve crossing, as an ''anti-backsliding measure.'' [133] The MY 2016 2 cycle test curves are therefore a floor for the MYs 2017–2025 curves. For passenger cars, which have minimal change in slope from the MY 2012–2016 rulemakings and no change in cut points, there are no curve crossing issues in the proposed standards.

The minimum stringency determination was done using the two cycle curves. Stringency adjustments for air conditioning and other credits were calculated after curves that did not cross were determined in two cycle space. The year over year increase in these adjustments cause neither the GHG nor CAFE curves (with A/C) to contact the 2016 curves when charted.

7. Once the agencies determined the complete mathematical function shape, how did the agencies adjust the curves to develop the proposed standards and regulatory alternatives?

The curves discussed above all reflect the addition of technology to individual vehicle models to reduce technology differences between vehicle models before fitting curves. This application of technology was conducted not to directly determine the proposed standards, but rather for purposes of technology adjustments, and set aside considerations regarding potential rates of application (*i.e.,* phase-in caps), and considerations regarding economic implications of applying specific technologies to specific vehicle models. The following sections describe further adjustments to the curves discussed above, that affect both the shape of the curve, and the location of the curve, that helped the agencies determine curves that defined the proposed standards.

a. Adjusting for Year over Year Stringency

As in the MYs 2012–2016 rules, the agencies developed curves defining regulatory alternatives for consideration by ''shifting'' these curves. For the MYs 2012–2016 rules, the agencies did so on an absolute basis, offsetting the fitted curve by the same value (in gpm or g/mi) at all footprints. In developing this proposal, the agencies have reconsidered the use of this approach, and have concluded that after MY 2016, curves should be offset on a relative basis—that is, by adjusting the entire gpm-based curve (and, equivalently, the CO_2 curve) by the same percentage rather than the same absolute value. The agencies' estimates of the effectiveness of these technologies are all expressed in relative terms—that is, each technology (with the exception of A/C) is estimated to reduce fuel consumption (the inverse of fuel economy) and CO_2 emissions by a specific percentage of

[133] 74 Fed. Reg. at 14370 (Mar. 30, 2009).

fuel consumption without the technology. It is, therefore, more consistent with the agencies' estimates of technology effectiveness to develop the proposed standards and regulatory alternatives by applying a proportional offset to curves expressing fuel consumption or emissions as a function of footprint. In addition, extended indefinitely (and without other compensating adjustments), an absolute offset would eventually (*i.e.,* at very high average stringencies) produce negative (gpm or g/mi) targets. Relative offsets avoid this potential outcome. Relative offsets do cause curves to become, on a fuel consumption and CO_2 basis, flatter at greater average stringencies; however, as discussed above, this outcome remains consistent with the agencies' estimates of technology effectiveness. In other words, given a relative decrease in average required fuel consumption or CO_2 emissions, a curve that is flatter by the same relative amount should be equally challenging in terms of the potential to achieve compliance through the addition of fuel-saving technology.

On this basis, and considering that the ''flattening'' occurs gradually for the regulatory alternatives the agencies have evaluated, the agencies tentatively conclude that this approach to offsetting the curves to develop year-by-year regulatory alternatives neither re-creates a situation in which manufacturers are likely to respond to standards in ways that compromise highway safety, nor undoes the attribute-based standard's more equitable balancing of compliance burdens among disparate manufacturers. The agencies invite comment on these conclusions, and on any other means that might avoid the potential outcomes—in particular, negative fuel consumption and CO_2 targets—discussed above.

b. Adjusting for anticipated improvements to mobile air conditioning systems

The fuel economy values in the agencies' market forecast are based on the 2-cycle (*i.e.,* city and highway) fuel economy test and calculation procedures that do not reflect potential improvements in air conditioning system efficiency, refrigerant leakage, or refrigerant Global Warming Potential (GWP). Recognizing that there are significant and cost effective potential air conditioning system improvements available in the rulemaking timeframe (discussed in detail in Chapter 5 of the draft joint TSD), the agencies are increasing the stringency of the target curves based on the agencies' assessment of the capability of manufacturers to implement these changes. For the proposed CAFE standards and alternatives, an offset is included based on air conditioning system efficiency improvements, as these improvements are the only improvements that effect vehicle fuel economy. For the proposed GHG standards and alternatives, a stringency increase is included based on air conditioning system efficiency, leakage and refrigerant improvements. As discussed above in Chapter 5 of the join TSD, the air conditioning system improvements affect a vehicle's fuel efficiency or CO_2 emissions performance as an additive stringency increase, as compared to other fuel efficiency improving technologies which are multiplicative. Therefore, in adjusting target curves for improvements in the air conditioning system performance, the agencies are adjusting the target curves by additive stringency increases (or vertical shifts) in the curves.

For the GHG target curves, the offset for air conditioning system performance is being handled in the same manner as for the MY 2012–2016 rules. For the CAFE target curves, NHTSA for the first time is proposing to account for potential improvements in air conditioning system performance. Using this methodology, the agencies first use a multiplicative stringency adjustment for the sloped portion of the curves to reflect the effectiveness on technologies other than air conditioning system technologies, creating a series of curve shapes that are ''fanned'' based on two-cycle performance. Then the curves are offset vertically by the air conditioning improvement by an equal amount at every point.

D. Joint Vehicle Technology Assumptions

For the past four to five years, the agencies have been working together closely to follow the development of fuel consumption and GHG reducing technologies. Two major analyses have been published jointly by EPA and NHTSA: The Technical Support Document to support the MYs 2012–2016 final rule and the 2010 Technical Analysis Report (which supported the 2010 Notice of Intent). The latter of these analyses was also done in conjunction with CARB. Both of these analyses have both been published within the past 18 months. As a result, much of the work is still relevant and we continue to rely heavily on these references. However, some technologies—and what we know about them—are changing so rapidly that the analysis supporting this proposal contains a considerable amount of new work on technologies included in this rule, some of which were included in prior rulemakings, and others that were not.

Notably, we have updated our battery costing methodology significantly since the MYs 2012–2016 final rule and even relative to the 2010 TAR. We are now using a peer reviewed model developed by Argonne National Laboratory for the Department of Energy which provides us with more rigorous estimates for battery costs and allows us to estimate future costs specific to hybrids, plug-in hybrids and electric vehicles all of which have different battery design characteristics.

We also have new cost data from more recently completed tear down and other cost studies by FEV which were not available in either the MYs 2012–2016 final rule or the 2010 TAR. These new studies analyzed a 8-speed automatic transmission replacing 6-speed automatic transmission, a 8-speed dual clutch transmission replacing 6-speed dual clutch transmission, a power-split hybrid powertrain with an I4 engine replacing a conventional engine powertrain with V6 engine, a mild hybrid with stop-start technology and an I4 engine replacing a conventional I4 engine, and the Fiat Multi-Air engine technology. We discuss the new tear down studies in Section II.D.2 of this preamble. Based on this, we have updated some of the FEV-developed costs relative to what we used in the 2012–2016 final rule, although these costs are consistent with those used in the 2010 TAR. Furthermore, we have completely re-worked our estimated costs associated with mass reduction relative to both the MYs 2012–2016 final rule and the 2010 TAR.

As would be expected given that some of our cost estimates were developed several years ago, we have also updated all of our base direct manufacturing costs to put them in terms of more recent dollars (2009 dollars for this proposal). We have also updated our methodology for calculating indirect costs associated with new technologies since both the MYs 2012–2016 final rule and the TAR. We continue to use the indirect cost multiplier (ICM) approach used in those analyses, but have made important changes to the calculation methodology—changes done in response to ongoing staff evaluation and public input.

Lastly, we have updated many of the technologies' effectiveness estimates largely based on new vehicle simulation work conducted by Ricardo Engineering. This simulation work provides the effectiveness estimates for a number of the technologies most heavily relied on in the agencies' analysis of potential standards for MYs 2017–2025.

The agencies have also reviewed the findings and recommendations in the updated NAS report ''Assessment of Fuel Economy Technologies for Light-Duty Vehicles'' that was completed after the MYs 2012–2016 final rule was issued,[134] and NHTSA has performed a sensitivity analysis (contained in its PRIA) to examine the impact of using some of the NAS cost and effectiveness estimates on the proposed standards.

Each of these changes is discussed briefly in the remainder of this section and in much greater detail in Chapter 3 of the draft joint TSD. First we provide a brief summary of the technologies we have considered in this proposal before highlighting the above-mentioned items that are new for this proposal. We request comment on all aspects of our analysis as discussed here and detailed in the draft joint TSD.

1. What technologies did the Agencies Consider?

For this proposal, the agencies project that manufacturers can add a variety of technologies to each of their vehicle models and or platforms in order to improve the vehicles' fuel economy and GHG performance. In order to analyze a variety of regulatory alternative scenarios, it is essential to have a thorough understanding of the technologies available to the manufacturers. This analysis includes an assessment of the cost, effectiveness, availability, development time, and manufacturability of various technologies within the normal redesign and refresh periods of a vehicle line (or in the design of a new vehicle). As we describe in the draft Joint TSD, when a technology can be applied can affect the cost as well as the technology penetration rates (or phase-in caps) that are projected in the analysis.

The agencies considered dozens of vehicle technologies that manufacturers could use to improve the fuel economy and reduce CO_2 emissions of their vehicles during the MYs 2017–2025 timeframe. Many of the technologies considered are available today, are well known, and could be incorporated into vehicles once product development decisions are made. These are ''near-term'' technologies and are identical or very similar to those anticipated in the agencies' analyses of compliance strategies for the MYs 2012–2016 final rule. For this rulemaking, given its time frame, other technologies are also considered that are not currently in production, but that are beyond the initial research phase, and are under development and expected to be in production in the next 5–10 years. Examples of these technologies are downsized and turbocharged engines operating at combustion pressures even higher than today's turbocharged engines, and an emerging hybrid architecture combined with an 8 speed dual clutch transmission, a combination that is not available today. These are technologies which the agencies believe can, for the most part, be applied both to cars and trucks, and which are expected to achieve significant improvements in fuel economy and reductions in CO_2 emissions at reasonable costs in the MYs 2017 to 2025 timeframe. The agencies did not consider technologies that are currently in an initial stage of research because of the uncertainty involved in the availability and feasibility of implementing these technologies with significant penetration rates for this analysis. The agencies recognize that due to the relatively long time frame between the date of this proposal and 2025, it is very possible that new and innovative technologies will make their way into the fleet, perhaps even in significant numbers, that we have not considered in this analysis. We expect to reconsider such technologies as part of the mid-term evaluation, as appropriate, and possibly could be used to generate credits under a number of the proposed flexibility and incentive programs provided in the proposed rules.

The technologies considered can be grouped into four broad categories: Engine technologies; transmission technologies; vehicle technologies (such as mass reduction, tires and aerodynamic treatments); and electrification technologies (including hybridization and changing to full electric drive).[135] The specific technologies within each broad group are discussed below. The list of technologies presented below is nearly identical to that presented in both the MYs 2012–2016 final rule and the 2010 TAR, with the following new technologies added to the list since the last final rule: The P2 hybrid, a newly emerging hybridization technology that was also considered in the 2010 TAR; continued improvements in gasoline engines, with greater efficiencies and downsizing; continued significant efficiency improvements in transmissions; and ongoing levels of improvement to some of the seemingly more basic technologies such as lower rolling resistance tires and aerodynamic treatments, which are among the most cost effective technologies available for reducing fuel consumption and GHGs. Not included in the list below are technologies specific to air conditioning system improvements and off-cycle controls, which are presented in Section II.F of this NPRM and in Chapter 5 of the draft Joint TSD.

a. Types of Engine Technologies Considered

Low-friction lubricants including low viscosity and advanced low friction lubricant oils are now available with improved performance. If manufacturers choose to make use of these lubricants, they may need to make engine changes and conduct durability testing to accommodate the lubricants. The costs in our analysis consider these engine changes and testing requirements. This level of low friction lubricants is expected to exceed 85 percent penetration by the 2017 MY.

Reduction of engine friction losses can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve efficient engine operation. This level of engine friction reduction is expected to exceed 85 percent penetration by the 2017 MY.

Advanced Low Friction Lubricant and Second Level of Engine Friction Reduction are new for this analysis. As technologies advance between now and the rulemaking timeframe, there will be further development in low friction lubricants and engine friction reductions. The agencies grouped the development in these two areas into a single technology and applied them for MY 2017 and beyond.

Cylinder deactivation disables the intake and exhaust valves and prevents fuel injection into some cylinders during light-load operation. The engine runs temporarily as though it were a smaller engine which substantially reduces pumping losses.

Variable valve timing alters the timing of the intake valves, exhaust valves, or both, primarily to reduce pumping losses, increase specific power, and control residual gases.

Discrete variable valve lift increases efficiency by optimizing air flow over a broader range of engine operation which

[134] ''Assessment of Fuel Economy Technologies for Light-Duty Vehicles,'' National Research Council of the National Academies, June 2010.

[135] NHTSA's analysis considers these technologies in five groups rather than four—hybridization is one category, and ''electrification/accessories'' is another.

reduces pumping losses. This is accomplished by controlled switching between two or more cam profile lobe heights.

Continuous variable valve lift is an electromechanical or electrohydraulic system in which valve timing is changed as lift height is controlled. This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled.

Stoichiometric gasoline direct-injection technology injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge as well as combustion quality within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency.

Turbo charging and downsizing increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. Engines of this type use gasoline direct injection (GDI) and dual cam phasing. This reduces pumping losses at lighter loads in comparison to a larger engine. We continue to include an 18 bar brake mean effective pressure (BMEP) technology (as in the MYs 2012–2016 final rule) and are also including both 24 bar BMEP and 27 bar BMEP technologies. The 24 bar BMEP technology would use a single-stage, variable geometry turbocharger which would provide a higher intake boost pressure available across a broader range of engine operation than conventional 18 bar BMEP engines. The 27 bar BMEP technology requires additional boost and thus would use a two-stage turbocharger necessitating use of cooled exhaust gas recirculation (EGR) as described below. The 18 bar BMEP technology is applied with 33 percent engine downsizing, 24 bar BMEP is applied with 50 percent engine downsizing, and 27 bar BMEP is applied with 56 percent engine downsizing.

Cooled exhaust-gas recirculation (EGR) reduces the incidence of knocking combustion with additional charge dilution and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this assessment would use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. For this proposal, cooled EGR is considered to be a technology that can be added to a 24 bar BMEP engine and is an enabling technology for 27 bar BMEP engines.

Diesel engines have several characteristics that give superior fuel efficiency, including reduced pumping losses due to lack of (or greatly reduced) throttling, high pressure direct injection of fuel, a combustion cycle that operates at a higher compression ratio, and a very lean air/fuel mixture relative to an equivalent-performance gasoline engine. This technology requires additional enablers, such as a NO_x adsorption catalyst system or a urea/ammonia selective catalytic reduction system for control of NO_x emissions during lean (excess air) operation.

b. Types of Transmission Technologies Considered

Improved automatic transmission controls optimize the shift schedule to maximize fuel efficiency under wide ranging conditions and minimizes losses associated with torque converter slip through lock-up or modulation. The first level of controls is expected to exceed 85 percent penetration by the 2017 MY.

Shift optimization is a strategy whereby the engine and/or transmission controller(s) emulates a CVT by continuously evaluating all possible gear options that would provide the necessary tractive power and select the best gear ratio that lets the engine run in the most efficient operating zone.

Six-, seven-, and eight-speed automatic transmissions are optimized by changing the gear ratio span to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions. While a six speed transmission application was most prevalent for the MYs 2012–2016 final rule, eight speed transmissions are expected to be readily available and applied in the MYs 2017 through 2025 timeframe.

Dual clutch or automated shift manual transmissions are similar to manual transmissions, but the vehicle controls shifting and launch functions. A dual-clutch automated shift manual transmission (DCT) uses separate clutches for even-numbered and odd-numbered gears, so the next expected gear is pre-selected, which allows for faster and smoother shifting. The 2012–2016 final rule limited DCT applications to a maximum of 6-speeds. For this proposal we have considered both 6-speed and 8-speed DCT transmissions.

Continuously variable transmission commonly uses V-shaped pulleys connected by a metal belt rather than gears to provide ratios for operation. Unlike manual and automatic transmissions with fixed transmission ratios, continuously variable transmissions can provide fully variable and an infinite number of transmission ratios that enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions. The CVT is maintained for existing baseline vehicles and not considered for future vehicles in this proposal due to the availability of more cost effective transmission technologies.

Manual 6-speed transmission offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission.

High Efficiency Gearbox (automatic, DCT or manual)—continuous improvement in seals, bearings and clutches, super finishing of gearbox parts, and development in the area of lubrication, all aimed at reducing frictional and other parasitic load in the system for an automatic or DCT type transmission.

c. Types of Vehicle Technologies Considered

Lower-rolling-resistance tires have characteristics that reduce frictional losses associated with the energy dissipated mainly in the deformation of the tires under load, thereby improving fuel economy and reducing CO_2 emissions. New for this proposal (and also marking an advance over low rolling resistance tires considered during the heavy duty greenhouse gas rulemaking, see 76 FR at 57207, 57229) is a second level of lower rolling resistance tires that reduce frictional losses even further. The first level of low rolling resistance tires will have 10 percent rolling resistance reduction while the 2nd level would have 20 percent rolling resistance reduction compared to 2008 baseline vehicle. The first level of lower rolling resistance tires is expected to exceed 85 percent penetration by the 2017 MY.

Low-drag brakes reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors.

Front or secondary axle disconnect for four-wheel drive systems provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses.

Aerodynamic drag reduction can be achieved via two approaches, either reducing the drag coefficients or reducing vehicle frontal area. To reduce the drag coefficient, skirts, air dams, underbody covers, and more aerodynamic side view mirrors can be applied. In addition to the standard aerodynamic treatments, the agencies have included a second level of aerodynamic technologies which could include active grill shutters, rear visors, and larger under body panels. The first level of aero dynamic drag improvement is estimated to reduce aerodynamic drag by 10 percent relative to the baseline 2008 vehicle while the second level would reduce aero dynamic drag by 20 percent relative to 2008 baseline vehicles. The second level of aerodynamic technologies was not considered in the MYs 2012–2016 final rule.

Mass Reduction can be achieved in many ways, such as material substitution, design optimization, part consolidation, improving manufacturing process, etc. The agencies applied mass reduction of up to 20 percent relative to MY 2008 levels in this NPRM compared to only 10 percent in 2012–2016 final rule. The agencies also determined effectiveness values for hybrid, plug-in and electric vehicles based on net mass reduction, or the delta between the applied mass reduction (capped at 20 percent) and the added mass of electrification components. In assessing compliance strategies and in structuring the standards, the agencies only considered amounts of vehicle mass reduction that would result in what we estimated to be no adverse effect on overall fleet safety. The agencies have an extensive discussion of mass reduction technologies as well as the cost of mass reduction in chapter 3 of the draft joint TSD.

d. Types of Electrification/Accessory and Hybrid Technologies Considered

Electric power steering (EPS)/Electro-hydraulic power steering (EHPS) is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive. Manufacturers have informed the agencies that full EPS systems are being developed for all light-duty vehicles, including large trucks. However, the agencies have applied the EHPS technology to large trucks and the EPS technology to all other light-duty vehicles.

Improved accessories (IACC) may include high efficiency alternators, electrically driven (*i.e.,* on-demand) water pumps and cooling fans. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors. New for this proposal is a second level of IACC (IACC2) which consists of the IACC technologies and the addition of a mild regeneration strategy and a higher efficiency alternator. The first level of IACC improvements is expected to be at more than 85 percent penetration by the 2017MY.

12-volt Stop-Start, sometimes referred to as idle-stop or 12-volt micro hybrid is the most basic hybrid system that facilitates idle-stop capability. These systems typically incorporate an enhanced performance battery and other features such as electric transmission and cooling pumps to maintain vehicle systems during idle-stop.

Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG) sometimes referred to as a mild hybrid, provides idle-stop capability and uses a higher voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator, that is belt driven and that can recover braking energy while the vehicle slows down (regenerative braking). This mild hybrid technology is not included by either agency as an enabling technology in the analysis supporting this proposal, although some automakers have expressed interest in possibly using the technology during the rulemaking time frame. EPA and NHTSA are providing incentives to encourage this and similar hybrid technologies on pick-up trucks in particular, as described in Section II.F, and the agencies are in the process of including this technology for the final rule analysis as we expand our understanding of the associated costs and limitations.

Integrated Motor Assist (IMA)/Crank integrated starter generator (CISG) provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the wiring harness. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator that is crankshaft mounted and can recover braking energy while the vehicle slows down (regenerative braking). The IMA technology is not included by either agency as an enabling technology in the analysis supporting this proposal, although it is included as a baseline technology because it exists in our 2008 baseline fleet.

P2 Hybrid is a newly emerging hybrid technology that uses a transmission integrated electric motor placed between the engine and a gearbox or CVT, much like the IMA system described above except with a wet or dry separation clutch which is used to decouple the motor/transmission from the engine. In addition, a P2 hybrid would typically be equipped with a larger electric machine. Disengaging the clutch allows all-electric operation and more efficient brake-energy recovery. Engaging the clutch allows efficient coupling of the engine and electric motor and, when combined with a DCT transmission, reduces gear-train losses relative to power-split or 2-mode hybrid systems.

2–Mode Hybrid is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO_2 emissions at highway speeds relative to other types of hybrid electric drive systems. The 2-mode hybrid technology is not included by either agency as an enabling technology in the analysis supporting this proposal, although it is included as a baseline technology because it exists in our 2008 baseline fleet.

Power-split Hybrid is a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and a motor/generator. This motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. A second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels. The planetary gear splits engine power between the first motor/generator and the drive motor to either charge the battery or supply power to the wheels. The power-split hybrid technology is not included by either agency as an enabling technology in the analysis supporting this proposal, (the agencies evaluate the P2 hybrid technology discussed above where power-split hybrids might otherwise have been appropriate) although it is included as a baseline technology because it exists in our 2008 baseline fleet.

Plug-in hybrid electric vehicles (PHEV) are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs with more energy storage and a greater capability to be discharged than other hybrid electric vehicles. They also use a control system that allows the battery pack to be substantially depleted under electric-only or blended mechanical/electric operation and batteries that can be cycled in charge sustaining operation at a lower state of charge than is typical of other hybrid electric vehicles. These vehicles are sometimes referred to as Range Extended Electric Vehicles (REEV). In this MYs 2017–2025 analysis, PHEVs with several all-electric ranges—both a 20 mile and a 40 mile all-electric range—have been included as potential technologies.

Electric vehicles (EV) are equipped with all-electric drive and with systems powered by energy-optimized batteries charged primarily from grid electricity. EVs with several ranges—75 mile, 100 mile and 150 mile range—have been included as potential technologies.

e. Technologies Considered but Deemed ''Not Ready'' in the MYs 2017–2025 Timeframe

Fuel cell electric vehicles (FCEVs) utilize a full electric drive platform but consume electricity generated by an on-board fuel cell and hydrogen fuel. Fuel cells are electro-chemical devices that directly convert reactants (hydrogen and oxygen via air) into electricity, with the potential of achieving more than twice the efficiency of conventional internal combustion engines. High pressure gaseous hydrogen storage tanks are used by most automakers for FCEVs that are currently under development. The high pressure tanks are similar to those used for compressed gas storage in more than 10 million CNG vehicles worldwide, except that they are designed to operate at a higher pressure (350 bar or 700 bar vs. 250 bar for CNG). While we expect there will be some limited introduction of FCEVs into the market place in the time frame of this rule, we expect this introduction to be relatively small, and thus FCEVs are not considered in the modeling analysis conducted for this proposal.

There are a number of other technologies that the agencies have not considered in their analysis, but may be considered for the final rule. These include HCCI, ''multi-air'', and camless valve actuation, and other advanced engines currently under development.

2. How did the agencies determine the costs of each of these technologies?

As noted in the introduction to this section, most of the direct cost estimates for technologies carried over from the MYs 2012–2016 final rule and subsequently used in this proposal are fundamentally unchanged since the MYs 2012–2016 final rule analysis and/or the 2010 TAR. We say ''fundamentally'' unchanged since the basis of the direct manufacturing cost estimates have not changed; however, the costs have been updated to more recent dollars, the learning effects have resulted in further cost reductions for some technologies, the indirect costs are calculated using a modified methodology and the impact of long-term ICMs is now present during the rulemaking timeframe. Besides these changes, there are also some other notable changes to the costs used in previous analyses. We highlight these changes in Section II.D.2.a, below. We highlight the changes to the indirect cost methodology and adjustments to more recent dollars in Sections II.D.2.b and c. Lastly, we present some updated terminology used for our approach to estimating learning effects in an effort to eliminate confusion with our past terminology. This is discussed in Section II.D.2.d, below.

The agencies note that the technology costs included in this proposal take into account only those associated with the initial build of the vehicle. Although comments were received to the MYs 2012–2016 rulemaking that suggested there could be additional maintenance required with some new technologies (*e.g.,* turbocharging, hybrids, etc.), and that additional maintenance costs could occur as a result, the agencies believe that it is equally possible that maintenance costs could decrease for some vehicles, especially when considering full electric vehicles (which lack routine engine maintenance) or the replacement of automatic transmissions with simpler dual-clutch transmissions. The agencies request comment on the possible maintenance cost impacts associated with this proposal, reminding potential commenters that increased warranty costs are already considered as part of the ICMs.

a. Direct Manufacturing Costs (DMC)

For direct manufacturing costs (DMC) related to turbocharging, downsizing, gasoline direct injection, transmissions, as well as non-battery-related costs on hybrid, plug-in hybrid and electric vehicles, the agencies have relied on costs derived from teardown studies. For battery related DMC for HEVs, PHEVs and EVs, the agencies have relied on the BatPaC model developed by Argonne National Laboratory for the Department of Energy. For mass reduction DMC, the agencies have relied on several studies as described in detail in the draft Joint TSD. We discuss each of these briefly here and in more detail in the draft joint TSD. For the majority of the other technologies considered in this proposal and described above, the agencies have relied on the 2012–2016 final rule and sources described there for estimates of DMC.

i. Costs from Tear-down Studies

As a general matter, the agencies believe that the best method to derive technology cost estimates is to conduct studies involving tear-down and analysis of actual vehicle components. A ''tear-down'' involves breaking down a technology into its fundamental parts and manufacturing processes by completely disassembling actual vehicles and vehicle subsystems and precisely determining what is required for its production. The result of the tear-down is a ''bill of materials'' for each and every part of the relevant vehicle systems. This tear-down method of costing technologies is often used by manufacturers to benchmark their products against competitive products. Historically, vehicle and vehicle component tear-down has not been done on a large scale by researchers and regulators due to the expense required for such studies. While tear-down studies are highly accurate at costing technologies for the year in which the study is intended, their accuracy, like that of all cost projections, may diminish over time as costs are extrapolated further into the future because of uncertainties in predicting commodities (and raw material) prices, labor rates, and manufacturing practices. The projected costs may be higher or lower than predicted.

Over the past several years, EPA has contracted with FEV, Inc. and its subcontractor Munro & Associates, to conduct tear-down cost studies for a number of key technologies evaluated by the agencies in assessing the feasibility of future GHG and CAFE standards. The analysis methodology included procedures to scale the tear-down results to smaller and larger vehicles, and also to different technology configurations. FEV's methodology was documented in a report published as part of the MY 2012–2016 rulemaking, detailing the costing of the first tear-down conducted in this work (#1 in the below list).[136] This report was peer reviewed by experts in the industry and revised by FEV in response to the peer review

[136] U.S. EPA, ''Light-Duty Technology Cost Analysis Pilot Study,'' Contract No. EP–C–07–069, Work Assignment 1–3, December 2009, EPA–420–R–09–020, Docket EPA–HQ–OAR–2009–0472–11282.

comments.[137] Subsequent tear-down studies (#2–5 in the below list) were documented in follow-up FEV reports made available in the public docket for the MY 2012–2016 rulemaking.[138]

Since then, FEV's work under this contract work assignment has continued. Additional cost studies have been completed and are available for public review.[139] The most extensive study, performed after the MY 2012–2016 Final Rule, involved whole-vehicle tear-downs of a 2010 Ford Fusion powersplit hybrid and a conventional 2010 Ford Fusion. (The latter served as a baseline vehicle for comparison.) In addition to providing powersplit HEV costs, the results for individual components in these vehicles were subsequently used by FEV/Munro to cost another hybrid technology, the P2 hybrid, which employs similar hardware. This approach to costing P2 hybrids was undertaken because P2 HEVs were not yet in volume production at the time of hardware procurement for tear-down. Finally, an automotive lithium-polymer battery was torn down and costed to provide supplemental battery costing information to that associated with the NiMH battery in the Fusion. This HEV cost work, including the extension of results to P2 HEVs, has been extensively documented in a new report prepared by FEV.[140] Because of the complexity and comprehensive scope of this HEV analysis, EPA commissioned a separate peer review focused exclusively on it. Reviewer comments generally supported FEV's methodology and results, while including a number of suggestions for improvement many of which were subsequently incorporated into FEV's analysis and final report. The peer review comments and responses are available in the rulemaking docket.[141] [142]

Over the course of this work assignment, teardown-based studies have been performed thus far on the technologies listed below. These completed studies provide a thorough evaluation of the new technologies' costs relative to their baseline (or replaced) technologies.

1. Stoichiometric gasoline direct injection (SGDI) and turbocharging with engine downsizing (T–DS) on a DOHC (dual overhead cam) I4 engine, replacing a conventional DOHC I4 engine.
2. SGDI and T–DS on a SOHC (single overhead cam) on a V6 engine, replacing a conventional 3-valve/cylinder SOHC V8 engine.
3. SGDI and T–DS on a DOHC I4 engine, replacing a DOHC V6 engine.
4. 6-speed automatic transmission (AT), replacing a 5-speed AT.
5. 6-speed wet dual clutch transmission (DCT) replacing a 6-speed AT.
6. 8-speed AT replacing a 6-speed AT.
7. 8-speed DCT replacing a 6-speed DCT.
8. Power-split hybrid (Ford Fusion with I4 engine) compared to a conventional vehicle (Ford Fusion with V6). The results from this tear-down were extended to address P2 hybrids. In addition, costs from individual components in this tear-down study were used by the agencies in developing cost estimates for PHEVs and EVs.
9. Mild hybrid with stop-start technology (Saturn Vue with I4 engine), replacing a conventional I4 engine. (Although results from this cost study are included in the rulemaking docket, they were not used by the agencies in this rulemaking's technical analyses.)
10. Fiat Multi-Air engine technology. (Although results from this cost study are included in the rulemaking docket, they were not used by the agencies in this rulemaking's technical analyses.)

Items 6 through 10 in the list above are new since the 2012–2016 final rule.

In addition, FEV and EPA extrapolated the engine downsizing costs for the following scenarios that were based on the above study cases:

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
2. Downsizing a DOHC V8 to a DOHC V6.
3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
4. Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

The agencies have relied on the findings of FEV for estimating the cost of the technologies covered by the tear-down studies.

ii. Costs of HEV, EV & PHEV

The agencies have also reevaluated the costs for HEVs, PHEVs, and EVs since both the 2012–2016 final rule and the 2010 TAR. First, electrified vehicle technologies are developing rapidly and the agencies sought to capture results from the most recent analysis. Second, the 2012–2016 rule employed a single $/kWhr estimate and did not consider the specific vehicle and technology application for the battery when we estimated the cost of the battery. Specifically, batteries used in HEVs (high power density applications) versus EVs (high energy density applications) need to be considered appropriately to reflect the design differences, the chemical material usage differences and differences in $/kWhr as the power to energy ratio of the battery changes for different applications.

To address these issues for this proposal, the agencies have done two things. First, EPA has developed a spreadsheet tool that was used to size the motor and battery based on the different road load of various vehicle classes. Second, the agencies have used a battery cost model developed by Argonne National Laboratory (ANL) for the Vehicle Technologies Program of the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy.[143] The model developed by ANL allows users to estimate unique battery pack costs using user customized input sets for different hybridization applications, such as strong hybrid, PHEV and EV. The DOE has established long term industry goals and targets for advanced battery systems as it does for many energy efficient technologies. ANL was funded by DOE to provide an independent assessment of Li-ion battery costs because of ANL's expertise in the field as one of the primary DOE National Laboratories responsible for basic and applied battery energy storage technologies for future HEV, PHEV and EV applications. Since publication of the 2010 TAR, ANL's battery cost model has been peer-reviewed and ANL has updated the model and documentation to incorporate suggestions from peer-reviewers, such as including a battery management system, a battery disconnect unit, a thermal management system, etc.[144] In this proposal, NHTSA and EPA have used the recently revised version of this updated model.

The agencies are using the ANL model as the basis for estimating large-

[137] FEV pilot study response to peer review document November 6, 2009, is at EPA–HQ–OAR–2009–0472–11285.

[138] U.S. EPA, ''Light-duty Technology Cost Analysis—Report on Additional Case Studies,'' EPA–HQ–OAR–2009–0472–11604.

[139] FEV, Inc., ''Light-Duty Technology Cost Analysis, Report on Additional Transmission, Mild Hybrid, and Valvetrain Technology Case Studies'', November 2011.

[140] FEV, Inc., ''Light-Duty Technology Cost Analysis, Power-Split and P2 HEV Case Studies'', EPA–420–R–11–015, November 2011.

[141] ICF, ''Peer Review of FEV Inc. Report Light Duty Technology Cost Analysis, Power-Split and P2 Hybrid Electric Vehicle Case Studies'', EPA–420–R–11–016, November 2011.

[142] FEV and EPA, ''FEV Inc. Report 'Light Duty Technology Cost Analysis, Power-Split and P2 Hybrid Electric Vehicle Case Studies', Peer Review Report—Response to Comments Document'', EPA–420–R–11–017, November 2011.

[143] ANL BatPac model Docket number EPA–HQ–OAR–2010–0799.

[144] Nelson, P.A., Santinit, D.J., Barnes, J. ''Factors Determining the Manufacturing Costs of Lithium-Ion Batteries for PHEVs,'' 24th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition EVS–24, Stavenger, Norway, May 13–16, 2009 (*www.evs24.org*).

format lithium-ion batteries for this assessment for the following reasons. The model was developed by scientists at ANL who have significant experience in this area. The model uses a bill of materials methodology for developing cost estimates. The ANL model appropriately considers the vehicle application's power and energy requirements, which are two of the fundamental parameters when designing a lithium-ion battery for an HEV, PHEV, or EV. The ANL model can estimate production costs based on user defined inputs for a range of production volumes. The ANL model's cost estimates, while generally lower than the estimates we received from the OEMs, are consistent with some of the supplier cost estimates that EPA received from large-format lithium-ion battery pack manufacturers. This includes data which was received from on-site visits done by the EPA in the 2008–2011 time frame. Finally, the ANL model has been described and presented in the public domain and does not rely upon confidential business information (which could not be reviewed by the public).

The potential for future reductions in battery cost and improvements in battery performance relative to current batteries will play a major role in determining the overall cost and performance of future PHEVs and EVs. The U.S. Department of Energy manages major battery-related R&D programs and partnerships, and has done so for many years, including the ANL model utilized in this report. DOE has reviewed the battery cost projections underlying this proposal and supports the use of the ANL model for the purposes of this rulemaking.

We have also estimated cost associated with in-home chargers and installation of in-home chargers expected to be necessary for PHEVs and EVs. Charger costs are covered in more detail in chapter 3 of the draft Joint TSD.

iii. Mass Reduction Costs

The agencies have revised the costs for mass reduction from the MYs 2012–2016 rule and the 2010 Technical Assessment Report. For this proposal, the agencies are relying on a wide assortment of sources from the literature as well as data provided from a number of OEMs. Based on this review, the agencies have estimated a new cost curve such that the costs increase as the levels of mass reduction increase. For the final rule the agencies will consider any new studies that become available, including two studies that the agencies are sponsoring and expect will be completed in time to inform the final rule. These studies are discussed in TSD chapter 3.

b. Indirect Costs (IC)

i. Markup Factors to Estimate Indirect Costs

For this analysis, indirect costs are estimated by applying indirect cost multipliers (ICM) to direct cost estimates. ICMs were derived by EPA as a basis for estimating the impact on indirect costs of individual vehicle technology changes that would result from regulatory actions. Separate ICMs were derived for low, medium, and high complexity technologies, thus enabling estimates of indirect costs that reflect the variation in research, overhead, and other indirect costs that can occur among different technologies. ICMs were also applied in the MYs 2012–2016 rulemaking.

Prior to developing the ICM methodology,[145] EPA and NHTSA both applied a retail price equivalent (RPE) factor to estimate indirect costs. RPEs are estimated by dividing the total revenue of a manufacturer by the direct manufacturing costs. As such, it includes all forms of indirect costs for a manufacturer and assumes that the ratio applies equally for all technologies. ICMs are based on RPE estimates that are then modified to reflect only those elements of indirect costs that would be expected to change in response to a regulatory-induced technology change. For example, warranty costs would be reflected in both RPE and ICM estimates, while marketing costs might only be reflected in an RPE estimate but not an ICM estimate for a particular technology, if the new regulatory-induced technology change is not one expected to be marketed to consumers. Because ICMs calculated by EPA are for individual technologies, many of which are small in scale, they often reflect a subset of RPE costs; as a result, for low complexity technologies, the RPE is typically higher than the ICM. This is not always the case, as ICM estimates for particularly complex technologies, specifically hybrid technologies (for near term ICMs), and plug-in hybrid battery and full electric vehicle technologies (for near term and long term ICMs), reflect higher than average indirect costs, with the resulting ICMs for those technologies equaling or exceeding the averaged RPE for the industry.

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this proposed action group all technologies into four broad categories and treat them as if individual technologies within each of the categories (''low'', ''medium'', ''high1'' and ''high2'' complexity) will have the same ratio of indirect costs to direct costs. This simplification means it is likely that the direct cost for some technologies within a category will be higher and some lower than the estimate for the category in general. More importantly, the ICM estimates have not been validated through a direct accounting of actual indirect costs for individual technologies. Rather, the ICM estimates were developed using adjustment factors developed in two separate occasions: the first, a consensus process, was reported in the RTI report; the second, a modified Delphi method, was conducted separately and reported in an EPA memo.[146] Both these panels were composed of EPA staff members with previous background in the automobile industry; the memberships of the two panels overlapped but were not identical.[147] The panels evaluated each element of the industry's RPE estimates and estimated the degree to which those elements would be expected to change in proportion to changes in direct manufacturing costs. The method and estimates in the RTI report were peer reviewed by three industry experts and subsequently by reviewers for the International Journal of Production Economics. RPEs themselves are inherently difficult to estimate because the accounting statements of manufacturers do not neatly categorize all cost elements as either direct or indirect costs. Hence, each researcher developing an RPE estimate must apply a certain amount of judgment to the allocation of the costs. Since empirical estimates of ICMs are ultimately derived from the same data used to measure RPEs, this affects both measures. However, the value of RPE has not been measured for specific technologies, or for groups of specific technologies. Thus applying a single

[145] The ICM methodology was developed by RTI International, under contract to EPA. The results of the RTI report were published in Alex Rogozhin, Michael Gallaher, Gloria Helfand, and Walter McManus, ''Using Indirect Cost Multipliers to Estimate the Total Cost of Adding New Technology in the Automobile Industry.'' International Journal of Production Economics 124 (2010): 360–368.

[146] Helfand, Gloria, and Sherwood, Todd. ''Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies.'' Memorandum, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, August 2009.

[147] NHTSA staff participated in the development of the process for the second, modified Delphi panel, and reviewed the results as they were developed, but did not serve on the panel.

average RPE to any given technology by definition overstates costs for very simple technologies, or understates them for advanced technologies.

In every recent GHG and fuel economy rulemaking proposal, we have requested comment on our ICM factors and whether it is most appropriate to use ICMs or RPEs. We have generally received little to no comment on the issue specifically, other than basic comments that the ICM values are too low. In addition, in the June 2010 NAS report, NAS noted that the under the initial ICMs, no technology would be assumed to have indirect costs as high as the average RPE. NRC found that ''RPE factors certainly do vary depending on the complexity of the task of integrating a component into a vehicle system, the extent of the required changes to other components, the novelty of the technology, and other factors. However, until empirical data derived by means of rigorous estimation methods are available, the committee prefers to use average markup factors.'' [148] The committee also stated that ''The EPA (Rogozhin et al., 2009), however, has taken the first steps in attempting to analyze this problem in a way that could lead to a practical method of estimating technology-specific markup factors'' where ''this problem'' spoke to the issue of estimating technology-specific markup factors and indirect cost multipliers.[149]

The agencies note that, since the committee completed their work, EPA has published its work in the Journal of Production Economics [150] and has also published a memorandum furthering the development of ICMs,[151] neither of which the committee had at their disposal. Further, having published two final rulemakings—the 2012–2016 light-duty rule (see 75 FR 25324) and the more recent heavy-duty GHG rule (see 76 FR 57106)—as well as the 2010 TAR where ICMs served as the basis for all or most of the indirect costs, EPA believes that ICMs are indeed fully developed for regulatory purposes. As thinking has matured, we have adjusted our ICM factors such that they are slightly higher and, importantly, we have changed the way in which the factors are applied.

The first change—increased ICM factors—has been done as a result of further thought among EPA and NHTSA that the ICM factors presented in the original RTI report for low and medium complexity technologies should no longer be used and that we should rely solely on the modified-Delphi values for these complexity levels. For that reason, we have eliminated the averaging of original RTI values with modified-Delphi values and instead are relying solely on the modified-Delphi values for low and medium complexity technologies. The second change—the way the factors are applied—results in the warranty portion of the indirect costs being applied as a multiplicative factor (thereby decreasing going forward as direct manufacturing costs decrease due to learning), and the remainder of the indirect costs being applied as an additive factor (thereby remaining constant year-over-year and not being reduced due to learning). This second change has a comparatively large impact on the resultant technology costs and, we believe, more appropriately estimates costs over time. In addition to these changes, a secondary-level change was also made as part of this ICM recalculation to ICMs. That change was to revise upward the RPE level reported in the original RTI report from an original value of 1.46 to 1.5, to reflect the long term average RPE. The original RTI study was based on 2008 data. However, an analysis of historical RPE data indicates that, although there is year to year variation, the average RPE has remained roughly constant at 1.5. ICMs will be applied to future years' data and, therefore, NHTSA and EPA staffs believe that it would be appropriate to base ICMs on the historical average rather than a single year's result. Therefore, ICMs have been adjusted to reflect this average level. These changes to the ICMs and the methodology are described in greater detail in Chapter 3 of the draft Joint TSD.

ii. Stranded Capital

Because the production of automotive components is capital-intensive, it is possible for substantial capital investments in manufacturing equipment and facilities to become ''stranded'' (where their value is lost, or diminished). This would occur when the capital is rendered useless (or less useful) by some factor that forces a major change in vehicle design, plant operations, or manufacturer's product mix, such as a shift in consumer demand for certain vehicle types. It can also be caused by new standards that phase-in at a rate too rapid to accommodate planned replacement or redisposition of existing capital to other activities. The lost value of capital equipment is then amortized in some way over production of the new technology components.

It is difficult to quantify accurately any capital stranding associated with new technology phase-ins under the proposed standards because of the iterative dynamic involved—that is, the new technology phase-in rate strongly affects the potential for additional cost due to stranded capital, but that additional cost in turn affects the degree and rate of phase-in for other individual competing technologies. In addition, such an analysis is very company-, factory-, and manufacturing process-specific, particularly in regard to finding alternative uses for equipment and facilities. Nevertheless, in order to account for the possibility of stranded capital costs, the agencies asked FEV to perform a separate bounding analysis of potential stranded capital costs associated with rapid phase-in of technologies due to new standards, using data from FEV's primary teardown-based cost analyses.[152]

The assumptions made in FEV's stranded capital analysis with potential for major impacts on results are:

All manufacturing equipment was bought brand new when the old technology started production (no carryover of equipment used to make the previous components that the old technology itself replaced).

10-year normal production runs: Manufacturing equipment used to make old technology components is straight-line depreciated over a 10-year life.

Factory managers do not optimize capital equipment phase-outs (that is, they are assumed to routinely repair and replace equipment without regard to whether or not it will soon be scrapped due to adoption of new vehicle technology).

Estimated stranded capital is amortized over 5 years of annual production at 450,000 units (of the new technology components). This annual production is identical to that assumed in FEV's primary teardown-based cost analyses. The 5-year recovery period is chosen to help ensure a conservative analysis; the actual recovery would of course vary greatly with market conditions.

[148] NRC, Finding 3–2 at page 3–23.

[149] NRC at page 3–19.

[150] Alex Rogozhin, Michael Gallaher, Gloria Helfand, and Walter McManus, ''Using Indirect Cost Multipliers to Estimate the Total Cost of Adding New Technology in the Automobile Industry.'' International Journal of Production Economics 124 (2010): 360–368.

[151] Helfand, Gloria, and Sherwood, Todd. ''Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies.'' Memorandum, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, August 2009.

[152] FEV, Inc., ''Potential Stranded Capital Analysis on EPA Light-Duty Technology Cost Analysis'', Contract No. EP–C–07–069 Work Assignment 3–3. November 2011.

The stranded capital analysis was performed for three transmission technology scenarios, two engine technology scenarios, and one hybrid technology scenario. The methodology used by EPA in applying the results to the technology costs is described in Chapter 3.8.7 and Chapter 5.1 of EPA's draft RIA. The methodology used by NHTSA in applying the results to the technology costs is described in NHTSA's preliminary RIA section V.

c. Cost Adjustment to 2009 Dollars

This simple change is to update any costs presented in earlier analyses to 2009 dollars using the GDP price deflator as reported by the Bureau of Economic Analysis on January 27, 2011. The factors used to update costs from 2007 and 2008 dollars to 2009 dollars are shown below. For the final rule, we are considering moving to 2010 dollars but, for this analysis, given the timing of conducting modeling runs and developing inputs to those runs, the factors for converting to 2010 dollars were not yet available.

Table II-7 GDP Price Deflators Used in this Proposal

	2007	2008	2009
Price Index for Gross Domestic Product	106.3	108.6	109.6
Factor applied to convert to 2009 dollars	1.031	1.009	1.00

Source: Bureau of Economic Analysis, Table 1.1.4. Price Indexes for Gross Domestic Product, downloaded 1/27/2011, last revised 12/22/2010.

d. Cost Effects Due to Learning

For many of the technologies considered in this rulemaking, the agencies expect that the industry should be able to realize reductions in their costs over time as a result of "learning effects," that is, the fact that as manufacturers gain experience in production, they are able to reduce the cost of production in a variety of ways. The agencies continue to apply learning effects in the same way as we did in both the MYs 2012–2016 final rule and in the 2010 TAR. However, we have employed some new terminology in an effort to eliminate some confusion that existed with our old terminology. This new terminology was described in the recent heavy-duty GHG final rule (see 76 FR 57320). Our old terminology suggested we were accounting for two completely different learning effects—one based on volume production and the other based on time. This was not the case since, in fact, we were actually relying on just one learning phenomenon, that being the learning-by-doing phenomenon that results from cumulative production volumes.

As a result, the agencies have also considered the impacts of manufacturer learning on the technology cost estimates by reflecting the phenomenon of volume-based learning curve cost reductions in our modeling using two algorithms depending on where in the learning cycle (*i.e.,* on what portion of the learning curve) we consider a technology to be—"steep" portion of the curve for newer technologies and "flat" portion of the curve for more mature technologies. The observed phenomenon in the economic literature which supports manufacturer learning cost reductions are based on reductions in costs as production volumes increase with the highest absolute cost reduction occurring with the first doubling of production. The agencies use the terminology "steep" and "flat" portion of the curve to distinguish among newer technologies and more mature technologies, respectively, and how learning cost reductions are applied in cost analyses.

Learning impacts have been considered on most but not all of the technologies expected to be used because some of the expected technologies are already used rather widely in the industry and, presumably, quantifiable learning impacts have already occurred. The agencies have applied the steep learning algorithm for only a handful of technologies considered to be new or emerging technologies such as PHEV and EV batteries which are experiencing heavy development and, presumably, rapid cost declines in coming years. For most technologies, the agencies have considered them to be more established and, hence, the agencies have applied the lower flat learning algorithm. For more discussion of the learning approach and the technologies to which each type of learning has been applied the reader is directed to Chapter 3 of the draft Joint TSD. Note that, since the agencies had to project how learning will occur with new technologies over a long period of time, we request comments on the assumptions of learning costs and methodology. In particular, we are interested in input on the assumptions for advanced 27-bar BMEP cooled exhaust gas recirculation (EGR) engines, which are currently still in the experimental stage and not expected to be available in volume production until 2017. For our analysis, we have based estimates of the costs of this engine on current (or soon to be current) production technologies (*e.g.,* gasoline direct injection fuel systems, engine downsizing, cooled EGR, 18-bar BMEP capable turbochargers), and assumed that, since learning (and the associated cost reductions) begins in 2012 for them that it also does for the similar technologies used in 27-bar BMEP engines. We seek comment on the appropriateness of this assumption.[153]

3. How did the agencies determine the effectiveness of each of these technologies?

In 2007 EPA conducted a detailed vehicle simulation project to quantify the effectiveness of a multitude of technologies for the MYs 2012–2016

[153] EPA notes that our modeling projections for the proposed CO_2 standards show a technology penetration rate of 2% in the 2021MY and 5% in the 2025MY for 27-bar BMEP engines and, thus, our cost estimates are not heavily reliant on this technology.

rule (as well as the 2010 NOI). This technical work was conducted by the global engineering consulting firm, Ricardo, Inc. and was peer reviewed and then published in 2008. For this current rule, EPA has conducted another peer reviewed study with Ricardo to broaden the scope of the original project in order to expand the range of vehicle classes and technologies considered, consistent with a longer-term outlook through model years MYs 2017–2025. The extent of the project was vast, including hundreds of thousands of vehicle simulation runs. The results were, in turn, employed to calibrate and update EPA's lumped parameter model, which is used to quantify the synergies and dis-synergies associated with combining technologies together for the purposes of generating inputs for the agencies respective OMEGA and CAFE modeling.

Additionally, there were a number of technologies that Ricardo did not model explicitly. For these, the agencies relied on a variety of sources in the literature. A few of the values are identical to those presented in the MYs 2012–2016 final rule, while others were updated based on the newer version of the lumped parameter model. More details on the Ricardo simulation, lumped parameter model, as well as the effectiveness for supplemental technologies are described in Chapter 3 of the draft Joint TSD.

The agencies note that the effectiveness values estimated for the technologies considered in the modeling analyses may represent average values, and do not reflect the virtually unlimited spectrum of possible values that could result from adding the technology to different vehicles. For example, while the agencies have estimated an effectiveness of 0.6 to 0.8 percent, depending on the vehicle subclass for low friction lubricants, each vehicle could have a unique effectiveness estimate depending on the baseline vehicle's oil viscosity rating. Similarly, the reduction in rolling resistance (and thus the improvement in fuel economy and the reduction in CO_2 emissions) due to the application of low rolling resistance tires depends not only on the unique characteristics of the tires originally on the vehicle, but on the unique characteristics of the tires being applied, characteristics which must be balanced between fuel efficiency, safety, and performance. Aerodynamic drag reduction is much the same—it can improve fuel economy and reduce CO_2 emissions, but it is also highly dependent on vehicle-specific functional objectives. For purposes of the proposal, NHTSA and EPA believe that employing average values for technology effectiveness estimates, as adjusted depending on vehicle subclass, is an appropriate way of recognizing the potential variation in the specific benefits that individual manufacturers (and individual vehicles) might obtain from adding a fuel-saving technology.

E. Joint Economic and Other Assumptions

The agencies' analysis of CAFE and GHG standards for the model years covered by this proposed rulemaking rely on a range of forecast information, estimates of economic variables, and input parameters. This section briefly describes the agencies' proposed estimates of each of these values. These values play a significant role in assessing the benefits of both CAFE and GHG standards.

In reviewing these variables and the agencies' estimates of their values for purposes of this NPRM, NHTSA and EPA reconsidered comments that the agencies previously received on both the Interim Joint TAR and during the MYs 2012–2016 light duty vehicle rulemaking and also reviewed newly available literature. As a consequence, for today's proposal, the agencies are proposing to update some economic assumptions and parameter estimates, while retaining a majority of values consistent with the Interim Joint TAR and the MYs 2012–2016 final rule. To review the parameters and assumptions the agencies used in the 2012–2016 final rule, please refer to 75 FR 25378 and Chapter 4 of the Joint Technical Support Document that accompanied the final rule.[154] The proposed values summarized below are discussed in greater detail in Chapter 4 of the joint TSD that accompanies this proposal and elsewhere in the preamble and respective RIAs. The agencies seek comment on all of the assumptions discussed below.

Costs of fuel economy-improving technologies—These inputs are discussed in summary form above and in more detail in the agencies' respective sections of this preamble, in Chapter 3 of the draft joint TSD, and in the agencies' respective RIAs. The technology direct manufacturing cost estimates used in this analysis are intended to represent manufacturers' direct costs for high-volume production of vehicles with these technologies in the year for which we state the cost is considered "valid." Technology direct manufacturing cost estimates are fundamentally unchanged from those employed by the agencies in the 2012–2016 final rule, the heavy-duty truck rule (to the extent relevant), and TAR for most technologies, although revised costs are used for batteries, mass reduction, transmissions, and a few other technologies. Indirect costs are accounted for by applying near-term indirect cost multipliers ranging from 1.24 to 1.77 to the estimates of vehicle manufacturers' direct costs for producing or acquiring each technology, depending on the complexity of the technology and the time frame over which costs are estimated. These values are reduced to 1.19 to 1.50 over the long run as some aspects of indirect costs decline. Indirect cost markup factors have been revised from previous rulemakings and the Interim Joint TAR to reflect the agencies current thinking regarding a number of issues. These changes are discussed in detail in Section II.D.2 of this preamble and in Chapter 3 of the draft joint TSD. Details of the agencies' technology cost assumptions and how they were derived can be found in Chapter 3 of the draft joint TSD.

Potential opportunity costs of improved fuel economy—This issue addresses the possibility that achieving the fuel economy improvements required by alternative CAFE or GHG standards would require manufacturers to compromise the performance, carrying capacity, safety, or comfort of their vehicle models. If it did so, the resulting sacrifice in the value of these attributes to consumers would represent an additional cost of achieving the required improvements, and thus of manufacturers' compliance with stricter standards. Currently the agencies project that these vehicle attributes will not change as a result of this rule. Section II.C above and Chapter 2 of the draft joint TSD describes how the agency carefully selected an attribute-based standard to minimize manufacturers' incentive to reduce vehicle capabilities. While manufacturers may choose to do this for other reasons, the agencies continue to believe that the rule itself will not result in such changes. Additionally, EPA and NHTSA have sought to include the cost of maintaining these attributes as part of the cost estimates for technologies that are included in the cost analysis for the proposal. For example, downsized engines are assumed to be turbocharged, so that they provide the same performance and utility even though they are smaller.[155] Nonetheless, it is

[154] See *http://www.epa.gov/otaq/climate/regulations/420r10901.pdf.*

[155] The agencies do not believe that adding fuel-saving technology should preclude future improvements in performance, safety, or other attributes, though it is possible that the costs of

possible that in some cases, the technology cost estimates may not include adequate allowance for the necessary efforts by manufacturers to maintain vehicle acceleration performance, payload, or utility while improving fuel economy and reducing GHG emissions. As described in Section III.D.3 and Section IV.G, there are two possible exceptions in cases where some vehicle types are converted to hybrid or full electric vehicles (EVs), but, in such cases, we believe that sufficient options would exist for consumers concerned about the possible loss of utility (*e.g.,* they would purchase the non-hybridized version of the vehicle or not buy an EV) that welfare loss should not necessarily be assumed. Although consumer vehicle demand models can measure these effects, past analyses using such models have not produced consistent estimates of buyers' willingness-to-pay for higher fuel economy, and it is difficult to decide whether one data source, model specification, or estimation procedure is clearly preferred over another. Thus, the agencies seek comment on how to estimate explicitly the changes in vehicle buyers' choices and welfare from the combination of higher prices for new vehicle models, increases in their fuel economy, and any accompanying changes in vehicle attributes such as performance, passenger- and cargo-carrying capacity, or other dimensions of utility.

The on-road fuel economy "gap"—Actual fuel economy levels achieved by light-duty vehicles in on-road driving fall somewhat short of their levels measured under the laboratory test conditions used by EPA to establish compliance with the proposed CAFE and GHG standards. The modeling approach in this proposal follows the 2012–2016 final rule and the Interim Joint TAR. In calculating benefits of the program, the agencies estimate that actual on-road fuel economy attained by light-duty vehicles that operate on liquid fuels will be 20 percent lower than published fuel economy ratings for vehicles that operate on liquid fuels. For example, if the measured CAFE fuel economy value of a light truck is 20 mpg, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80).[156] Based on manufacturer confidential business information, as well as data derived from the 2006 EPA fuel economy label rule, the agencies use a 30 percent gap for consumption of wall electricity for electric vehicles and plug-in hybrid electric vehicles.[157]

Fuel prices and the value of saving fuel—Projected future fuel prices are a critical input into the preliminary economic analysis of alternative standards, because they determine the value of fuel savings both to new vehicle buyers and to society, and fuel savings account for the majority of the proposed rule's estimated benefits. For this proposed rule, the agencies are using the most recent fuel price projections from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2011 reference case forecast. The forecasts of fuel prices reported in EIA's AEO 2011 extend through 2035. Fuel prices beyond the time frame of AEO's forecast were estimated using an average growth rate for the years 2017–2035 to each year after 2035. This is the same methodology used by the agencies in the 2012–2016 rulemaking, in the heavy duty truck and engine rule (76 FR 57106), and in the Interim Joint TAR. For example, these forecasts of gasoline fuel prices in 2009$ include $3.25 per gallon in 2017, $3.39 in 2021 and $3.71 in 2035. Extrapolating as described above, retail gasoline prices reach $4.16 per gallon in 2050 (measured in constant 2009 dollars). As discussed in Chapter 4 of the draft Joint TSD, while the agencies believe that EIA's AEO reference case generally represents a reasonable forecast of future fuel prices for purposes of use in our analysis of the benefits of this rule, we recognize that there is a great deal of uncertainty in any such forecast that could affect our estimates. The agencies request comment on how best to account for uncertainty in future fuel prices.

Consumer valuation of fuel economy and payback period—In estimating the value of fuel economy improvements to potential vehicle buyers that would result from alternative CAFE and GHG standards, the agencies assume that buyers value the resulting fuel savings over only part of the expected lifetimes of the vehicles they purchase. Specifically, we assume that buyers value fuel savings over the first five years of a new vehicle's lifetime, and that buyers discount the value of these future fuel savings. The five-year figure represents the current average term of consumer loans to finance the purchase of new vehicles.

Vehicle sales assumptions—The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number that are expected to be produced and sold. The agencies relied on the AEO 2011 Reference Case for forecasts of total vehicle sales, while the baseline market forecast developed by the agencies (discussed in Section II.B and in Chapter 1 of the TSD) divided total projected sales into sales of cars and light trucks.

Vehicle lifetimes and survival rates—As in the 2012–2016 final rule and Interim Joint TAR, we apply updated values of age-specific survival rates for cars and light trucks to adjusted forecasts of passenger car and light truck sales to determine the number of these vehicles expected to remain in use during each year of their lifetimes. These values remain unchanged from prior analyses.

Vehicle miles traveled—We calculated the total number of miles that cars and light trucks produced in each model year will be driven during each year of their lifetimes using estimates of annual vehicle use by age tabulated from the Federal Highway Administration's 2001 National Household Travel Survey (NHTS),[158] adjusted to account for the effects on vehicle use of subsequent increases in fuel prices. In order to insure that the resulting mileage schedules imply reasonable estimates of future growth in *total* car and light truck use, we calculated the rate of future growth in annual mileage at each age that would be necessary for total car and light truck travel to increase at the rates forecast in the AEO 2011 Reference Case. The growth rate in average annual car and light truck use produced by this calculation is approximately 1 percent per year through 2030 and 0.5 percent thereafter. We applied these growth rates applied to the mileage figures derived from the 2001 NHTS to estimate annual mileage by vehicle age during each year of the expected lifetimes of MY 2017–2025 vehicles. A similar approach to estimating future vehicle use was used in the 2012–2016 final rule and Interim Joint TAR, but the

these additions may be affected by the presence of fuel-saving technology.

[156] U.S. Environmental Protection Agency, Final Technical Support Document, Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates, EPA420–R–06–017, December 2006.

[157] See 71 FR at 77887, and U.S. Environmental Protection Agency, Final Technical Support Document, Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates, EPA420–R–06–017, December 2006 for general background on the analysis. See also EPA's Response to Comments (EPA–420–R–11–005) to the 2011 labeling rule, page 189, first paragraph, specifically the discussion of the derived five cycle equation and the non-linear adjustment with increasing MPG.

[158] For a description of the Survey, see *http://www.bts.gov/programs/national_household_travel_survey/* (last accessed Sept. 9, 2011).

future growth rates in average vehicle use have been revised for this proposal.

Accounting for the rebound effect of higher fuel economy—The rebound effect refers to the increase in vehicle use that results if an increase in fuel efficiency lowers the cost of driving. For purposes of this NPRM, the agencies elected to continue to use a 10 percent rebound effect in their analyses of fuel savings and other benefits from higher standards, consistent with the 2012–2016 light-duty vehicle rulemaking and the Interim Joint TAR. That is, we assume a 10 percent decrease in fuel cost per mile resulting from our proposed standards would result in a 1 percent increase in the annual number of miles driven at each age over a vehicle's lifetime. In Chapter 4 of the joint TSD, we provide a detailed explanation of the basis for our rebound estimate, including a summary of new literature published since the 2012–2016 rulemaking that lends further support to the 10 percent rebound estimate. We also refer the reader to Chapters X and XII of NHTSA's PRIA and Chapter 4 of the EPA DRIA that accompanies this preamble for sensitivity and uncertainty analyses of alternative rebound assumptions.

Benefits from increased vehicle use—The increase in vehicle use from the rebound effect provides additional benefits to drivers, who may make more frequent trips or travel farther to reach more desirable destinations. This additional travel provides benefits to drivers and their passengers by improving their access to social and economic opportunities away from home. The analysis estimates the economic benefits from increased rebound-effect driving as the sum of the fuel costs they incur in that additional travel plus the consumer surplus drivers receive from the improved accessibility their travel provides. As in the 2012–2016 final rule we estimate the economic value of this consumer surplus using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven.

Added costs from congestion, accidents, and noise—Although it provides benefits to drivers as described above, increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed over the day and where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses. At the same time, this travel also increases costs associated with traffic accidents, and increased traffic noise. The agencies rely on estimates of congestion, accident, and noise costs caused by automobiles and light trucks developed by the Federal Highway Administration to estimate these increased external costs caused by added driving.[159] This method is consistent with the 2012–2016 final rule.

Petroleum consumption and import externalities—U.S. consumption of imported petroleum products also impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) higher prices for petroleum products resulting from the effect of increased U.S. demand for imported oil on the world oil price (''monopsony costs''); (2) the expected costs associated with the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion the U.S. economy against the effects of oil supply disruptions.[160] Although the reduction in the global price of petroleum and refined products due to decreased demand for fuel in the U.S. resulting from this rule represents a benefit to the U.S. economy, it simultaneously represents an economic loss to other countries that produce and sell oil or petroleum products to the U.S. Recognizing the redistributive nature of this ''monopsony effect'' when viewed from a global perspective (which is consistent with the agencies' use of a global estimate for the social cost of carbon to value reductions in CO_2 emissions, the energy security benefits estimated to result from this program exclude the value of this monopsony effect. In contrast, the macroeconomic disruption and adjustment costs that arise from sudden reductions in the supply of imported oil to the U.S. do not have offsetting impacts outside of the U.S., so the estimated reduction in their expected value stemming from reduced U.S. petroleum imports is included in the energy security benefits estimated for this program. U.S. military costs are excluded from the analysis because their attribution to particular missions or activities is difficult. Also, historical variation in U.S. military costs have not been associated with changes in U.S. petroleum imports, although we recognize that more broadly, there may be significant (if unquantifiable) benefits in improving national security by reducing oil imports. Similarly, since the size or other factors affecting the cost of maintaining the SPR historically have not varied in response to changes in U.S. oil import levels, changes in the costs of the SPR are excluded from the estimates of the energy security benefits of the program. To summarize, the agencies have included only the macroeconomic disruption and adjustment costs portion of the energy security benefits to estimate the monetary value of the total energy security benefits of this program. Based on a recent update of an earlier peer-reviewed Oak Ridge National Laboratory study that was used in support of the both the 2012–2016 light duty vehicle and the 2014–2018 medium- and heavy-duty vehicle rulemaking, we estimate that each gallon of fuel saved will reduce the expected macroeconomic disruption and adjustment costs of sudden reductions in the supply of imported oil to the U.S. economy by $0.185 (2009$) in 2025. Each gallon of fuel saved as a consequence of higher standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.[161] The energy security analysis conducted for this proposal also estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel.[162] [163] The energy security

[159] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study; http://www.fhwa.dot.gov/policy/hcas/final/index.htm* (last accessed Sept. 9, 2011).

[160] See, *e.g.,* Bohi, Douglas R. and W. David Montgomery (1982). Oil Prices, Energy Security, and Import Policy Washington, DC: Resources for the Future, Johns Hopkins University Press; Bohi, D. R., and M. A. Toman (1993). ''Energy and Security: Externalities and Policies,'' Energy Policy 21:1093–1109; and Toman, M. A. (1993). ''The Economics of Energy Security: Theory, Evidence, Policy,'' in A. V. Kneese and J. L. Sweeney, eds. (1993). Handbook of Natural Resource and Energy Economics, Vol. III. Amsterdam: North-Holland, pp. 1167–1218.

[161] Each gallon of fuel saved is assumed to reduce imports of refined fuel by 0.5 gallons, and the volume of fuel refined domestically by 0.5 gallons. Domestic fuel refining is assumed to utilize 90 percent imported crude petroleum and 10 percent domestically-produced crude petroleum as feedstocks. Together, these assumptions imply that each gallon of fuel saved will reduce imports of refined fuel and crude petroleum by 0.50 gallons + 0.50 gallons*90 percent = 0.50 gallons + 0.45 gallons = 0.95 gallons.

[162] Leiby, Paul. Oak Ridge National Laboratory. ''Approach to Estimating the Oil Import Security

methodology used in this proposal is the same as that used by the agencies in both the 2012–2016 light duty vehicle and 2014–2018 medium- and heavy-duty vehicle rulemakings. In those rulemakings, the agencies addressed comments about the magnitude of their energy security estimates and methodological issues such as whether to include the monopsony benefits in energy security calculations.

Air pollutant emissions—

◦ *Impacts on criteria air pollutant emissions*—Criteria air pollutants emitted by vehicles and during fuel production and distribution include carbon monoxide (CO), hydrocarbon compounds (usually referred to as ''volatile organic compounds,'' or VOC), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and sulfur oxides (SO_X). Although reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of these pollutants, additional vehicle use associated with the rebound effect, and additional electricity production will increase emissions. Thus the net effect of stricter standards on emissions of each criteria pollutant depends on the relative magnitudes of reduced emissions from fuel refining and distribution, and increases in emissions resulting from added vehicle use. The agencies' analysis assumes that the per-mile emission rates for cars and light trucks produced during the model years affected by the proposed rule will remain constant at the levels resulting from EPA's Tier 2 light duty vehicle emissions standards. The agencies' approach to estimating criteria air pollutant emissions is consistent with the method used in the 2012–2016 final rule (where the agencies received no significant adverse comments), although the agencies employ a more recent version of the EPA's MOVES (Motor Vehicle Emissions Simulator) model.

◦ *Economic value of reductions in criteria pollutant emissions*—For the purpose of the joint technical analysis, EPA and NHTSA estimate the economic value of the human health benefits associated with reducing population exposure to $PM_{2.5}$ using a ''benefit-per-ton'' method. These $PM_{2.5}$-related benefit-per-ton estimates provide the total monetized benefits to human health (the sum of reductions in premature mortality and premature morbidity) that result from eliminating one ton of directly emitted $PM_{2.5,}$ or one ton of other pollutants that contribute to atmospheric levels of $PM_{2.5}$ (such as NO_X, SO_X, and VOCs), from a specified source. These unit values remain unchanged from the 2012–2016 final rule, and the agencies received no significant adverse comment on the analysis. Note that the agencies' analysis includes no estimates of the direct health or other benefits associated with reductions in emissions of criteria pollutants other than $PM_{2.5}$.

◦ *Impacts on greenhouse gas (GHG) emissions*—NHTSA estimates reductions in emissions of carbon dioxide (CO_2) from passenger car and light truck use by multiplying the estimated reduction in consumption of fuel (gasoline and diesel) by the quantity or mass of CO_2 emissions released per gallon of fuel consumed. EPA directly calculates reductions in total CO_2 emissions from the projected reductions in CO_2 emissions by each vehicle subject to the proposed rule.[164] Both agencies also calculate the impact on CO_2 emissions that occur during fuel production and distribution resulting from lower fuel consumption, as well as the emission impacts due to changes in electricity production. Although CO_2 emissions account for nearly 95 percent of total GHG emissions that result from fuel combustion during vehicle use, emissions of other GHGs are potentially significant as well because of their higher ''potency'' as GHGs than that of CO_2 itself. EPA and NHTSA therefore also estimate the change in upstream and downstream emissions of non-CO_2 GHGs that occur during the aforementioned processes due to their respective standards.[165] The agencies approach to estimating GHG emissions is consistent with the method used in the 2012–2016 final rule and the Interim Joint TAR.

◦ *Economic value of reductions in CO_2 emissions*—EPA and NHTSA assigned a dollar value to reductions in CO_2 emissions using recent estimates of the ''social cost of carbon'' (SCC) developed by a federal interagency group that included the two agencies. As that group's report observed, ''The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.''[166] Published estimates of the SCC vary widely as a result of uncertainties about future economic growth, climate sensitivity to GHG emissions, procedures used to model the economic impacts of climate change, and the choice of discount rates.[167] The SCC estimates used in this analysis were developed through an interagency process that included EPA, DOT/NHTSA, and other executive branch entities, and concluded in February 2010. We first used these SCC estimates in the benefits analysis for the 2012–2016 light-duty vehicle rulemaking. We have continued to use these estimates in other rulemaking analyses, including the Greenhouse Gas Emission Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles (76 FR 57106, p. 57332) . The SCC Technical Support Document (SCC TSD) provides a complete discussion of the methods used to develop these SCC estimates.

The value of changes in driving range—By reducing the frequency with which drivers typically refuel their vehicles, and by extending the upper limit of the range they can travel before requiring refueling, improving fuel economy and reducing GHG emissions provides additional benefits to their owners. The primary benefits from the reduction in the number of required refueling cycles are the value of time saved to drivers and other adult vehicle occupants, as well as the savings to owners in terms of the cost of the fuel that would have otherwise been consumed in transit during those (now no longer required) refueling trips. Using recent data on vehicle owners' refueling patterns gathered from a survey conducted by the National Automotive Sampling System (NASS), NHTSA was able to better estimate parameters associated with refueling trips. NASS data provided NHTSA with

Premium for the MY 2017–2025 Light Duty Vehicle Proposal'' 2011.

[163] Note that this change in world oil price is not reflected in the AEO projections described earlier in this section.

[164] The weighted average CO_2 content of certification gasoline is estimated to be 8,887 grams per gallon, while that of diesel fuel is estimated to be approximately 10,200 grams per gallon.

[165] There is, however, an exception. NHTSA does not and cannot claim benefit from reductions in downstream emissions of HFCs because they do not relate to fuel economy, while EPA does because all GHGs are relevant for purposes of EPA's Clean Air Act standards.

[166] SCC TSD, see page 2. Docket ID EPA–HQ–OAR–2009–0472–114577, *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon,* with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury (February 2010). Also available at *http://epa.gov/otaq/climate/regulations.htm*

[167] SCC TSD, see pages 6–7.

the ability to estimate the average time required for a refueling trip, the average time and distance drivers typically travel out of their way to reach fueling stations, the average number of adult vehicle occupants, the average quantity of fuel purchased, and the distribution of reasons given by drivers for refueling. From these estimates, NHTSA constructed an updated set of economic assumptions to update those used in the 2012–2016 FRM in calculating refueling-related benefits. The 2012–2016 FRM discusses NHTSA's intent to utilize the NASS data on refueling trip characteristics in future rulemakings. While the NASS data improve the precision of the inputs used in the analysis of the benefits resulting from fewer refueling cycles, the framework of the analysis remains essentially the same as in the 2012–2016 final rule. Note that this topic and associated benefits were not covered in the Interim Joint TAR. Detailed discussion and examples of the agencies' approach are provided in Chapter VIII of NHTSA's PRIA and Chapter 8 of EPA's DRIA.

Discounting future benefits and costs—Discounting future fuel savings and other benefits is intended to account for the reduction in their value to society when they are deferred until some future date, rather than received immediately.[168] The discount rate expresses the percent decline in the value of these future fuel-savings and other benefits—as viewed from today's perspective—for each year they are deferred into the future. In evaluating the non-climate related benefits of the final standards, the agencies have employed discount rates of both 3 percent and 7 percent, consistent with the 2012–2016 final rule and OMB Circular A–4 guidance.

For the reader's reference, Table II–8 and Table II–9 below summarize the values used to calculate the impacts of each proposed standard. The values presented in this table are summaries of the inputs used for the models; specific values used in the agencies' respective analyses may be aggregated, expanded, or have other relevant adjustments. See Joint TSD 4 and each agency's respective RIA for details. The agencies seek comment on the economic assumptions presented in the table.

In addition, the agencies analyzed the sensitivity of their estimates of the benefits and costs associated with this proposed rule to variation in the values of many of these economic assumptions and other inputs. The values used in these sensitivity analyses and their results are presented their agencies' respective RIAs. A wide range of estimates is available for many of the primary inputs that are used in the agencies' CAFE and GHG emissions models. The agencies recognize that each of these values has some degree of uncertainty, which the agencies further discuss in the draft Joint TSD. The agencies have tested the sensitivity of their estimates of costs and benefits to a range of assumptions about each of these inputs, and present these sensitivity analyses in their respective RIAs. For example, NHTSA conducted separate sensitivity analyses for, among other things, discount rates, fuel prices, the social cost of carbon, the rebound effect, consumers' valuation of fuel economy benefits, battery costs, mass reduction costs, the value of a statistical life, and the indirect cost markup factor. This list is similar in scope to the list that was examined in the MY 2012–2016 final rule, but includes battery costs and mass reduction costs, while dropping military security and monopsony costs. NHTSA's sensitivity analyses are contained in Chapter X of NHTSA's PRIA. EPA conducted sensitivity analyses on the rebound effect, battery costs, mass reduction costs, the indirect cost markup factor and on the cost learning curves used in this analysis. These analyses are found in Chapters 3 and 4 of the EPA DRIA. In addition, NHTSA performs a probabilistic uncertainty analysis examining simultaneous variation in the major model inputs including technology costs, technology benefits, fuel prices, the rebound effect, and military security costs. This information is provided in Chapter XII of NHTSA's PRIA. These uncertainty parameters are consistent with those used in the MY 2012–2016 final rule. The agencies will consider conducting additional sensitivity and uncertainty analyses for the final rule as appropriate.

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[168] Because all costs associated with improving vehicles' fuel economy and reducing CO_2 emissions are assumed to be incurred at the time they are produced, these costs are already expressed in their present values as of each model year affected by the proposed rule, and require discounting only for the purpose of expressing them as present values as of a common year.

Table II-8 Economic Values for Benefits Computations (2009$)

Fuel Economy Rebound Effect	10%
"Gap" between test and on-road MPG for liquid-fueled vehicles	20%
"Gap" between test and on-road wall electricity consumption for electric and plug-in hybrid electric vehicles	30%
Value of refueling time per ($ per vehicle-hour)	$21.27 Cars $21.62 Trucks
Average tank volume refilled during refueling stop	65%
Annual growth in average vehicle use	1.1% through 2030, 0.5% thereafter
Fuel Prices (2017-50 average, $/gallon)	
Retail gasoline price	$3.71
Pre-tax gasoline price	$3.35
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$ 0.00
Price Shock Component	$ 0.185 in 2025
Military Security Component	$ 0.00
Total Economic Costs ($/gallon)	$ 0.185 in 2025

Emission Damage Costs (2020, $/short ton)	
Carbon monoxide	$ 0
Volatile organic compounds (VOC)	$ 1,300
Nitrogen oxides (NO_X) – vehicle use	$ 5,500
Nitrogen oxides (NO_X) – fuel production and distribution	$ 5,300
Particulate matter ($PM_{2.5}$) – vehicle use	$ 300,000
Particulate matter ($PM_{2.5}$) – fuel production and distribution	$ 250,000
Sulfur dioxide (SO_2)	$ 32,000
Annual CO_2 Damage Cost (per metric ton)	Variable, depending on discount rate and year (see Table II-9 for 2017 estimate)
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.056
Accidents	$ 0.024
Noise	$ 0.001
Total External Costs	$ 0.080
External Costs from Additional Light Truck Use ($/vehicle-mile)	

Congestion	$0.049
Accidents	$0.027
Noise	$0.001
Total External Costs	$0.077
Discount Rates Applied to Future Benefits	3%, 7%

Table II-9 Social Cost of CO_2 ($/metric ton), 2017 (2009$)

Discount Rate	**5%**	**3%**	**2.5%**	**3%**
Source of Estimate	Mean of Estimated Values			95th percentile estimate
2017 Estimate	$6	$26	$41	$78

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F. Air Conditioning Efficiency CO_2 Credits and Fuel Consumption Improvement Values, Off-cycle Reductions, and Full-size Pickup Trucks

For MYs 2012–2016, EPA provided an option for manufacturers to generate credits for complying with GHG standards by incorporating efficiency improving vehicle technologies that would reduce CO_2 and fuel consumption from air conditioning (A/C) operation or from other vehicle operation that is not captured by the Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET), also collectively known as the ''two-cycle'' test procedure. EPA referred to these credits as ''off-cycle credits.''

For this proposal, EPA, in coordination with NHTSA, is proposing under their EPCA authorities to allow manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of A/C efficiency and off-cycle technologies. This proposed expansion is a change from the 2012–16 final rule where EPA only provided the A/C efficiency and off-cycle credits for the GHG program. EPA is not proposing to allow these increases for compliance with the CAFE program for MYs 2012–2016, nor to allow any compliance with the CAFE program as a result of reductions in direct A/C emissions resulting from leakage of HFCs from air conditioning systems, which remains a flexibility unique to the GHG program.

The agencies believe that because of the significant amount of credits and fuel consumption improvement values offered under the A/C program (up to 5.0 g/mi for cars and 7.2 g/mi for trucks which is equivalent to a fuel consumption improvement value of 0.000563 gal/mi for cars and 0.000586 gal/mi for trucks) that manufacturers will maximize the benefits these credits and fuel consumption improvement values afford. Consistent with the 2012–2016 final rule, EPA will continue to adjust the stringency of the two-cycle tailpipe CO_2 standards in order to account for this projected widespread penetration of A/C credits (as described more fully in Section III.C), and NHTSA has also accounted for expected A/C efficiency improvements in determining the maximum feasible CAFE standards. The agencies discuss these proposed CO_2 credits/fuel consumption improvement values below and in more detail in the Joint TSD (Chapter 5). EPA discusses additional proposed GHG A/C leakage credits that are unrelated to CO_2 and fuel consumption (though they are part of EPA's CO_2 equivalent calculation) in Section III.C below.

EPA, in coordination with NHTSA, is also proposing to add for MYs 2017–2025 a new incentive for Advanced Technology for Full Sized Pickup Trucks. Under its EPCA authority for CAFE and under its CAA authority for GHGs, EPA is proposing GHG credits and fuel economy improvement values for manufacturers that hybridize a significant quantity of their full size pickup trucks, or that use other technologies that significantly reduce CO_2 emissions and fuel consumption. Further discussions of the A/C, off-cycle, and the advanced technology for pick-up truck incentive programs are provided below.

1. Proposed Air Conditioning CO_2 Credits and Fuel Consumption Improvement Values

The credits/fuel consumption improvement values for higher-efficiency air conditioning technologies are very similar to those EPA included in the 2012–2016 GHG final rule. The proposed credits/fuel consumption improvement values represent an improved understanding of the relationships between A/C technologies and CO_2 emissions and fuel consumption. Much of this understanding results from a new vehicle simulation tool that EPA has developed and the agencies are using for this proposal. EPA designed this model to simulate in an integrated way the dynamic behavior of the several key systems that affect vehicle efficiency: The engine, electrical, transmission, and vehicle systems. The simulation model is supported by data from a wide range of sources; Chapter 2 of the Draft Regulatory Impact Analysis discusses its development in more detail.

The agencies have identified several technologies that are key to the amount of fuel a vehicle consumes and thus the amount of CO_2 it emits. Most of these technologies already exist on current vehicles, but manufacturers can improve the energy efficiency of the technology designs and operation. For example, most of the additional air conditioning related load on an engine is due to the compressor which pumps the refrigerant around the system loop. The less the compressor operates, the less load the compressor places on the engine resulting in less fuel consumption and CO_2 emissions. Thus, optimizing compressor operation with cabin demand using more sophisticated sensors, controls and control strategies, is one path to improving the overall efficiency of the A/C system. Additional components or control strategies are available to manufacturers to reduce the air conditioning load on the engine which are discussed in more detail in Chapter 5 of the joint TSD. Overall, the agencies have concluded that these improved technologies could together reduce A/C-related CO_2 and fuel consumption of today's typical air conditioning systems by 42%. The agencies propose to use this level of improvement to represent the maximum efficiency credit available to a manufacturer.

Demonstrating the degree of efficiency improvement that a manufacturer's air conditioning systems achieve—thus quantifying the appropriate amount of GHG credit and CAFE fuel consumption improvement value the manufacturer is eligible for—would ideally involve a performance test. That is, a test that would directly measure CO_2 (and thus allow calculation of fuel consumption) before and after the incorporation of the improved technologies. Progress toward such a test continues. As mentioned in the introduction to this section, the primary vehicle emissions and fuel consumption test, the Federal Test Procedure (FTP) or ''two-cycle'' testing, does not require or simulate air conditioning usage through the test cycle. The SC03 test is designed to identify any effect the air conditioning system has on other emissions when it is operating under extreme conditions, but is not designed to measure the small differences in CO_2 due to different A/C technologies.

At the time of the final rule for the 2012–2016 GHG program, EPA concluded that a practical, performance-based test procedure capable of quantifying efficiency credits was not yet available. However, EPA introduced a specialized new procedure that it believed would be appropriate for the more limited purpose of demonstrating that the design improvements for which a manufacturer was earning credits produced actual efficiency improvements. EPA's test is a fairly simple test, performed while the vehicle is at idle. Beginning with the 2014 model year, the A/C Idle Test was to be used to qualify a manufacturer to be able to use the technology lookup table (''menu'') approach to quantify credits. That is, a manufacturer would need to achieve a certain CO_2 level on the Idle Test in order to access the ''menu'' and generate GHG efficiency credits.

Since that final rule was published, several manufacturers have provided data that raises questions about the ability of the Idle Test to fulfill its intended purpose. Especially for small, lower-powered vehicles, the data also shows that it is difficult to achieve reasonable test-to-test repeatability. The manufacturers have also informed EPA (in meetings subsequent to the 2012–2016 final rule) that the Idle Test does not accurately capture the improvements from many of the technologies listed in the menu. EPA has been aware of all of these issues, and proposing to modify the Idle Test such that the threshold would be a function of engine displacement, in contrast to the flat threshold from the previous rule. EPA continues to consider this Idle Test to be a reasonable measure of some A/C CO_2 emissions as there is significant real-world driving activity at idle, and the Idle Test significantly exercises a number of the A/C technologies from the menu. Sec III.C.1.b.i below and Chapter 5 (5.1.3.5) of the Joint TSD describe further the adjustments EPA is proposing to the Idle Test for manufacturers to qualify for MYs 2014–2016 A/C efficiency credits. EPA proposes that manufacturers continue to use the menu for MYs 2014–2016 to determine credits for the GHG program. This was also the approach that EPA used for efficiency credits in the MY2012–2016 GHG rule. However for MYs 2017–2025, EPA is proposing a new test procedure to demonstrate the effectiveness of A/C efficiency technologies and credits as described below. For MYs 2014–2016, EPA requests comment on substituting the Idle Test requirement with a reporting requirement from this new test procedure as described in Section III.C.1.b.i below.

In order to correct the shortcomings of the available tests, EPA has developed a four-part performance test, called the AC17. The test includes the SC03 driving cycle, the fuel economy highway cycle, in addition to a pre-conditioning cycle, and a solar soak period. EPA is proposing that manufacturers use this test to demonstrate that new or improved A/C technologies actually result in efficiency improvements. Since the appropriateness of the test is still being evaluated, EPA proposes that manufacturers continue to use the menu to determine credits and fuel consumption improvement values for the GHG and CAFE programs. This design-based approach would assign CO_2 credit to each efficiency-improving air conditioning technology that the manufacturer incorporates in a vehicle model. The sum of these values for all technologies would be the amount of CO_2 credit generated by that vehicle, up to a maximum of 5.0 g/mi for car and 7.2 g/mi for trucks. As stated above, this is equivalent to a fuel consumption value of 0.000563 gallons/mi for cars and 0.000586 gallons/mi for trucks. EPA will consult with NHTSA on the amount of fuel consumption improvement value manufacturers may factor into their CAFE calculations if there are adjustments that may be required in the future. Table II–10 presents the proposed CO_2 credit and CAFE fuel consumption improvement values for each of the efficiency-reducing air conditioning technologies considered in this rule. More detail is provided on the calculation of indirect A/C CAFE fuel consumption improvement values in chapter 5 of the TSD. EPA is proposing very specific definitions of each of the technologies in the table below which are discussed in Chapter 5 of the draft joint TSD to ensure that the air conditioner technology used by manufacturers seeking these credits corresponds with the technology used to derive the credit/fuel consumption improvement values.

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Table II-10 A/C Efficiency Credits and Fuel Consumption Improvement Values

Technology Description	Estimated reduction in A/C CO_2 Emissions and Fuel Consumption	Car A/C Efficiency Credit (g/mi CO_2)	Truck A/C Efficiency Credit (g/mi CO_2)	Car A/C Efficiency Fuel Consumption Improvement (gallon / mi)	Truck A/C Efficiency Fuel Consumption Improvement (gallon / mi)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	1.5	2.2	0.000169	0.000248
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	1.0	1.4	0.000113	0.000158
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed based on additional analysis)	30%	1.5	2.2	0.000169	0.000248
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	20%	1.0	1.4	0.000113	0.000158

Blower motor control which limit wasted electrical energy (e.g. pulsewidth modulated power controller)	15%	0.8	1.1	0.000090	0.000124
Internal heat exchanger (or suction line heat exchanger)	20%	1.0	1.4	0.000113	0.000158
Improved evaporators and condensers (with engineering analysis on each component indicating a COP improvement greater than 10%, when compared to previous design)	20%	1.0	1.4	0.000113	0.000158
Oil Separator (internal or external to compressor)	10%	0.8	0.7	0.000090	0.000079

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As mentioned above, EPA, working with manufacturers and CARB, has made significant progress in developing a more robust test that may eventually be capable of measuring differences in A/C efficiency. While EPA believes that more testing and development will be necessary before the new test could be used directly to quantify efficiency credits and fuel consumption improvement values, EPA is proposing that the test be used to demonstrate that new or improved A/C technologies result in reductions in GHG emissions and fuel consumption. EPA is proposing the AC17 test as a reporting-only alternative to the Idle Test for MYs 2014–2016, and as a prerequisite for generating Efficiency Credits and fuel consumption improvement values for MY 2017 and later. To demonstrate that a vehicle's A/C system is delivering the efficiency benefits of the new technologies, manufacturers would run the AC17 test procedure on a vehicle that incorporates the new technologies, with the A/C system off and then on, and then compare that result to the result from a previous model year or baseline vehicle with similar vehicle characteristics, except that the comparison vehicle would not have the new technologies. If the test result with the new technology demonstrated an emission reduction that is greater than or equal to the menu-based credit potential of those technologies, the manufacturer would generate the appropriate credit based on the menu. However, if the test result did not demonstrate the full menu-based potential of the technology, partial credit could still be earned, in proportion to how far away the result was from the expected menu-based credit amount.

EPA discusses the new test in more detail in Section III.C.1.b below and in Chapter 5 (5.1.3.5) of the joint TSD. Due to the length of time to conduct the test procedure, EPA is also proposing that required testing on the new AC17 test procedure be limited to a subset of vehicles. The agencies request comment on this approach to establishing A/C efficiency credits and fuel consumption improvement values and the use of the new A/C test.

For the CAFE program, EPA is proposing to determine a fleet average fuel consumption improvement value in a manner consistent with the way a fleet average CO_2 credits will be determined. EPA would convert the metric tons of CO_2 credits for air conditioning, off-cycle, and full size pick-up to fleet-wide fuel consumption improvement values, consistent with the way EPA would convert the improvements in CO_2 performance to metric tons of credits. See discussion in section III. C. There would be separate improvement values for each type of credit, calculated separately for cars and for trucks. These improvement values would be subtracted from the manufacturer's two-cycle-based fleet fuel consumption value to yield a final new fleet fuel consumption value, which would be inverted to determine a final fleet fuel CAFE value. EPA considered, but is not proposing, an approach where the fuel consumption improvement values would be accounted for at the individual vehicle level. In this case a credit-adjusted MPG value would have to be calculated for each vehicle that accrues air conditioning, off-cycle, or pick-up truck credits, and a credit-adjusted CAFE would be calculated by sales-weighting each vehicle. EPA found that a significant issue with this approach is that the credit programs do not align with the way fuel economy and GHG emissions are currently reported to EPA or to NHTSA, *i.e.,* at the model type level. Model types are similar in basic engine and transmission characteristics, but credits are expected to vary within a model type, possibly considerably. For example, within a model type the credits could vary by body style, trim level, footprint, and the type of air conditioning systems and other GHG reduction technologies installed. Manufacturers would have to report sales volumes for each unique combination of all of these factors in order to enable EPA to perform the CAFE averaging calculations. This would require a dramatic and expensive overhaul of EPA's data systems, and the manufacturers would likely face similar impacts. The vehicle-specific approach would also likely introduce more opportunities for errors resulting from data entry and rounding, since each vehicle's base fuel economy would be modified by multiple consumption values reported to at least six decimal places. The proposed approach would instead focus on calculating the GHG credits correctly and summing them for each of the car and truck fleets, and the step of transforming to a fuel consumption improvement value is relatively straightforward. However, given that the vehicle-specific and fleet-based approaches yield the same end result, EPA requests comment on whether one approach or the other is preferable, and if so, why a specific approach is preferable.

2. Off-Cycle CO_2 Credits

For MYs 2012–2016, EPA provided an option for manufacturers to generate adjustments (credits) for employing new and innovative technologies that achieve CO_2 reductions which are not reflected on current 2-cycle test procedures. For this proposal, EPA, in coordination with NHTSA, is proposing to apply the off-cycle credits and equivalent fuel consumption improvement values to both the CAFE and GHG programs. This proposed expansion is a change from the 2012–16 final rule where only EPA provided the off-cycle credits for the GHG program. For MY 2017 and later, EPA is proposing that manufacturers may continue to use off-cycle credits for GHG compliance and begin to use fuel consumption improvement values for CAFE compliance. In addition, EPA is proposing a set of defined (*e.g.* default) values for identified off-cycle technologies that would apply unless the manufacturer demonstrates to EPA that a different value for its technology is appropriate.

Starting with MY2008, EPA started employing a ''five-cycle'' test methodology to measure fuel economy for the fuel economy label. However, for GHG and CAFE compliance, EPA continues to use the established ''two-cycle'' (city and highway test cycles, also known as the FTP and HFET) test methodology. As learned through development of the ''five-cycle'' methodology and researching this proposal, EPA and NHTSA recognize that there are technologies that provide real-world GHG emissions and fuel consumption improvements, but those improvements are not fully reflected on the ''two-cycle'' test.

During meetings with vehicle manufacturers, EPA received comments that the approval process for generating off-cycle credits was complicated and did not provide sufficient certainty on the amount of credits that might be approved. Commenters also maintained that it is impractical to measure small incremental improvements on top of a large tailpipe measurement, similar to comments received related to quantifying air conditioner improvements. These same manufacturers believed that such a process could stifle innovation and fuel efficient technologies from penetrating into the vehicle fleet.

In response to these concerns, EPA is proposing a menu with a number of technologies that the agency believes will show real-world CO_2 and fuel consumption benefits which can be reasonably quantified by the agencies at this time. This list of pre-approved technologies includes a quantified default value that would apply unless the manufacturer demonstrates to EPA that a different value for a technology is appropriate. This list is similar to the menu driven approach described in the previous section on A/C efficiency credits. The estimates of these credits were largely determined from research, analysis and simulations, rather from full vehicle testing, which would have been cost and time prohibitive. These predefined estimates are somewhat conservative to avoid the potential for windfall. If manufactures believe their specific off-cycle technology achieves larger improvement, they may apply for greater credits and fuel consumption improvement values with supporting data. For technologies not listed, EPA is proposing a case-by-case approach for approval of off-cycle credits and fuel consumption improvement values, similar to the approach in the 2012–2016 rule but with important modifications to streamline the approval process. EPA will also consult with NHTSA during the review process. See section III.C below; technologies for which EPA is proposing default off-cycle credit values and fuel consumption improvement values are shown in Table II—11 below. Fuel consumption improvement values under the CAFE program based on off-cycle technology would be equivalent to the off-cycle credit allowed by EPA under the GHG program, and these amounts would be determined using the same procedures and test methods as are proposed for use in EPA's GHG program.

EPA and NHTSA are not proposing to adjust the stringency of the standards based on the availability of off-cycle credits and fuel consumption improvement values. There are a number of reasons for this. First, the agencies have limited technical information on the cost, development time necessary, and manufacturability of many of these technologies. The analysis presented below (and in greater detail in Chapter 5 of the joint TSD) is limited to quantifying the effectiveness of the technology (for the purposes of quantifying credits and fuel consumption improvement values). It is based on a combination of data and engineering analysis for each technology. Second, for most of these technologies the agencies have no data on what the rates of penetration of these technologies would be during the rule timeframe. Thus, with the exception of active aerodynamic improvements and stop start technology, the agencies do not have adequate information available to consider the technologies on the list when determining the appropriate GHG emissions or CAFE standards. The agencies expect to continue to improve their understanding of these technologies over time. If further information is obtained during the comment period that supports consideration of these technologies in setting the standards, EPA and NHTSA will reevaluate their positions. However, given the current lack of detailed information about these technologies, the agencies do not expect that it will be able to do more for the final rule than estimate some general amount of reasonable projected cost savings from generation of off-cycle credits and fuel consumption improvement values. Therefore, effectively the off-cycle credits and fuel consumption improvement values allow manufacturers additional flexibility in selecting technologies that may be used to comply with GHG emission and CAFE standards.

Two technologies on the list—active aerodynamic improvements and stop start—are in a different position than the other technologies on the list. Both of these technologies are included in the agencies' modeling analysis of technologies projected to be available for use in achieving the reductions needed for the standards. We have information on their effectiveness, cost, and availability for purposes of considering them along with the various other technologies we consider in determining the appropriate CO_2 emissions standard. These technologies are among those listed in Chapter 3 of the joint TSD and have measureable benefit on the 2-cycle test. However, in the context of off-cycle credits and fuel consumption improvement values, stop start is any technology which enables a vehicle to automatically turn off the engine when the vehicle comes to a rest and restart the engine when the driver applies pressure to the accelerator or releases the brake. This includes HEVs and PHEVs (but not EVs). In addition, active grill shutters is just one of various technologies that can be used as part of aerodynamic design improvements (as part of the ''aero2'' technology). The modeling and other analysis developed for determining the appropriate emissions standard includes these technologies, using the effectiveness values on the 2-cycle test. This is consistent with our consideration of all of the other technologies included in these analyses. Including them on the list for off-cycle credit and fuel consumption improvement value generation, for purposes of compliance with the standards, would recognize that these technologies have a higher degree of effectiveness than reflected in their 2-cycle effectiveness. As discussed in Sections III.C and Chapter 5 of the joint TSD, the agencies have taken into account the generation of off-cycle credits and fuel consumption improvement values by these two technologies in determining the appropriateness of the proposed standards, considering the amount of credit and fuel consumption improvement value, the projected degree of penetration of these technologies, and other factors. The proposed standards are appropriate recognizing that these technologies would also generate off-cycle credits and fuel consumption improvement values. Section III.D has a more detailed discussion on the feasibility of the standards within the context of the flexibilities (such as off-cycle credits and fuel consumption improvement values) proposed in this rule.

For these technologies that provide a benefit on five-cycle testing, but show less benefit on two cycle testing, in order to quantify the emissions impacts of these technologies, EPA will simply subtract the two-cycle benefit from the five-cycle benefit for the purposes of assigning credit and fuel consumption improvement values for this pre-approved list. Other technologies, such as more efficient lighting show no benefit over any test cycle. In these cases, EPA will estimate the average amount of usage using MOVES [169] data if possible and use this to calculate a duty-cycle-weighted benefit (or credit and fuel consumption improvement value). In the 2012–2016 rule, EPA stated a technology must have ''real world GHG reductions not significantly captured on the current 2-cycle tests* * *'' For this proposal, EPA is proposing to modify this requirement to allow technologies as long as the incremental benefit in the real-world is significantly better than on the 2-cycle test. There are environmental benefits to encouraging these kinds of technologies that might not otherwise be employed, beyond the level that the 2-cycle standards already do, thus we are now allowing credits and fuel consumption improvement values to be generated where the technology achieves an incremental benefit that is significantly better than on the 2-cycle test, as is the case for the technologies on the list.

EPA and NHTSA evaluated many more technologies for off-cycle credits and fuel consumption improvement values and decided that the following technologies should be eligible for off-cycle credits and fuel consumption improvement values. These eleven technologies eligible for credits and fuel consumption improvement values are shown in Table II–11 below. EPA is proposing that a CAFE improvement value for off-cycle improvements be determined at the fleet level by converting the CO_2 credits determined under the EPA program (in metric tons of CO_2) for each fleet (car and truck) to a fleet fuel consumption improvement value. This improvement value would then be used to adjust the fleet's CAFE level upward. See the proposed regulations at 40 CFR 600.510–12. Note that while the table below presents fuel consumption values equivalent to a given CO_2 credit value, these consumption values are presented for informational purposes and are not meant to imply that these values will be used to determine the fuel economy for individual vehicles.

[169] MOVES is EPA's MOtor Vehicle Emissions Simulator. This model contains (in its database) a wide variety of fleet and activity data as well as national ambient temperature conditions.

Table II-11 Off-cycle Technologies and Proposed Credits and Equivalent Fuel Consumption Improvement Values for Cars and Light Trucks

Technology	Cars		Light Trucks	
	g/mi	gallons/mi	g/mi	gallons/mi
High Efficiency Exterior Lighting	1.1	0.000124	1.1	0.000124
Engine Heat Recovery	0.7	0.000778	0.7	0.000778
Solar Roof Panels	3.0	0.000338	3.0	0.000338
Active Aerodynamic Improvements	0.6	0.0000675	1.0	0.000113
Engine Start-Stop	2.9	0.000326	4.5	0.000506
Electric Heater Circulation Pump	1.0	0.000123	1.5	0.000169
Active Transmission Warm-Up	1.8	0.000203	1.8	0.000203
Active Engine Warm-Up	1.8	0.000203	1.8	0.000203
Solar Control	Up to 3.0	Up to 0.000338	Up to 4.3	Up to 0.000484

Table II–11 shows the proposed list of off-cycle technologies and credits and equivalent fuel consumption improvement values for cars and trucks. The credits and fuel consumption improvement values for engine heat recovery and solar roof panels are scalable, depending on the amount of energy these systems can generate for the vehicle. The Solar/Thermal control technologies are varied and are limited to 3 and 4.3 g/mi (car and truck respectively) total.

To ensure that the off cycle technology used by manufacturers seeking these credits and fuel consumption improvement values corresponds with the technology used to derive the credit and fuel consumption improvement values, EPA is proposing very specific definitions of each of the technologies in the table of the list of technologies in Chapter 5 of the draft joint TSD. The agencies are requesting comment on all aspects of the off-cycle credit and fuel consumption improvement value program, and would welcome any data to support an adjustment to this table, whether it is to adjust the values or to add or remove technologies.

Vehicle Simulation Tool

Chapter 2 of the RIA provides a detailed description of the vehicle simulation tool that EPA has been developing. This tool is capable of simulating a wide range of conventional and advanced engines, transmissions, and vehicle technologies over various driving cycles. It evaluates technology package effectiveness while taking into account synergy (and dis-synergy) effects among vehicle components and estimates GHG emissions for various combinations of technologies. For the 2017 to 2025 GHG proposal, this simulation tool was used to assist estimating the amount of GHG credits for improved A/C systems and off-cycle technologies. EPA seeks public comments on this approach of using the tool for directly generating and fine-tuning some of the credits in order to capture the amount of GHG reductions provided by primarily off-cycle technologies.

There are a number of technologies that could bring additional GHG reductions over the 5-cycle drive test (or in the real world) compared to the combined FTP/Highway (or two) cycle test. These are called off-cycle technologies and are described in chapter 5 of the Joint TSD in detail. Among them are technologies related to reducing vehicle's electrical loads, such as High Efficiency Exterior Lights, Engine Heat Recovery, and Solar Roof Panels. In an effort to streamline the process for approving off-cycle credits, we have set a relatively conservative estimate of the credit based on our efficacy analysis. EPA seeks comment on utilizing the model in order to quantify the credits more accurately, if actual data of electrical load reduction and/or on-board electricity generation by one or more of these technologies is available through data submission from manufacturers. Similarly, there are technologies that would provide additional GHG reduction benefits in the 5-cycle test by actively reducing the vehicle's aerodynamic drag forces. These are referred to as active aerodynamic technologies, which include but are not limited to active grill shutters and active suspension lowering. Like the electrical load reduction technologies, the vehicle simulation tool can be used to more accurately estimate the additional GHG reductions (therefore the credits) provided by these active aerodynamic technologies over the 5-cycle drive test. EPA seeks comment on using the simulation tool in order to quantify these credits. In order to do this properly, manufacturers would be expected to submit two sets of coast-down coefficients (with and without the active aerodynamic technologies). Or, they could submit two sets of aerodynamic drag coefficient (with and without the active aerodynamic technologies) as a function of vehicle speed.

There are other technologies that would result in additional GHG reduction benefits that cannot be fully captured on the combined FTP/Highway cycle test. These technologies typically reduce engine loads by utilizing advanced engine controls, and they range from enabling the vehicle to turn off the engine at idle, to reducing cabin temperature and thus A/C compressor loading when the vehicle is restarted. Examples include Engine Start-Stop, Electric Heater Circulation Pump, Active Engine/Transmission Warm-Up, and Solar Control. For these types of technologies, the overall GHG reduction largely depends on the control and calibration strategies of individual manufacturers and vehicle types. Also, the current vehicle simulation tool does not have the capability to properly simulate the vehicle behaviors that depend on thermal conditions of the vehicle and its surroundings, such as Active Engine/Transmission Warm-Up and Solar Control. Therefore, the vehicle simulation may not provide full benefits of the technologies on the GHG reductions. For this reason, the agency is not proposing to use the simulation tool to generate the GHG credits for these technologies at this time, though future versions of the model may be more capable of quantifying the efficacy of these off-cycle technologies as well.

3. Advanced Technology Incentives for Full Sized Pickup Trucks

The agencies recognize that the standards under consideration for MY 2017–2025 will be most challenging to large trucks, including full size pickup trucks that are often used for commercial purposes and have generally higher payload and towing capabilities, and cargo volumes than other light-duty vehicles. In Section II.C and Chapter 2 of the joint TSD, EPA and NHTSA describe the proposal to adjust the slope of the truck curve compared to the 2012–2016 rule. In Sections III.B and IV.F, EPA and NHTSA describe the progression of the truck standards. In this section, the agencies describe a credit and fuel consumption improvement value for full size pickup trucks to incentivize advanced technologies on this class of vehicles.

The agencies' goal is to incentivize the penetration into the marketplace of "game changing" technologies for these pickups, including their hybridization. For that reason, EPA, in coordination with NHTSA, is proposing credits and corresponding equivalent fuel consumption improvement values for manufacturers that hybridize a significant quantity of their full size pickup trucks, or use other technologies that significantly reduce CO_2 emissions and fuel consumption. This proposed credit and corresponding equivalent fuel consumption improvement value would be available on a per-vehicle basis for mild and strong HEVs, as well as other technologies that significantly improve the efficiency of the full sized pickup class.[170] The credits and fuel consumption improvement values would apply for purposes of compliance with both the GHG emissions standards and the CAFE standards. This provides the incentive to begin transforming this most challenging category of vehicles toward use of the most advanced technologies.

Access to this credit and fuel consumption improvement value is conditioned on a minimum penetration of the technologies in a manufacturer's full size pickup truck fleet. To ensure its use for only full sized pickup trucks, EPA is proposing a very specific definition for a full sized pickup truck based on minimum bed size and minimum towing capability. The specifics of this proposed definition can be found in Chapter 5 of the draft joint TSD (see Section 5.3.1). This proposed definition is meant to ensure that smaller pickup trucks, which do not offer the same level of utility (*e.g.,* bed size, towing capability and/or payload capability) and thus may not face the same technical challenges to improving fuel economy and reducing CO_2 emissions as compared to full sized pickup trucks, do not qualify.[171] For this proposal, a full sized pickup truck would be defined as meeting requirements 1 and 2, below, as well as either requirement 3 or 4, below:

1. The vehicle must have an open cargo box with a minimum width between the wheelhouses of 48 inches measured as the minimum lateral distance between the limiting interferences (pass-through) of the wheelhouses. The measurement would exclude the transitional arc, local protrusions, and depressions or pockets, if present.[172] An open cargo box means a vehicle where the cargo bed does not have a permanent roof or cover. Vehicles sold with detachable covers are considered "open" for the purposes of these criteria.

2. Minimum open cargo box length of 60 inches defined by the lesser of the pickup bed length at the top of the body (defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate; this would be measured at the height of the top of the open pickup bed along vehicle centerline and the pickup bed length at the floor) and the pickup bed length at the floor (defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate; this would be measured at the cargo floor surface along vehicle centerline).[173]

3. Minimum Towing Capability—the vehicle must have a GCWR (gross combined weight rating) minus GVWR (gross vehicle weight rating) value of at least 5,000 pounds.[174]

[170] Note that EPA's proposed calculation methodology in 40 CFR 600.510–12 does not use vehicle-specific fuel consumption adjustments to determine the CAFE increase due to the various incentives allowed under the proposed program. Instead, EPA would convert the total CO_2 credits due to each incentive program from metric tons of CO_2 to a fleetwide CAFE improvement value. The fuel consumption values are presented to give the reader some context and explain the relationship between CO_2 and fuel consumption improvements.

[171] As discussed in TSD Section 5.3.1, EPA is seeking comment on expanding the scope of this credit to somewhat smaller pickups, provided they have the towing and/or hauling capabilities of the larger full-size trucks.

[172] This dimension is also known as dimension W202 as defined in Society of Automotive Engineers Procedure J1100.

[173] The pickup body length at the top of the body is also known as dimension L506 in Society of Automotive Engineers Procedure J1100. The pickup body length at the floor is also known as dimension L505 in Society of Automotive Engineers Procedure J1100.

[174] Gross combined weight rating means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment. Gross vehicle weight rating means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment. Curb weight is defined in 40 CFR 86.1803, consistent with the provisions of 40 CFR 1037.140.

4. Minimum Payload Capability—the vehicle must have a GVWR (gross vehicle weight rating) minus curb weight value of at least 1,700 pounds.

The technical basis for these proposed definitions is found in Section III.C below and Chapter 5 of the joint TSD. EPA is proposing that mild HEV pickup trucks would be eligible for a per-truck 10 g/mi CO_2 credit (equal to a 0.001125 gal/mi fuel consumption improvement value) during MYs 2017–2021 if the mild HEV technology is used on a minimum percentage of a company's full sized pickups. That minimum percentage would be 30 percent of a company's full sized pickup production in MY 2017 with a ramp up to at least 80 percent of production in MY 2021.

EPA is also proposing that strong HEV pickup trucks would be eligible for a per-truck 20 g/mi CO_2 credit (equal to a 0.002250 gal/mi fuel consumption improvement value) during MYs 2017–2025 if the strong HEV technology is used on a minimum percentage of a company's full sized pickups. That minimum percentage would be 10 percent of a company's full sized pickup production in each year over the model years 2017–2025.

To ensure that the hybridization technology used by manufacturers seeking one of these credits and fuel consumption improvement values meets the intent behind the incentives, EPA is proposing very specific definitions of what qualifies as a mild and a strong HEV. These definitions are described in detail in Chapter 5 of the draft joint TSD (see section 5.3.3).

For similar reasons, EPA is also proposing a performance-based incentive credit and equivalent fuel consumption improvement value for full size pickup trucks that achieve an emission level significantly below the applicable target.[175] EPA, in coordination with NHTSA, proposes this credit to be either 10 g/mi CO_2 (equivalent to 0.001125 gal/mi for the CAFE program) or 20 g/mi CO_2 (equivalent to 0.002250 gal/mi for the CAFE program) for pickups achieving 15 percent or 20 percent, respectively, better CO_2 than their footprint based target in a given model year. Because the footprint target curve has been adjusted to account for A/C related credits, the CO_2 level to be compared with the target would also include any A/C related credits generated by the vehicle. Further details on this performance-based incentive are in Section III.C below and in Chapter 5 of the draft joint TSD (see Section 5.3.4). The 10 g/mi (equivalent to 0.001125 gal/mi) performance-based credit and fuel consumption improvement value would be available for MYs 2017 to 2021 and a vehicle meeting the requirements would receive the credit and fuel consumption improvement value until MY 2021 unless its CO_2 level increases or fuel economy decreases. The 20 g/mi CO_2 (equivalent to 0.0023 gal/mi fuel consumption improvement value) performance-based credit would be available for a maximum of 5 years within the model years of 2017 to 2025, provided its CO_2 level and fuel consumption does not increase. The rationale for these limits is because of the year over year progression of the stringency of the truck target curves. The credits and fuel consumption improvement values would begin in the model year of introduction, and could not extend past MY 2021 for the 10 g/mi credit (equivalent to 0.001125 gal/mi) and MY 2025 for the 20 g/mi credit (equivalent to 0.002250 gal/mi).

As with the HEV-based credit and fuel consumption improvement value, the performance-based credit and fuel consumption improvement value requires that the technology be used on a minimum percentage of a manufacturer's full-size pickup trucks. That minimum percentage for the 10 g/mi GHG credit (equivalent to 0.001125 gal/mi fuel consumption improvement value) would be 15 percent of a company's full sized pickup production in MY 2017 with a ramp up to at least 40 percent of production in MY 2021. The minimum percentage for the 20 g/mi credit (equivalent to 0.002250 gal/mi fuel consumption improvement value) would be 10 percent of a company's full sized pickup production in each year over the model years 2017–2025.

Importantly, the same vehicle could not receive credit and fuel consumption improvement under both the HEV and the performance-based approaches. EPA and NHTSA request comment on all aspects of this proposed pickup truck incentive credit and fuel consumption improvement value, including the proposed definitions for full sized pickup truck and mild and strong HEV.

G. Safety Considerations in Establishing CAFE/GHG Standards

1. Why do the agencies consider safety?

The primary goals of the proposed CAFE and GHG standards are to reduce fuel consumption and GHG emissions from the on-road light-duty vehicle fleet, but in addition to these intended effects, the agencies also consider the potential of the standards to affect vehicle safety.[176] As a safety agency, NHTSA has long considered the potential for adverse safety consequences when establishing CAFE standards,[177] and under the CAA, EPA considers factors related to public health and human welfare, and safety, in regulating emissions of air pollutants from mobile sources.[178] Safety trade-offs associated with fuel economy increases have occurred in the past (particularly before NHTSA CAFE standards were attribute-based), and the agencies must be mindful of the possibility of future ones. These past safety trade-offs may have occurred because manufacturers chose, at the time, to build smaller and lighter vehicles—partly in response to CAFE standards—rather than adding more expensive fuel-saving technologies (and maintaining vehicle size and safety), and the smaller and lighter vehicles did not fare as well in crashes as larger and heavier vehicles. Historically, as shown in FARS data analyzed by NHTSA, the safest cars generally have been heavy and large, while the cars with the highest fatal-crash rates have been light and small. The question, then, is whether past is necessarily prologue when it comes to potential changes in vehicle size (both footprint and "overhang") and mass in response to these proposed future CAFE and GHG standards. Manufacturers have stated that they will reduce vehicle mass as one of the cost-effective means of increasing fuel economy and reducing CO_2 emissions in order to meet the proposed standards, and the

[175] The 15 and 20 percent thresholds would be based on CO_2 performance compared to the applicable CO_2 vehicle target for both CO_2 credits and corresponding CAFE fuel consumption improvement values. As with A/C and off-cycle credits, EPA would convert the total CO_2 credits due to the pick-up incentive program from metric tons of CO_2 to a fleetwide equivalent CAFE improvement value.

[176] In this rulemaking document, "vehicle safety" is defined as societal fatality rates per vehicle miles traveled (VMT), which include fatalities to occupants of all the vehicles involved in the collisions, plus any pedestrians.

[177] This practice is recognized approvingly in case law. As the United States Court of Appeals for the DC Circuit stated in upholding NHTSA's exercise of judgment in setting the 1987–1989 passenger car standards, "NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program." *Competitive Enterprise Institute* v. *NHTSA ("CEI I"),* 901 F.2d 107, 120 at n. 11 (DC Cir. 1990).

[178] See *NRDC* v. *EPA, 655 F. 2d 318, 332 n. 31 (DC Cir. 1981). (EPA may consider safety in developing standards under section 202 (a) and did so appropriately in the given instance).*

agencies have incorporated this expectation into our modeling analysis supporting the proposed standards. Because the agencies discern a historical relationship between vehicle mass, size, and safety, it is reasonable to assume that these relationships will continue in the future. The question of whether vehicle design can mitigate the adverse effects of mass reduction is discussed below.

Manufacturers are less likely than they were in the past to reduce vehicle footprint in order to reduce mass for increased fuel economy. The primary mechanism in this rulemaking for mitigating the potential negative effects on safety is the application of footprint-based standards, which create a disincentive for manufacturers to produce smaller-footprint vehicles. See section II. C.1, above. This is because, as footprint decreases, the corresponding fuel economy/GHG emission target becomes more stringent. We also believe that the shape of the footprint curves themselves is approximately ''footprint-neutral,'' that is, that it should neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. Upsizing footprint is also discouraged through the curve ''cut-off'' at larger footprints.[179] However, the footprint-based standards do not discourage downsizing the portions of a vehicle in front of the front axle and to the rear of the rear axle, or of other areas of the vehicle outside the wheels. The crush space provided by those portions of a vehicle can make important contributions to managing crash energy. Additionally, simply because footprint-based standards create no incentive to downsize vehicles does not mean that manufacturers will not downsize if doing so makes it easier to meet the overall CAFE/GHG standard, as for example if the smaller vehicles are so much lighter that they exceed their targets by much greater amounts. On balance, however, we believe the target curves and the incentives they provide generally will not encourage down-sizing (or up-sizing) in terms of footprint reductions (or increases).[180] Consequently, all of our analyses are based on the assumption that this rulemaking, in and of itself, will not result in any differences in the sales weighted distribution of vehicle sizes.

Given that we expect manufacturers to reduce vehicle mass in response to the proposed standards, and do not expect manufacturers to reduce vehicle footprint in response to the proposed standards, the agencies must attempt to predict the safety effects, if any, of the proposed standards based on the best information currently available. This section explained why the agencies consider safety; the following section discusses how the agencies consider safety.

2. How do the agencies consider safety?

Assessing the effects of vehicle mass reduction and size on societal safety is a complex issue. One part of estimating potential safety effects involves trying to understand better the relationship between mass and vehicle design. The extent of mass reduction that manufacturers may be considering to meet more stringent fuel economy and GHG standards may raise different safety concerns from what the industry has previously faced. The principal difference between the heavier vehicles, especially truck-based LTVs, and the lighter vehicles, especially passenger cars, is that mass reduction has a different effect in collisions with another car or LTV. When two vehicles of unequal mass collide, the change in velocity (delta V) is higher in the lighter vehicle, similar to the mass ratio proportion. As a result of the higher change in velocity, the fatality risk may also increase. Removing more mass from the heavier vehicle than in the lighter vehicle by amounts that bring the mass ratio closer to 1.0 reduces the delta V in the lighter vehicle, possibly resulting in a net societal benefit.

Another complexity is that if a vehicle is made lighter, adjustments must be made to the vehicle's structure such that it will be able to manage the energy in a crash while limiting intrusion into the occupant compartment after adopting materials that may be stiffer. To maintain an acceptable occupant compartment deceleration, the effective front end stiffness has to be managed such that the crash pulse does not increase as stiffer yet lighter materials are utilized. If the energy is not well managed, the occupants may have to ''ride down'' a more severe crash pulse, putting more burdens on the restraint systems to protect the occupants. There may be technological and physical limitations to how much the restraint system may mitigate these effects.

The agencies must attempt to estimate now, based on the best information currently available to us, how the assumed levels of mass reduction without additional changes (*i.e.* footprint, performance, functionality) might affect the safety of vehicles, and how lighter vehicles might affect the safety of drivers and passengers in the entire on-road fleet, as we are analyzing potential future CAFE and GHG standards. The agencies seek to ensure that the standards are designed to encourage manufacturers to pursue a path toward compliance that is both cost-effective and safe.

To estimate the possible safety effects of the MY 2017–2025 standards, then, the agencies have undertaken research that approaches this question from several angles. First, we are using a statistical approach to study the effect of vehicle mass reduction on safety historically, as discussed in greater detail in section C below. Statistical analysis is performed using the most recent historical crash data available, and is considered as the agencies' best estimate of potential mass-safety effects. The agencies recognize that negative safety effects estimated based on the historical relationships could potentially be tempered with safety technology advances in the future, and may not represent the current or future fleet. Second, we are using an engineering approach to investigate what amount of mass reduction is affordable and feasible while maintaining vehicle safety and other major functionalities such as NVH and acceleration performance. Third, we are also studying the new challenges these lighter vehicles might bring to vehicle safety and potential countermeasures available to manage those challenges effectively.

The sections below discuss more specifically the state of the research on the mass-safety relationship, and how the agencies integrate that research into our assessment of the potential safety effects of the MY 2017–2025 CAFE and GHG standards.

[179] The agencies recognize that at the other end of the curve, manufacturers who make small cars and trucks below 41 square feet (the small footprint cut-off point) have some incentive to downsize their vehicles to make it easier to meet the constant target. That cut-off may also create some incentive for manufacturers who do not currently offer models that size to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars and trucks smaller than 41 square feet: most consumers likely have some minimum expectation about interior volume, for example, among other things. Additionally, vehicles in this segment are the lowest price point for the light-duty automotive market, with several models in the $10,000-$15,000 range. Manufacturers who find themselves incentivized by the cut-off will also find themselves adding technology to the lowest price segment vehicles, which could make it challenging to retain the price advantage. Because of these two reasons, the agencies believe that the incentive to increase the sales of vehicles smaller than 41 square feet due to this rulemaking, if any, is small. *See* Section II.C.1 above and Chapter 1 of the draft Joint TSD for more information on the agencies' choice of ''cut-off'' points for the footprint-based target curves.

[180] This statement makes no prediction of how consumer choices of vehicle size will change in the future, independent of this proposal.

3. What is the current state of the research on statistical analysis of historical crash data?

a. Background

Researchers have been using statistical analysis to examine the relationship of vehicle mass and safety in historical crash data for many years, and continue to refine their techniques over time. In the MY 2012–2016 final rule, the agencies stated that we would conduct further study and research into the interaction of mass, size and safety to assist future rulemakings, and start to work collaboratively by developing an interagency working group between NHTSA, EPA, DOE, and CARB to evaluate all aspects of mass, size and safety. The team would seek to coordinate government supported studies and independent research, to the greatest extent possible, to help ensure the work is complementary to previous and ongoing research and to guide further research in this area.

The agencies also identified three specific areas to direct research in preparation for future CAFE/GHG rulemaking in regards to statistical analysis of historical data.

First, NHTSA would contract with an independent institution to review the statistical methods that NHTSA and DRI have used to analyze historical data related to mass, size and safety, and to provide recommendation on whether the existing methods or other methods should be used for future statistical analysis of historical data. This study will include a consideration of potential near multicollinearity in the historical data and how best to address it in a regression analysis. The 2010 NHTSA report was also peer reviewed by two other experts in the safety field—Charles Farmer (Insurance Institute for Highway Safety) and Anders Lie (Swedish Transport Administration).[181]

Second, NHTSA and EPA, in consultation with DOE, would update the MYs 1991–1999 database on which the safety analyses in the NPRM and final rule are based with newer vehicle data, and create a common database that could be made publicly available to help address concerns that differences in data were leading to different results in statistical analyses by different researchers.

And third, in order to assess if the design of recent model year vehicles that incorporate various mass reduction methods affect the relationships among vehicle mass, size and safety, the agencies sought to identify vehicles that are using material substitution and smart design, and to try to assess if there is sufficient crash data involving those vehicles for statistical analysis. If sufficient data exists, statistical analysis would be conducted to compare the relationship among mass, size and safety of these smart design vehicles to vehicles of similar size and mass with more traditional designs.

Significant progress has been made on these tasks since the MY 2012–2016 final rule, as follows: The independent review of recent and updated statistical analyses of the relationship between vehicle mass, size, and crash fatality rates has been completed. NHTSA contracted with the University of Michigan Transportation Research Institute (UMTRI) to conduct this review, and the UMTRI team led by Paul Green evaluated over 20 papers, including studies done by NHTSA's Charles Kahane, Tom Wenzel of the US Department of Energy's Lawrence Berkeley National Laboratory, Dynamic Research, Inc., and others. UMTRI's basic findings will be discussed below. Some commenters in recent CAFE rulemakings, including some vehicle manufacturers, suggested that the designs and materials of more recent model year vehicles may have weakened the historical statistical relationships between mass, size, and safety. The agencies agree that the statistical analysis would be improved by using an updated database that reflects more recent safety technologies, vehicle designs and materials, and reflects changes in the overall vehicle fleet. The agencies also believe, as UMTRI also found, that different statistical analyses may have had different results because they each used slightly different datasets for their analyses. In order to try to mitigate this problem and to support the current rulemaking, NHTSA has created a common, updated database for statistical analysis that consists of crash data of model years 2000–2007 vehicles in calendar years 2002–2008, as compared to the database used in prior NHTSA analyses which was based on model years 1991–1999 vehicles in calendar years 1995–2000. The new database is the most up-to-date possible, given the processing lead time for crash data and the need for enough crash cases to permit statistically meaningful analyses. NHTSA has made the new databases available to the public,[182] enabling other researchers to analyze the same data and hopefully minimizing discrepancies in the results that would have been due to inconsistencies across databases.[183] The agencies recognize, however, that the updated database may not represent the future fleet, because vehicles have continued and will continue to change.

The agencies are aware that several studies have been initiated using NHTSA's 2011 newly established safety database. In addition to a new Kahane study, which is discussed in section II.G.4, other on-going studies include two by Wenzel at Lawrence Berkeley National Laboratory (LBNL) under contract with the U.S. DOE, and one by Dynamic Research, Inc. (DRI) contracted by the International Council on Clean Transportation (ICCT). These studies may take somewhat different approaches to examine the statistical relationship between fatality risk, vehicle mass and size. In addition to a detailed assessment of the NHTSA 2011 report, Wenzel is expected to consider the effect of mass and footprint reduction on casualty risk per crash, using data from thirteen states. Casualty risk includes both fatalities and serious or incapacitating injuries. DRI is expected to use a two-stage approach to separate the effect of mass reduction on two components of fatality risk, crash avoidance and crashworthiness. The LBNL assessment of the NHTSA 2011 report is available in the docket for this NPRM.[184] The casualty risk effect study was not available in time to inform this NPRM. The completed final peer reviewed-report on both assessments will be available prior to the final rule. DRI has also indicated that it expects its study to be publicly available prior to the final rule. The agencies will consider these studies and any others that become available, and the results may influence the safety analysis for the final rule.

Other researchers are free to download the database from NHTSA's Web site, and we expect to see additional papers in the coming months and as comments to the rulemaking that may also inform our consideration of these issues for the final rule. Kahane's updated study for 2011 is currently undergoing peer-review, and is available

[181] All three of the peer reviews are in docket, NHTSA–2010–0152. You can access the docket at *http://www.regulations.gov/#!home* by typing 'NHTSA–2010–0152' where it says ''enter keyword or ID'' and then clicking on ''Search.''

[182] The new databases are available at *http://www.nhtsa.gov/fuel-economy* (look for ''Download Crash Databases for Statistical Analysis of Relationships Between Vehicles' Fatality Risk, Mass, and Footprint.''

[183] 75 Fed. Reg. 25324 (May 7, 2010); the discussion of planned statistical analyses is on pp. 25395–25396.

[184] Wenzel, T.P. (2011b). *Assessment of NHTSA's Report ''Relationships between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTVs'',* available at

in the docket for this rulemaking for review by commenters.

Finally, EPA and NHTSA with DOT's Volpe Center, part of the Research and Innovative Technology Administration (RITA), attempted to investigate the implications of ''Smart Design,'' by identifying and describing the types of ''Smart Design'' and methods for using ''Smart Design'' to result in vehicle mass reduction, selecting analytical pairs of vehicles, and using the appropriate crash database to analyze vehicle crash data. The analysis identified several one-vehicle and two-vehicle crash datasets with the potential to shed light on the issue, but the available data for specific crash scenarios was insufficient to produce consistent results that could be used to support conclusions regarding historical performance of ''smart designs.''

Undertaking these tasks has helped the agencies come closer to resolving some of the ongoing debates in statistical analysis research of historical crash data. We intend to apply these conclusions going forward, and we believe that the public discussion of the issues will be facilitated by the research conducted. The following sections discuss the findings from these studies and others in greater detail, to present a more nuanced picture of the current state of the statistical research.

b. NHTSA Workshop on Vehicle Mass, Size and Safety

On February 25, 2011, NHTSA hosted a workshop on mass reduction, vehicle size, and fleet safety at the Headquarters of the U.S. Department of Transportation in Washington, DC.[185] The purpose of the workshop was to provide the agencies with a broad understanding of current research in the field and provide stakeholders and the public with an opportunity to weigh in on this issue. NHTSA also created a public docket to receive comments from interested parties that were unable to attend.

The speakers included Charles Kahane of NHTSA, Tom Wenzel of Lawrence Berkeley National Laboratory, R. Michael Van Auken of Dynamic Research Inc. (DRI), Jeya Padmanaban of JP Research, Inc., Adrian Lund of the Insurance Institute for Highway Safety, Paul Green of the University of Michigan Transportation Research Institute (UMTRI), Stephen Summers of NHTSA, Gregg Peterson of Lotus Engineering, Koichi Kamiji of Honda, John German of the International Council on Clean Transportation (ICCT), Scott Schmidt of the Alliance of Automobile Manufacturers, Guy Nusholtz of Chrysler, and Frank Field of the Massachusetts Institute of Technology.

The wide participation in the workshop allowed the agencies to hear from a broad range of experts and stakeholders. The contributions were particularly relevant to the agencies' analysis of the effects of weight reduction for this proposed rule. The presentations were divided into two sessions that addressed the two expansive sets of issues—statistical evidence of the roles of mass and size on safety, and engineering realities—structural crashworthiness, occupant injury and advanced vehicle design.

The first session focused on previous and ongoing statistical studies of crash data that attempt to identify the relative effects of vehicle mass and size on fleet safety. There was consensus that there is a complicated relationship with many confounding influences in the data. Wenzel summarized a recent study he conducted comparing four types of risk (fatality or casualty risk, per vehicle registration-years or per crash) using police-reported crash data from five states.[186] He showed that the trends in risk for various classes of vehicles (*e.g.,* non-sports car passenger cars, vans, SUVs, crossover SUVs, pickups) were similar regardless of what risk was being measured (fatality or casualty) or what exposure metric was used (*e.g.,* registration years, police-reported crashes, etc.). In general, most trends showed a lower risk for drivers of larger, heavier vehicles.

Although Wenzel's analysis was focused on differences in the four types of risk on the relative risk by vehicle type, he cautioned that, when analyzing casualty risk per crash, analysts should control for driver age and gender, crash location (urban vs. rural), and the state in which the crash occurred (to account for crash reporting biases).

Several participants pointed out that analyses must also control for individual technologies with significant safety effects (*e.g.,* Electronic Stability Control, airbags).It was not always conclusive whether a specialty vehicle group (*e.g.,* sports cars, two-door cars, early crossover SUVs) were outliers that confound the trend or unique datasets that isolate specific vehicle characteristics. Unfortunately, specialty vehicle groups are usually adopted by specific driver groups, often with outlying vehicle usage or driver behavior patterns. Green, who conducted an independent review of the previous statistical analyses, suggested that evaluating residuals will give an indication of whether or not a data subset can be legitimately removed without inappropriately affecting the analytical results.

It was recognized that the physics of a two-vehicle crash require that the lighter vehicle experience a greater change in velocity, which often leads to disproportionately more injury risk. Lund noted persistent historical trends that, in any time period, occupants of the smallest and lightest vehicles had, on average, fatality rates approximately twice those of occupants of the largest and heaviest vehicles but predicted ''the sky will not fall'' as the fleet downsizes, we will not see an increase in absolute injury risk because smaller cars will become increasingly protective of their occupants. Padmanaban also noted in her research of the historical trends that mass ratio and vehicle stiffness are significant predictors with mass ratio consistently the dominant parameter when correlating harm. Reducing the mass of any vehicle may have competing societal effects as it increases the injury risk in the lightened vehicle and decreases them in the partner vehicle

The separation of key parameters was also discussed as a challenge to the analyses, as vehicle size has historically been highly correlated with vehicle mass. Presenters had varying approaches for dealing with the potential multicollinearity between these two variables. Van Auken of DRI stated that there was latitude in the value of Variance Inflation Factor (VIF, a measure of multicollinearity) that would call results into question, and suggested that the large value of VIF for curb weight might imply ''perhaps the effect of weight is too small in comparison to other factors.'' Green, of UMTRI, stated that highly correlated variables may not be appropriate for use in a predictive model and that ''match[ing] on footprint'' (*i.e.,* conducting multiple analyses for data subsets with similar footprint values) may be the most effective way to resolve the issue.

There was no consensus on the overall effect of the maneuverability of smaller, lighter vehicles. German noted that lighter vehicles should have improved handling and braking characteristics and ''may be more likely to avoid collisions''. Lund presented

[185] A video recording, transcript, and the presentations from the NHTSA workshop on mass reduction, vehicle size and fleet safety is available at *http://www.nhtsa.gov/fuel-economy* (look for ''NHTSA Workshop on Vehicle Mass-Size-Safety on Feb. 25'')

[186] Wenzel, T.P. (2011a). *Analysis of Casualty Risk per Police-Reported Crash for Model Year 2000 to 2004 Vehicles, using Crash Data from Five States,* March 2011, LBNL–4897E, available at: *http://eetd.lbl.gov/EA/teepa/pub.html#Vehicle*

crash involvement data that implied that, among vehicles of similar function and use rates, crash risk does not go down for more ''nimble'' vehicles. Several presenters noted the difficulties of projecting past data into the future as new technologies will be used that were not available when the data were collected. The advances in technology through the decades have dramatically improved safety for all weight and size classes. A video of IIHS's 50th anniversary crash test of a 1959 Chevrolet Bel Air and 2009 Chevrolet Malibu graphically demonstrated that stark differences in design and technology that can possibly mask the discrete mass effects, while videos of compatibility crash tests between smaller, lighter vehicles and contemporary larger, heavier vehicles graphically showed the significance of vehicle mass and size.

Kahane presented results from his 2010 report[187] that found that a scenario which took some mass out of heavier vehicles but little or no mass out of the lightest vehicles did not impact safety in absolute terms. Kahane noted that if the analyses were able to consider the mass of both vehicles in a two-vehicle crash, the results may be more indicative of future crashes. There is apparent consistency with other presentations (*e.g.,* Padmanaban, Nusholtz) that reducing the overall ranges of masses and mass ratios seems to reduce overall societal harm. That is, the effect of mass reduction exclusively does not appear to be a ''zero sum game'' in which any increase in harm to occupants of the lightened vehicle is precisely offset by a decrease in harm to the occupants of the partner vehicle. If the mass of the heavier vehicle is reduced by a larger percentage, the changes in velocity from the collision are more nearly equal and the injuries suffered in the lighter vehicle are likely to be reduced more than the injuries in the heavier vehicle are increased. Alternatively, a fixed mass reduction (say, 100 lbs) in all vehicles could increase societal harm whereas a fixed percentage mass reduction is more likely to be neutral.

Padmanaban described a series of studies conducted in recent years. She included numerous vehicle parameters including bumper height and several measures of vehicle size and stiffness and also commented on previous analyses that using weight and wheelbase together in a logistic model distorts the estimates, resulting in inflated variance with wrong signs and magnitudes in the results. Her results consistently showed that vehicle mass ratio was a more important parameter than those describing vehicle geometry or stiffness. Her ultimate conclusion was that removing mass (*e.g.,* 100 lbs.) from all passenger cars would cause an overall increase in fatalities in truck-to-car crashes while removing the same amount from light trucks would cause an overall decrease in fatalities.

c. Report by Green et al., UMTRI—''Independent Review: Statistical Analyses of Relationship Between Vehicle Curb Weight, Track Width, Wheelbase and Fatality Rates,'' April 2011.

As explained above, NHTSA contracted with the University of Michigan Transportation Research Institute (UMTRI) to conduct an independent review;[188] of a set of statistical analyses of relationships between vehicle curb weight, the footprint variables (track width, wheelbase) and fatality rates from vehicle crashes. The purpose of this review was to examine analysis methods, data sources, and assumptions of the statistical studies, with the objective of identifying the reasons for any differences in results. Another objective was to examine the suitability of the various methods for estimating the fatality risks of future vehicles.

UMTRI reviewed a set of papers, reports, and manuscripts provided by NHTSA (listed in Appendix A of UMTRI's report, which is available in the docket to this rulemaking) that examined the statistical relationships between fatality or casualty rates and vehicle properties such as curb weight, track width, wheelbase and other variables.

It is difficult to summarize a study of that length and complexity for purposes of this discussion, but fundamentally, the UMTRI team concluded the following:

> Differences in data may have complicated comparisons of earlier analyses, but if the methodology is robust, and the methods were applied in a similar way, small changes in data should not lead to different conclusions. The main conclusions and findings should be reproducible. The data base created by Kahane appears to be an impressive collection of files from appropriate sources and the best ones available for answering the research questions considered in this study.
>
> In statistical analysis simpler models generally lead to improved inference, assuming the data and model assumptions are appropriate. In that regard, the disaggregate logistic regression model used by NHTSA in the 2003 report[189] seems to be the most appropriate model, and valid for the analysis in the context that it was used: finding general associations between fatality risk and mass—and the general directions of the reported associations are correct.
>
> The two-stage logistic regression model in combination with the two-step aggregate regression used by DRI seems to be more complicated than is necessary based on the data being analyzed, and summing regression coefficients from two separate models to arrive at conclusions about the effects of reductions in weight or size on fatality risk seems to add unneeded complexity to the problem.
>
> One of the biggest issues regarding this work is the historical correlation between curb weight, wheelbase, and track width. Including three variables that are highly correlated in the same model can have adverse effects on the fit of the model, especially with respect to the parameter estimates, as discussed by Kahane. UMTRI makes no conclusions about multicollinearity, other than to say that inferences made in the presence of multicollinearity should be judged with great caution. At the NHTSA workshop on size, safety and mass, Paul Green suggested that a matched analysis, in which regressions are run on the relationship between mass reduction and risk separately for vehicles of similar footprint, could be undertaken to investigate the effect of multicollinearity between vehicle mass and size. Kahane has combined wheelbase and track width into one variable (footprint) to compare with curb weight. NHTSA believes that the 2011 Kahane analysis has done all it can to lessen concerns about multicollinearity, but a concern still exists. In considering other studies provided by NHTSA for evaluation by the UMTRI team:

○ Papers by Wenzel, and Wenzel and Ross, addressing associations between fatality risk per vehicle registration-year, weight, and size by vehicle model contribute to understanding some of the relationships between risk, weight, and size. However, least squares linear regression models, without

[187] Kahane, C. J. (2010). ''Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991–1999 and Other Passenger Cars and LTVs,'' *Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012–MY 2016 Passenger Cars and Light Trucks.* Washington, DC: National Highway Traffic Safety Administration, pp. 464–542, available at *http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE_2012–2016_FRIA_04012010.pdf.*

[188] The review is independent in the sense that it was conducted by an outside third party without any interest in the reported outcome.

[189]

modification, are not exposure-based risk models and inference drawn from these models tends to be weak since they do not account for additional differences in vehicles, drivers, or crash conditions that could explain the variance in risk by vehicle model.

◦ A 2009 J.P. Research paper focused on the difficulties associated with separating out the contributions of weight and size variables when analyzing fatality risk properly recognized the problem arising from multicollinearity and included a clear explanation of why fatality risk is expected to increase with increasing mass ratio. UMTRI concluded that the increases in fatality risk associated with a 100-pound reduction in weight allowing footprint to vary with weight as estimated by Kahane and JP Research, are broadly more convincing than the 6.7 percent reduction in fatality risk associated with mass reduction while holding footprint constant, as reported by DRI.

◦ A paper by Nusholtz et al. focused on the question of whether vehicle size can reasonably be the dominant vehicle factor for fatality risk, and finding that changing the mean mass of the vehicle population (leaving variability unchanged) has a stronger influence on fatality risk than corresponding (feasible) changes in mean vehicle dimensions, concluded unequivocally that reducing vehicle mass while maintaining constant vehicle dimensions will increase fatality risk. UMTRI concluded that if one accepts the methodology, this conclusion is robust against realistic changes that may be made in the force vs. deflection characteristics of the impacting vehicles.

◦ Two papers by Robertson, one a commentary paper and the other a peer-reviewed journal article, were reviewed. The commentary paper did not fit separate models according to crash type, and included passenger cars, vans, and SUVs in the same model. UMTRI concluded that some of the claims in the commentary paper appear to be overstated, and intermediate results and more documentation would help the reader determine if these claims are valid. The second paper focused largely on the effects of electronic stability control (ESC), but generally followed on from the first paper except that curb weight is not fit and fuel economy is used as a surrogate.

The UMTRI study provided a number of useful suggestions that Kahane considered in updating his 2011 analysis, and that have been incorporated into the safety effects estimates for the current rulemaking.

d. Report by Dr. Charles Kahane, NHTSA—''Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTVs,'' 2011

The relationship between a vehicle's mass, size, and fatality risk is complex, and it varies in different types of crashes. NHTSA, along with others, has been examining this relationship for over a decade. The safety chapter of NHTSA's April 2010 final regulatory impact analysis (FRIA) of CAFE standards for MY 2012–2016 passenger cars and light trucks included a statistical analysis of relationships between fatality risk, mass, and footprint in MY 1991–1999 passenger cars and LTVs (light trucks and vans), based on calendar year (CY) 1995–2000 crash and vehicle-registration data.[190] The 2010 analysis used the same data as the 2003 analysis, but included vehicle mass and footprint in the same regression model.

The principal findings of NHTSA's 2010 analysis were that mass reduction in lighter cars, even while holding footprint constant, would significantly increase societal fatality risk, whereas mass reduction in the heavier LTVs would significantly reduce net societal fatality risk, because it would reduce the fatality risk of occupants in lighter vehicles which collide with the heavier LTVs. NHTSA concluded that, as a result, any reasonable combination of mass reductions while holding footprint constant in MY 2012–2016 vehicles—concentrated, at least to some extent, in the heavier LTVs and limited in the lighter cars—would likely be approximately safety-neutral; it would not significantly increase fatalities and might well decrease them.

NHTSA's 2010 report partially agreed and partially disagreed with analyses published during 2003–2005 by Dynamic Research, Inc. (DRI). NHTSA and DRI both found a significant protective effect for footprint, and that reducing mass *and* footprint together (downsizing) on smaller vehicles was harmful. DRI's analyses estimated a significant overall reduction in fatalities from mass reduction in all light-duty vehicles if wheelbase and track width were maintained, whereas NHTSA's report showed overall fatality reductions only in the heavier LTVs, and benefits only in some types of crashes for other vehicle types. Much of NHTSA's 2010 report, as well as recent work by DRI, involved sensitivity tests on the databases and models, which generated a range of estimates somewhere between the initial DRI and NHTSA results.[191]

Immediately after issuing the final rule for MYs 2012–2016 CAFE and GHG standards in May 2010, NHTSA and EPA began work on the next joint rulemaking to develop CAFE and GHG standards for MY 2017 to 2025 and beyond. The preamble to the 2012–2016 final rule stated that NHTSA, working closely with EPA and the Department of Energy (DOE), would perform a new statistical analysis of the relationships between fatality rates, mass and footprint, updating the crash and exposure databases to the latest available model years, refining the methodology in response to peer reviews of the 2010 report and taking into account changes in vehicle technologies. The previous databases of MY 1991–1999 vehicles in CY 1995–2000 crashes has become outdated as new safety technologies, vehicle designs and materials were introduced. The new databases comprising MY 2000–2007 vehicles in CY 2002–2008 crashes with the most up-to-date possible, given the processing lead time for crash data and the need for enough crash cases to permit statistically meaningful analyses. NHTSA has made the new databases available to the public,[192] enabling other researchers to analyze the same data and hopefully minimizing discrepancies in the results due to inconsistencies across the data used.[193]

One way to estimate these effects is via statistical analyses of societal fatality

[190] Kahane, C. J. (2010). ''Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991–1999 and Other Passenger Cars and LTVs,'' *Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012–MY 2016 Passenger Cars and Light Trucks.* Washington, DC: National Highway Traffic Safety Administration, pp. 464–542, available at *http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE_2012-2016_FRIA_04012010.pdf.*

[191] Van Auken, R. M., and Zellner, J. W. (2003). *A Further Assessment of the Effects of Vehicle Weight and Size Parameters on Fatality Risk in Model Year 1985–98 Passenger Cars and 1986–97 Light Trucks.* Report No. DRI–TR–03–01. Torrance, CA: Dynamic Research, Inc.; Van Auken, R. M., and Zellner, J. W. (2005a). *An Assessment of the Effects of Vehicle Weight and Size on Fatality Risk in 1985 to 1998 Model Year Passenger Cars and 1985 to 1997 Model Year Light Trucks and Vans.* Paper No. 2005–01–1354. Warrendale, PA: Society of Automotive Engineers; Van Auken, R. M., and Zellner, J. W. (2005b). *Supplemental Results on the Independent Effects of Curb Weight, Wheelbase, and Track on Fatality Risk in 1985–1998 Model Year Passenger Cars and 1986–97 Model Year LTVs.* Report No. DRI–TR–05–01. Torrance, CA: Dynamic Research, Inc.; Van Auken, R.M., and Zellner, J. W. (2011). ''Updated Analysis of the Effects of Passenger Vehicle Size and Weight on Safety,'' *NHTSA Workshop on Vehicle Mass-Size-Safety,* Washington, February 25, 2011, *http://www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/MSSworkshop_VanAuken.pdf*

[192] *http://www.nhtsa.gov/fuel-economy.*

[193] 75 FR 25324 (May 7, 2010); the discussion of planned statistical analyses is on pp. 25395–25396.

rates per vehicle miles traveled (VMT), by vehicles' mass and footprint, for the current on-road vehicle fleet. The basic analytical method used for the 2011 NHTSA report is the same as in NHTSA's 2010 report: Cross-sectional analyses of the effect of mass and footprint reductions on the *societal* fatality rate per billion vehicle miles of travel (VMT), while controlling for driver age and gender, vehicle type, vehicle safety features, crash times and locations, and other factors. Separate logistic regression models are run for three types of vehicles and nine types of crashes. Societal fatality rates include occupants of all vehicles in the crash, as well as non-occupants, such as pedestrians and cyclists. NHTSA's 2011 Report [194] analyzes MY 2000–2007 cars and LTVs in CY 2002–2008 crashes. Fatality rates were derived from FARS data, 13 State crash files, and registration and mileage data from R.L. Polk.

The most noticeable change in MY 2000–2007 vehicles from MY 1991–1999 has been the increase in crossover utility vehicles (CUV), which are SUVs of unibody construction, often but not always built upon a platform shared with passenger cars. CUVs have blurred the distinction between cars and trucks. The new analysis treats CUVs and minivans as a separate vehicle class, because they differ in some respects from pickup-truck-based LTVs and in other respects from passenger cars. In the 2010 report, the many different types of LTVs were combined into a single analysis and NHTSA believes that this may have made the analyses too complex and might have contributed to some of the uncertainty in the results.

The new database has accurate VMT estimates, derived from a file of odometer readings by make, model, and model year recently developed by R.L. Polk and purchased by NHTSA.[195] For the 2011 report, the relative distribution of crash types has been changed to reflect the projected distribution of crashes during the period from 2017 to 2025, based on the estimated effectiveness of electronic stability control (ESC) in reduction the number of fatalities in rollover crashes and crashes with a stationary object. The annual target population of fatalities or the annual fatality distribution baseline [196] was not decreased in the period between 2017 and 2025 for the safety statistics analysis, but is taken into account later in the Volpe model analysis, since all vehicles in the future will be equipped with ESC.[197]

For the 2011 report, vehicles are now grouped into five classes rather than four: passenger cars (including both 2-door and 4-door cars) are split in half by median weight; CUVs and minivans; and truck-based LTVs, which are also split in half by median weight of the model year 2000–2007 vehicles. Table II–12 presents the estimated percent increase in U.S. societal fatality risk per ten billion VMT for each 100-pound reduction in vehicle mass, while holding footprint constant, for each of the five classes of vehicles.

Table II-12 Results of 2011 NHTSA report Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

MY 2000-2007 CY 2002-2008	Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint Constant	
	Point Estimate	95% Confidence Bounds
Cars < 3,106 pounds	1.44	+ .29 to +2.59
Cars ≥ 3,106 pounds	.47	- .58 to +1.52
CUVs and minivans	- .46	-1.75 to + .83
Truck-based LTVs < 4,594 pounds	.52	- .43 to +1.46
Truck-based LTVs ≥ 4,594 pounds	- .39	-1.06 to + .27

Only the 1.44 percent risk increase in the lighter cars is statistically significant. There are non-significant increases in the heavier cars and the lighter truck-based LTVs, and non-significant societal benefits for mass

[194] Kahane, C. J. (2011). ''Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTVs,'' July 2011. The report is available in the NHTSA docket, NHTSA–2010–0152. You can access the docket at *http://www.regulations.gov/#!home* by typing 'NHTSA–2010–0152' where it says ''enter keyword or ID'' and then clicking on ''Search.''

[195] In the 1991–1999 data base, VMT was estimated only by vehicle class, based on NASS CDS data.

[196] MY 2004–2007 vehicles with fatal crashes occurred in CY 2004–2008 are selected as the annual fatality distribution baseline in the Kahane analysis.

[197] In the Volpe model, NHTSA assumed that the safety trend would result in 12.6 percent reduction between 2007 and 2020 due to the combination of ESC, new safety standard, and behavior changes anticipated.

reduction in CUVs, minivans, and the heavier truck-based LTVs. Based on these results, potential combinations of mass reductions that maintain footprint and are proportionately somewhat higher for the heavier vehicles may be safety-neutral or better as point estimates and, in any case, unlikely to significantly increase fatalities. The primarily non-significant results are not due to a paucity of data, but because the societal effect of mass reduction while maintaining footprint, if any, is small.

MY 2000–2007 vehicles of all types are heavier and larger than their MY 1991–1999 counterparts. The average mass of passenger cars increased by 5 percent from 2000 to 2007 and the average mass of pickup trucks increased by 19 percent. Other types of vehicles became heavier, on the average, by intermediate amounts. There are several reasons for these increases: during this time frame, some of the lighter make-models were discontinued; many models were redesigned to be heavier and larger; and consumers more often selected stretched versions such as crew cabs in their new-vehicle purchases.

It is interesting to compare the new results to NHTSA's 2010 analysis of MY 1991–1999 vehicles in CY 1995–2000, especially the new point estimate to the ''actual regression result scenario'' in the 2010 report:

Table II-13 2010 Report: MY 1991-1999, CY 1995-2000 Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

	Actual Regression Result Scenario	Upper-Estimate Scenario	Lower-Estimate Scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	0.90	0.90	0.44
LTVs < 3,870 pounds	0.17	0.55	0.41
LTVs ≥ 3,870 pounds	-1.90	-0.62	-0.73

Table II-14 Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

	NHTSA (2010)	NHTSA (2011)
Lighter cars	2.21%	1.43%
Heavier cars	0.89%	0.48%
Lighter LTVs	0.17%*	0.52%
Heavier LTVs	-1.90%*	-0.40%
CUV/ minivan		-0.47%

*Includes CUV/minivan

The new results are directionally the same as in 2010: fatality increase in the lighter cars, safety benefit in the heavier LTVs, but the effects may have become weaker at both ends. (The agencies do not consider this conclusion to be definitive because of the relatively wide confidence bounds of the estimates.) The fatality increase in the lighter cars tapered off from 2.21 percent to 1.44 percent while the societal benefit of mass reduction in the heaviest LTVs diminished from 1.90 percent to 0.39 percent and is no longer statistically significant.

The agencies believe that the changes may be due to a combination of both changes in the characteristics of newer vehicles and revisions to the analysis. NHTSA believes, above all, that several light, small car models with poor safety performance were discontinued by 2000 or during 2000–2007. Also, the tendency of light, small vehicles to be driven poorly is not as strong as it used to be—perhaps in part because safety improvements in lighter and smaller vehicles have made some good drivers more willing to buy them. Both agencies believe that at the other end of the weight/size spectrum, blocker beams and other voluntary compatibility improvements in LTVs, as well as compatibility-related self-protection improvements to cars, have made the heavier LTVs less aggressive in collisions with lighter vehicles (although the effect of mass disparity remains). This report's analysis of CUVs and minivans as a separate class of vehicles may have relieved some inaccuracies in the 2010 regression results for LTVs. Interestingly, the new actual-regression results are quite close to the previous report's ''lower-estimate scenario,'' which was an attempt to adjust for supposed inaccuracies in some regressions and for a seemingly excessive trend toward higher crash rates in smaller and lighter cars.

The principal difference between the heavier vehicles, especially truck-based LTVs, and the lighter vehicles, especially passenger cars, is that mass reduction has a different effect in collisions with another car or LTV. When two vehicles of unequal mass collide, the delta V is higher in the lighter vehicle, in the same proportion as the mass ratio. As a result, the fatality risk is also higher. Removing some mass from the heavy vehicle reduces delta V in the lighter vehicle, where fatality risk is high, resulting in a large benefit, offset by a small penalty because delta V increases in the heavy vehicle, where fatality risk is low—adding up to a net societal benefit. Removing some mass from the lighter vehicle results in a large penalty offset by a small benefit—adding up to net harm. These considerations drive the overall result: fatality increase in the lighter cars, reduction in the heavier LTVs, and little effect in the intermediate groups. However, in some types of crashes, especially first event rollovers and impacts with fixed objects, mass reduction is usually not harmful and often beneficial, because the lighter vehicles respond more quickly to braking and steering and are often more stable because their center of gravity is lower. Offsetting that benefit is the continuing historical tendency of lighter and smaller vehicles to be driven less well—although it continues to be unknown why that is so, and to what extent, if any, the lightness or smallness of the vehicle contributes to people driving it less safely.

The estimates of the model are formulated for each 100-pound reduction in mass; in other words, if risk increases by 1 percent for 100 pounds reduction in mass, it would increase by 2 percent for a 200-pound reduction, and 3 percent for a 300-pound reduction (more exactly, 2.01 percent and 3.03 percent, because the effects work like compound interest). Confidence bounds around the point estimates will grow wider by the same proportions.

The regression results are best suited to predict the effect of a small change in mass, leaving all other factors, including footprint, the same. With each additional change from the current environment, the model may become somewhat less accurate and it is difficult to assess the sensitivity to additional mass reduction greater than 100 pounds. The agencies recognize that the light-duty vehicle fleet in the 2017–2025 timeframe will be different than the 2000–2007 fleet analyzed for this study. Nevertheless, one consideration provides some basis for confidence. This is NHTSA's fourth evaluation of the effects of mass reduction and/or downsizing, comprising databases ranging from MY 1985 to 2007. The results of the four studies are not identical, but they have been consistent up to a point. During this time period, many makes and models have increased substantially in mass, sometimes as much as 30–40 percent.[198] If the statistical analysis has, over the past years, been able to accommodate mass increases of this magnitude, perhaps it will also succeed in modeling the effects of mass reductions on the order of 10–20 percent, if they occur in the future.

e. Report by Tom Wenzel, LBNL, ''An Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTVs'' ', 2011

DOE contracted with Tom Wenzel of Lawrence Berkeley National Laboratory to conduct an assessment of NHTSA's updated 2011 study of the effect of mass and footprint reductions on U.S. fatality risk per vehicle miles traveled, and to provide an analysis of the effect of mass and footprint reduction on casualty risk per police-reported crash, using independent data from thirteen states. The assessment has been completed and reviewed by NHTSA and EPA staff, and a draft final version is included in the docket of today's rulemaking; the separate analysis of crash data from thirteen states will be completed and included in the docket shortly. Both reports will be peer reviewed by outside experts.

The LBNL report replicates Kahane's analysis for NHTSA, using the same data and methods, and in many cases using the same SAS programs. The Wenzel report finds that although mass reduction in lighter (less than 3,106 lbs) cars leads to a statistically significant 1.44% increase in fatality risk per vehicle miles travelled (VMT), the increase is small. He tests this result for sensitivity to changes in specifications of the regression models and what data are used. In addition Wenzel shows that there is a wide range in fatality rates by vehicle model for models that have the same mass, even after accounting for differences in drivers' age and gender, safety features installed, and crash times and locations. This section summarizes the results of the Wenzel assessment of the most recent NHTSA analysis.

The LBNL report highlights the effect of the other driver, vehicle, and crash control variables, in addition to the effect of mass and footprint reduction, on risk. Some of the other variables NHTSA included in its regression models have much larger effects on fatality risk than mass or footprint reduction. For example, the models indicate that a 100-lb increase in the mass of a lighter car results in a 1.44% reduction in fatality risk; this is the largest estimated effect of changes in vehicle mass, and the only one that is statistically significant. For comparison this reduction in fatality risk could also be achieved by a 13% increase in 4-door sedans equipped with ESC.

The 1.44% increase in risk from reducing mass in the lighter cars was

[198] For example, one of the most popular models of small 4-door sedans increased in curb weight from 1,939 pounds in MY 1985 to 2,766 pounds in MY 2007, a 43 percent increase. A high-sales mid-size sedan grew from 2,385 to 3,354 pounds (41%); a best-selling pickup truck from 3,390 to 4,742 pounds (40%) in the basic model with 2-door cab and rear-wheel drive; and a popular minivan from 2,940 to 3,862 pounds (31%).

tested for sensitivity changes in the specification of, or the data used in, the regression models. For example, using the current distribution of crashes, rather than adjusting the distribution to that expected after full adoption of ESC, reduces the effect to 1.18%; excluding the calendar year variables from the model, which may be weakening the modeled benefits of vehicle safety technologies, reduces the effect to 1.39%; and including vehicle make in the model increases the effect to 1.81%. The results also are sensitive to the selection of data to include in the analysis: Excluding bad drivers increases the effect to 2.03%, while excluding crashes involving alcohol or drugs increases the effect to 1.66%, and including sports, police, and all-wheel drive cars increases the effect to 1.64%. Finally, changing the definition of risk also affects the result for lighter cars: Using the number of fatalities per induced exposure crash reduces the effect to −0.24% (that is, a 0.24% reduction in risk), while using the number of fatal crashes (rather than total fatalities) per VMT increases the effect to 1.84%. These sensitivity tests, except one, changed the estimated coefficient by less than 1 percentage point, which is within its statistical confidence bounds of 0.29 to 2.59 percent and may be considered compatible with the baseline result. Using two or more variables that are strongly correlated in the same regression model (referred to as multicollinearity) can lead to inaccurate results. However, the correlation between vehicle mass and footprint may not be strong enough to cause serious concern. Experts suggest that a correlation of greater than 0.60 (or a variance inflation factor of 2.5) raises concern about multicollinearity.[199] The correlation between vehicle mass and footprint ranges from over 0.80 for four-door sedans, pickups, and SUVs, to about 0.65 for two-door cars and CUVs, to 0.26 for minivans; when pickups and SUVs are considered together, the correlation between mass and footprint is 0.65. Wenzel notes that the 2011 NHTSA report recognizes that the ''near'' multicollinearity between mass and footprint may not be strong enough to invalidate the results from a regression model that includes both variables. In addition, NHTSA included several analyses to address possible effects of the near-multicollinearity between mass and footprint.

First, NHTSA ran a sensitivity model specification, where footprint is not held constant, but rather allowed to vary as mass varies (*i.e.* NHTSA ran a regression model which includes mass but not footprint). If the multicollinearity was so great that including both variables in the same model gave misleading results, removing footprint from the model could give mass coefficients five or more percentage points different than keeping it in the model. NHTSA's sensitivity test indicates that when footprint is allowed to vary with mass, the effect of mass reduction on risk increases from 1.44% to 2.64% for lighter cars, and from a non-significant 0.47% to a statistically-significant 1.94% for heavier cars (changes of less than two percentage points); however, the effect of mass reduction on light trucks is unchanged, and is still not statistically significant for CUVs/minivans.

Second, NHTSA conducted a stratification analysis of the effect of mass reduction on risk by dividing vehicles into deciles based on their footprint, and running a separate regression model for each vehicle and crash type, for each footprint decile (3 vehicle types times 9 crash types times 10 deciles equals 270 regressions). This analysis estimates the effect of mass reduction on risk separately for vehicles with similar footprint. The analysis indicates that mass reduction does not consistently increase risk across all footprint deciles for any combination of vehicle type and crash type. Mass reduction increases risk in a majority of footprint deciles for 13 of the 27 crash and vehicle combinations, but few of these increases are statistically significant. On the other hand, mass reduction *decreases* risk in a majority of footprint deciles for 9 of the 27 crash and vehicle combinations; in some cases these risk reductions are large and statistically significant.[200] If reducing vehicle mass while maintaining footprint inherently leads to an increase in risk, the coefficients on mass reduction should be more consistently positive, and with a larger R^2, across the 27 vehicle/crash combinations, than shown in the analysis. These findings are consistent with the conclusion of the basic regression analyses, namely, that the effect of mass reduction while holding footprint constant, if any, is small.

One limitation of using logistic regression to estimate the effect of mass reduction on risk is that a standard statistic to measure the extent to which the variables in the model explain the range in risk, equivalent to the $R^2\leq$ statistic in a linear regression model, does not exist. (SAS does generate a pseudo-R^2 value for logistic regression models; in almost all of the NHTSA regression models this value is less than 0.10). For this reason LBNL conducted an analysis of risk versus mass by vehicle model. LBNL used the results of the NHTSA logistic regression model to predict the number of fatalities expected after accounting for all vehicle, driver, and crash variables included in the NHTSA regression model except for vehicle weight and footprint. LBNL then plotted expected fatality risk per VMT by vehicle model against the mass of each model, and analyzed the change in risk as mass increases, as well as how much of the change in risk was explained by all of the variables included in the model.

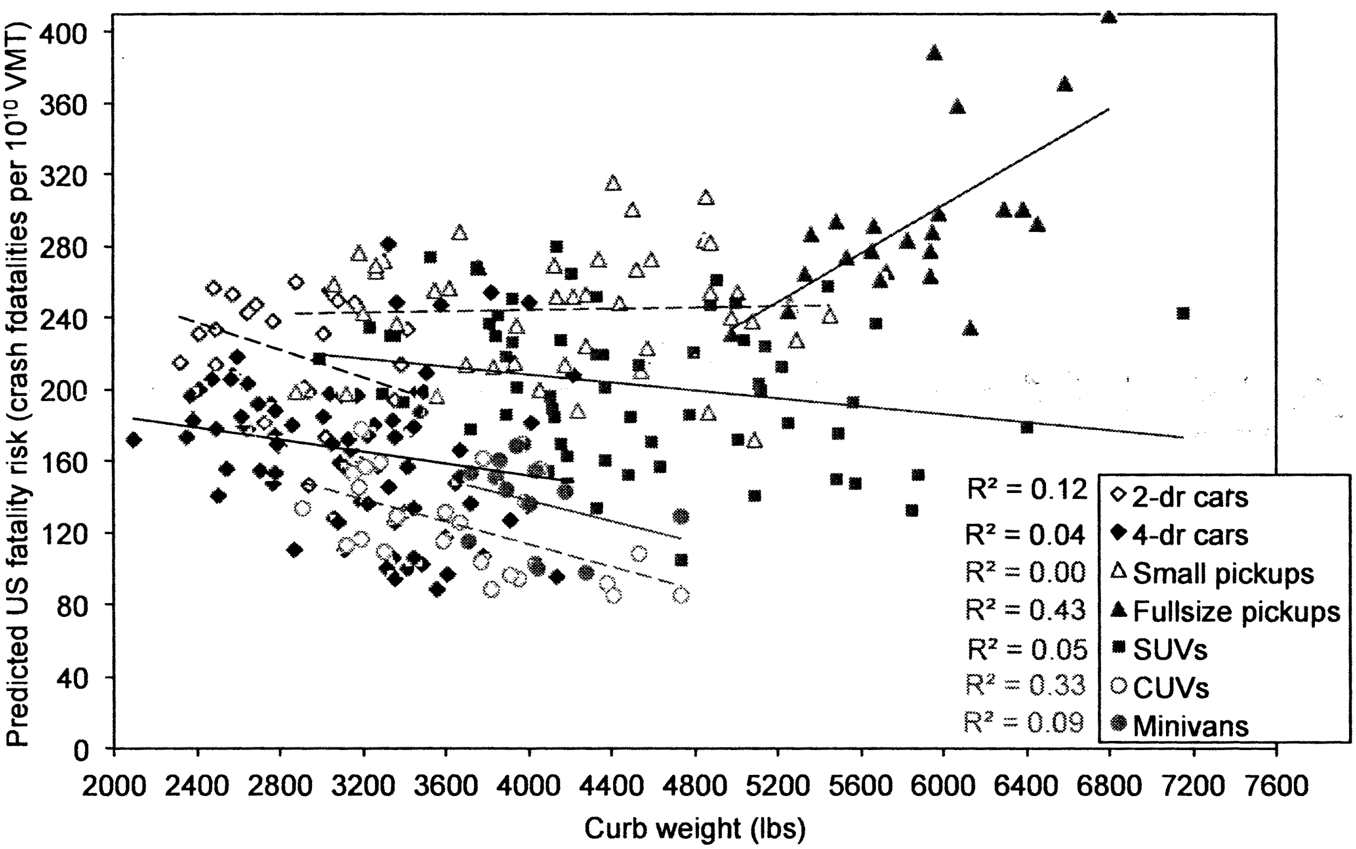
The analysis indicates that, after accounting for all the variables, risk does decrease as mass increases; however, risk and mass are not strongly correlated, with the R^2 ranging from 0.33 for CUVs to less than 0.15 for all other vehicle types (as shown in Figure x). This means that, on average, risk decreases as mass increases, but the variation in risk among individual vehicle models is stronger than the trend in risk from light to heavy vehicles. For fullsize (*i.e.* 3/4- and 1-ton) pickups, risk increases as mass increases, with an R^2 of 0.43, consistent with NHTSA's basic regression results for the heavier LTVs (societal risk increases as mass increases). LBNL also examined the relationship between residual risk, that is the remaining unexplained risk after accounting for all vehicle, driver and crash variables, and mass, and found similarly poor correlations. This implies that the remaining factors not included in the regression model that account for the observed range in risk by vehicle model also are not correlated with mass. (LBNL found similar results when the analysis compared risk to vehicle footprint.)

Figure II–2 indicates that some vehicles on the road today have the same, or lower, fatality rates than models that weigh substantially more, and are substantially larger in terms of footprint. After accounting for differences in driver age and gender, safety features installed, and crash times and locations, there are numerous examples of different models with similar weight and footprint yet widely varying fatality rates. The variation of fatality rates among individual models may reflect differences in vehicle

[199] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, April 1, 2010, Section II.G.3., page 139.

[200] And in 5 of the 27 crash and vehicle combinations, mass reduction increased risk in 5 deciles and decreased risk in 5 deciles.

design, differences in the drivers who choose such vehicles (beyond what can be explained by demographic variables such as age and gender), and statistical variation of fatality rates based on limited data for individual models. Differences in vehicle design can, and already do, mitigate some safety penalties from reduced mass; this is consistent with NHTSA's opinion that some of the changes in its regression results between the 2003 study and the 2011 study are due to the redesign or removal of certain smaller and lighter models of poor design.



f. Based on this information, what do the agencies consider to be the current state of statistical research on vehicle mass and safety?

The agencies believe that statistical analysis of historical crash data continues to be an informative and important tool in assessing the potential safety impacts of the proposed standards. The effect of mass reduction while maintaining footprint is a complicated topic and there are open questions whether future designs will reduce the historical correlation between weight and size. It is important to note that while the updated database represents more current vehicles with technologies more representative of vehicles on the road today, they still do not fully represent what vehicles will be on the road in the 2017–2025 timeframe. The vehicles manufactured in the 2000–2007 timeframe were not subject to footprint-based fuel economy standards. The agencies expect that the attribute-based standards will likely facilitate the design of vehicles such that manufacturers may reduce mass while maintaining footprint. Therefore, it is possible that the analysis for 2000–2007 vehicles may not be fully representative of the vehicles that will be on the road in 2017 and beyond.

While we recognize that statistical analysis of historical crash data may not be the only way to think about the future relationship between vehicle mass and safety, we also recognize that other assessment methods are also subject to uncertainties, which makes statistical analysis of historical data an important starting point if employed mindfully and recognized for how it can be useful and what its limitations may be.

NHTSA undertook the independent review of statistical studies and held the mass-safety workshop in February 2011 in order to help the agencies sort through the ongoing debates over what statistical analysis of historical data is actually telling us. Previously, the agencies have assumed that differences in results were due in part to inconsistent databases; by creating the updated common database and making it publicly available, we are hopeful that that aspect of the problem has been resolved, and moreover, the UMTRI review suggested that differences in data were probably less significant than the agencies may have thought. Statistical analyses of historical crash data should be examined for potential multicollinearity issues. The agencies will continue to monitor issues with multicollinearity in our analyses, and hope that outside researchers will do the same. And finally, based on the findings of the independent review, the agencies continue to be confident that Kahane's analysis is one of the best for the purpose of analyzing potential safety effects of future CAFE and GHG standards. UMTRI concluded that Kahane's approach is valid, and Kahane has continued and refined that approach for the current analysis. The NHTSA 2011 statistical fatality report finds directionally similar but less statistically significant relationships between vehicle mass, size, and footprint, as discussed above. Based on these findings, the agencies believe that in the future, fatalities due to mass reduction will be best reduced if mass reduction is concentrated in the heaviest vehicles. NHTSA considers part of the reason that more recent historical data shows a dampened effect in the relationship between mass reduction and safety is that all vehicles, including traditionally lighter ones, grew heavier during that timeframe (2000s). As lighter vehicles might become more prevalent in the fleet again over the next decade, it is possible that the trend could strengthen again. On the other hand, extensive use of new lightweight materials and optimized vehicle design may weaken the relationship. Future updated analyses will be necessary to determine how the effect of mass reduction on risk changes over time.

Both agencies agree that there are several identifiable safety trends already in place or expected to occur in the foreseeable future that are not accounted for in the study, since they were not in effect at the time that the vehicles in question were manufactured. For example, there are two important new safety standards that have already been issued and will be phasing in after MY 2008. FMVSS No. 126 (49 CFR § 571.126) requires electronic stability control in all new vehicles by MY 2012, and the upgrade to FMVSS No. 214 (Side Impact Protection, 49 CFR § 571.214) will likely result in all new vehicles being equipped with head-curtain air bags by MY 2014. Additionally, we anticipate continued improvements in driver (and passenger) behavior, such as higher safety belt use rates. All of these may tend to reduce the absolute number of fatalities. On the other hand, as crash avoidance technology improves, future statistical analysis of historical data may be complicated by a lower number of crashes. In summary, the agencies have relied on the coefficients in the Kahane 2011 study for estimating the potential safety effects of the proposed CAFE and GHG standards for MYs 2017–2025, based on our assumptions regarding the amount of mass reduction that could be used to meet the standards in a cost-effective way without adversely affecting safety. Section E below discusses the methodology used by the agencies in more detail; while the results of the safety effects analysis are less significant than the results in the MY 2012–2016 final rule, the agencies still believe that any statistically significant results warrant careful consideration of the assumptions about appropriate levels of mass reduction on which to base future CAFE and GHG standards, and have acted accordingly in developing the proposed standards.

4. How do the agencies think technological solutions might affect the safety estimates indicated by the statistical analysis?

As mass reduction becomes a more important technology option for manufacturers in meeting future CAFE and GHG standards, manufacturers will invest more and more resources in developing increasingly lightweight vehicle designs that meet their needs for manufacturability and the public's need for vehicles that are also safe, useful, affordable, and enjoyable to drive. There are many different ways to reduce mass, as discussed in Chapter 3 of this TSD and in Sections II, III, and IV of the preamble, and a considerable amount of information is available today on lightweight vehicle designs currently in production and that may be able to be put into production in the rulemaking timeframe. Discussion of lightweight material designs from NHTSA's workshop is presented below.

Besides ''lightweighting'' technologies themselves, though, there are a number of considerations when attempting to evaluate how future technological developments might affect the safety estimates indicated by the statistical analysis. As discussed in the first part of this chapter, for example, careful changes in design and/or materials used might mitigate some of the potential decrease in safety from mass reduction—through improved distribution of crash pulse energy, etc.—but these techniques can sometimes cause other problems, such as increased crash forces on vehicle occupants that have to be mitigated, or greater aggressivity against other vehicles in crashes. Manufacturers may develop new and better restraints—air bags, seat belts, etc.—to protect occupants in lighter vehicles in crashes, but NHTSA's current safety standards for restraint systems are designed based on the current fleet, not the yet-unknown future fleet. The agency will need to monitor trends in the crash data to see whether changes to the safety standards (or new safety standards) become necessary. Manufacturers are also increasingly investigating a variety of crash avoidance technologies—ABS, electronic stability control (ESC), lane departure warnings, vehicle-to-vehicle (V2V) communications—that, as they become more prevalent in the fleet, are expected to reduce the number of overall crashes, and fatal, crashes. Until these technologies are present in the fleet in greater numbers, however, it will be difficult to assess whether they can mitigate the observed relationship between vehicle mass and safety in the historical data.

Along with the California Air Resources Board (CARB), the agencies have initiated several projects to estimate the maximum potential for advanced materials and improved designs to reduce mass in the MY 2017–2021 timeframe, while continuing to meeting safety regulations and maintaining functionality of vehicles. Another NHTSA-sponsored study will estimate the effects of these design changes on overall fleet safety.

A. NHTSA has awarded a contract to Electricore, with EDAG and George Washington University (GWU) as subcontractors, to study the maximum feasible amount of mass reduction for a mid-size car—specifically, a Honda Accord. The study tore down a MY 2011 Honda Accord, studied each component and sub-system, and then redesigned each component and sub-system trying to maximize the amount of mass reduction with technologies that are considered feasible for 200,000 units per year production volume during the time frame of this rulemaking. Electricore and its sub-contractors are consulting industry leaders and experts for each component and sub-system when deciding which technologies are feasible. Electricore and its sub-contractors are also building detailed CAD/CAE/powertrain models to validate vehicle safety, stiffness, NVH, durability, drivability and powertrain performance. For OEM-supplied parts, a detailed cost model is being built based on a Technical Cost Modeling (TCM) approach developed by the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory's research[201] to estimate the costs to OEMs for manufacturing parts. The cost will be broken down into each of the operations involved in the manufacturing; for example, for a sheet metal part, production costs will be estimated from the blanking of the steel coil to the final operation to fabricate the component. Total costs are then categorized into fixed cost, such as tooling, equipment, and facilities; and variable costs such as labor, material, energy, and maintenance. These costs will be assessed through an interactive process between the product designer, manufacturing engineers, and cost

[201] Frank Field, Randolph Kirchain and Richard Roth, Process cost modeling: Strategic engineering and economic evaluation of materials technologies, JOM Journal of the Minerals, Metals and Materials Society, Volume 59, Number 10, 21–32. *Available at http://msl.mit.edu/pubs/docs/Field_KirchainCM_StratEvalMatls.pdf* (last accessed Aug. 22, 2011).

analysts. For OEM-purchased parts, the cost will be estimated by consultation with experienced cost analysts and Tier 1 system suppliers. This study will help to inform the agencies about the feasible amount of mass reduction and the cost associated with it. NHTSA intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

B. EPA has awarded a similar contract to FEV, with EDAG and Monroe & Associates, Inc. as subcontractors, to study the maximum feasible amount of mass reduction for a mid-size CUV (cross over vehicle) specifically, a Toyota Venza. The study tears down a MY 2010 vehicle, studies each component and sub-system, and then redesigns each component and sub-system trying to maximize the amount of mass reduction with technologies that are considered feasible for high volume production for a 2017 MY vehicle. FEV in coordination with EDAG is building detailed CAD/CAE/powertrain models to validate vehicle safety, stiffness, NVH, durability, drivability and powertrain performance to assess the safety of this new design. This study builds upon the low development (20% mass reduction) design in the 2010 Lotus Engineering study ''An Assessment of Mass Reduction Opportunities for a 2017–2020 Model Year Vehicle Program''. This study builds upon the low development (20% mass reduction) design in the 2010 Lotus Engineering study ''An Assessment of Mass Reduction Opportunities for a 2017–2020 Model Year Vehicle Program''. This study will undergo a peer review. EPA intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

C. California Air Resources Board (CARB) has awarded a contract to Lotus Engineering, to study the maximum feasible amount of mass reduction for a mid-size CUV (cross over vehicle) specifically, a Toyota Venza. The study will concentrate on the Body-in-White and closures in the high development design (40% mass reduction) in the Lotus Engineering study cited above. The study will provide an updated design with crash simulation, detailed costing and manufacturing feasibility of these two systems for a MY2020 high volume production vehicle. This study will undergo a peer review. EPA intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

D. NHTSA has contracted with George Washington University (GWU) to build a fleet simulation model to study the impact and relationship of light-weight vehicle design and injuries and fatalities. This study will also include an evaluation of potential countermeasures to reduce any safety concerns associated with lightweight vehicles. NHTSA will include three light-weighted vehicle designs in this study: the one from Electricore/EDAG/GWU mentioned above, one from Lotus Engineering funded by California Air Resource Board for the second phase of the study, evaluating mass reduction levels around 35 percent of total vehicle mass, and two funded by EPA and the International Council on Clean Transportation (ICCT). This study will help to inform the agencies about the possible safety implications for light-weight vehicle designs and the appropriate counter-measures,[202] if applicable, for these designs, as well as the feasible amounts of mass reduction. All of these analyses are expected to be finished and peer-reviewed before July 2012, in time to inform the final rule.

a. NHTSA workshop on vehicle mass, size and safety

As stated above, in section C.2, on February 25, 2011, NHTSA hosted a workshop on mass reduction, vehicle size, and fleet safety at the Headquarters of the US Department of Transportation in Washington, DC. The purpose of the workshop was to provide the agencies with a broad understanding of current research in the field and provide stakeholders and the public with an opportunity to weigh in on this issue. The agencies also created a public docket to receive comments from interested parties that were unable to attend. The presentations were divided into two sessions that addressed the two expansive sets of issues. The first session explored statistical evidence of the roles of mass and size on safety, and is summarized in section C.2. The second session explored the engineering realities of structural crashworthiness, occupant injury and advanced vehicle design, and is summarized here. The speakers in the second session included Stephen Summers of NHTSA, Gregg Peterson of Lotus Engineering, Koichi Kamiji of Honda, John German of the International Council on Clean Transportation (ICCT), Scott Schmidt of the Alliance of Automobile Manufacturers, Guy Nusholtz of Chrysler, and Frank Field of the Massachusetts Institute of Technology.

The second session explored what degree of weight reduction and occupant protection are feasible from technical, economic, and manufacturing perspectives. Field emphasized that technical feasibility alone does not constitute feasibility in the context of vehicle mass reduction. Sufficient material production capacity and viable manufacturing processes are essential to economic feasibility. Both Kamiji and German noted that both good materials and good designs will be necessary to reduce fatalities. For example, German cited the examples of hexagonally structured aluminum columns, such as used in the Honda Insight, that can improve crash absorption at lower mass, and of high-strength steel components that can both reduce weight and improve safety. Kamiji made the point that widespread mass reduction will reduce the kinetic energy of all crashes which should produce some beneficial effect.

Summers described NHTSA's plans for a model to estimate fleetwide safety effects based on an array of vehicle-to-vehicle computational crash simulations of current and anticipated vehicle designs. In particular, three computational models of lightweight vehicles are under development. They are based on current vehicles that have been modified to substantially reduce mass. The most ambitious was the ''high development'' derivative of a Toyota Venza developed by Lotus Engineering and discussed by Mr. Peterson. Its structure currently contains about 75% aluminum, 12% magnesium, 8% steel, and 5% advanced composites. Peterson expressed confidence that the design had the potential to meet federal safety standards. Nusholtz emphasized that computational crash simulations involving more advanced materials were less reliable than those involving traditional metals such as aluminum and steel.

Nusholtz presented a revised data-based fleet safety model in which important vehicle parameters were modeled based on trends from current NCAP crash tests. For example, crash pulses and potential intrusion for a particular size vehicle were based on existing distributions. Average occupant deceleration was used to estimate injury risk. Through a range of simulations of modified vehicle fleets, he was able to estimate the net effects of various design strategies for lighter weight vehicles, such as various scaling approaches for vehicle stiffness or intrusion. The approaches were selected based on engineering requirements for modified

[202] Countermeasures could potentially involve improved front end structure, knee bags, seat ramps, buckle pretensioners, and others.

vehicles. Transition from the current fleet was considered. He concluded that protocols resulting in safer transitions (*e.g.,* removing more mass from heavier vehicles with appropriate stiffness scaling according to a 3⁄2 power law) were not generally consistent with those that provide the greatest reduction in GHG production.

German discussed several important points on the future of mass reduction. Similar to Kahane's discussion of the difficulties of isolating the impact of weight reduction, German stated that other important variables, such as vehicle design and compatibility factors, must be held constant in order for size or weight impacts to be quantified in statistical analyses. He presented results that, compared to driver, driving influences, and vehicle design influences, the safety impacts of size and weight are small and difficult to quantify. He noted that several scenarios, such as rollovers, greatly favored the occupants of smaller and lighter cars once a crash occurred. He pointed out that if size and design are maintained, lower weight should translate into a lower total crash force. He thought that advanced material designs have the potential to ''decouple'' the historical correlation between vehicle size and weight, and felt that effective design and driver attributes may start to dominate size and weight issues in future vehicle models.

Other presenters noted industry's perspective of the effect of incentivizing weight reduction. Field highlighted the complexity of institutional changes that may be necessitated by weight reduction, including redesign of material and component supply chains and manufacturing infrastructure. Schmidt described an industry perspective on the complicated decisions that must be made in the face of regulatory change, such as evaluating goals, gains, and timing.

Field and Schmidt noted that the introduction of technical innovations is generally an innate development process involving both tactical and strategic considerations that balance desired vehicle attributes with economic and technical risk. In the absence of challenging regulatory requirements, a substantial technology change is often implemented in stages, starting with lower volume pilot production before a commitment is made to the infrastructure and supply chain modifications necessary for inclusion on a high-volume production model. Joining, damage characterization, durability, repair, and significant uncertainty in final component costs are also concerns. Thus, for example, the widespread implementation of high-volume composite or magnesium structures might be problematic in the short or medium term when compared to relatively transparent aluminum or high strength steel implementations. Regulatory changes will affect how these tradeoffs are made and these risks are managed.

Koichi Kamiji presented data showing in increased use of high strength steel in their Honda product line to reduced vehicle mass and increase vehicle safety. He stated that mass reduction is clearly a benefit in 42% of all fatal crashes because absolute energy is reduced. He followed up with slides showing the application of certain optimized it designs can improve safety even when controlling for weight and size.

A philosophical theme developed that explored the ethics of consciously allowing the total societal harm associated with mass reduction to approach the anticipated benefits of enhanced safety technologies. Although some participants agreed that there may eventually be specific fatalities that would not have occurred without downsizing, many also agreed that safety strategies will have to be adapted to the reality created by consumer choices, and that ''We will be ok if we let data on what works—not wishful thinking—guide our strategies.''

5. How have the agencies estimated safety effects for the proposed standards?

a. What was the agencies' methodology for estimating safety effects for the proposed standards?

As explained above, the agencies consider the 2011 statistical analysis of historical crash data by NHTSA to represent the best estimates of the potential relationship between mass reduction and fatality increases in the future fleet. This section discusses how the agencies used NHTSA's 2011 analysis to calculate specific estimates of safety effects of the proposed standards, based on the analysis of how much mass reduction manufacturers might use to meet the proposed standards.

Neither the proposed CAFE/GHG standards nor the agencies' analysis mandates mass reduction, or mandates that mass reduction occur in any specific manner. However, mass reduction is one of the technology applications available to the manufacturers and a degree of mass reduction is used by both agencies' models to determine the capabilities of manufacturers and to predict both cost and fuel consumption/emissions impacts of improved CAFE/GHG standards. We note that the amount of mass reduction selected for this rulemaking is based on our assumptions about how much is technologically feasible without compromising safety. While we are confident that manufacturers will build safe vehicles, we cannot predict with certainty that they will choose to reduce mass in exactly the ways that the agencies have analyzed in response to the standards. In the event that manufacturers ultimately choose to reduce mass and/or footprint in ways not analyzed or anticipated by the agencies, the safety effects of the rulemaking may likely differ from the agencies' estimates.

NHTSA utilized the 2011 Kahane study relationships between weight and safety, expressed as percent changes in fatalities per 100-pound weight reduction while holding footprint constant. However, as mentioned previously, there are several identifiable safety trends already occurring, or expected to occur in the foreseeable future, that are not accounted for in the study. For example, the two important new safety standards that were discussed above for electronic stability control and head curtain airbags, have already been issued and began phasing in after MY 2008. The recent shifts in market shares from pickups and SUVs to cars and CUVs may continue, or accelerate, if gasoline prices remain high, or rise further. The growth in vehicle miles travelled may continue to stagnate if the economy does not improve, or gasoline prices remain high. And improvements in driver (and passenger) behavior, such as higher safety belt use rates, may continue. All of these will tend to reduce the absolute number of fatalities in the future. The agency estimated the overall change in fatalities by calendar year after adjusting for ESC, Side Impact Protection, and other Federal safety standards and behavioral changes projected through this time period. The smaller percent changes in risk from mass reduction (from the 2011 NHTSA analysis), coupled with the reduced number of baseline fatalities, results in smaller absolute increases in fatalities than those predicted in the 2010 rulemaking.

NHTSA examined the impacts of identifiable safety trends over the lifetime of the vehicles produced in each model year. An estimate of these impacts was contained in a previous agency report.[203] The impacts were estimated on a year-by-year basis, but could be examined in a combined fashion. Using this method, we estimate a 12.6 percent reduction in fatality levels between 2007 and 2020 for the combination of safety standards and behavioral changes anticipated (ESC, head-curtain air bags, and increased belt use). Since the same safety standards are taking effect in the same years, the estimates derived from applying NHTSA fatality percentages to a baseline of 2007 fatalities were thus multiplied by 0.874 to account for changes that NHTSA believes will take place in passenger car and light truck safety between the 2007 baseline on-road fleet used for this particular safety analysis and year 2025.

To estimate the amount of mass reduction to apply in the rulemaking analysis, the agencies considered fleet safety effects for mass reduction. As previously discussed and shown in Table II–15, the Kahane 2011 study shows that applying mass reduction to CUVs and light duty trucks will generally decrease societal fatalities, while applying mass reduction to passenger cars will increase fatalities. The CAFE model uses coefficients from the Kahane study along with the mass reduction level applied to each vehicle model to project societal fatality effects in each model year. NHTSA used the CAFE model and conducted iterative modeling runs varying the maximum amount of mass reduction applied to each subclass in order to identify a combination that achieved a high level of overall fleet mass reduction while not adversely affecting overall fleet safety. These maximum levels of mass reduction for each subclass were then used in the CAFE model for the rulemaking analysis. The agencies believe that mass reduction of up to 20 percent is feasible on light trucks, CUVs and minivans,[204] but that less mass reduction should be implemented on other vehicle types to avoid increases in societal fatalities. For this proposal, NHTSA used the mass reduction levels shown in Table II–15.

Table II-15 Mass Reduction Levels Applied in CAFE Model

Absolute %	Subcompact and Subcompact Perf. PC	Compact and Compact Perf. PC	Midsize PC and Midsize Perf. PC	Large PC and Large Perf. PC	Minivan LT	Small, Midsize and Large LT
MR1*	0.0%	2.0%	1.5%	1.5%	1.5%	1.5%
MR2	0.0%	0.0%	5.0%	7.5%	7.5%	7.5%
MR3	0.0%	0.0%	0.0%	10.0%	10.0%	10.0%
MR4	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%
MR5	0.0%	0.0%	0.0%	0.0%	20.0%	20.0%

Notes:

*MR1-MR5: different levels of mass reduction used in CAFE model

For the CAFE model, these percentages apply to a vehicle's total weight, including the powertrain. Table II–16 shows the amount of mass reduction in pounds for these percentage mass reduction levels for a typical vehicle weight in each subclass.

[203] Countermeasures could potentially involve improved front end structure, knee bags, seat ramps, buckle pretensioners, and others.

Blincoe, L. and Shankar, U., ''The Impact of Safety Standards and Behavioral Trends on Motor Vehicle Fatality Rates,'' DOT HS 810 777, January 2007. See Table 4 comparing 2020 to 2007 (37,906/43,363 = 12.6% reduction (1 − .126 = .874). Since 2008 was a recession year, it does not seem appropriate to use that as a baseline. We believe this same ratio should hold for this analysis which should compare 2025 to 2008. Thus, we are inclined to continue to use the same ratio.

[204] When applying mass reduction, NHSTA capped the maximum amount of mass reduction to 20 percent for any individual vehicle class. The 20 percent cap is the maximum amount of mass reduction the agencies believe to be feasible in MYs 2017–2025 time frame.

Table II-16 Examples of Mass Reduction in Pound for Different Vehicle Subclasses

Mass Reduction (lbs)	Subcom-pact and Subcompact Perf. PC	Compact and Compact Perf. PC	Midsize PC and Midsize Perf. PC	Large PC and Large Perf. PC	Minivan LT	Small LT	Midsize LT	Large LT
Typical Vehicle Weight (lbs)	2795	3359	3725	4110	4250	3702	4260	5366
MR1 (lbs)	0	67	56	62	64	56	64	80
MR2 (lbs)	0	0	186	308	319	278	320	402
MR3 (lbs)	0	0	0	411	425	370	426	537
MR4 (lbs)	0	0	0	0	638	555	639	805
MR5 (lbs)	0	0	0	0	850	740	852	1073

After applying the mass reduction levels in the CAFE model, Table II–17 shows the results of NHTSA's safety analysis separately for each model year.[205] These are estimated increases or decreases in fatalities over the lifetime of the model year fleet. A positive number means that fatalities are projected to increase, a negative number (indicated by parentheses) means that fatalities are projected to decrease. The results are significantly affected by the assumptions put into the Volpe model to take more weight out of the heavy LTVs, CUVs, and minivans than out of other vehicles. As the negative coefficients only appear for LTVs greater than 4,594 lbs., CUVs, and minivans, a statistically improvement in safety can only occur if more weight is taken out of these vehicles than passenger cars or smaller light trucks. Combining passenger car and light truck safety estimates for the proposed standards results in an increase in fatalities over the lifetime of the nine model years of MY 2017–2025 of 4 fatalities, broken up into an increase of 61 fatalities in passenger cars and 56 decrease in fatalities in light trucks. NHTSA also analyzed the results for different regulatory alternatives in Chapter IX of its PRIA; the difference in the results by alternative depends upon how much weight reduction is used in that alternative and the types and sizes of vehicles that the weight reduction applies to.

[205] NHTSA has changed the definitions of a passenger car and light truck for fuel economy purposes between the time of the Kahane 2003 analysis and this proposed rule. About 1.4 million 2 wheel drive SUVs have been redefined as passenger cars instead of light trucks. The Kahane 2011 analysis continues with the definitions used in the Kahane 2003 analysis. Thus, there are different definitions between Tables IX–1 and IX–2 (which use the old definitions) and Table IX–3 (which uses the new definitions).

Table II-17 NHTSA Calculated Mass-Safety-Related Fatality Impacts of the Proposed Standards over the Lifetime of the Vehicles Produced in each Model Year

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	(2)	(0)	11	16	15	13	12	1	(2)	63
Light trucks	3	(7)	0	(13)	(8)	(15)	(12)	(8)	0	(56)
Total	1	(8)	12	3	7	(2)	0	(8)	(2)	4

Using the same coefficients from the 2011 Kahane study, EPA used the OMEGA model to conduct a similar analysis. After applying these percentage increases to the estimated weight reductions per vehicle size by model year assumed in the Omega model, Table II–18 shows the results of EPA's safety analysis separately for each model year. These are estimated increases or decreases in fatalities over the lifetime of the model year fleet. A positive number means that fatalities are projected to increase; a negative number means that fatalities are projected to decrease. For details, see the EPA RIA Chapter 3.

Table II-18 EPA Calculated Mass-Safety-Related Fatality Impacts of the Proposed Standards over the Lifetime of the Vehicles Produced in each Model Year

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	-3	-5	-8	-11	-14	8	32	58	86	143
Light trucks	-1	-1	-2	-2	-4	-35	-67	-99	-133	-343
Total	-3	-7	-10	-13	-18	-27	-34	-41	-47	-201

b. Why might the real-world effects be less than or greater than what the agencies have calculated?

As discussed above the ways in which future technological advances could potentially mitigate the safety effects estimated for this rulemaking: lightweight vehicles could be designed to be both stronger and not more aggressive; restraint systems could be improved to deal with higher crash pulses in lighter vehicles; crash avoidance technologies could reduce the number of overall crashes; roofs could be strengthened to improve safety in rollovers. As also stated above, however, while we are confident that manufacturers will strive to build safe vehicles, it will be difficult for both the agencies and the industry to know with certainty ahead of time how crash trends will change in the future fleet as lightweighted vehicles become more prevalent. Going forward, we will have to continue to monitor the crash data as well as changes in vehicle weight relative to what we expect.

Additionally, we note that the total amount of mass reduction used in the agencies' analysis for this rulemaking were chosen based on our assumptions about how much is technologically feasible without compromising safety. Again, while we are confident that manufacturers are motivated to build safe vehicles, we cannot predict with certainty that they will choose to reduce mass in exactly the ways that the agencies have analyzed in response to the standards. In the event that manufacturers ultimately choose to reduce mass and/or footprint in ways not analyzed by the agencies, the safety effects of the rulemaking may likely differ from the agencies' estimates.

The agencies acknowledge the proposal does not prohibit manufacturers from redesigning vehicles to change wheelbase and/or track width (footprint). However, as NHTSA explained in promulgating MY2008–2011 light truck CAFE standards and MY2011 passenger car and light truck CAFE standards, and as the agencies jointly explained in promulgating MY2012–2016 CAFE and GHG standards, the agencies believes such engineering changes are significant enough to be unattractive as a measure to undertake solely to reduce compliance burdens. Similarly, the agencies acknowledge that a manufacturer could, without actually reengineering specific vehicles to increase footprint, shift production toward those that perform well compared to their respective footprint-based targets. However, NHTSA and, more recently NHTSA and EPA have previously explained, because such production shifts would run counter to market demands, they would also be competitively unattractive. Based on this regulatory design, the analysis assumes this proposal will not have either of the effects described above.

As discussed in Chapter 2 of the Draft Joint TSD, the agencies note that the standard is flat for vehicles smaller than 41 square feet and that downsizing in this category could help achieve overall compliance, if the vehicles are desirable to consumers. The agencies note that less than 10 percent of MY2008 passenger cars were below 41 square feet, and due to the overall lower level of utility of these vehicles, and the engineering challenges involved in ensuring that these vehicles meet all applicable federal motor vehicle safety standards (FMVSS), we expect a significant increase in this segment of the market in the future is unlikely. Please see Chapter 2 of the Draft Joint TSD for additional discussion.

We seek comment on the appropriateness of the overall analytic assumption that the attribute-based aspect of the proposed standards will have no effect on the overall distribution of vehicle footprints. Notwithstanding the agencies current judgment that such deliberate reengineering or production shift are unlikely as pure compliance strategies, both agencies are considering the potential future application of vehicle choice models, and anticipate that doing so could result in estimates that market shifts induced by changes in vehicle prices and fuel economy levels could lead to changes in fleet's footprint distribution. However, neither agency is currently able to include vehicle choice modeling in our analysis.

As discussed in Chapter 2 of the Draft Joint TSD, the agencies note that the standard is flat for vehicles smaller than 41 square feet and that downsizing in this category could help achieve overall compliance, if the vehicles are desirable to consumers. The agencies note that less than 10 percent of MY2008 passenger cars were below 41 square feet, and due to the overall lower level of utility of these vehicles, and the engineering challenges involved in ensuring that these vehicles meet all applicable federal motor vehicle safety standards (FMVSS), we expect a significant increase in this segment of the market in the future is unlikely. Please see Chapter 2 of the Draft Joint TSD for additional discussion.

c. Do the agencies plan to make any changes in these estimates for the final rule?

As discussed above, the agencies have based our estimates of safety effects due to the proposed standards on Kahane's 2011 report. That report is currently undergoing peer review and is docketed for public review;[206] the peer review comments and response to peer review comments, along with any revisions to the report in response to that review, will also be docketed there. Depending on the results of the peer review, our calculation of safety effects for the final rule will also be revised accordingly. The agencies will also consider any comments received on the proposed rule, and determine at that time whether and how our estimates should be changed in response to those comments. Additional studies published by the agencies or other independent researchers as previously discussed will also be considered, along with any other relevant information.

III. EPA Proposal for MYs 2017–2025 Greenhouse Gas Vehicle Standards

A. Overview of EPA Rule

1. Introduction

Soon after the completion of the successful model years (MYs) 2012–2016 rulemaking in May 2010, the President, with support from the auto manufacturers, requested that EPA and NHTSA work to extend the National Program to MYs 2017–2025 light duty vehicles. The agencies were requested to develop ''a coordinated national program under the CAA (Clean Air Act) and the EISA (Energy Independence and Security Act of 2007) to improve fuel efficiency and to reduce greenhouse gas emissions of passenger cars and light-duty trucks of model years 2017–2025.'' [207] EPA's proposal grows directly out of our work with NHTSA and CARB in developing such a continuation of the National Program. This proposal provides important benefits to society and consumers in the form of reduced emissions of greenhouse gases (GHGs), reduced consumption of oil, and fuel savings for consumers, all at reasonable costs. It provides industry with the important certainty and leadtime needed to implement the technology changes that will achieve these benefits, as part of a harmonized set of federal requirements. Acting now to address the standards for MYs 2017–2025 will allow for the important continuation of the National Program that started with MYs 2012–2016.

EPA is proposing GHG emissions standards for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles (hereafter light vehicles) for MYs 2017 through 2025. These vehicle categories, which include cars, sport utility vehicles, minivans, and pickup trucks used for personal

[206] Kahane, C. J. (2011). ''Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000–2007 Passenger Cars and LTVs,'', July 2011. The report is available in the NHTSA docket, NHTSA–2010–0152. You can access the docket at *http://www.regulations.gov/#!home* by typing 'NHTSA–2010–0152' where it says ''enter keyword or ID'' and then clicking on ''Search.''

[207] The Presidential Memorandum is found at: *http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.*

transportation, are responsible for almost 60% of all U.S. transportation related GHG emissions.

If finalized, this proposal would be the second EPA rule to regulate light vehicle GHG emissions under the Clean Air Act (CAA), building upon the GHG emissions standards for MYs 2012–2016 that were established in 2010,[208] and the third rule to regulate GHG emissions from the transportation sector.[209] Combined with the standards already in effect for MYs 2012–2016, the proposed standards would result in MY 2025 light vehicles emitting approximately one-half of the GHG emissions of MY 2010 vehicles and would represent the most significant federal action ever taken to reduce GHG emissions (and improve fuel economy) in the U.S.

From a societal standpoint, the proposed GHG emissions standards are projected to save approximately 2 billion metric tons of GHG emissions and 4 billion barrels of oil over the lifetimes of those vehicles sold in MYs 2017–2025. EPA estimates that fuel savings will far outweigh higher vehicle costs, and that the net benefits to society will be in the range of $311 billion (at 7% discount rate) to $421 billion (3% discount) over the lifetimes of those vehicles sold in MYs 2017–2025. Just in calendar year 2040 alone, after the on-road vehicle fleet has largely turned over to vehicles sold in MY 2025 and later, EPA projects GHG emissions savings of 462 million metric tons, oil savings of 2.63 million barrels per day, and net benefits of $144 billion using the $22/ton CO_2 social cost of carbon value.

EPA estimates that these proposed standards will save consumers money. Higher costs for new technology, sales taxes, and insurance will add, on average in the first year, about $2100 for consumers who buy a new vehicle in MY 2025. But those consumers who drive their MY 2025 vehicle for its entire lifetime will save, on average, $5200 (7% discount rate) to $6600 (3% discount) in fuel savings, for a net lifetime savings of $3000–$4400. For those consumers who purchase their new MY 2025 vehicle with cash, the discounted fuel savings will offset the higher vehicle cost in less than 4 years, and fuel savings will continue for as long as the consumer owns the vehicle. Those consumers that buy a new vehicle with a 5-year loan will benefit from a monthly cash flow savings of $12 (or about $140 per year), on average, as the monthly fuel savings more than offsets the higher monthly payment due to the higher incremental vehicle cost.

The proposed standards are designed to allow full consumer choice, in that they are footprint-based, *i.e.,* larger vehicles have higher absolute GHG emissions targets and smaller vehicles have lower absolute GHG emissions targets. While the GHG emissions targets do become more stringent each year, the emissions targets have been selected to allow compliance by vehicles of all sizes and with current levels of vehicle attributes such as utility, size, safety, and performance. Accordingly, these proposed standards are projected to allow consumers to choose from the same mix of vehicles that are currently in the marketplace.

Section I above provides a comprehensive overview of the joint EPA/NHTSA proposal, including the history and rationale for a National Program that allows manufacturers to build a single fleet of light vehicles that can satisfy all federal and state requirements for GHG emissions and fuel economy, the level and structure of the proposed GHG emissions and corporate average fuel economy (CAFE) standards, the compliance flexibilities proposed to be available to manufacturers, the mid-term evaluation, and a summary of the costs and benefits of the GHG and CAFE standards based on a ''model year lifetime analysis.''

In this Section III, EPA provides more detailed information about EPA's proposed GHG emissions standards. After providing an overview of key information in this section (III.A), EPA discusses the proposed standards (III.B); the vehicles covered by the standards, various compliance flexibilities available to manufacturers, and a mid-term evaluation (III.C); the feasibility of the proposed standards (III.D); provisions for certification, compliance, and enforcement (III.E); the reductions in GHG emissions projected for the proposed standards and the associated effects of these reductions (III.F); the impact of the proposal on non-GHG emissions and their associated effects (III.G); the estimated cost, economic, and other impacts of the proposal (III.H); and various statutory and executive order issues (III.I).

2. Why is EPA proposing this Rule?

a. Light Duty Vehicle Emissions Contribute to Greenhouse Gases and the Threat of Climate Change

Greenhouse gases (GHGs) are gases in the atmosphere that effectively trap some of the Earth's heat that would otherwise escape to space. GHGs are both naturally occurring and anthropogenic. The primary GHGs of concern that are directly emitted by human activities include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

These gases, once emitted, remain in the atmosphere for decades to centuries. They become well mixed globally in the atmosphere and their concentrations accumulate when emissions exceed the rate at which natural processes remove GHGs from the atmosphere. The heating effect caused by the human-induced buildup of GHGs in the atmosphere is very likely the cause of most of the observed global warming over the last 50 years. The key effects of climate change observed to date and projected to occur in the future include, but are not limited to, more frequent and intense heat waves, more severe wildfires, degraded air quality, heavier and more frequent downpours and flooding, increased drought, greater sea level rise, more intense storms, harm to water resources, continued ocean acidification, harm to agriculture, and harm to wildlife and ecosystems. A more in depth explanation of observed and projected changes in GHGs and climate change, and the impact of climate change on health, society, and the environment is included in Section III.F below.

Mobile sources represent a large and growing share of U.S. GHG emissions and include light-duty vehicles, light-duty trucks, medium duty passenger vehicles, heavy duty trucks, airplanes, railroads, marine vessels and a variety of other sources. In 2007, all mobile sources emitted 30% of all U.S. GHGs, and have been the source of the largest absolute increase in U.S. GHGs since 1990. Transportation sources, which do not include certain off highway sources such as farm and construction equipment, account for 27% of U.S. GHG emissions, and motor vehicles (CAA section 202(a)), which include light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, heavy-duty trucks, buses, and motorcycles account for 23% of total U.S. GHGs.

Light duty vehicles emit carbon dioxide, methane, nitrous oxide and hydrofluorocarbons. Carbon dioxide (CO2) is the end product of fossil fuel combustion. During combustion, the carbon stored in the fuels is oxidized and emitted as CO2 and smaller amounts of other carbon compounds. Methane (CH4) emissions are a function of the methane content of the motor fuel, the amount of hydrocarbons passing uncombusted through the

[208] 75 FR 25324 (May 7, 2010).

[209] 76 FR 57106 (September 15, 2011) established GHG emission standards for heavy-duty vehicles and engines for model years 2014–2018.

engine, and any post-combustion control of hydrocarbon emissions (such as catalytic converters). Nitrous oxide (N_2O) (and nitrogen oxide (NO_X)) emissions from vehicles and their engines are closely related to air-fuel ratios, combustion temperatures, and the use of pollution control equipment. For example, some types of catalytic converters installed to reduce motor vehicle NO_X, carbon monoxide (CO) and hydrocarbon (HC) emissions can promote the formation of N_2O. Hydrofluorocarbons (HFC) are progressively replacing chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) in these vehicles' cooling and refrigeration systems as CFCs and HCFCs are being phased out under the Montreal Protocol and Title VI of the CAA. There are multiple emissions pathways for HFCs with emissions occurring during charging of cooling and refrigeration systems, during operations, and during decommissioning and disposal.

b. Basis for Action Under the Clean Air Act

Section 202(a)(1) of the Clean Air Act (CAA) states that ''the Administrator shall by regulation prescribe (and from time to time revise) * * * standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles * * *, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.'' The Administrator has found that the elevated concentrations of a group of six GHGs in the atmosphere may reasonably be anticipated to endanger public health and welfare, and that emissions of GHGs from new motor vehicles and new motor vehicle engines contribute to this air pollution.

As a result of these findings, section 202(a) requires EPA to issue standards applicable to emissions of that air pollutant, and authorizes EPA to revise them from time to time. This preamble describes the proposed revisions to the current standards to control emissions of CO2 and HFCs from new light-duty motor vehicles.[210] For further discussion of EPA's authority under section 202(a), see Section I.D. of the preamble.

[210] EPA is not proposing to amend the substantive standards adopted in the 2012–2016 light-duty vehicle rule for N_2O and CH_4, but is proposing revisions to the options that manufacturers have in meeting the N2O and CH4 standards, and to the timeframe for manufacturers to begin measuring N2O emissions. See Section III.B below.

c. EPA's Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act

On December 15, 2009, EPA published its findings that elevated atmospheric concentrations of GHGs are reasonably anticipated to endanger the public health and welfare of current and future generations, and that emissions of GHGs from new motor vehicles contribute to this air pollution. Further information on these findings may be found at 74 FR 66496 (December 15, 2009) and 75 FR 49566 (Aug. 13, 2010).

3. What is EPA proposing?

a. Light-Duty Vehicle, Light-Duty Truck, and Medium-Duty Passenger Vehicle Greenhouse Gas Emission Standards and Projected Emissions Levels

EPA is proposing tailpipe carbon dioxide (CO_2) standards for cars and light trucks based on the CO_2 emissions-footprint curves for cars and light trucks that are shown above in Section I.B.3 and below in Section III.B. These curves establish different CO_2 emissions targets for each unique car and truck footprint value. Generally, the larger the vehicle footprint, the higher the corresponding vehicle CO_2 emissions target. Vehicle CO_2 emissions will be measured over the EPA city and highway tests. Under this proposal, various incentives and credits are available for manufacturers to demonstrate compliance with the standards. See Section I.B for a comprehensive overview of both the EPA CO_2 emissions-footprint standard curves and the various compliance flexibilities that are proposed to be available to the manufacturers in meeting the EPA tailpipe CO_2 standards.

EPA projects that the proposed tailpipe CO_2 emissions-footprint curves would yield a fleetwide average light vehicle CO_2 emissions compliance target level in MY 2025 of 163 grams per mile, which would represent an average reduction of 35 percent relative to the projected average light vehicle CO_2 level in MY 2016. On average, car CO_2 emissions would be reduced by about 5 percent per year, while light truck CO2 emissions would be reduced by about 3.5 percent per year from MY 2017 through 2021, and by about 5 percent per year from MY 2022 through 2025.

The following three tables, Table III–1 through Table III–3, summarize EPA's projections of what the proposed standards would mean in terms of projected CO_2 emissions reductions for passenger cars, light trucks, and the overall fleet combining passenger cars and light trucks for MYs 2017–2025. It is important to emphasize that these projections are based on technical assumptions by EPA about various matters, including the mix of cars and trucks, as well as the mix of vehicle footprint values, in the fleet in varying years. It is possible that the actual CO_2 emissions values will be either higher or lower than the EPA projections.

In each of these tables, the column ''Projected CO_2 Compliance Target'' represents our projected fleetwide average CO_2 compliance target value based on the proposed CO_2-footprint curve standards as well as the projected mixes of cars and trucks and vehicle footprint levels. This Compliance Target represents the projected fleetwide average of the projected standards for the various manufacturers.

The column(s) under ''Incentives'' represent the emissions impact of the proposed multiplier incentive for EV/PHEV/FCVs and the proposed pickup truck incentives. These incentives allow manufacturers to meet their Compliance Targets with CO2 emissions levels slightly higher than they would otherwise have to be, but do not reflect actual real-world CO_2 emissions reductions. As such they reduce the emissions reductions that the CO_2 standards would be expected to achieve.

The column ''Projected Achieved CO2'' is the sum of the CO_2 Compliance Target and the value(s) in the ''Incentive'' columns. This Achieved CO_2 value is a better reflection of the CO_2 emissions benefits of the standards, since it accounts for the incentive programs. One incentive that is not reflected in these tables is the 0 gram per mile compliance value for EV/PHEV/FCVs. The 0 gram per mile value accurately reflects the tailpipe CO_2 gram per mile achieved by these vehicles; however, the use of this fuel does impact the overall GHG reductions associated with the proposed standards due to fuel production and distribution-related upstream GHG emissions which are projected to be greater than the upstream GHG emissions associated with gasoline from oil. The combined impact of the 0 gram per mile and multiplier incentive for EV/PHEV/FCVs on overall program GHG emissions is discussed in more detail below in Section III.C.2.

The columns under ''Credits'' quantify the projected CO_2 emissions credits that we project manufacturers will achieve through improvements in air conditioner refrigerants and efficiency. These credits reflect real world emissions reductions, so they do not raise the levels of the Achieved CO_2 values, but they do allow manufacturers to comply with their compliance targets with 2-cycle test CO_2 emissions values higher than otherwise. One other credit program that could similarly affect the 2-cycle CO_2 values is the off-cycle credit program, but it is not included in this table due to the uncertainty inherent in projecting the future use of these technologies. The off-cycle credits, like A/C credits, reflect real world reductions, so they would not change the CO2 Achieved values.

The column "Projected 2-cycle CO2" is the projected fleetwide 2-cycle CO_2 emissions values that manufacturers would have to achieve in order to be able to comply with the proposed standards. This value is the sum of the projected fleetwide credit, incentive, and Compliance Target values.[211]

Table III-1 EPA Projections for Fleetwide Tailpipe Emissions Compliance with Proposed CO_2 Standards – Passenger Cars (Grams per mile)

		Incentives (1)		Credits (2)		
Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	Projected Achieved CO_2	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2016 (base)	225	--	225	5.4	4.8	235
2017	213	2.2	215	7.8	5.0	228
2018	202	2.1	205	9.3	5.0	219
2019	192	2.0	194	10.8	5.0	210
2020	182	1.5	184	12.3	5.0	201
2021	173	1.0	174	13.8	5.0	193
2022	165	--	165	13.8	5.0	184
2023	158	--	158	13.8	5.0	177
2024	151	--	151	13.8	5.0	169
2025	144	--	144	13.8	5.0	163

(1) The one incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.

(2) The one credit not reflected in this table is the off-cycle credit. See text for explanation.

[211] For MY 2016, the Temporary Leadtime Allowance Alternative Standards are available to manufacturers. In the MYs 2012–2016 rule, we estimated the impact of this credit in MY 2016 to be 0.1 gram/mile. Due to the small magnitude, we have not included this in the following tables for the MY 2016 base year.

Table III-2 EPA Projections for Fleetwide Tailpipe Emissions Compliance with Proposed CO_2 Standards – Light Trucks

(Grams per mile)

		Incentives (1)				Credits (2)		
Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	Pickup Mild HEV + Perf	Pickup Strong HEV + Perf	Projected Achieved CO_2	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2016 (base)	298[212]	--	--	--	298	6.6	4.8	309
2017	295	0.0	0.3	0.0	295	7.0	5.0	307
2018	285	0.0	0.4	0.1	285	11.0	6.5	303
2019	277	0.1	0.6	0.2	278	13.4	7.2	299
2020	270	0.1	0.7	0.2	271	15.3	7.2	293
2021	250	0.0	0.8	0.4	251	17.2	7.2	275
2022	237	--	--	0.5	238	17.2	7.2	262
2023	225	--	--	0.6	226	17.2	7.2	250
2024	214	--	--	0.6	214	17.2	7.2	239
2025	203	--	--	0.7	204	17.2	7.2	228

(1) The one incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.

(2) The one credit not reflected in this table is the off-cycle credit. See text for explanation.

[212] The projected fleet compliance levels for 2016 are different for trucks and the fleet than were projected in the 2012-2016 rule. Our assessment for this proposal is based on a predicted 2016 truck value of 297 g/mi. That is because the standards are footprint based and the fleet projections, hence the footprint distributions, change slightly with each update of our projections, as described below. In addition, the actual fleet compliance levels for any model year will not be known until the end of that model year based on actual vehicle sales.

Table III-3 EPA Projections for Fleetwide Tailpipe Emissions Compliance with Proposed CO_2 Standards –

Combined Cars and Trucks (Grams per mile)

		Incentives (1)				Credits (2)		
Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	Pickup Mild HEV + Perf	Pickup Strong HEV + Perf	Projected Achieved CO_2	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2016 (base)	250[213]	--	--	--	250	5.8	4.8	263
2017	243	1.4	0.1	0.0	245	7.5	5.0	257
2018	232	1.3	0.2	0.0	234	9.9	5.5	249
2019	223	1.3	0.2	0.1	224	11.7	5.8	242
2020	213	1.0	0.3	0.1	214	13.4	5.8	234
2021	200	0.6	0.3	0.1	201	15.0	5.8	222
2022	190	--	--	0.2	190	15.0	5.8	211
2023	181	--	--	0.2	181	15.0	5.8	202
2024	172	--	--	0.2	172	14.9 (3)	5.7 (3)	193
2025	163	--	--	0.2	163.6	14.9	5.7	184

(1) The one incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.

(2) The one credit not reflected in this table is the off-cycle credit. See text for explanation.

(3) The projected A/C refrigerant and A/C efficiency credits decline by 0.1 g/mi in MY 2024 due to a slight change in projected car-truck market shares.

[213] The projected fleet compliance levels for 2016 are different for trucks and the fleet than were projected in the 2012-2016 rule. Our assessment for this proposal is based on a predicted 2016 combined car and truck value of 252 g/mi. That is because the standards are footprint based and the fleet projections, hence the footprint distributions, change slightly with each update of our projections, as described below. In addition, the actual fleet compliance levels for any model year will not be known until the end of that model year based on actual vehicle sales.

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Table III–4 shows the projected real world CO_2 emissions and fuel economy values associated with the proposed CO_2 standards. These real world estimates, similar to values shown on new vehicle labels, reflect the fact that the way cars and trucks are operated in the real world generally results in higher CO_2 emissions and lower fuel economy than laboratory test results used to determine compliance with the standards, which are performed under tightly controlled conditions. There are many assumptions that must be made for these projections, and real world CO_2 emissions and fuel economy performance can vary based on many factors.

The real world tailpipe CO_2 emissions projections in Table III–4 are calculated starting with the projected 2-cycle CO_2 emissions values in Table III–1 through Table III–3, subtracting the air conditioner efficiency credits, and then multiplying by a factor of 1.25. The 1.25 factor is an approximation of the ratio of real world CO_2 emissions to 2-cycle test CO_2 emissions for the fleet in the recent past. It is not possible to know the appropriate factor for future vehicle fleets, as this factor will depend on many factors such as technology performance, driver behavior, climate conditions, fuel composition, etc. Issues associated with future projections of this factor are discussed in TSD 4. Air conditioner efficiency credits were subtracted from the 2-cycle CO_2 emissions values as air conditioning efficiency improvements will increase real world fuel economy. The real world fuel economy value is calculated by dividing 8887 grams of CO_2 per gallon of gasoline by the real world tailpipe CO_2 emissions value.

Table III-4 EPA Projections for the Average, Real World Fleetwide Tailpipe CO_2 Emissions and Fuel Economy Associated with the Proposed CO_2 Standards

Model Year	Real World Tailpipe CO_2 (grams per mile)			Real World Fuel Economy (miles per gallon)		
	Cars	Trucks	Cars + Trucks	Cars	Trucks	Cars + Trucks
2016 (base)	288	380	323	30.9	23.4	27.5
2017	279	378	315	31.9	23.5	28.2
2018	268	371	304	33.2	24.0	29.2
2019	256	365	295	34.7	24.3	30.1
2020	245	357	285	36.3	24.9	31.2
2021	235	335	270	37.8	26.5	32.9
2022	224	319	257	39.7	27.9	34.6
2023	215	304	245	41.3	29.2	36.3
2024	205	290	234	43.4	30.6	38.0
2025	198	276	223	44.9	32.2	40.0

As discussed both in Section I and later in this Section III, EPA either already has adopted or is proposing provisions for averaging, banking, and trading of credits, that allow annual credits for a manufacturer's over-compliance with its unique fleet-wide average standard, carry-forward and carry-backward of credits, the ability to transfer credits between a manufacturer's car and truck fleets, and credit trading between manufacturers. EPA is proposing a one-time carry-forward of any credits such that any credits generated in MYs 2010–2016 can be used through MY 2021. These provisions are not expected to change the emissions reductions achieved by the standards, but should significantly reduce the cost of achieving those reductions. The tables above do not reflect the year to year impact of these provisions. For example, EPA expects that many manufacturers may generate credits by over complying with the standards for cars, and transfer such credits to its truck fleet. Table III–1 (cars) and Table III–2 (trucks) do not reflect such transfers. If on an industry wide basis more credits are transferred from cars to trucks than vice versa, you would expect to achieve greater reductions from cars than reflected in Table III–1 (lower CO_2 gram/miles values) and less reductions from trucks than reflected in Table III–2 (higher CO_2 gram/mile values). Credit transfers between cars and trucks would not be expected to change the results for the combined fleet, reflected in Table III–3.

The proposed rule would also exclude from coverage a limited set of vehicles: emergency and police vehicles, and vehicles manufactured by small businesses. As discussed in Section III.B below, these exclusions have very limited impact on the total GHG emissions reductions from the light-duty vehicle fleet. We also do not anticipate significant impacts on total GHG emissions reductions from the proposed provisions allowing small volume manufacturers to petition EPA for alternative standards. See Section III.B.5 below.

b. Environmental and Economic Benefits and Costs of EPA's Standards

i. Model Year Lifetime Analysis

Section I.C provides a comprehensive discussion of the projected benefits and costs associated with the proposed MYs 2017–2025 GHG and CAFE standards based on a ''model year lifetime'' analysis, *i.e.,* the benefits and costs associated with the lifetime operation of the new vehicles sold in these nine model years. It is important to note that while the incremental vehicle costs associated with MY 2017 vehicles will in fact occur in calendar year 2017, the benefits associated with MY 2017 vehicles will be split among all the calendar years from 2017 through the calendar year during which the last MY 2017 vehicle would be retired.

Table III–5 provides a summary of the GHG emissions and oil savings associated with the lifetime operation of all the vehicles sold in each model year. Cumulatively, for the nine model years from 2017 through 2025, the proposed standards are projected to save approximately 2 billion metric tons of GHG emissions and 4 billion barrels of oil.

Table III–6 provides a summary of the most important projected economic impacts of the proposed GHG emissions standards based on this model year lifetime analytical approach. These monetized dollar values are all discounted to the first year of each model year, then summed up across all model years. With a 3% discount rate, cumulative incremental vehicle technology cost for MYs 2017–2025 vehicles is $140 billion, fuel savings is $444 billion, other monetized benefits are $117 billion, and program net benefits are projected to be $421 billion. Using a 7% discount rate, the projected program net benefits are $311 billion.

As discussed previously, EPA recognizes that some of these same benefits and costs are also attributable to the CAFE standard contained in this joint proposal, although the GHG program achieves greater reductions of both GHG emissions and petroleum. More details associated with this model year lifetime analysis of the proposed GHG standards are presented in Sections III.F and III.H.

Table III-5 Summary of GHG Emissions and Oil Savings for Proposed CO_2 Standard Model Year Lifetime Analysis

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Cumulative MY 2017-2025
GHG Savings (MMT)	29	70	108	151	220	273	322	372	422	1,967
Oil Savings (Billion Barrels)	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	3.9

Table III-6 Summary of Key Projected Economic Impacts, on a Lifetime Present Value Basis, for Proposed CO2 Standard (1)

Model Year Lifetime Analysis (Billions of 2009 dollars)

	3% Discount Rate	7% Discount Rate
Incremental Vehicle Technology Cost	$140	$138
Societal Fuel Savings (2)	$444	$347
Other Benefits	$117	$101
Program Net Benefits	$421	$311

(1) Present value discounts all values to the first year of each MY, then sums those present values across MYs, in 2009 dollars.

(2) All fuel impacts are calculated with pre-tax fuel prices of $2.85 per gallon in calendar year 2017, rising to $3.18 per gallon in calendar year 2025, and $3.49 per gallon in calendar year 2040, and electricity prices of $0.10 per kWh in 2017 and 2025, and $0.11 per kWh in 2040, all in 2009 dollars.

ii. Calendar Year Analysis

In addition to the model year lifetime analysis projections summarized above, EPA also performs a ''calendar year'' analysis that projects the environmental and economic impacts associated with the proposed tailpipe CO_2 standards during specific calendar years out to 2050. This calendar year approach reflects the timeframe when the benefits would be achieved and the costs incurred. Because the EPA tailpipe CO_2 emissions standards will remain in effect unless and until they are changed, the projected impacts in this calendar year analysis beyond calendar year 2025 reflect vehicles sold in model years after 2025 (*e.g.,* most of the benefits in calendar year 2040 would be due to vehicles sold after MY 2025).

Table III–7 provides a summary of the most important projected benefits and costs of the proposed EPA GHG emissions standards based on this calendar year analysis. In calendar year 2025, EPA projects GHG savings of 151 million metric tons and oil savings of 0.83 million barrels per day. These would grow to 547 million metric tons of GHG savings and 3.12 million barrels of oil per day by calendar year 2050. Program net benefits are projected to be $18 billion in calendar year 2025, growing to $198 billion in calendar year 2050. Program net benefits over the 34-year period from 2017 through 2050 are projected to have a net present value in 2012 of $600 billion (7% discount rate) to $1.4 trillion (3% discount rate).

More details associated with this calendar year analysis of the proposed

GHG standards are presented in Sections III.F and III.H.

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Table III-7 Summary of Key Projected Impacts for Proposed CO_2 Standard – Calendar Year (CY) Analysis (1)

	CY 2017	CY 2020	CY 2025	CY 2030	CY 2040	CY 2050	CY 2017-2050 Net Present Value in 2012	
							3% discount	7% discount
GHG Savings (MMT per Year)	2.4	29	151	297	462	547	--	--
Oil Savings (Million Barrels per Year)	4.6	54.2	301	609	962	1,140	--	--
Oil Savings (Million Barrels per Day)	0.013	0.15	0.83	1.67	2.63	3.12	--	--
Incremental Vehicle Technology Cost (billions of 2009$)	$2.3	$8.5	$34	$36	$40	$45	$551	$243
Societal Fuel Savings (billions of 2009$) (2)	$0.57	$7.1	$41	$86	$144	$187	$1510	$579
Other Benefits (billions of 2009$)	$0.14	$1.7	$10	$22	$40	$56	$413	$263
Program Net Benefits (billions of 2009$) (2) (3)	-$1.6	$0.33	$18	$72	$144	$198	$1370	$599

(1) Values in columns 2 through 7 are undiscounted annual values, values in columns 8 and 9 are discounted to a net present value in 2012.

(2) All fuel impacts are calculated with pre-tax fuel prices of $2.85 per gallon in calendar year 2017, rising to $3.18 per gallon in calendar year 2025, and $3.49 per gallon in calendar year 2040, and electricity prices of $0.10 per kWh in 2017 and 2025, and $0.11 per kWh in 2040, all in 2009 dollars.

(3) Assuming the 3% average SCC value and other benefits of the proposed program not presented in this table

Incremental Vehicle Technology Cost (billions of 2009$)	$2.3	$8.5	$34	$36	$40	$45	$551	$243
Societal Fuel Savings (billions of 2009$) (2)	$0.57	$7.1	$41	$86	$144	$187	$1510	$579
Other Benefits (billions of 2009$)	$0.14	$1.7	$10	$22	$40	$56	$413	$263
Program Net Benefits (billions of 2009$) (2) (3)	-$1.6	$0.33	$18	$72	$144	$198	$1370	$599

(1) Values in columns 2 through 7 are undiscounted annual values, values in columns 8 and 9 are discounted to a net present value in 2012.

(2) All fuel impacts are calculated with pre-tax fuel prices of $2.85 per gallon in calendar year 2017, rising to $3.18 per gallon in calendar year 2025, and $3.49 per gallon in calendar year 2040, and electricity prices of $0.10 per kWh in 2017 and 2025, and $0.11 per kWh in 2040, all in 2009 dollars.

(3) Assuming the 3% average SCC value and other benefits of the proposed program not presented in this table

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iii. Consumer Analysis

The model year lifetime and calendar year analytical approaches discussed above aggregate the environmental and economic impacts across the nationwide light vehicle fleet. EPA has also projected the average impact of the proposed GHG standards on individual consumers who own and drive MY 2025 light vehicles over their lifetimes.

Table III–8 shows, on average, several key consumer impacts associated with the proposed tailpipe CO_2 standard for

MY 2025 vehicles. Some of these factors are dependent on the assumed discount factors, and this table uses the same 3% and 7% discount factors used throughout this preamble. EPA uses AEO2011 fuel price projections of $3.25 per gallon in calendar year 2017, rising to $3.54 per gallon in calendar year 2025 and $3.85 per gallon in calendar year 2040.

EPA projects that the new technology necessary to meet the proposed MY 2025 standard would add, on average, an extra $1950 (including markup) to the sticker price of a new MY 2025 light-duty vehicle. Including higher vehicle sales taxes and first-year insurance costs, the projected incremental first-year cost to the consumer is about $2100 on average. The projected incremental lifetime vehicle cost to the consumer, reflecting higher insurance premiums over the life of the vehicle, is, on average, about $2200. For all of the consumers who drive MY 2025 light-duty vehicles, the proposed standards are projected to yield a net savings of $3000 (7% discount rate) to $4400 (3% discount) over the lifetime of the vehicle, as the discounted lifetime fuel savings of $5200–$6600 is 2.4 to 3 times greater than the $2200 incremental lifetime vehicle cost to the consumer.

Of course, many vehicles are owned by more than one consumer. The payback period and monthly cash flow approaches are two ways to evaluate the economic impact of the MY 2025 standard on those new car buyers who do not own the vehicle for its entire lifetime. Projected payback periods of 3.7–3.9 years means that, for a consumer that buys a new vehicle with cash, the discounted fuel savings for that consumer would more than offset the incremental lifetime vehicle cost in 4 years. If the consumer owns the vehicle beyond this payback period, the vehicle will save money for the consumer. For a consumer that buys a new vehicle with a 5-year loan, the monthly cash flow savings of $12 (or about $140 per year) shows that the consumer would benefit immediately as the monthly fuel savings more than offsets the higher monthly payment due to the higher incremental first-year vehicle cost.

The final entries in Table III–8 show the CO_2 and oil savings that would be associated with the MY 2025 vehicles on average, both on a lifetime basis and in the first full year of operation. On average, a consumer who owns a MY 2025 vehicle for its entire lifetime is projected to emit 20 fewer metric tons of CO_2 and consume 2200 fewer gallons of gasoline due to the proposed standards.

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Table III-8 Summary of Key Projected Consumer Impacts for Proposed MY 2025 CO_2 Standard (1) (2)

	3% Discount Rate	7% Discount Rate
Incremental Vehicle Technology Cost	$1950	
Incremental First-Year Vehicle Cost to Consumer (3)	$2100	
Incremental Lifetime Vehicle Cost to Consumer (4)	$2200	$2200
Lifetime Consumer Fuel Savings (5)	$6600	$5200
Lifetime Consumer Net Savings (6)	$4400	$3000
Payback Period for Cash Purchase (years)	3.7	3.9
Monthly Cash Flow Savings Based on 5-Year Loan	$12	
Annual Cash Flow Savings Based on 5-Year Loan	$140	
First Year CO_2 Savings (Metric Tons) (7)	1.6	
Lifetime CO_2 Savings (Metric Tons) (7)	20	
First Year Gasoline/Oil Savings (Gallons) (7)	180	
Lifetime Gasoline/Oil Savings (Gallons) (7)	2200	

(1) Average impact of all MY 2025 light vehicles, excluding rebound effect.

(2) Most values have been rounded to two significant digits in this summary table and therefore may be slightly different than tables elsewhere that report values to three or four significant digits.

(3) Incremental First-Year Vehicle Cost to Consumer includes the incremental vehicle technology cost, a 5.3% average nationwide sales tax, and a 1.85% increase in first-year insurance premiums.

(4) Incremental Lifetime Vehicle Cost to Consumer includes the incremental vehicle technology cost, a 5.3% average nationwide sales tax, and the discounted cost associated with incremental lifetime insurance premiums.

(5) All fuel impacts are calculated with fuel prices, including fuel taxes, of $3.25 per gallon in calendar year 2017, rising to $3.54 per gallon in calendar year 2025, and $3.85 per gallon in calendar year 2040, and electricity prices of $0.10 per kWh in 2017 and 2025, and $0.11 per kWh in 2040, all in 2009 dollars.

(6) Lifetime Consumer Fuel Savings minus Incremental Lifetime Vehicle Cost to Consumer.

(7) CO_2 and gasoline savings reflect vehicle tailpipe-only and do not include CO_2 and oil savings associated with fuel production and distribution.

First Year Gasoline/Oil Savings (Gallons) (7)	180
Lifetime Gasoline/Oil Savings (Gallons) (7)	2200

(1) Average impact of all MY 2025 light vehicles, excluding rebound effect.

(2) Most values have been rounded to two significant digits in this summary table and therefore may be slightly different than tables elsewhere that report values to three or four significant digits.

(3) Incremental First-Year Vehicle Cost to Consumer includes the incremental vehicle technology cost, a 5.3% average nationwide sales tax, and a 1.85% increase in first-year insurance premiums.

(4) Incremental Lifetime Vehicle Cost to Consumer includes the incremental vehicle technology cost, a 5.3% average nationwide sales tax, and the discounted cost associated with incremental lifetime insurance premiums.

(5) All fuel impacts are calculated with fuel prices, including fuel taxes, of $3.25 per gallon in calendar year 2017, rising to $3.54 per gallon in calendar year 2025, and $3.85 per gallon in calendar year 2040, and electricity prices of $0.10 per kWh in 2017 and 2025, and $0.11 per kWh in 2040, all in 2009 dollars.

(6) Lifetime Consumer Fuel Savings minus Incremental Lifetime Vehicle Cost to Consumer.

(7) CO_2 and gasoline savings reflect vehicle tailpipe-only and do not include CO_2 and oil savings associated with fuel production and distribution.

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4. Basis for the GHG Standards Under Section 202(a)

EPA has significant discretion under section 202(a) of the Act in how to structure the standards that apply to the emission of the air pollutant at issue here, the aggregate group of six GHGs, as well as to the content of such standards. See generally 74 FR at 49464–65. EPA statutory authority under section 202(a)(1) of the Clean Air Act (CAA) is discussed in more detail in Section I.D of the preamble. In this rulemaking, EPA is proposing a CO_2 tailpipe emissions standard that provides for credits based on reductions of HFCs, as the appropriate way to issue standards applicable to emissions of the single air pollutant, the aggregate group of six GHGs. EPA is not proposing to change the methane and nitrous oxide standards already in place (although EPA is proposing certain changes to the compliance mechanisms for these standards as explained in Section III.B below). EPA is not setting any standards for perfluorocarbons or sulfur hexafluoride, as they are not emitted by motor vehicles. The following is a summary of the basis for the proposed GHG standards under section 202(a), which is discussed in more detail in the following portions of Section III.

With respect to CO_2 and HFCs, EPA is proposing attribute-based light-duty car and truck standards that achieve large and important emissions reductions of GHGs. EPA has evaluated the technological feasibility of the standards, and the information and analysis performed by EPA indicates that these standards are feasible in the lead time provided. EPA and NHTSA have carefully evaluated the effectiveness of individual technologies as well as the interactions when technologies are combined. EPA projects that manufacturers will be able to meet the standards by employing a wide variety of technologies that are already commercially available. EPA's analysis also takes into account certain flexibilities that will facilitate compliance. These flexibilities include averaging, banking, and trading of various types of credits. For a few very small volume manufacturers, EPA is proposing to allow manufacturers to petition for alternative standards.

EPA, as a part of its joint technology analysis with NHTSA, has performed what we believe is the most comprehensive federal vehicle technology analysis in history. We carefully considered the cost to manufacturers of meeting the standards, estimating piece costs for all candidate technologies, direct manufacturing costs, cost markups to account for manufacturers' indirect costs, and manufacturer cost reductions attributable to learning. In estimating manufacturer costs, EPA took into account manufacturers' own practices such as making major changes to vehicle technology packages during a planned redesign cycle. EPA then projected the average cost across the industry to employ this technology, as well as manufacturer-by-manufacturer costs. EPA considers the per vehicle costs estimated by this analysis to be within a reasonable range in light of the emissions reductions and benefits achieved. EPA projects, for example, that the fuel savings over the life of the vehicles will more than offset the increase in cost associated with the technology used to meet the standards. As explained in Section III.D.6 below, EPA has also investigated potential standards both more and less stringent than those being proposed and has rejected them. Less stringent standards would forego emission reductions which are feasible, cost effective, and cost feasible, with short consumer payback periods. EPA judges that the proposed standards are appropriate and preferable to more stringent alternatives based largely on consideration of cost—both to manufacturers and to consumers—and the potential for overly aggressive penetration rates for advanced technologies relative to the penetration rates seen in the proposed standards, especially in the face of unknown degree of consumer acceptance of both the increased costs and the technologies themselves.

EPA has also evaluated the impacts of these standards with respect to reductions in GHGs and reductions in oil usage. For the lifetime of the model year 2017–2025 vehicles we estimate GHG reductions of approximately 2 billion metric tons and fuel reductions of about 4 billion barrels of oil. These are important and significant reductions. EPA has also analyzed a variety of other impacts of the standards, ranging from the standards' effects on emissions of non-GHG pollutants, impacts on noise, energy, safety and congestion. EPA has also quantified the cost and benefits of the standards, to the extent practicable. Our analysis to date indicates that the overall quantified benefits of the standards far outweigh the projected costs. We estimate the total net social benefits (lifetime present value discounted to the first year of the model year) over the life of MY 2017–2025 vehicles to be $421 billion with a 3% discount rate and $311 billion with a 7% discount rate.

Under section 202(a), EPA is called upon to set standards that provide adequate lead-time for the development and application of technology to meet the standards. EPA's standards satisfy this requirement given the present existence of the technologies on which the proposed rule is predicated and the substantial lead times afforded under the proposal (which by MY2025 allow for multiple vehicle redesign cycles and so affords opportunities for adding technologies in the most cost efficient manner, see 75 FR at 25407). In setting the standards, EPA is called upon to weigh and balance various factors, and to exercise judgment in setting standards that are a reasonable balance of the relevant factors. In this case, EPA has considered many factors, such as cost, impacts on emissions (both GHG and non-GHG), impacts on oil conservation, impacts on noise, energy, safety, and other factors, and has where practicable quantified the costs and benefits of the proposed rule. In summary, given the technical feasibility of the standard, the cost per vehicle in light of the savings in fuel costs over the lifetime of the vehicle, the very significant reductions in emissions and in oil usage, and the significantly greater quantified benefits compared to quantified costs, EPA is confident that the standards are an appropriate and reasonable balance of the factors to consider under section 202(a). See *Husqvarna AB v. EPA,* 254 F. 3d 195, 200 (DC Cir. 2001) (great discretion to balance statutory factors in considering level of technology-based standard, and statutory requirement ''to [give appropriate] consideration to the cost of applying * * * technology'' does not mandate a specific method of cost analysis); see also *Hercules Inc.* v. *EPA,* 598 F. 2d 91, 106 (DC Cir. 1978) (''In reviewing a numerical standard we must ask whether the agency's numbers are within a zone of reasonableness, not whether its numbers are precisely right''); *Permian Basin Area Rate Cases,* 390 U.S. 747, 797 (1968) (same); *Federal Power Commission* v. *Conway Corp.,* 426 U.S. 271, 278 (1976) (same); *Exxon Mobil Gas Marketing Co.* v. *FERC,* 297 F. 3d 1071, 1084 (DC Cir. 2002) (same).

EPA recognizes that most of the technologies that we are considering for purposes of setting standards under section 202(a) are commercially available and already being utilized to a limited extent across the fleet, or will soon be commercialized by one or more major manufacturers. The vast majority of the emission reductions that would result from this rule would result from the increased use of these technologies. EPA also recognizes that this rule would enhance the development and commercialization of more advanced technologies, such as PHEVs and EVs and strong hybrids as well. In this technological context, there is no clear cut line that indicates that only one projection of technology penetration could potentially be considered feasible for purposes of section 202(a), or only one standard that could potentially be considered a reasonable balancing of the factors relevant under section 202(a). EPA therefore evaluated several alternative standards, some more stringent than the promulgated standards and some less stringent.

See Section III.D.6 for EPA's analysis of alternative GHG emissions standards.

5. Other Related EPA Motor Vehicle Regulations

a. EPA's Recent Heavy-Duty GHG Emissions Rulemaking

EPA and NHTSA recently conducted a joint rulemaking to establish a comprehensive Heavy-Duty National Program that will reduce greenhouse gas emissions and fuel consumption for on-road heavy-duty vehicles beginning in MY 2014 (76 FR 57106 (September 15, 2011)). EPA's final carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions standards, along with NHTSA's final fuel consumption standards, are tailored to each of three regulatory categories of heavy-duty vehicles: (1) Combination Tractors; (2) Heavy-duty Pickup Trucks and Vans; and (3) Vocational Vehicles. The rules include separate standards for the engines that power combination tractors and vocational vehicles. EPA also set hydrofluorocarbon standards to control leakage from air conditioning systems in combination tractors and heavy-duty pickup trucks and vans.

The agencies estimate that the combined standards will reduce CO_2 emissions by approximately 270 million metric tons and save 530 million barrels of oil over the life of vehicles sold during the 2014 through 2018 model years, providing $49 billion in net societal benefits when private fuel savings are considered. See 76 FR at 57125–27.

b. EPA's Plans for Further Standards for Light Vehicle Criteria Pollutants and Gasoline Fuel Quality

In the May 21, 2010 Presidential Memorandum, in addition to addressing GHGs and fuel economy, the President also requested that EPA examine its broader motor vehicle air pollution control program. The President requested that ''*[t]he Administrator of the EPA review for adequacy the current nongreenhouse gas emissions regulations for new motor vehicles, new motor vehicle engines, and motor vehicle fuels, including tailpipe emissions standards for nitrogen oxides and air toxics, and sulfur standards for gasoline. If the Administrator of the EPA finds that new emissions regulations are required, then I request that the Administrator of the EPA promulgate such regulations as part of a comprehensive approach toward regulating motor vehicles.*''[214] EPA is currently in the process of conducting an assessment of the potential need for additional controls on light-duty vehicle non-GHG emissions and gasoline fuel quality. EPA has been actively engaging in technical conversations with the automobile industry, the oil industry, nongovernmental organizations, the states, and other stakeholders on the potential need for new regulatory action, including the areas that are specifically mentioned in the Presidential Memorandum. EPA will coordinate all future actions in this area with the State of California.

Based on this assessment, in the near future, EPA expects to propose a separate but related program that would, in general, affect the same set of new vehicles on the same timeline as would the proposed light-duty GHG emissions standards. It would be designed to address air quality problems with ozone and PM, which continue to be serious problems in many parts of the country, and light-duty vehicles continue to play a significant role.

EPA expects that this related program, called ''Tier 3'' vehicle and fuel standards, would among other things propose tailpipe and evaporative standards to reduce non-GHG pollutants from light-duty vehicles, including volatile organic compounds, nitrogen oxides, particulate matter, and air toxics. EPA's intent, based on extensive interaction to date with the automobile manufacturers and other stakeholders, is to propose a Tier 3 program that would allow manufacturers to proceed with

[214] The Presidential Memorandum is found at: *http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.*

coordinated future product development plans with a full understanding of the major regulatory requirements they will be facing over the long term. This coordinated regulatory approach would allow manufacturers to design their future vehicles so that any technological challenges associated with meeting both the GHG and Tier 3 standards could be efficiently addressed.

It should be noted that under EPA's current regulations, GHG emissions and CAFE compliance testing for gasoline vehicles is conducted using a defined fuel that does not include any amount of ethanol.[215] If the certification test fuel is changed to some ethanol-based fuel through a future rulemaking, EPA would be required under EPCA to address the need for a test procedure adjustment to preserve the level of stringency of the CAFE standards.[216] EPA is committed to doing so in a timely manner to ensure that any change in certification fuel will not affect the stringency of future GHG emission standards.

B. Proposed Model Year 2017–2025 GHG Standards for Light-duty Vehicles, Light-duty Trucks, and Medium duty Passenger Vehicles

EPA is proposing new emissions standards to control greenhouse gases (GHGs) from MY 2017 and later light-duty vehicles. EPA is proposing new emission standards for carbon dioxide (CO_2) on a gram per mile (g/mile) basis that will apply to a manufacturer's fleet of cars, and a separate standard that will apply to a manufacturer's fleet of trucks. CO_2 is the primary greenhouse gas resulting from the combustion of vehicular fuels, and the amount of CO_2 emitted is directly correlated to the amount of fuel consumed. EPA is proposing to conduct a mid-term evaluation of the GHG standards and other requirements for MYs 2022–2025, as further discussed in Section III.B.3 below.

EPA is not proposing changes to the CH_4 and N_2O emissions standards, but is proposing revisions to the options that manufacturers have in meeting the CH_4 and N_2O standards, and to the timeframe for manufacturers to begin measuring N_2O emissions. These proposed changes are not intended to change the stringency of the CH_4 and N_2O standards, but are aimed at addressing implementation concerns regarding the standards.

The opportunity to earn credits toward the fleet-wide average CO_2 standards for improvements to air conditioning systems remains in place for MY 2017 and later, including improvements to address both hydrofluorocarbon (HFC) refrigerant losses (*i.e.,* system leakage) and indirect CO_2 emissions related to the air conditioning efficiency and load on the engine. The CO_2 standards proposed for cars and trucks take into account EPA's projection of the average amount of credits expected to be generated across the industry. EPA is proposing several revisions to the air conditioning credits provisions, as discussed in Section III.C.1.

The MY 2012–2016 Final Rule established several program elements that remain in place, where EPA is not proposing significant changes. The proposed standards described below would apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles (MDPVs). As an overall group, they are referred to in this preamble as light-duty vehicles or simply as vehicles. In this preamble section, passenger cars may be referred to simply as "cars", and light-duty trucks and MDPVs as "light trucks" or "trucks."[217]

EPA is not proposing changes to the averaging, banking, and trading program elements, as discussed in Section III.B.4, with the exception of our proposal for a one-time carry-forward of any credits generated in MY 2010–2016 to be used anytime through MY2021. The previous rulemaking also established provisions for MY 2016 and later FFVs, where the emissions levels of these vehicles are based on tailpipe emissions performance and the amount of alternative fuel used. These provisions remain in place without change.

Several provisions are being proposed that allow manufacturer's to generate credits for use in complying with the standards or that provide additional incentives for use of advanced technology. These include credits for technology that reduces CO_2 emissions during off-cycle operation that is not reasonably accounted for by the 2-cycle tests used for compliance purposes. EPA is proposing various changes to this program to streamline its use compared to the MYs 2012–2016 program. These provisions are discussed in section III.C. In addition, EPA is proposing the use of multipliers to provide an incentive for the use of EVs, PHEVs, and FCVs, as well as a specified gram/mile credit for full size pick-up trucks that meet various efficiency performance criteria and/or include hybrid technology at a minimum level of production volumes. These provisions are also discussed in Section III.C. As discussed in those sections, while these additional credit provisions do not change the level of the standards proposed for cars and trucks, unlike the provisions for AC credits, they all support the reasonableness of the standards proposed for MYs 2017–2025.

1. What Fleet-wide Emissions Levels Correspond to the CO_2 Standards?

EPA is proposing standards that are projected to require, on an average industry fleet wide basis, 163 grams/mile of CO_2 in model year 2025. The level of 163 grams/mile CO_2 would be equivalent on a mpg basis to 54.5 mpg, if this level was achieved solely through improvements in fuel efficiency.[218][219] For passenger cars, the proposed footprint curves call for reducing CO_2 by 5 percent per year on average from the model year 2016 passenger car standard through model year 2025. In recognition of manufacturers' unique challenges in improving the GHG emissions of full-size pickup trucks as we transition from the MY 2016 standards to MY 2017 and later, while preserving the utility (*e.g.,* towing and payload capabilities) of those vehicles, EPA is proposing a lower annual rate of improvement for light-duty trucks in the early years of the program. For light-duty trucks, the footprint curves call for reducing CO_2 by 3.5 percent per year on average from the model year 2016 truck standard through model year 2021. EPA is also proposing to change the slopes of the CO_2-footprint curves for light-duty trucks from those in the 2012–2016 rule, in a manner that effectively means that the annual rate of improvement for smaller light-duty trucks in model years 2017 through 2021 would be higher than 3.5 percent, and the annual rate of improvement for larger light-duty trucks over the same time period would be lower than 3.5 percent to account for the unique challenges for improving the GHG of large light trucks while maintaining cargo hauling and towing utility. For model years 2022 through 2025, EPA is proposing a reduction of CO_2 for light-

[215] *See* 40 CFR 86.113–94(a).

[216] EPCA requires that CAFE tests be determined from the EPA test procedures in place as of 1975, or procedures that give comparable results. 49 USC 32904(c).

[217] GHG emissions standards would use the same vehicle category definitions used for MYs 2012–2016 and as are used in the CAFE program.

[218] In comparison, the MY 2016 CO_2 standard is projected to achieve a national fleet-wide average, covering both cars and trucks, of 250 g/mile.

[219] Real-world CO_2 is typically 25 percent higher and real-world fuel economy is typically 20 percent lower than the CO_2 and CAFE values discussed here. The reference to CO_2 here refers to CO_2 equivalent reductions, as this level includes some reductions in emissions of greenhouse gases other than CO_2, from refrigerant leakage, as one part of the AC related reductions.

duty trucks of 5 percent per year on average starting from the model year 2021 truck standard.

EPA's proposed standards include EPA's projection of average industry wide CO_2-equivalent emission reductions from A/C improvements, where the proposed footprint curve is made more stringent by an amount equivalent to this projection of A/C credits. This projection of A/C credits builds on the projections from MYs 2012–2016, with the increases in credits mainly due to the full penetration of low GWP alternative refrigerant by MY 2021. The proposed car standards would begin with MY 2017, with a generally linear increase in stringency from MY 2017 through MY 2025 for cars. The truck standards have a more gradual increase for MYs 2017–2020 then more rapidly in MY 2021. For MYs 2021–2025, the truck standards increase in stringency generally in a linear fashion. EPA proposes to continue to have separate standards for cars and light trucks, and to have identical definitions of cars and trucks as NHTSA, in order to harmonize with CAFE standards. The tables in this section below provide overall fleet average levels that are projected for both cars and light trucks over the phase-in period which is estimated to correspond with the proposed standards. The actual fleet-wide average g/mi level that would be achieved in any year for cars and trucks will depend on the actual production for that year, as well as the use of the various credit and averaging, banking, and trading provisions. For example, in any year, manufacturers would be able to generate credits from cars and use them for compliance with the truck standard, or vice versa. Such transfer of credits between cars and trucks is not reflected in the table below. In Section III.F, EPA discusses the year-by-year estimate of emissions reductions that are projected to be achieved by the standards.

In general, the proposed schedule of standards acts as a phase-in to the MY 2025 standards, and reflects consideration of the appropriate lead-time and engineering redesign cycles for each manufacturer to implement the requisite emission reductions technology across its product line. Note that MY 2025 is the final model year in which the standards become more stringent. The MY 2025 CO_2 standards would remain in place for MY 2025 and later model years, until revised by EPA in a future rulemaking. EPA estimates that, on a combined fleet-wide national basis, the 2025 MY proposed standards would require a level of 163 g/mile CO_2. The derivation of the 163 g/mile estimate is described in Section III.B.2. EPA has estimated the overall fleet-wide CO_2-equivalent emission (target) levels that correspond with the proposed attribute-based standards, based on the projections of the composition of each manufacturer's fleet in each year of the program. Tables Table III–9 and Table III–10 provide these target estimates for each manufacturer.

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Table III-9 Estimated Fleet CO_2-equivalent Levels Corresponding to the Proposed Standards (Targets) for Cars (g/mile)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	210	200	190	180	171	163	156	149	142
BMW	216	205	195	185	175	168	160	153	146
Chrysler/Fiat	218	207	196	187	176	168	161	153	146
Daimler	226	215	205	194	184	176	168	161	153
Ferrari	222	211	201	191	181	173	165	158	150
Ford	218	207	196	187	177	169	162	154	147
Geely-Volvo	220	209	198	188	178	170	163	155	148
General Motors	217	206	196	186	176	168	161	153	146
Honda	210	200	189	180	170	163	155	148	142
Hyundai	211	201	190	181	171	163	156	149	142
Kia	213	202	192	182	172	165	157	150	143
Lotus	195	185	175	166	157	150	143	137	131
Mazda	210	200	190	180	171	163	156	149	142
Mitsubishi	207	197	187	177	168	160	153	146	139
Nissan	214	204	193	184	174	166	159	152	145
Porsche	195	185	175	166	157	150	143	137	131
Spyker-Saab	210	199	189	180	170	162	155	148	141
Subaru	204	194	184	174	165	158	151	144	137
Suzuki	196	186	177	167	158	151	144	138	132

Tata-JLR	237	225	214	203	193	184	176	168	161
Tesla	195	185	175	166	157	150	143	137	131
Toyota	209	199	189	179	169	162	155	148	141
Volkswagen	207	196	186	177	167	160	153	146	139

Table III-10 Estimated Fleet CO_2-equivelent Levels Corresponding to the Proposed Standards (Targets) for Light Trucks (g/mile)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BMW	283	272	264	255	236	225	214	204	194
Chrysler/Fiat	293	283	275	266	246	234	223	212	201
Daimler	299	289	280	272	253	241	229	218	208
Ferrari	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ford	305	296	288	282	262	250	237	224	213
Geely-Volvo	278	266	258	250	231	220	209	199	189
General Motors	309	299	291	283	262	249	236	224	213
Honda	279	269	261	252	233	222	211	201	191
Hyundai	277	266	258	249	231	219	209	198	188
Kia	289	279	271	262	243	231	220	209	199
Lotus	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mazda	272	259	252	244	226	216	206	195	186
Mitsubishi	266	254	246	238	220	209	199	189	180

Nissan	293	282	274	266	248	236	224	212	202
Porsche	286	274	266	257	238	226	215	205	195
Spyker-Saab	278	265	258	249	230	219	208	198	188
Subaru	263	251	243	235	217	206	196	186	177
Suzuki	269	257	249	240	222	211	201	191	181
Tata-JLR	270	258	250	241	223	212	202	191	182
Tesla	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Toyota	292	281	273	266	246	234	222	211	200
Volkswagen	295	284	276	267	248	236	225	214	203

Companies with "N/A" do not presently have trucks in their fleet.

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These estimates were aggregated based on projected production volumes into the fleet-wide averages for cars, trucks, and the entire fleet, shown in Table III–11.[220] The combined fleet estimates are based on the assumption of a fleet mix of cars and trucks that vary over the MY 2017–2025 timeframe. This fleet mix distribution can be found in Chapter 1 of the join TSD.

[220] Due to rounding during calculations, the estimated fleet-wide CO_2-equivalent levels may vary by plus or minus 1 gram.

Table III-11 Estimated Fleet-wide CO_2-equivalent Levels Corresponding to the Proposed Standards

	Cars	Trucks	Fleet
Model Year	CO_2 (g/mi)	CO_2 (g/mi)	CO_2 (g/mi)
2017	213	295	243
2018	202	285	232
2019	192	277	223
2020	182	270	213
2021	173	250	200
2022	165	237	190
2023	158	225	181
2024	151	214	172
2025 and later	144	203	163

As shown in Table III–11, fleet-wide CO_2-equivalent emission levels for cars under the approach are projected to decrease from 213 to 144 grams per mile between MY 2017 and MY 2025. Similarly, fleet-wide CO_2-equivalent emission levels for trucks are projected to decrease from 295 to 203 grams per mile. These numbers do not include the effects of other flexibilities and credits in the program.[221] The estimated achieved values can be found in Chapter 3 of the Regulatory Impact Analysis (RIA).

As noted above, EPA is proposing standards that would result in increasingly stringent levels of CO_2 control from MY 2017 though MY 2025. Applying the CO_2 footprint curves applicable in each model year to the vehicles (and their footprint distributions) expected to be sold in each model year produces progressively more stringent estimates of fleet-wide CO_2 emission targets. The standards achieve important CO_2 emissions reductions through the application of feasible control technology at reasonable cost, considering the needed lead time for this program and with proper consideration of manufacturer product redesign cycles. EPA has analyzed the feasibility of achieving the proposed CO_2 standards, based on projections of the adoption of technology to reduce emissions of CO_2, during the normal redesign process for cars and trucks, taking into account the effectiveness and cost of the technology. The results of the analysis are discussed in detail in Section III.D below and in the draft RIA. EPA also presents the overall estimated costs and benefits of the car and truck proposed CO_2 standards in Section III.H. In developing the proposal, EPA has evaluated the kinds of technologies that could be utilized by the automobile industry, as well as the associated costs for the industry and fuel savings for the consumer, the magnitude of the GHG and oil reductions that may be achieved, and other factors relevant under the CAA.

With respect to the lead time and cost of incorporating technology improvements that reduce GHG emissions, EPA places important weight on the fact that the proposed rule provides a long planning horizon to achieve the very challenging emissions standards being proposed, and provides manufacturers with certainty when planning future products. The time-frame and levels for the standards are expected to provide manufacturers the time needed to develop and incorporate technology that will achieve GHG reductions, and to do this as part of the normal vehicle redesign process. Further discussing of lead time, redesigns and feasibility can be found in Section III–D and Chapter 3 of the joint TSD.

In the MY 2012–2016 Final Rule, EPA established several provisions which will continue to apply for the proposed MY2017–2025 standards. Consistent with the requirement of CAA section 202(a)(1) that standards be applicable to vehicles ''for their useful life,'' CO_2 vehicle standards would apply for the useful life of the vehicle. Under section 202(i) of the Act, which authorized the Tier 2 standards, EPA established a useful life period of 10 years or 120,000

[221] Nor do they reflect ABT.

miles, whichever first occurs, for all light-duty vehicles and light-duty trucks.[222] This useful life was applied to the MY 2012–2016 GHG standards and EPA is not proposing any changes to the useful life for MYs 2017–2025. Also, as with MYs 2012–2016, EPA proposes that the in-use emission standard would be 10% higher for a model than the emission levels used for certification and compliance with the fleet average that is based on the footprint curves. As with the MY2012–2016 standards, this will address issues of production variability and test-to-test variability. The in-use standard is discussed in Section II*I.E.* Finally, EPA is not proposing any changes to the test procedures over which emissions are measured and weighted to determine compliance with the standards. These procedures are the Federal Test Procedure (FTP or ''city'' test) and the Highway Fuel Economy Test (HFET or ''highway'' test).

2. What Are the Proposed CO_2 Attribute-based Standards?

As with the MY 2012–2016 standards, EPA is proposing separate car and truck standards, that is, vehicles defined as cars have one set of footprint-based curves for MY 2017–2025 and vehicles defined as trucks have a different set for MY 2017–2025. In general, for a given footprint the CO_2 g/mi target for trucks would be less stringent than for a car with the same footprint. EPA's approach for establishing the footprint curves for model years 2017 and later, including changes from the approach used for the MY2012–2016 footprint curves, is discussed in Section II.C and Chapter 2 of the joint TSD. The curves are described mathematically by a family of piecewise linear functions (with respect to vehicle footprint) that gradually and continually ramp down from the MY 2016 curve established in the previous rule. As Section II.C describes, EPA has modified the curves from 2016, particularly for trucks. To make this modification, we wanted to ensure that starting from the 2016 curve, there is a gradual transition to the new slopes and cut point (out to 74 sq ft from 66 sq ft). The transition is also designed to prevent the curve from one year from crossing the previous year's curve.

Written in mathematic notation, the form of the proposed function is as follows: [223]

[222] See 65 FR 6698 (February 10, 2000).

[223] See proposed Regulatory text, which are the official coefficients and equation. The information proposed here is a summary version.

Passenger Car Target = min (b,max(a, c * footprint+d))

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a	194.7	184.9	175.3	166.1	157.2	150.2	143.3	136.8	130.5
b	262.7	250.1	238.0	226.2	214.9	205.5	196.5	187.8	179.5
c	4.53	4.35	4.17	4.01	3.84	3.69	3.54	3.40	3.26
d	8.9	6.5	4.2	1.9	-0.4	-1.1	-1.8	-2.5	-3.2

Light Truck Target = min(min (b,max(a, c * footprint+d)),min(f,max(e, g*footprint+h)

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a	238.1	226.8	219.5	211.9	195.4	185.7	176.4	167.6	159.1
b	347.2	341.7	338.6	336.7	334.8	320.8	305.6	291.0	277.1
c	4.87	4.76	4.68	4.57	4.28	4.09	3.91	3.74	3.58
d	38.3	31.6	27.7	24.6	19.8	17.8	16.0	14.2	12.5
e	246.4	240.9	237.8	235.9	234.0	234.0	234.0	234.0	234.0
f	347.4	341.9	338.8	336.9	335.0	335.0	335.0	335.0	335.0
g	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04
h	80.5	75.0	71.9	70.0	68.1	68.1	68.1	68.1	68.1

Figure 3 - Car Curves

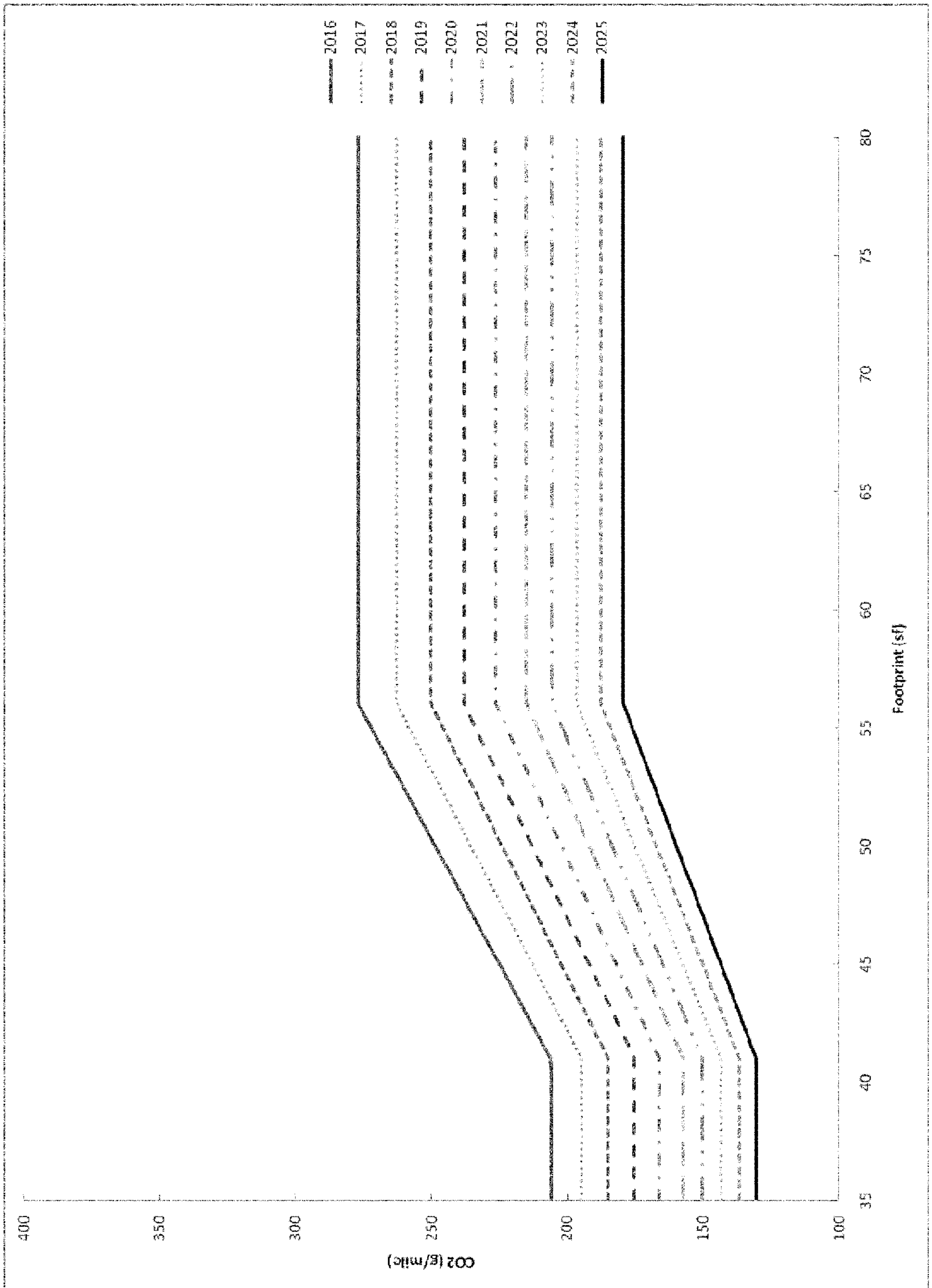
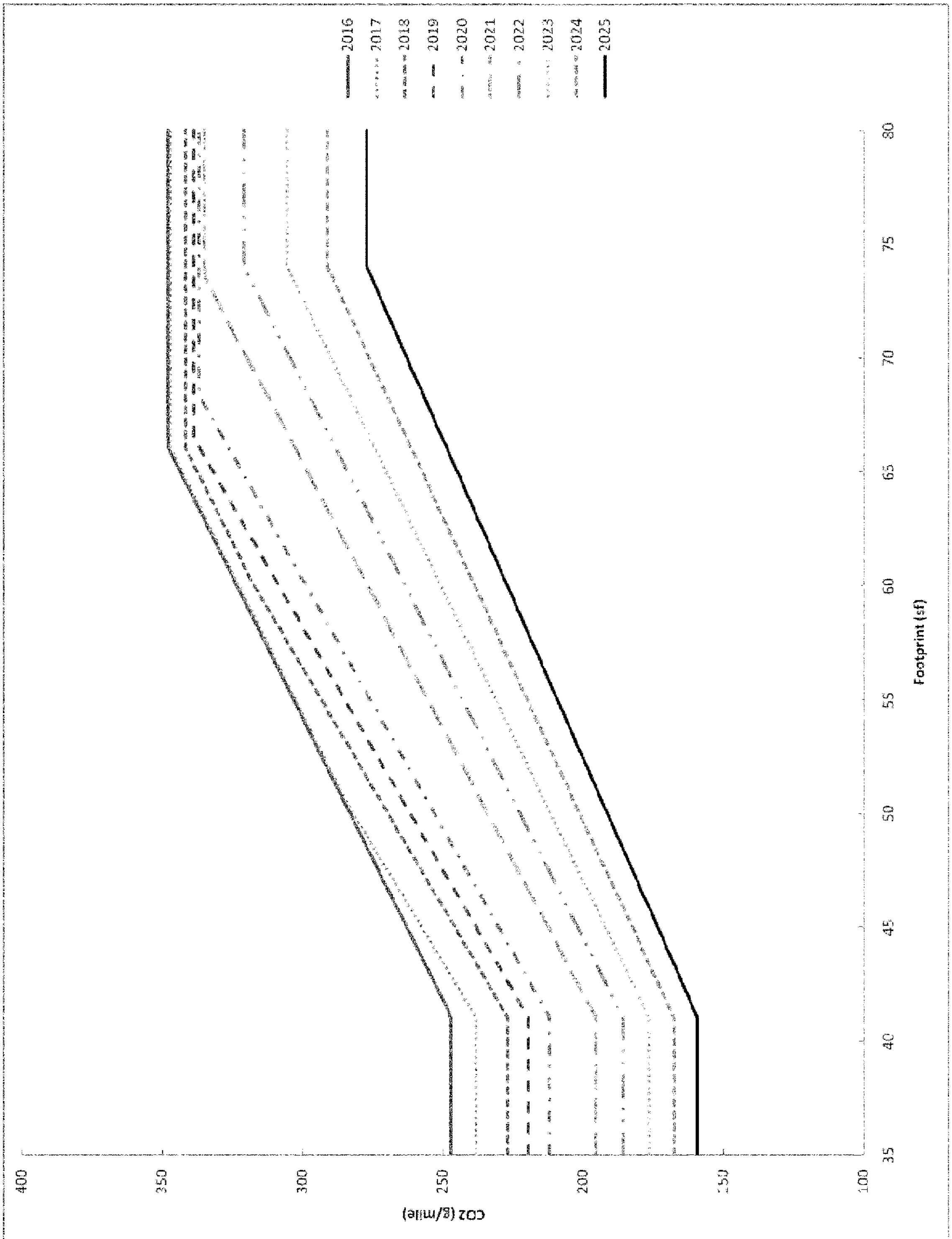


Figure 4 –Truck Curves



The car curves are largely similar to 2016 curve in slope. By contrast, the MY 2017 and later truck curves are steeper relative to the MY 2016 curve, but gradually flatten as a result of the multiplicative increase of the standards. As a further change from the MYs 2012–2016 rule, the truck curve does not reach the ultimate cutpoint of 74 sq ft until 2022. The gap between the 2020 curve and the 2021 curve is indicative of design of the truck standards described earlier, where a significant proportion of the increased stringency over the first five years occurs between MY 2020 and MY 2021. Finally, the gradual flattening of both the car and the trucks curves is noticeable. For further discussion of these topics, please see Section II.C and Chapter 2 of the joint TSD.

3. Mid-Term Evaluation

Given the long time frame at issue in setting standards for MY2022–2025 light-duty vehicles, and given NHTSA's obligation to conduct a separate rulemaking in order to establish final standards for vehicles for those model years, EPA and NHTSA will conduct a comprehensive mid-term evaluation and agency decision-making as described below. Up to date information will be developed and compiled for the evaluation, through a collaborative, robust and transparent process, including public notice and comment. The evaluation will be based on (1) A holistic assessment of all of the factors considered by the agencies in setting standards, including those set forth in the rule and other relevant factors, and (2) the expected impact of those factors on the manufacturers' ability to comply, without placing decisive weight on any particular factor or projection. The comprehensive evaluation process will lead to final agency action by both agencies.

Consistent with the agencies' commitment to maintaining a single national framework for regulation of vehicle emissions and fuel economy, the agencies fully expect to conduct the mid-term evaluation in close coordination with the California Air Resources Board (CARB). Moreover, the agencies fully expect that any adjustments to the standards will be made with the participation of CARB and in a manner that ensures continued harmonization of state and Federal vehicle standards.

EPA will conduct a mid-term evaluation of the later model year light-duty GHG standards (MY2022–2025). The evaluation will determine whether those standards are appropriate under section 202(a) of the Act. Under the regulations proposed today, EPA would be legally bound to make a final decision, by April 1, 2018, on whether the MY 2022–2025 GHG standards are appropriate under section 202(a), in light of the record then before the agency.

EPA, NHTSA and CARB will jointly prepare a draft Technical Assessment Report (TAR) to inform EPA's determination on the appropriateness of the GHG standards and to inform NHTSA's rulemaking for the CAFE standards for MYs 2022–2025. The TAR will examine the same issues and underlying analyses and projections considered in the original rulemaking, including technical and other analyses and projections relevant to each agency's authority to set standards as well as any relevant new issues that may present themselves. There will be an opportunity for public comment on the draft TAR, and appropriate peer review will be performed of underlying analyses in the TAR. The assumptions and modeling underlying the TAR will be available to the public, to the extent consistent with law.

EPA will also seek public comment on whether the standards are appropriate under section 202(a), *e.g.* comments to affirm or change the GHG standards (either more or less stringent). The agencies will carefully consider comments and information received and respond to comments in their respective subsequent final actions.

EPA and NHTSA will consult and coordinate in developing EPA's determination on whether the MY 2022–2025 GHG standards are appropriate under section 202(a) and NHTSA's NPRM.

In making its determination, EPA will evaluate and determine whether the MY2022–2025 GHG standards are appropriate under section 202(a) of the CAA based on a comprehensive, integrated assessment of all of the results of the review, as well as any public comments received during the evaluation, taken as a whole. The decision making required of the Administrator in making that determination is intended to be as robust and comprehensive as that in the original setting of the MY2017–2025 standards.

In making this determination, EPA will consider information on a range of relevant factors, including but not limited to those listed in the proposed rule and below:

1. Development of powertrain improvements to gasoline and diesel powered vehicles.
2. Impacts on employment, including the auto sector.
3. Availability and implementation of methods to reduce weight, including any impacts on safety.
4. Actual and projected availability of public and private charging infrastructure for electric vehicles, and fueling infrastructure for alternative fueled vehicles.
5. Costs, availability, and consumer acceptance of technologies to ensure compliance with the standards, such as vehicle batteries and power electronics, mass reduction, and anticipated trends in these costs.
6. Payback periods for any incremental vehicle costs associated with meeting the standards.
7. Costs for gasoline, diesel fuel, and alternative fuels.
8. Total light-duty vehicle sales and projected fleet mix.
9. Market penetration across the fleet of fuel efficient technologies.
10. Any other factors that may be deemed relevant to the review.

If, based on the evaluation, EPA decides that the GHG standards are appropriate under section 202(a), then EPA will announce that final decision and the basis for EPA's decision. The decision will be final agency action which also will be subject to judicial review on its merits. EPA will develop an administrative record for that review that will be no less robust than that developed for the initial determination to establish the standards. In the midterm evaluation, EPA will develop a robust record for judicial review that is the same kind of record that would be developed and before a court for judicial review of the adoption of standards.

Where EPA decides that the standards are not appropriate, EPA will initiate a rulemaking to adopt standards that are appropriate under section 202(a), which could result in standards that are either less or more stringent. In this rulemaking EPA will evaluate a range of alternative standards that are potentially effective and reasonably feasible, and the Administrator will propose the alternative that in her judgment is the best choice for a standard that is appropriate under section 202(a).[224] If EPA initiates a rulemaking, it will be a joint rulemaking with NHTSA. Any final action taken by EPA at the end of that rulemaking is also judicially reviewable.

The MY 2022–2025 GHG standards will remain in effect unless and until EPA changes them by rulemaking.

NHTSA intends to issue conditional standards for MYs 2022–2025 in the LDV rulemaking being initiated this fall for MY2017 and later model years. The CAFE standards for MYs 2022–2025 will be determined with finality in a subsequent, de novo notice and comment rulemaking conducted in full compliance with section 32902 of title 49 U.S.C. and other applicable law.

[224] The provisions of CAA section 202(b)(1)(C) are not applicable to any revisions of the greenhouse standards adopted in a later rulemaking based on the mid-term evaluation. Section 202(b)(1)(C) refers to EPA's authority to revise ''any standard prescribed or previously revised under this subsection,'' and indicates that ''[a]ny revised standard'' shall require a reduction of emissions from the standard that was previously applicable. These provisions apply to standards that are adopted under subsection 202(b) of the Act and are later revised. These provisions are limited by their terms to such standards, and do not otherwise limit EPA's general authority under section 202(a) to adopt standards and revise them ''from time to time.'' Since the greenhouse gas standards are not adopted under subsection 202(b), section 202(b)(1)(C) does not apply to these standards or any subsequent revision of these standards.

Accordingly, NHTSA's development of its proposal in that later rulemaking will include the making of economic and technology analyses and estimates that are appropriate for those model years and based on then-current information.

Any rulemaking conducted jointly by the agencies or by NHTSA alone will be timed to provide sufficient lead time for industry to make whatever changes to their products that the rulemaking analysis deems feasible based on the new information available. At the very latest, the three agencies will complete the mid-term evaluation process and subsequent rulemaking on the standards that may occur in sufficient time to promulgate final standards for MYs 2022–2025 with at least 18 months lead time, but additional lead time may be provided.

EPA understands that California intends to propose a mid-term evaluation in its program that is coordinated with EPA and NHTSA and is based on a similar set of factors as outlined in this Appendix A. The rules submitted to EPA for a waiver under the CAA will include such a mid-term evaluation. EPA understands that California intends to continue promoting harmonized state and federal vehicle standards. EPA further understands that California's 2017–2025 standards to be submitted to EPA for a waiver under the Clean Air Act will deem compliance with EPA greenhouse gas emission standards, even if amended after 2012, as compliant with California's. Therefore, if EPA revises it standards in response to the mid-term evaluation, California may need to amend one or more of its 2022–2025 MY standards and would submit such amendments to EPA with a request for a waiver, or for confirmation that said amendments fall within the scope of an existing waiver, as appropriate.

4. Averaging, Banking, and Trading Provisions for CO_2 Standards

In the MY 2012–2016 rule, EPA adopted credit provisions for credit carry-back, credit carry-forward, credit transfers, and credit trading. For EPA's purposes, these kinds of provisions are collectively termed Averaging, Banking, and Trading (ABT), and have been an important part of many mobile source programs under CAA Title II, both for fuels programs as well as for engine and vehicle programs.[225] As in the MY2012–2016 program, EPA is proposing basically the same comprehensive program for averaging, banking, and trading of credits which together will help manufacturers in planning and implementing the orderly phase-in of emissions control technology in their production, consistent with their typical redesign schedules. ABT is important because it can help to address many issues of technological feasibility and lead-time, as well as considerations of cost. ABT is an integral part of the standard setting itself, and is not just an add-on to help reduce costs. In many cases, ABT resolves issues of cost or technical feasibility, allowing EPA to set a standard that is numerically more stringent. The ABT provisions are integral to the fleet averaging approach established in the MY 2012–2016 rule. EPA is proposing to change the credit carry-forward provisions as described below, but the program otherwise would remain in place unchanged for model years 2017 and later.

As noted above, the ABT provisions consist primarily of credit carry-back, credit carry-forward, credit transfers, and credit trading. A manufacturer may have a deficit at the end of a model year after averaging across its fleet using credit transfers between cars and trucks—that is, a manufacturer's fleet average level may fail to meet the required fleet average standard. Credit carry-back refers to using credits to offset any deficit in meeting the fleet average standards that had accrued in a prior model year. A deficit must be offset within 3 model years using credit carry-back provisions. After satisfying any needs to offset pre-existing debits within a vehicle category, remaining credits may be banked, or saved for use in future years. This is referred to as credit carry-forward. The EPCA/EISA statutory framework for the CAFE program includes a 5-year credit carry-forward provision and a 3-year credit carry-back provision. In the MYs 2012–2016 program, EPA chose to adopt 5-year credit carry-forward and 3-year credit carry-back provisions as a reasonable approach that maintained consistency between the agencies' provisions. EPA is proposing to continue with this approach in this rulemaking. (A further discussion of the ABT provisions can be found at 75 FR 25412–14 May 7, 2010).

Although the credit carry-forward and carry-back provisions would generally remain in place for MY 2017 and later, EPA is proposing to allow all unused credits generated in MY 2010–2016 to be carried forward through MY 2021. This amounts to the normal 5 year carry-forward for MY 2016 and later credits but provides additional carry-forward years for credits earned in MYs 2010–2015. Extending the life for MY 2010–2015 credits would provide greater flexibility for manufacturers in using the credits they have generated. These credits would help manufacturers resolve lead-time issues they might face in the model years prior to 2021 as they transition from the 2016 standards to the progressively more stringent standards for 2017 and later. It also provides an additional incentive to generate credits earlier, for example in MYs 2014 and 2015, because those credits may be used through 2021, thereby encouraging the earlier use of additional CO_2 reducing technology.

While this provision provides greater flexibility in how manufacturers use credits they have generated, it would not change the overall CO_2 benefits of the National Program, as EPA does not expect that any of the credits would have expired as they likely would be used or traded to other manufacturers. EPA believes the proposed approach provides important additional flexibility in the early years of the new MY2017 and later standards. EPA requests comments on the proposed approach for carrying over MY 2010–2015 credits through MY 2021.

EPA is not proposing to allow MY 2009 early credits to be carried forward beyond the normal 5 years due to concerns expressed during the 2012–2016 rulemaking that there may be the potential for large numbers of credits that could be generated in MY 2009 for companies that are over-achieving on CAFE and that some of these credits could represent windfall credits.[226] In response to these concerns, EPA placed restrictions the use of MY 2009 credits (for example, MY 2009 credits may not be traded) and does not believe expanding the use of MY 2009 credits would be appropriate. Under the MY 2012–2016 early credits program, manufacturers have until the end of MY 2011 (reports must be submitted by April 2012), when the early credits program ends, to submit early credit reports. Therefore, EPA does not yet have information on the amount of early MY2009 credits actually generated by manufacturers to assess whether or not they could be viewed as windfall. Nevertheless, because these concerns continue, EPA is proposing not to extend the MY 2009 credit transfers past the existing 5-years limit.

Transferring credits refers to exchanging credits between the two averaging sets, passenger cars and trucks, within a manufacturer. For

[225] See 75 FR at 25412–413.

[226] 75 FR at 25442. Moreover, as pointed out in the earlier rulemaking, there can be no legitimate expectation that these 2009 MY credits could be used as part of a compliance strategy in model years after 2014, and thus no reason to carry forward the credits past 5 years due to action in reliance by manufacturers.

example, credits accrued by over-compliance with a manufacturer's car fleet average standard could be used to offset debits accrued due to that manufacturer not meeting the truck fleet average standard in a given year. Finally, accumulated credits may be traded to another manufacturer. In EPA's CO_2 program, there are no limits on the amount of credits that may be transferred or traded.

The averaging, banking, and trading provisions are generally consistent with those included in the CAFE program, with a few notable exceptions. As with EPA's approach (except for the proposal discussed above for a one-time extended carry-forward of MY2010–2016 credits), CAFE allows five year carry-forward of credits and three year carry-back, per EISA. CAFE transfers of credits across a manufacturer's car and truck averaging sets are also allowed, but with limits established by EISA on the use of transferred credits. The amount of transferred credits that can be used in a year is limited under CAFE, and transferred credits may not be used to meet the CAFE minimum domestic passenger car standard, also per statute. CAFE allows credit trading, but again, traded credits cannot be used to meet the minimum domestic passenger car standard.

5. Small Volume Manufacturer Standards

In adopting the CO_2 standards for MY 2012–2016, EPA recognized that for very small volume manufacturers, the CO_2 standards adopted for MY 2012–2016 would be extremely challenging and potentially infeasible absent credits from other manufacturers. EPA therefore deferred small volume manufacturers (SVMs) with annual U.S. sales less than 5,000 vehicles from having to meet CO_2 standards until EPA is able to establish appropriate SVM standards. As part of establishing eligibility for the exemption, manufacturers must make a good faith effort to secure credits from other manufacturers, if they are reasonably available, to cover the emissions reductions they would have otherwise had to achieve under applicable standards.

These small volume manufacturers face a greater challenge in meeting CO_2 standards compared to large manufacturers because they only produce a few vehicle models, mostly focusing on high performance sports cars and luxury vehicles. These manufacturers have limited product lines across which to average emissions, and the few models they produce often have very high CO_2 levels. As SVMs noted in discussions, SVMs only produce one or two vehicle types but must compete directly with brands that are part of larger manufacturer groups that have more resources available to them. There is often a time lag in the availability of technologies from suppliers between when the technology is supplied to large manufacturers and when it is available to small volume manufacturers. Also, incorporating new technologies into vehicle designs costs the same or more for small volume manufacturers, yet the costs are spread over significantly smaller volumes. Therefore, SVMs typically have longer model life cycles in order to recover their investments. SVMs further noted that despite constraints facing them, SVMs need to innovate in order to differentiate themselves in the market and often lead in incorporating technological innovations, particularly lightweight materials.

In the MY 2012–2016 Final Rule, EPA noted that it intended to conduct a follow-on rulemaking to establish appropriate standards for these manufacturers. In developing this proposal, the agencies held detailed technical discussions with the manufacturers eligible for the exemption under the MY 2012–2016 program and reviewed detailed product plans of each manufacturer. EPA continues to believe that SVMs would face great difficulty meeting the primary CO_2 standards and that establishing challenging but less stringent SVM standards is appropriate given the limited products offering of SVMs. EPA believes it is important to establish standards that will require SVMs to continue to innovate to reduce emissions and do their ''fair share'' under the GHG program. However, selecting a single set of standards that would apply to all SVMs is difficult because each manufacturer's product lines vary significantly. EPA is concerned that a standard that would be appropriate for one manufacturer may not be feasible for another, potentially driving them from the domestic market. Alternatively, a less stringent standard may only cap emissions for some manufacturers, providing little incentive to reduce emissions.

Based on this, rather than conducting a separate rulemaking, as part of this MY 2017–2025 rulemaking EPA is proposing to allow SVMs to petition EPA for an alternative CO_2 standard for these model years. The proposed approach for SVM standards and eligibility requirements are described below. EPA is also requesting comments on extending eligibility for the proposed SVM standards to very small manufacturers that are owned by large manufacturers but are able to establish that they are operationally independent.

EPA considered a variety of approaches and believes a case-by-case approach for establishing SVM standards would be appropriate. EPA is proposing to allow eligible SVMs the option to petition EPA for alternative standards. An SVM utilizing this option would be required to submit data and information that the agency would use in addition to other available information to establish CO_2 standards for that specific manufacturer. EPA requests comments on all aspects of the proposed approach described in detail below.

a. Overview of Existing Case-by-Case Approaches

A case-by-case approach for establishing standards for SVMs has been adopted by NHTSA for CAFE, CARB in their 2009–2016 GHG program, and the European Union (EU) for European CO_2 standards. For the CAFE program, EPCA allows manufacturers making less than 10,000 vehicles per year worldwide to petition the agency to have an alternative standard set for them.[227] NHTSA has adopted alternative standards for some small volume manufacturers under these CAFE provisions and continually reviews applications as they are submitted.[228] Under the CAFE program, petitioners must include projections of the most fuel efficient production mix of vehicle configurations for a model year and a discussion demonstrating that the projections are reasonable. Petitioners must include, among other items, annual production data, efforts to comply with applicable fuel economy standards, and detailed information on vehicle technologies and specifications. The petitioner must explain why they have not pursued additional means that would allow them to achieve higher average fuel economy. NHTSA publishes a proposed decision in the **Federal Register** and accepts public comments. Petitions may be granted for up to three years.

For the California GHG standards for MYs 2009–2016, CARB established a process that would start at the beginning of MY2013, where small volume manufacturers would identify all MY

[227] See 49 U.S.C. 32902(d) and 49 CFR Part 525. Under the CAFE program, manufacturers who manufacture less than 10,000 passenger cars worldwide annually may petition for an exemption from generally-applicable CAFE standards, in which case NHTSA will determine what level of CAFE would be maximum feasible for that particular manufacturer if the agency determines that doing so is appropriate.

[228] Alternative CAFE standards are provided in 49 CFR 531.5 (e).

2012 vehicle models certified by large volume manufacturers that are comparable to the SVM's planned MY 2016 vehicle models.[229] The comparison vehicles were to be selected on the basis of horsepower and power to weight ratio. The SVM was required to demonstrate the appropriateness of the comparison models selected. CARB would then provide a target CO_2 value based on the emissions performance of the comparison vehicles to the SVM for each of their vehicle models to be used to calculate a fleet average standard for each test group for MY2016 and later. Since CARB provides that compliance with the National Program for MYs 2012–2016 will be deemed compliance with the CARB program, it has not taken action to set unique SVM standards, but its program nevertheless was a useful model to consider.

The EU process allows small manufacturers to apply for a derogation from the primary CO_2 emissions reduction targets.[230] Applications for 2012 were required to be submitted by manufacturers no later than March 31, 2011, and the Commission will assess the application within 9 months of the receipt of a complete application. Applications for derogations for 2012 have been submitted by several manufacturers and non confidential versions are currently available to the public.[231] In the EU process, the SVM proposes an alternative emissions target supported by detailed information on the applicant's economic activities and technological potential to reduce CO_2 emissions. The application also requires information on individual vehicle models such as mass and specific CO_2 emissions of the vehicles, and information on the characteristics of the market for the types of vehicles manufactured. The proposed alternative emissions standards may be the same numeric standard for multiple years or a declining standard, and the alternative standards may be established for a maximum period of five years. Where the European Commission is satisfied that the specific emissions target proposed by the manufacturer is consistent with its reduction potential, including the economic and technological potential to reduce its specific emissions of CO_2, and taking into account the characteristics of the market for the type of car manufactured, the Commission will grant a derogation to the manufacturer.

b. EPA's Proposed Framework for Case-by-Case SVM Standards

EPA proposes that SVMs will become subject to the GHG program beginning with MY 2017. Starting in MY 2017, an SVM would be required to meet the primary program standards unless EPA establishes alternative standards for the manufacturer. EPA proposes that eligible manufacturers seeking alternative standards must petition EPA for alternative standards by July 30, 2013, providing the information described below. If EPA finds that the application is incomplete, EPA would notify the manufacturer and provide an additional 30 days for the manufacturer to provide all necessary information. EPA would then publish a notice in the **Federal Register** of the manufacturer's petition and recommendations for an alternative standard, as well as EPA's proposed alternative standard. Non confidential business information portions of the petition would be available to the public for review in the docket. After a period for public comment, EPA would make a determination on an alternative standard for the manufacturer and publish final notice of the determination in the **Federal Register** for the general public as well as the applicant. EPA expects the process to establish the alternative standard to take about 12 months once a complete application is submitted by the manufacturer.

EPA proposes that manufacturers would petition for alternative standards for up to 5 model years (*i.e.,* MYs 2017—2021) as long as sufficient information is available on which to base the alternative standards (see application discussion below). This initial round of establishing case-by-case standards would be followed by one or more additional rounds until standards are established for the SVM for all model years up to and including MY 2025. For the later round(s) of standard setting, EPA proposes that the SVM must submit their petition 36 months prior to the start of the first model year for which the standards would apply in order to provide sufficient time for EPA to evaluate and set alternative standards (*e.g.,* January 1, 2018 for MY 2022). The 36 month requirement would not apply to new market entrants, discussed in section III.C.5.e below. The subsequent case-by-case standard setting would follow the same notice and comment process as outlined above.

EPA also proposes that if EPA does not establish SVM standards for a manufacturer at least 12 months prior to the start of the model year in cases where the manufacturer provided all required information by the established deadline, the manufacturer may request an extension of the alternative standards currently in place, on a model year by model year basis. This would provide assurance to manufacturers that they would have at least 12 months lead time to prepare for the upcoming model year.

EPA requests comments on allowing SVMs to comply early with the MY 2017 SVM standards established for them. Manufacturers may want to certify to the MY 2017 standards in earlier model years (*e.g.,* MY 2015 or MY 2016). Under the MY 2012–2016 program, SVMs are eligible for an exemption from the standards as long as they have made a good faith effort to purchase credits. By certifying to the SVM alternative standard early in lieu of this exemption, manufacturers could avoid having to seek out credits to purchase in order to maintain this exemption. EPA would not allow certification for vehicles already produced by the manufacturer, so the applicability of this provision would be limited due to the timing of establishing the SVM standards. Manufacturers interested in the possibility of early compliance would be able to apply for SVM standards earlier than the required July 30, 2013 deadline proposed above. An early compliance option also may be beneficial for new manufacturers entering the market that qualify as SVMs.

c. Petition Data and Information Requirements

As described in detail in section I.D.2, EPA establishes motor vehicle standards under section 202(a) that are based on technological feasibility, and considering lead time, safety, costs and other impacts on consumers, and other factors such as energy impacts associated with use of the technology. EPA proposes to require that SVMs submit the data and information listed below which EPA would use, in addition to other relevant information, in determining an appropriate alternative standard for the SVM. EPA would also consider data and information provided by commenters during the comment process in determining the final level of the SVM's standards. As noted above, other case-by-case standard setting approaches have been adopted by NHTSA, the European Union, and CARB and EPA has considered the data requirements of those programs in developing the proposed data and information requirements detailed below. EPA

[229] 13 CCR 1961.1(D).

[230] Article 11 of Regulation (EC) No 443/2009 and EU No 63/2011. See also ''Frequently asked questions on application for derogation pursuant to Aticle 11 of Regulation (EC) 443/2009.''

[231] *http://ec.europa.eu/clima/documentation/transport/vehicles/cars_en.htm.*

requests comments on the following proposed data requirements.

EPA proposes that SVMs would provide the following information as part of their petition for SVM standards:

Vehicle Model and Fleet Information

MYs that the application covers—up to 5 MYs. Sufficient information must be provided to establish alternative standards for each year

Vehicle models and sales projections by model for each MY

Description of models (vehicle type, mass, power, footprint, expected pricing)

Description of powertrain

Production cycle for each model including new vehicle model introductions

Vehicle footprint based targets and projected fleet average standard under primary program by model year

Technology Evaluation

CO_2 reduction technologies employed or expected to be on the vehicle model(s) for the applicable model years, including effectiveness and cost information

—Including A/C and potential off-cycle technologies

Evaluation of similar vehicles to those produced by the petitioning SVM and certified in MYs 2012–2013 (or latest 2 MYs for later applications) for each vehicle model including CO_2 results and any A/C credits generated by the models

—Similar vehicles must be selected based on vehicle type, horsepower, mass, power-to-weight, vehicle footprint, vehicle price range and other relevant factors as explained by the SVM

Discussion of CO_2 reducing technologies employed on vehicles offered by the manufacturer outside of the U.S. market but not in the U.S., including why those vehicles/technologies are not being introduced in the U.S. market as a way of reducing overall fleet CO_2 levels

Evaluation of technologies projected by EPA as technologies likely to be used to meet the MYs 2012–2016 and MYs 2017–2025 standards that are not projected to be fully utilized by the petitioning SVM and explanation of reasons for not using the technologies, including relevant cost information [232]

SVM Projected Standards

The most stringent CO_2 level estimated by the SVM to be feasible and appropriate by model and MY and the technological and other basis for the estimate

For each MY, projection of the lowest fleet average CO_2 production mix of vehicle models and discussion demonstrating that these projections are reasonable

A copy of any applications submitted to NHTSA for MY 2012 and later alternative standards

Eligibility

U.S. sales for previous three model years and projections for production volumes over the time period covered by the application

Complete information on ownership structure in cases where SVM has ties to other manufacturers with U.S. vehicle sales

EPA proposes to weigh several factors in determining what CO_2 standards are appropriate for a given SVMs fleet. These factors would include the level of technology applied to date by the manufacturer, the manufacturer's projections for the application of additional technology, CO_2 reducing technologies being employed by other manufacturers including on vehicles with which the SVM competes directly and the CO_2 levels of those vehicles, and the technological feasibility and reasonableness of employing additional technology not projected by the manufacturer in the time-frame for which standards are being established. EPA would also consider opportunities to generate A/C and off-cycle credits that are available to the manufacturer. Lead time would be a key consideration both for the initial years of the SVM standard, where lead time would be shorter due to the timing of the notice and comment process to establish the standards, and for the later years where manufacturers would have more time to achieve additional CO_2 reductions.

d. SVM Credits Provisions

As discussed in Section III.B.4, EPA's program includes a variety of credit averaging, banking, and trading provisions. EPA proposes that these provisions would generally apply to SVM standards as well, with the exception that SVMs would not be allowed to trade credits to other manufacturers. Because SVMs would be meeting alternative, less stringent standards compared to manufacturers in the primary program, EPA proposes that SVM would not be allowed to trade (*i.e.,* sell or otherwise provide) CO_2 credits that the SVM generates against the SVM standards to other manufacturers. SVMs would be able to use credits purchased from other manufacturers generated in the primary program. Although EPA does not expect significant credits to be generated by SVMs due to the manufacturer-specific standard setting approach being proposed, SVMs would be able to generate and use credits internally, under the credit carry-forward and carry-back provisions. Under a case-by-case approach, EPA would not view such credits as windfall credits and not allowing internal banking could stifle potential innovative approaches for SVMs. SVMs would also be able to transfer credits between the car and light trucks categories.

e. SVM Standards Eligibility

i. Current SVMs

The MY 2012–2016 rulemaking limited eligibility for the SVM deferment to manufacturers in the U.S. market in MY 2008 or MY 2009 with U.S. sales of less than 5,000 vehicles per year. After initial eligibility has been established, the SVM remains eligible for the exemption if the rolling average of three consecutive model years of sales remains below 5,000 vehicles. Manufacturers going over the 5,000 vehicle rolling average limit would have two additional model years to transition to having to meet applicable CO_2 standards. Based on these eligibility criteria, there are three companies that qualify currently as SVMs under the MY2012–2016 standards: Aston Martin, Lotus, and McLaren.[233] These manufacturers make up much less than one percent of total U.S. vehicles sales, so the environmental impact of these alternative standards would be very small. EPA continues to believe that the 5,000 vehicle cut-point and rolling three year average approach is appropriate and proposes to retain it as a primary criterion for SVMs to remain eligible for SVM standards. The 5,000 vehicle threshold allows for some sales growth by SVMs, as the SVMs in the market today typically have annual sales of below 2,000 vehicles. However, EPA wants to ensure that standards for as few vehicles as possible are included in the SVM standards to minimize the environmental impact, and therefore believes it is appropriate that manufacturers with U.S. sales growing to above 5,000 vehicles per year be required to comply with the primary standards. Manufacturers with unusually strong sales in a given year would still likely remain eligible, based on the three year rolling average. However, if a manufacturer expands in

[232] See 75 FR 25444 (Section III.D) for MY 2012–2016 technologies and Section III.D below for discussion of projected MY 2017–2025 technologies.

[233] Under the MY 2012–2016 program, manufacturers must also make a good faith effort to purchase CO_2 credits in order to maintain eligibility for SVM status.

the U.S. market on a permanent basis such that they consistently sell more than 5,000 vehicles per year, they would likely increase their rolling average to above 5,000 and no longer be eligible. EPA believes a manufacturer will be able to consider these provisions, along with other factors, in its planning to significantly expand in the U.S. market. As discussed below, EPA is not proposing to continue to tie eligibility to having been in the market in MY 2008 or MY 2009, or any other year and is instead proposing eligibility criteria for new SVMs newly entering the U.S. market.

ii. New SVMs (New Entrants to the U.S. Market)

As noted above, the SVM deferment under the MY 2012–2016 program included a requirement that a manufacturer had to have been in the U.S. vehicle market in MY 2008 or MY 2009. This provision ensured that a known universe of manufacturers would be eligible for the exemption in the short term and manufacturers would not be driven from the market as EPA proceeded to develop appropriate SVM standards. EPA is not proposing to include such a provision for the SVM standards eligibility criteria for MY 2017–2025. EPA believes that with SVM standards in place, tying eligibility to being in the market in a prior year is no longer necessary because SVMs will be required to achieve appropriate levels of emissions control. Also, it could serve as a potential market barrier to competition by hindering new SVMs from entering the U.S. market.

For new market entrants, EPA proposes that a manufacturer seeking an alternative standard for MY2017–2025 must apply and that standards would be established through the process described above. The new SVM would not be able to certify their vehicles until the standards are established and therefore EPA would expect the manufacturer to submit an application as early as possible but at least 30 months prior to when they expect to begin producing vehicles in order to provide enough time for EPA to evaluate standards and to follow the notice and comment process to establish the standards and for certification. In addition to the information and data described below, EPA proposes to require new market entrants to provide evidence that the company intends to enter the U.S. market within the time frame of the MY2017–2025 SVM standards. Such evidence would include documentation of work underway to establish a dealer network, appropriate financing and marketing plans, and evidence the company is working to meet other federal vehicle requirements such as other EPA emissions standards and NHTSA vehicle safety standards. EPA is concerned about the administrative burden that could be created for the agency by companies with no firm plans to enter the U.S. market submitting applications in order to see what standard might be established for them. This information, in addition to a complete application with the information and data outlined above, would provide evidence of the seriousness of the applicant. As part of this review, EPA reserves the right to not undertake its SVM standards development process for companies that do not exhibit a serious and documented effort to enter the U.S. market.

EPA remains concerned about the potential for gaming by a manufacturer that sells less than 5,000 vehicles in the first year, but with plans for significantly larger sales volumes in the following years. EPA believes that it would not be appropriate to establish SVM standards for a new market entrant that plans a steep ramp-up in U.S. vehicle sales. Therefore, EPA proposes that for new entrants, U.S. vehicle sales must remain below 5,000 vehicles for the first three years in the market. After the initial three years, the manufacturer must maintain a three year rolling average below 5,000 vehicles (*e.g.,* the rolling average of years 2, 3 and 4, must be below 5,000 vehicles). If a new market entrant does not comply with these provisions for the first five years in the market, vehicles sold above the 5,000 vehicle threshold would be found not to be covered by the alternative standards, and EPA expects the fleet average is therefore not in compliance with the standards and would be subject to enforcement action and also, the manufacturer would lose eligibility for the SVM standards until it has reestablished three consecutive years of sales below 5,000 vehicles.

By not tying the 5,000 vehicle eligibility criteria to a particular model year, it would be possible for a manufacturer already in the market to drop below the 5,000 vehicle threshold in a future year and attempt to establish eligibility. EPA proposes to treat such manufacturers as new entrants to the market for purposes of determining eligibility for SVM standards. However, the requirements to demonstrate that the manufacturer intends to enter the U.S. market obviously would not be relevant in this case, and therefore would not apply.

iii. Aggregation Requirements and an Operational Independence Concept

In determining eligibility for the MY 2012–2016 exemption, sales volumes must be aggregated across manufacturers according to the provisions of 40 CFR 86.1838–01(b)(3), which requires the sales of different firms to be aggregated in various situations, including where one firm has a 10% or more equity ownership of another firm, or where a third party has a 10% or more equity ownership of two or more firms. These are the same aggregation requirements used in other EPA small volume manufacturer provisions, such as those for other light-duty emissions standards.[234] EPA proposes to retain these aggregation provisions as part of the eligibility criteria for the SVM standards for MYs 2017–2025. Manufacturers also retain, no matter their size, the option to meet the full set of GHG requirements on their own, and do not necessarily need to demonstrate compliance as part of a corporate parent company fleet. However, as discussed below, EPA is seeking comments on allowing manufacturers that otherwise would not be eligible for the SVM standards due to these aggregation provisions, to demonstrate to the Administrator that they are ''operationally independent'' based on the criteria described below. Under such a concept, if the Administrator were to determine that a manufacturer was operationally independent, that manufacturer would be eligible for SVM standards.

During the 2012–2016 rule comment period, EPA received comments from Ferrari requesting that EPA allow a manufacturer to apply to EPA to establish SVM status based on the independence of its research, development, testing, design, and manufacturing from another firm that has ownership interest in that manufacturer. Ferrari is majority owned by Fiat and would be aggregated with other Fiat brands, including Chrysler, Maserati, and Alfa Romeo, for purposes of determining eligibility for SVM standards; therefore Ferrari does not meet the eligibility criteria for SVM status. However, Ferrari believes that it would qualify for such an ''operational independence'' concept, if such an option were provided. In the MY 2012–2016 Final Rule, EPA noted that it would further consider the issue of operational independence and seek public comments on this concept (see 75 FR 25420). In this proposal, EPA is

[234] For other programs, the eligibility cut point for SVM flexibility is 15,000 vehicles rather than 5,000 vehicles.

requesting comment on the concept of operational independence. Specifically, we are seeking comment on expanding eligibility for the SVM standards to manufacturers who would have U.S. annual sales of less than 5,000 vehicles and based on a demonstration that they are ''operationally independent'' of other companies. Under such an approach, EPA would be amending the limitation for SVM corporate aggregation provisions such that a manufacturer that is more than 10 percent owned by a large manufacturer would be allowed to qualify for SVM standards on the basis of its own sales, because it operates its research, design, production, and manufacturing independently from the parent company.

In seeking public comment on this concept of operational independence, EPA particularly is interested in comments regarding the degree to which this concept could unnecessarily open up the SVM standards to several smaller manufacturers that are integrated into large companies—smaller companies that may be capable of and planning to meet the CO_2 standards as part of the larger manufacturer's fleet. EPA also seeks comment on the concern that manufacturers could change their corporate structure to take advantage of such provisions (that is, gaming). EPA is therefore requesting comment on approaches, described below, to narrowly define the operational independence criteria to ensure that qualifying companies are truly independent and to avoid gaming to meet the criteria. EPA also requests comments on the possible implications of this approach on market competition, which we believe should be fully explored through the public comment process. EPA acknowledges that regardless of the criteria for operational independence, a small manufacturer under the umbrella of a large manufacturer is fundamentally different from other SVMs because the large manufacturer has several options under the GHG program to bring the smaller subsidiary into compliance, including the use of averaging or credit transfer provisions, purchasing credits from another manufacturer, or providing technical and financial assistance to the smaller subsidiary. Truly independent SVMs do not have the potential access to these options, with the exception of buying credits from another manufacturer. EPA requests comments on the need for and appropriateness of allowing companies to apply for less stringent SVM standards based on sales that are not aggregated with other companies because of operational independence.

EPA is considering and requesting comments on the operational independence criteria listed below. These criteria are meant to establish that a company, though owned by another manufacturer, does not benefit operationally or financially from this relationship, and should therefore be considered independent for purposes of calculating the sales volume for the SVM program. Manufacturers would need to demonstrate compliance with all of these criteria in order to be found to be operationally independent. By ''related manufacturers'' below, EPA means all manufacturers that would be aggregated together under the 10 percent ownership provisions contained in EPA's current small volume manufacturer definition (*i.e.,* the parent company and all subsidiaries where there is 10 percent or greater ownership).

EPA would need to determine, based on the information provided by the manufacturer in its application, that the manufacturer currently meets the following criteria and has met them for at least 24 months preceding the application submittal:

1. No financial or other support of economic value was provided by related manufacturers for purposes of design, parts procurement, R&D and production facilities and operation. Any other transactions with related manufacturers must be conducted under normal commercial arrangements like those conducted with other parties. Any such transactions shall be at competitive pricing rates to the manufacturer.
2. Maintains separate and independent research and development, testing, and production facilities.
3. Does not use any vehicle powertrains or platforms developed or produced by related manufacturers.
4. Patents are not held jointly with related manufacturers.
5. Maintains separate business administration, legal, purchasing, sales, and marketing departments; maintains autonomous decision making on commercial matters.
6. Overlap of Board of Directors is limited to 25 percent with no sharing of top operational management, including president, chief executive officer (CEO), chief financial officer (CFO), and chief operating officer (COO), and provided that no individual overlapping director or combination of overlapping directors exercises exclusive management control over either or both companies.
7. Parts or components supply agreements between related companies must be established through open market process and to the extent that manufacturer sells parts/components to non-related auto manufacturers, it does so through the open market at competitive pricing.

In addition to the criteria listed above, EPA also requests comments on the following programmatic elements and framework. EPA requests comments on requiring the manufacturer applying for operational independence to provide an attest engagement from an independent auditor verifying the accuracy of the information provided in the application.[235] EPA foresees possible difficulty verifying the information in the application, especially if the company is located overseas. The principal purpose of the attest engagement would be to provide an independent review and verification of the information provided. EPA also would require that the application be signed by the company president or CEO. After EPA approval, the manufacturer would be required to report within 60 days any material changes to the information provided in the application. A manufacturer would lose eligibility automatically after the material change occurs. However, EPA would confirm that the manufacturer no longer meets one or more of the criteria and thus is no longer considered operationally independent, and would notify the manufacturer. EPA would provide two model years lead time for the manufacturer to transition to the primary program. For example, if the manufacturer lost eligibility sometime in calendar year 2018 (based on when the material change occurs), the manufacturer would need to meet primary program standards in MY 2021.

In addition, EPA requests comments on whether or not a manufacturer losing eligibility should be able to re-establish itself as operationally independent in a future year and over what period of time they would need to meet the criteria to again be eligible. EPA requests comments on, for example, whether or not a manufacturer meeting the criteria for three to five consecutive years should be allowed to again be considered operationally independent.

6. Nitrous Oxide, Methane, and CO_2-equivalent Approaches

a. Standards and Flexibility

For light-duty vehicles, as part of the MY 2012–2016 rulemaking, EPA finalized standards for nitrous oxide (N_2O) of 0.010 g/mile and methane (CH_4) of 0.030 g/mile for MY 2012 and

[235] EPA has required attest engagements as part of its Reformulated Fuels program. See 40 CFR § 80.1164 and § 80.1464.

later vehicles. 75 FR at 25421–24. The light-duty vehicle standards for N_2O and CH_4 were established to cap emissions, where current levels are generally significantly below the cap. The cap would prevent future emissions increases, and were generally not expected to result in the application of new technologies or significant costs for the manufacturers for current vehicle designs. EPA also finalized an alternative CO_2 equivalent standard option, which manufacturers may choose to use in lieu of complying with the N_2O and CH_4 cap standards. The CO_2-equivalent standard option allows manufacturers to fold all 2-cycle weighted N_2O and CH_4 emissions, on a CO_2-equivalent basis, along with CO_2 into their CO_2 emissions fleet average compliance level.[236] The applicable CO_2 fleet average standard is not adjusted to account for the addition of N_2O and CH_4. For flexible fueled vehicles, the N_2O and CH_4 standards must be met on both fuels (*e.g.,* both gasoline and E–85).

After the light-duty standards were finalized, manufacturers raised concerns that for a few of the vehicle models in their existing fleet they were having difficulty meeting the N_2O and/or CH_4 standards, in the near-term. In such cases, manufacturers would still have the option of complying using the CO_2 equivalent alternative. On a CO_2 equivalent basis, folding in all N_2O and CH_4 emissions could add up to 3–4 g/mile to a manufacturer's overall fleet-average CO_2 emissions level because the alternative standard must be used for the entire fleet, not just for the problem vehicles. The 3–4 g/mile assumes all emissions are actually at the level of the cap. See 75 FR at 74211. This could be especially challenging in the early years of the program for manufacturers with little compliance margin because there is very limited lead time to develop strategies to address these additional emissions. Some manufacturers believe that the current CO_2-equivalent fleet-wide option ''penalizes'' them by requiring them to fold in both CH_4 and N_2O emissions for their entire fleet, even if they have difficulty meeting the cap on only one vehicle model.

In response to these concerns, as part of the heavy-duty GHG rulemaking, EPA requested comment on and finalized provisions allowing manufacturers to use CO_2 credits, on a CO_2-equivalent basis, to meet the light-duty N_2O and CH_4 standards.[237] Manufacturers have the option of using CO_2 credits to meet N_2O and CH_4 standards on a test group basis as needed for MYs 2012–2016. In their public comments to the proposal in the heavy-duty package, manufacturers urged EPA to extend this flexibility indefinitely, as they believed this option was more advantageous than the CO_2-equivalent fleet wide option (discussed previously) already provided in the light-duty program, because it allowed manufacturers to address N_2O and CH_4 separately and on a test group basis, rather than across their whole fleet. Further, manufacturers believed that since this option is allowed under the heavy-duty standards, allowing it indefinitely in the light-duty program would make the light- and heavy-duty programs more consistent. In the Final Rule for Heavy-Duty Vehicles, EPA noted that it would consider this issue further in the context of new standards for MYs 2017–2025 in the planned future light-duty vehicle rulemaking. 76 FR at 57194.

EPA has further considered this issue and is proposing to allow the additional option of using CO_2 credits to meet the light-duty vehicle N_2O and CH_4 standards to extend for all model years beyond MY 2016. EPA understands manufacturer concerns that if they use the CO_2-equivalent option for meeting the GHG standards, they would be penalized by having to incorporate all N_2O and CH_4 emissions across their entire fleet into their CO_2-equivalent fleet emissions level determination. EPA continues to believe that allowing CO_2 credits to meet CH_4 and N_2O standards on a CO_2-equivalent basis is a reasonable approach to provide additional flexibility without diminishing overall GHG emissions reductions.

EPA is also requesting comments on establishing an adjustment to the CO_2-equivalent standard for manufacturers selecting the CO_2-equivalent option established in the MY 2012–2016 rulemaking. Manufacturers would continue to be required to fold in all of their CH_4 and N_2O emissions, along with CO_2, into their CO_2-equivalent levels. They would then apply the agency-established adjustment factor to the CO_2-equivalent standard. For example, if the adjustment for CH_4 and N_2O combined was 1 to 2 g/mile CO_2-equivalent (taking into account the GWP of N_2O and CH_4), manufacturers would determine their CO_2 fleet emissions standard and add the 1 to 2 g/mile adjustment factor to it to determine their CO_2-equivalent standard. The adjustment factor would slightly increase the amount of allowed fleet average CO_2-equivalent emissions for the manufacturer's fleet. The purpose of this adjustment would be so manufacturers do not have to offset the typical N_2O and CH_4 vehicle emissions, while holding manufacturers responsible for higher than average N_2O and CH_4 emissions levels.

At this time, EPA is not proposing an adjustment value due to a current lack of N_2O test data on which to base the adjustment for N_2O. As discussed below, EPA and manufacturers are currently evaluating N_2O measurement equipment and insufficient data is available at this time on which to base an appropriate adjustment. For CH_4, manufacturers currently provide data during certification, and based on current vehicle data a fleet-wide adjustment for CH_4 in the range of 0.14 g/mile appears to be appropriate.[238] EPA requests comments on this concept and requests city and highway cycle N_2O data on current Tier 2 vehicles which could help serve as the basis for the adjustment.

EPA continues to believe that it would not be appropriate to base the adjustment on the cap standards because such an approach could have the effect of undermining the stringency of the CO_2 standards, as many vehicles would likely have CH_4 and N_2O levels much lower than the cap standards. EPA believes that if an appropriate adjustment could be developed and applied, it would help alleviate manufacturers' concerns discussed above and make the CO_2-equivalent approach a more viable option.

b. N_2O Measurement

For the N_2O standard, EPA finalized provisions in the MY 2012–2016 rule allowing manufacturers to support an application for a certificate by supplying a compliance statement based on good engineering judgment, in lieu of N_2O test data, through MY 2014. EPA required N_2O testing starting with MY 2015. See 75 FR at 25423. This flexibility provided manufacturers with lead time needed to make necessary

[236] The global warming potentials (GWP) used in this rule are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 100-year GWP values from the 1996 IPCC Second Assessment Report (SAR) are used in the official U.S. greenhouse gas inventory submission to the United Nations Framework Convention on Climate Change (per the reporting requirements under that international convention, which were last updated in 2006) . N_2O has a 100-year GWP of 298 and CH_4 has a 100-year GWP of 25 according to the 2007 IPCC AR4.

[237] See 76 FR at 57193–94.

[238] Average city/highway cycle CH_4 emissions based on MY2010–2012 gasoline vehicles certification data is about 0.0056 g/mile; multiplied by the methane GWP of 25, this level would result in a 0.14 g/mile adjustment. See memo to the docket, ''Analysis of Methane (CH_4) Certification Data for Model Year 2010–2012 Vehicles.''

facilities changes and install N_2O measurement equipment.

Since the final rule, manufacturers have raised concerns that the lead-time provided to begin N_2O measurement is not sufficient, as their research and evaluation of N_2O measurement instrumentation has involved a greater level of effort than previously expected. There are several analyzers available today for the measurement of N_2O. Over the last year since the MY 2012–2016 standards were finalized, EPA has continued to evaluate instruments for N_2O measurement and now believes instruments not evaluated during the 2012–2016 rulemaking have the potential to provide more precise emissions measurement and believe it would be prudent to provide manufacturers with additional time to evaluate, procure, and install equipment in their test cells.[239] Therefore, EPA believes that the manufacturer's concerns about the need for additional lead-time have merit, and is proposing to extend the ability for manufacturers to use compliance statements based on good engineering judgment in lieu of test data through MY 2016. Beginning in MY 2017, manufacturers would be required to measure N_2O emissions to verify compliance with the standard. This approach, if finalized, will provide the manufacturers with two additional years of lead-time to evaluate, procure, and install N_2O measurement systems throughout their certification laboratories.

7. Small Entity Exemption

In the MY 2012–2016 rule, EPA exempted entities from the GHG emissions standard, if the entity met the Small Business Administration (SBA) size criteria of a small business as described in 13 CFR 121.201.[240] This includes both U.S.-based and foreign small entities in three distinct categories of businesses for light-duty vehicles: small manufacturers, independent commercial importers (ICIs), and alternative fuel vehicle converters. EPA is proposing to continue this exemption for the MY 2017–2025 standards. EPA will instead consider appropriate GHG standards for these entities as part of a future regulatory action.

EPA has identified about 21 entities that fit the Small Business Administration (SBA) size criterion of a small business. EPA estimates there currently are approximately four small manufacturers including three electric vehicle small manufacturers that have recently entered the market, eight ICIs, and nine alternative fuel vehicle converters in the light-duty vehicle market. EPA estimates that these small entities comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., and therefore the exemption will have a negligible impact on the GHG emissions reductions from the standards. Further detail regarding EPA's assessment of small businesses is provided in Regulatory Flexibility Act Section III.J.3.

At least one small business manufacturer, Fisker Automotive, in discussions with EPA, has suggested that small businesses should have the option of voluntarily opting-in to the GHG standards. This manufacturer sells electric vehicles, and sees a potential market for selling credits to other manufacturers. EPA believes that there could be several benefits to this approach, as it would allow small businesses an opportunity to generate revenue to offset their technology investments and encourage commercialization of the innovative technology, and it would benefit any manufacturer seeking those credits to meet their compliance obligations. EPA is proposing to allow small businesses to waive their small entity exemption and opt-in to the GHG standards. Upon opting in, the manufacturer would be subject to all of the requirements that would otherwise be applicable. This would allow small entity manufacturers to earn CO_2 credits under the program, which may be an especially attractive option for the new electric vehicle manufacturers entering the market. EPA proposes to make the opt-in available starting in MY 2014, as the MY 2012, and potentially the MY 2013, certification process will have already occurred by the time this rulemaking is finalized. EPA is not proposing to retroactively certify vehicles that have already been produced. However, EPA proposes that manufacturers certifying to the GHG standards for MY 2014 would be eligible to generate credits for vehicles sold in MY 2012 and MY 2013 based on the number of vehicles sold and the manufacturer's footprint-based standard under the primary program that would have otherwise applied to the manufacturer if it were a large manufacturer. This approach would be similar to that used by EPA for early credits generated in MYs 2009–2011, where manufacturers did not certify vehicles to CO_2 standards in those years but were able to generate credits. See 75 FR at 25441. EPA believes it is appropriate to provide these credits to small entities, as the credits would be available to large manufacturers producing similar vehicles, and the credits further encourage manufacturers of advanced technology vehicles such as EVs. In addition to benefiting these small businesses, this option also has the potential to expand the pool of credits available to be purchased by other manufacturers. EPA proposes that manufacturers waiving their small entity exemption would be required to meet all aspects of the GHG standards and program requirements across their entire product line. EPA requests comments on the small business provisions described above.

8. Additional Leadtime Issues

The 2012–2016 GHG vehicle standards include Temporary Leadtime Allowance Alternative Standards (TLAAS) which provide alternative standards to certain intermediate sized manufacturers (those with U.S. sales between 5,000 and 400,000 during model year 2009) to accommodate two situations: manufacturers which traditionally paid fines instead of complying with CAFE standards, and limited line manufacturers facing special compliance challenges due to less flexibility afforded by averaging, banking and trading. See 75 FR at 25414–416. EPA is not proposing to continue this program for MYs 2017–2025. First, the allowance was premised on the need to provide adequate lead time, given the (at the time the rule was finalized) rapidly approaching MY 2012 deadline, and given that manufacturers were transitioning from a CAFE regime that allows fine-paying, to a Clean Air Act regime that does not. That concern is no longer applicable, given that there is ample lead time before the MY 2017 standards. More important, the Temporary Lead Time Allowance was just that—temporary—and EPA provided it to allow manufacturers to transition to full compliance in later model years. See 75 FR at 25416. EPA is thus not proposing to continue this provision.

In the context of the increasing stringency of standards in the latter phase of the program (*e.g.,* MY 2022–2025), one manufacturer suggested that EPA should consider providing limited line, intermediate volume manufacturers additional time to phase into the standards. The concern raised is that such limited line manufacturers face unique challenges securing competitive supplier contracts for new technologies, and have fewer vehicle lines to allocate the necessary upfront investment and risk inherent with new technology introduction. This

[239] ''Data from the evaluation of instruments that measure Nitrous Oxide (N_2O),'' Memorandum from Chris Laroo to Docket EPA–HQ–OAR–2010–0799, October 31, 2011.

[240] See final regulations at 40 CFR 86.1801–12(j).

manufacturer believes that as the standards become increasingly stringent in future years requiring the investment in new or advanced technologies, intermediate volume limited line manufacturers may have to pay a premium to gain access to these technologies which would put them at a competitive disadvantage. EPA seeks comment on this issue, and whether there is a need to provide some type of additional leadtime for intermediate volume limited line manufacturers to meet the latter year standards.

In the context of the increasing stringency of standards starting in MY 2017, as discussed, EPA is not proposing a continuation of the TLAAS. TLAAS was available to firms with a wide range of U.S. sales volumes (between 5,000 and 400,000 in MY 2009). One company with U.S. sales on the order of 25,000 vehicles per year has indicated that it believes that the CO_2 standards in today's proposal for MY 2017–2025 would present significant technical challenges for their company, due to the relatively small volume of products it sells in the U.S., limited ability to average across their limited line fleet, and the performance-oriented nature of its vehicles. This firm indicated that absent access several years in advance to CO_2 credits that it could purchase from other firms, this firm would need to significantly change the types of products they currently market in the U.S. beginning in model year 2017, even if it adds substantial CO_2 reducing technology to its vehicles. EPA requests comment on the potential need to include additional flexibilities for companies with U.S. vehicle sales on the order of 25,000 units per year, and what types of additional flexibilities would be appropriate. Potential flexibilities could include an extension of the TLAAS program for lower volume companies, or a one-to-three year delay in the applicable model year standard (*e.g.,* the proposed MY 2017 standards could be delayed to begin in MY 2018, MY 2019, or MY 2020). Commenters suggesting that additional flexibilities may be needed are encouraged to provide EPA with data supporting their suggested flexibilities.

9. Police and Emergency Vehicle Exemption From CO_2 Standards

Under EPCA, manufacturers are allowed to exclude police and other emergency vehicles from their CAFE fleet and all manufacturers that produce emergency vehicles have historically done so. EPA received comments in the MY 2012–2016 rulemaking that these vehicles should be exempt from the GHG emissions standards and EPA committed to further consider the issue in a future rulemaking.[241] After further consideration of this issue, EPA proposes to exempt police and other emergency vehicles from the CO_2 standards starting in MY 2012.[242] EPA believes it is appropriate to provide an exemption for these vehicles because of the unique features of vehicles designed specifically for law enforcement and emergency response purposes, which have the effect of raising their GHG emissions, as well as for purposes of harmonization with the CAFE program. EPA proposes to exempt vehicles that are excluded under EPCA and NHTSA regulations which define emergency vehicle as ''a motor vehicle manufactured primarily for use as an ambulance or combination ambulance-hearse or for use by the United States Government or a State or local government for law enforcement, or for other emergency uses as prescribed by regulation by the Secretary of Transportation.'' [243]

The unique features of these vehicles result in significant added weight including: heavy-duty suspensions, stabilizer bars, heavy-duty/dual batteries, heavy-duty engine cooling systems, heavier glass, bullet-proof side panels, and high strength sub-frame. Police pursuit vehicles are often equipped with specialty steel rims and increased rolling resistance tires designed for high speeds, and unique engine and transmission calibrations to allow high-power, high-speed chases. Police and emergency vehicles also have features that tend to reduce aerodynamics, such as emergency lights, increased ground clearance, and heavy-duty front suspensions.

EPA is concerned that manufacturers may not be able to sufficiently reduce the emissions from these vehicles, and would be faced with a difficult choice of compromising necessary vehicle features or dropping vehicles from their fleets, as they may not have credits under the fleet averaging provisions necessary to cover the excess emissions from these vehicles as standards become more stringent. Without the exemption, there could be situations where a manufacturer is more challenged in meeting the GHG standards simply due to the inclusion of these higher emitting emergency vehicles. Technical feasibility issues go beyond those of other high-performance vehicles and there is a clear public need for law enforcement and emergency vehicles that meet these performance characteristics as these vehicles must continue to be made available in the market. MY 2012–2016 standards, as well as MY 2017 and later standards would be fully harmonized with CAFE regarding the treatment of these vehicles. EPA requests comments on its proposal to exempt emergency vehicles from the GHG standards.

10. Test Procedures

EPA is considering revising the procedures for measuring fuel economy and calculating average fuel economy for the CAFE program, effective beginning in MY 2017, to account for three impacts on fuel economy not currently included in these procedures—increases in fuel economy because of increases in efficiency of the air conditioner; increases in fuel economy because of technology improvements that achieve ''off-cycle'' benefits; and incentives for use of certain hybrid technologies in full size pickup trucks, and for the use of other technologies that help those vehicles exceed their targets, in the form of increased values assigned for fuel economy. As discussed in section IV of this proposal, NHTSA would take these changes into account in determining the maximum feasible fuel economy standard, to the extent practicable. In this section, EPA discusses the legal framework for considering these changes, and the mechanisms by which these changes could be implemented. EPA invites comment on all aspects of this concept, and plans to adopt this approach in the final rule if it determines the changes are appropriate after consideration of all comments on these issues.

These changes would be the same as program elements that are part of EPA's greenhouse gas performance standards, discussed in section III.B.1 and 2, above. EPA is considering adopting these changes for A/C efficiency and off-cycle technology because they are based on technology improvements that affect real world fuel economy, and the incentives for light-duty trucks will promote greater use of hybrid technology to improve fuel economy in these vehicles. In addition, adoption of these changes would lead to greater coordination between the greenhouse gas program under the CAA and the fuel economy program under EPCA. As discussed below, these three elements would be implemented in the same

[241] 75 FR 25409.

[242] Manufacturers would exclude police and emergency vehicles from fleet average calculations (both for determining fleet compliance levels and fleet standards) starting in MY 2012. Because this would have the effect of making the fleet standards easier to meet for manufacturers, EPA does not believe there would be lead time issues associated with the exemption, even though it would take effect well into MY 2012.

[243] 49 U.S.C. 32902(e).

manner as in the EPA's greenhouse gas program—a vehicle manufacturer would have the option to generate these fuel economy values for vehicle models that meet the criteria for these ''credits,'' and to use these values in calculating their fleet average fuel economy.

a. Legal Framework

EPCA provides that:

(c) Testing and calculation procedures. The Administrator [of EPA] shall measure fuel economy for each model and calculate average fuel economy for a manufacturer under testing and calculation procedures prescribed by the Administrator. However * * *, the Administrator shall use the same procedures for passenger automobiles the Administrator used for model year 1975 * * *, or procedures that give comparable results. 49 U.S.C. 32904(c)

Thus, EPA is charged with developing and adopting the procedures used to measure fuel economy for vehicle models and for calculating average fuel economy across a manufacturer's fleet. While this provision provides broad discretion to EPA, it contains an important limitation for the measurement and calculation procedures applicable to passenger automobiles. For passenger automobiles, EPA has to use the same procedures used for model year 1975 automobiles, or procedures that give comparable results.[244] This limitation does not apply to vehicles that are not passenger automobiles. The legislative history explains that:

Compliance by a manufacturer with applicable average fuel economy standards is to be determined in accordance with test procedures established by the EPA Administrator. Test procedures so established would be the procedures utilized by the EPA Administrator for model year 1975, or procedures which yield comparable results. The words ''or procedures which yield comparable results'' are intended to give EPA wide latitude in modifying the 1975 test procedures to achieve procedures that are more accurate or easier to administer, so long as the modified procedure does not have the effect of substantially changing the average fuel economy standards. H.R. Rep. No. 94–340, at 91–92 (1975).[245]

EPA measures fuel economy for the CAFE program using two different test procedures—the Federal Test Procedure (FTP) and the Highway Fuel Economy Test (HFET). These procedures originated in the early 1970's, and were intended to generally represent city and highway driving, respectively. These two tests are commonly referred to as the ''2-cycle'' test procedures for CAFE. The FTP is also used for measuring compliance with CAA emissions standards for vehicle exhaust. EPA has made various changes to the city and highway fuel economy tests over the years. These have ranged from changes to dynamometers and other mechanical elements of testing, changes in test fuel properties, changes in testing conditions, to changes made in the 1990s when EPA adopted additional test procedures for exhaust emissions testing, called the Supplemental Federal Test Procedures (SFTP).

When EPA has made changes to the FTP or HFET, we have evaluated whether it is appropriate to provide for an adjustment to the measured fuel economy results, to comply with the EPCA requirement for passenger cars that the test procedures produce results comparable to the 1975 test procedures. These adjustments are typically referred to as a CAFE or fuel economy test procedure adjustment or adjustment factor. In 1985 EPA evaluated various test procedure changes made since 1975, and applied fuel economy adjustment factors to account for several of the test procedure changes that reduced the measured fuel economy, producing a significant CAFE impact for vehicle manufacturers. 50 FR 27172 (July 1, 1985). EPA defined this significant CAFE impact as any change or group of changes that has at least a one tenth of a mile per gallon impact on CAFE results. Id. at 27173. EPA also concluded in this proceeding that no adjustments would be provided for changes that removed the manufacturer's ability to take advantage of flexibilities in the test procedure and derive increases in measured fuel economy values which were not the result of design improvements or marketing shifts, and which would not result in any improvement in real world fuel economy. EPA likewise concluded that test procedure changes that provided manufacturers with an improved ability to achieve increases in measured fuel economy based on real world fuel economy improvements also would not warrant a CAFE adjustment. Id. at 27172, 27174, 27183. EPA adopted retroactive adjustments that had the effect of increasing measured fuel economy (to offset test procedure changes that reduced the measured fuel economy level) but declined to apply retroactive adjustments that reduced fuel economy.

The DC Circuit reviewed two of EPA's decisions on CAFE test procedure adjustments. *Center for Auto Safety et al.* v. *Thomas,* 806 F.2d 1071 (1986). First, the Court rejected EPA's decision to apply only positive retroactive adjustments, as the appropriateness of an adjustment did not depend on whether it increased or decreased measured fuel economy results. Second, the Court upheld EPA's decision to not apply any adjustment for the change in the test setting for road load power. The 1975 test procedure provided a default setting for road load power, as well as an optional, alternative method that allowed a manufacturer to develop an alternative road load power setting. The road load power setting affected the amount of work that the engine had to perform during the test, hence it affected the amount of fuel consumed during the test and the measured fuel economy. EPA changed the test procedure by replacing the alternative method in the 1975 procedure with a new alternative coast down procedure. Both the original and the replacement alternative procedures were designed to allow manufacturers to obtain the benefit of vehicle changes, such as changes in aerodynamic design, that improved real world fuel economy by reducing the amount of work that the engine needed to perform to move the vehicle. The Center for Auto Safety (CAS) argued that EPA was required to provide a test procedure adjustment for the new alternative coast down procedure as it increased measured fuel economy compared to the values measured for the 1975 fleet. In 1975, almost no manufacturers made use of the then available alternative method, while in later years many manufacturers made use of the option once it was changed to the coast down procedure. CAS argued this amounted to a change in test procedure that did not achieve comparable results, and therefore

[244] For purposes of this discussion, EPA need not determine whether the changes relating to A/C efficiency, off-cycle, and light-duty trucks involve changes to procedures that measure fuel economy or procedures for calculating a manufacturer's average fuel economy. The same provisions apply irrespective of which procedure is at issue. This discussion generally refers to procedures for measuring fuel economy for purposes of convenience, but the same analysis applies whether a measurement or calculation procedure is involved.

[245] Unlike the House Bill, the Senate bill did not restrict EPA's discretion to adopt or revise test procedures. Senate Bill 1883, section 503(6). However, the Senate Report noted that:

The fuel economy improvement goals set in section 504 are based upon the representative driving cycles used by the Environmental Protection Agency to determine automobile fuel economies for model year 1975. In the event that these driving cycles are changed in the future, it is the intent of this legislation that the numerical miles per gallon values of the fuel economy standards be revised to reflect a stringency (in terms of percentage-improvement from the baseline) that is the same as the bill requires in terms of the present test procedures. S. Rep. No. 94–179, at 19 (1975).

In Conference, the House version of the bill was adopted, which contained the restriction on EPA's authority.

required a test procedure adjustment. CAS did not contest that the coast down method and the prior alternative method achieved comparable results.

The DC Circuit rejected CAS' arguments, stating that:

The critical fact is that a procedure that credited reductions in a vehicle's road load power requirements achieved through improved aerodynamic design was available for MY1975 testing, and those manufacturers, however few in number, that found it advantageous to do so, employed that procedure. The manifold intake procedure subsequently became obsolete for other reasons, but its basic function, to measure real improvements in fuel economy through more aerodynamically efficient designs, lived on in the form of the coast down technique for measuring those aerodynamic improvements. We credit the EPA's finding that increases in measured fuel economy because of the lower road load settings obtainable under the coast down method, were increases ''likely to be observed on the road,'' and were *not* ''unrepresentative artifact[s] of the dynamometer test procedure.'' Such real improvements are exactly what Congress meant to measure when it afforded the EPA flexibility to change testing and calculating procedures. We agree with the EPA that no retroactive adjustment need be made on account of the coast down technique. *Center for Auto Safety et al* v. *EPA,* 806 F.2d 1071, 1077 (DC Cir. 1986)

Some years later, in 1996, EPA adopted a variety of test procedure changes as part of updating the emissions test procedures to better reflect real world operation and conditions. 61 FR 54852 (October 22, 1996). EPA adopted new test procedures to supplement the FTP, as well as modifications to the FTP itself. For example, EPA adopted a new supplemental test procedure specifically to address the impact of air conditioner use on exhaust emissions. Since this new test directly addressed the impact of A/C use on emissions, EPA removed the specified A/C horsepower adjustment that had been in the FTP since 1975. Id. at 54864, 54873. Later EPA determined that there was no need for CAFE adjustments for the overall set of test procedures changes to the FTP, as the net effect of the changes was no significant change in CAFE results.

As evidenced by this regulatory history, EPA's traditional approach is to consider the impact of potential test procedure changes on CAFE results for passenger automobiles and determine if a CAFE adjustment factor is warranted to meet the requirement that the test procedure produce results comparable to the 1975 test procedure. This involves evaluating the magnitude of the impact on measured fuel economy results. It also involves evaluating whether the change in measured fuel economy reflects real word fuel economy impacts from changes in technology or design, or whether it is an artifact of the test procedure or test procedure flexibilities such that the change in measured fuel economy does not reflect a real world fuel economy impact.

In this case, allowing credits for improvements in air conditioner efficiency and off-cycle efficiency for passenger cars would lead to an increase (*i.e.,* improvement) in the fuel economy results for the vehicle model. The impact on fuel economy and CAFE results clearly could be greater than one tenth of a mile per gallon (the level that EPA has previously indicated as having a substantial impact). The increase in fuel economy results would reflect real world improvements in fuel economy and not changes that are just artifacts of the test procedure or changes that come from closing a loophole or removing a flexibility in the current test procedure. However, these changes in procedure would not have the ''critical fact'' that the *CAS* Court relied upon—the existence of a 1975 test provision that was designed to account for the same kind of fuel economy improvements from changes in A/C or off-cycle efficiency. Under EPA's traditional approach, these changes would appear to have a significant impact on CAFE results, would reflect real world changes in fuel economy, but would not have a comparable precedent in the 1975 test procedure addressing the impact of these technology changes on fuel economy. EPA's traditional approach would be expected to lead to a CAFE adjustment factor for passenger cars to account for the impact of these changes.

However, EPA is considering whether a change in approach is appropriate based on the existence of similar EPA provisions for the greenhouse gas emissions procedures and standards. In the past, EPA has determined whether a CAFE adjustment factor for passenger cars would be appropriate in a context where manufacturers are subject to a CAFE standard under EPCA and there is no parallel greenhouse gas standard under the CAA. That is not the case here, as MY2017–2025 passenger cars will be subject to both CAFE and greenhouse gas standards. As such, EPA is considering whether it is appropriate to consider the impact of a CAFE procedure change in this broader context standard.

The term ''comparable results'' is not defined in section 32904(c), and the legislative history indicates that it is intended to address changes in procedure that result in a substantial change in the average fuel economy standard. As explained above, EPA has considered a change of one-tenth of a mile per gallon as having a substantial impact, based in part on the one tenth of a mile per gallon rounding convention in the statute for CAFE calculations. 48 FR 56526, 56528 fn.14 (December 21, 1983). A change in the procedure that changes fuel economy results to this or a larger degree has the effect of changing the stringency of the CAFE standard, either making it more or less stringent. A change in stringency of the standard changes the burden on the manufacturers, as well as the fuel savings and other benefits to society expected from the standard. A CAFE adjustment factor is designed to account for these impacts.

Here, however, there is a companion EPA standard for greenhouse gas emissions. In this case, the changes would have an impact on the fuel economy results and therefore the stringency of the CAFE standard, but would not appear to have a real world impact on the burden placed on the manufacturers, as the provisions would be the same as provisions in EPA's greenhouse gas standards. Similarly it would not appear to have a real world impact on the fuel savings and other benefits of the National Program which would remain identical. If that is the case, then it would appear reasonable to interpret section 32904(c) in these circumstances as not restricting these changes in procedure for passenger automobiles. The fuel economy results would be considered ''comparable results'' to the 1975 procedure as there would not be a substantial impact on real world CAFE stringency and benefits, given the changes in procedure are the same as provisions in EPA's companion greenhouse gas procedures and standards. EPA invites comment on this approach to interpreting section 32904(c), as well as the view that this would not have a substantial impact on either the burden on manufacturers or the benefits of the National Program.

EPA is also considering an alternative interpretation. Under this interpretation, the reference to the 1975 procedures in section 32904(c) would be viewed as a historic reference point, and not a codification of any specific procedures or fuel economy improvement technologies. The change in procedure would be considered within EPA's broad discretion to prescribe reasonable testing and calculation procedures, as these changes reflect real world improvements in design and accompanying real world improvements in fuel economy. The changes in procedure would reflect real world fuel economy improvements and increase harmonization with EPA's greenhouse gas program. Since the changes in procedure have an impact on fuel economy results and could have an impact on the stringency of the CAFE standard, EPA could consider two different approaches to offsetting the change in stringency.

In one approach EPA could maintain the stringency of the 2-cycle (FTP and HFET) CAFE standard by adopting a corresponding adjustment factor to the test results, ensuring that the stringency of the CAFE standard was not substantially changed by the change in procedure. This would be the traditional approach EPA has followed. Another approach would be for NHTSA to maintain the stringency of the 2-cycle CAFE standard by increasing that standard's stringency to offset any reduction in stringency associated with changes that increase fuel economy values. The effect of this adjustment to the standard would be to maintain at comparable levels the amount of CAFE to be achieved using technology whose effects on fuel economy are accounted for as measured under the 1975 test procedures. The effect of the adjustment to the standard would also typically be an additional amount of CAFE that would have to be achieved, for example by technology whose effects on fuel economy are not accounted for under the 1975 test procedures. Under this interpretation, this would maintain the level of stringency of the 2-cycle CAFE standard that would be adopted for passenger cars absent the changes in procedure. As with the interpretation discussed above, this alternative interpretation would be a major change from EPA's past interpretation and practice. In this joint rulemaking the alternative interpretation would apply to changes in procedure that are the same as the companion EPA greenhouse gas program. However, that would not be an important element in this alternative interpretation, which would apply irrespective of the similarity with EPA's greenhouse gas procedures and standards. EPA invites comment on this alternative interpretation.

The discussion above focuses on the procedures for passenger cars, as section 32904(c) only limits changes to the CAFE test and calculation procedures for these automobiles. There is no such limitation on the procedures for light-trucks. The credit provisions for improvements in air conditioner efficiency and off-cycle performance would apply to light-trucks as well. In addition, the limitation in section 32904(c) does not apply to the provisions for credits for use of hybrids in light-trucks, if certain criteria are met, as these provisions apply to light-trucks and not passenger automobiles.

b. Implementation of This Approach

As discussed in section IV, NHTSA would take these changes in procedure into account in setting the applicable CAFE standards for passenger cars and light-trucks, to the extent practicable. As in EPA's greenhouse gas program, the allowance of AC credits for cars and trucks results in a more stringent CAFE standard than otherwise would apply (although in the CAFE program the AC credits would only be for AC efficiency improvements, since refrigerant improvements do not impact fuel economy). The allowance of off-cycle credits has been considered in setting the CAFE standards for passenger car and light-trucks and credits for hybrid use in light pick-up trucks has not been expressly considered in setting the CAFE standards for light-trucks, because the agencies did not believe that it was possible to quantify accurately the extent to which manufacturers would rely on those credits, but if more accurate quantification were possible, NHTSA would consider incorporating those incentives into its stringency determination.

EPA further discusses the criteria and test procedures for determining AC credits, off-cycle technology credits, and hybrid/performance-based credits for full size pickup trucks in Section III.C below.

C. Additional Manufacturer Compliance Flexibilities

1. Air Conditioning Related Credits

A/C is virtually standard equipment in new cars and trucks today. Over 95% of the new cars and light trucks in the United States are equipped with A/C systems. Given the large number of vehicles with A/C in use in today's light duty vehicle fleet, their impact on the amount of energy consumed and on the amount of refrigerant leakage that occurs due to their use is significant.

EPA proposes that manufacturers be able to comply with their fleetwide average CO_2 standards described above by generating and using credits for improved (A/C) systems. Because such improved A/C technologies tend to be relatively inexpensive compared to other GHG-reducing technologies, EPA expects that most manufacturers would choose to generate and use such A/C compliance credits as a part of their compliance demonstrations. For this reason, EPA has incorporated the projected costs of compliance with A/C related emission reductions into the overall cost analysis for the program. As discussed in section II.F, and III.B.10, EPA, in coordination with NHTSA, is also proposing that manufacturers be able to include fuel consumption reductions resulting from the use of A/C efficiency improvements in their CAFE compliance calculations. Manufacturers would generate "fuel consumption improvement values" essentially equivalent to EPA CO_2 credits, for use in the CAFE program. The proposed changes to the CAFE program to incorporate A/C efficiency improvements are discussed below in section III.C.1.b.

As in the 2012–2016 final rule, EPA is structuring the A/C provisions as optional credits for achieving compliance, not as separate standards. That is, unlike standards for N_2O and CH_4, there are no separate GHG standards related to AC related emissions. Instead, EPA provides manufacturers the option to generate A/C GHG emission reductions that could be used as part of their CO_2 fleet average compliance demonstrations. As in the 2012–2016 final rule, EPA also included projections of A/C credit generation in determining the appropriate level of the proposed standards.[246]

In the time since the analyses supporting the 2012–2016 FRM were completed, EPA has re-assessed its estimates of overall A/C emissions and the fraction of those emissions that might be controlled by technologies that are or will be available to manufacturers.[247] As discussed in more detail in Chapter 5 of the Joint TSD (see Section 5.1.3.2), the revised estimates remain very similar to those of the earlier rule. This includes the leakage of refrigerant during the vehicle's useful life, as well as the subsequent leakage associated with maintenance and servicing, and with disposal at the end of the vehicle's life (also called "direct emissions"). The refrigerant universally used today is HFC–134a with a global warming potential (GWP) of 1,430.[248] Together these leakage emissions are equivalent to CO_2 emissions of 13.8 g/

[246] See Section II.F above and Section IV below for more information on the use of such credits in the CAFE program.

[247] The A/C-related emission inventories presented in this paragraph are discussed in Chapter 4 of the Draft RIA.

[248] The global warming potentials (GWP) used in this rule are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 1996 IPCC Second Assessment Report (SAR) 100-year GWP values are used in the official U.S. greenhouse gas inventory submission to the United Nations Framework Convention on Climate Change (per the reporting requirements under that international convention, which were last updated in 2006).

mi for cars and 17.2 g/mi for trucks. (Due to the high GWP of HFC–134a, a small amount of leakage of the refrigerant has a much greater global warming impact than a similar amount of emissions of CO_2 or other mobile source GHGs.) EPA also estimates that A/C efficiency-related emissions (also called ''indirect'' A/C emissions), account for CO_2–equivalent emissions of 11.9 g/mi for cars and 17.1 g/mi for trucks.[249] Chapter 5 of the Joint TSD (see Section 5.1.3.2) discusses the derivation of these estimates.

Achieving GHG reductions in the most cost-effective ways is a primary goal of the program, and EPA believes that allowing manufacturers to comply with the proposed standards by using credits generated from incorporating A/C GHG-reducing technologies is a key factor in meeting that goal.[250] EPA accounts for projected reductions from A/C related credits in developing the standards (curve targets), and includes these emission reductions in estimating the achieved benefits of the program. See Section II.D above.

Manufacturers can make very feasible improvements to their A/C systems to reduce leakage and increase efficiency. Manufacturers can reduce A/C leakage emissions by using components that tend to limit or eliminate refrigerant leakage. Also, manufacturers can significantly reduce the global warming impact of leakage emissions by adopting systems that use an alternative, low-GWP refrigerant, acceptable under EPA's SNAP program, as discussed below, especially if systems are also designed to minimize leakage.[251] Manufacturers can also increase the overall efficiency of the A/C system and thus reduce A/C-related CO_2 emissions. This is because the A/C system contributes to increased CO_2 emissions through the additional work required to operate the compressor, fans, and blowers. This additional work typically is provided through the engine's crankshaft, and delivered via belt drive to the alternator (which provides electric energy for powering the fans and blowers) and the A/C compressor (which pressurizes the refrigerant during A/C operation). The additional fuel used to supply the power through the crankshaft necessary to operate the A/C system is converted into CO_2 by the engine during combustion. This incremental CO_2 produced from A/C operation can thus be reduced by increasing the overall efficiency of the vehicle's A/C system, which in turn will reduce the additional load on the engine from A/C operation.

As with the earlier GHG rule, EPA is proposing two separate credit approaches to address leakage reductions and efficiency improvements independently. A leakage reduction credit would take into account the various technologies that could be used to reduce the GHG impact of refrigerant leakage, including the use of an alternative refrigerant with a lower GWP. An efficiency improvement credit would account for the various types of hardware and control of that hardware available to increase the A/C system efficiency. To generate credits toward compliance with the fleet average CO_2 standard, manufacturers would be required to attest to the durability of the leakage reduction and the efficiency improvement technologies over the full useful life of the vehicle.

EPA believes that both reducing A/C system leakage and increasing A/C efficiency would be highly cost-effective and technologically feasible for light-duty vehicles in the 2017–2025 timeframe. EPA proposes to maintain much of the existing framework for quantifying, generating, and using A/C Leakage Credits and Efficiency Credits. EPA expects that most manufacturers would choose to use these A/C credit provisions, although some may choose not to do so. Consistent with the 2012–2016 final rule, the proposed standard reflects this projected widespread penetration of A/C control technology.

The following table summarizes the maximum credits the EPA proposes to make available in the overall A/C program.

[247] The A/C-related emission inventories presented in this paragraph are discussed in Chapter 4 of the Draft RIA.

[248] The global warming potentials (GWP) used in this rule are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 1996 IPCC Second Assessment Report (SAR) 100-year GWP values are used in the official U.S. greenhouse gas inventory submission to the United Nations Framework Convention on Climate Change (per the reporting requirements under that international convention, which were last updated in 2006).

[249] Indirect emissions are additional CO_2 emitted due to the load of the A/C system on the engine.

Table III-12 Summary of Maximum Per-Vehicle Credit for A/C (in g/mi)

	2012-2016	2017-2025
Direct Max Credit Car Leakage	6.3	6.3
Direct Max Credit Car Alt Refrigerant	13.8	13.8
Direct Max Credit Truck Leakage	7.8	7.8
Direct Max Credit Truck Alt Refrigerant	17.2	17.2
Indirect Max Credit Car	5.7	5
Indirect Max Credit Truck	5.7	7.2

The next table shows the credits on a model year basis that EPA projects that manufacturers will generate on average (starting with the ending values from the 2012–2016 final rule). In the 2012–2016 rule, the total average car and total average truck credits accounted for the difference between the GHG and CAFE standards.

Table III-13 Projected Average Credits

	Car Credit leakage avg	**Car Credit efficiency avg**	Total Car Credit avg	**Truck Credit leakage avg**	**Truck Credit efficiency avg**	Total Truck Credit avg	Fleet Avg Combined Car & Truck Credit
2016	5.4	4.8	**10.2**	6.6	4.8	**11.5**	**10.6**
2017	7.8	5.0	**12.8**	7.0	5.0	**12.1**	**12.5**
2018	9.3	5.0	**14.3**	11.0	6.5	**17.5**	**15.5**
2019	10.8	5.0	**15.8**	13.4	7.2	**20.6**	**17.5**
2020	12.3	5.0	**17.3**	15.3	7.2	**22.5**	**19.1**
2021	13.8	5.0	**18.8**	17.2	7.2	**24.4**	**20.7**
2022	13.8	5.0	**18.8**	17.2	7.2	**24.4**	**20.7**
2023	13.8	5.0	**18.8**	17.2	7.2	**24.4**	**20.7**
2024	13.8	5.0	**18.8**	17.2	7.2	**24.4**	**20.7**
2025	13.8	5.0	**18.8**	17.2	7.2	**24.4**	**20.7**

The year-on-year progression of credits was determined as follows. The credits are assumed to increase starting from their MY 2016 value at a rate approximately commensurate with the increasing stringency of the 2017–2025 GHG standards, but not exceeding a 20% penetration rate increase in any given year, until the maximum credits are achieved by 2021. EPA expects that manufacturers would be changing over to alternative refrigerants at the time of complete vehicle redesign, which occurs about every 5 years, though in confidential meetings, some manufacturers/suppliers have informed EPA that a modification of the hardware for some alternative refrigerant systems may be able to be done between redesign periods. Given the significant number of credits for using low GWP refrigerants, as well as the variety of alternative refrigerants that appear to be available, EPA believes that a total phase-in of alternative refrigerants is likely to begin in the near future and be completed by no later than 2021 (as shown in Table III–13 above). EPA requests comment on our assumptions for the phase-in rate for alternative refrigerants.

The progression of the average credits (relative to the maximum) also defines the relative year-on-year costs as described in Chapter 3 of the Joint TSD. The costs are proportioned by the ratio of the average credit in any given year to the maximum credit. This is nearly equivalent to proportioning costs to technology penetration rates as is done for all the other technologies. However because the maximum efficiency credits for cars and trucks have changed since the 2012–2016 rule, proportioning to the credits provides a more realistic and smoother year-on-year sequencing of costs.[252]

EPA seeks comment on all aspects of the A/C credit program, including changes from the current A/C credit program and the details in the Joint TSD.

[252] In contrast, the technology penetration rates could have anomalous (and unrealistic) discontinuities that would be reflected in the cost progressions. This issue is only specific to A/C credits and costs and not to any other technology analysis in this proposal.

a. Air Conditioning Leakage (''Direct'') Emissions and Credits

i. Quantifying A/C Leakage Credits for Today's Refrigerant

As previously discussed, EPA proposes to continue the existing leakage credit program, with minor modifications. Although in general EPA continues to prefer performance-based standards whenever possible, A/C leakage is very difficult to accurately measure in a laboratory test, due to the typical slowness of such leaks and the tendency of leakage to develop unexpectedly as vehicles age. At this time, no appropriate performance test for refrigerant leakage is available. Thus, as in the existing MYs 2012–2016 program, EPA would associate each available leakage-reduction technology with associated leakage credit value, which would be added together to quantify the overall system credit, up to the maximum available credit. EPA's Leakage Credit method is drawn from the SAE J2727 method (HFC–134a Mobile Air Conditioning System Refrigerant Emission Chart, August 2008 version), which in turn was based on results from the cooperative ''IMAC'' study.[253] EPA is proposing to incorporate several minor modifications that SAE is making to the J2727 method, but these do not affect the proposed credit values for the technologies. Chapter 5 of the joint TSD includes a full discussion of why EPA is proposing to continue the design-based ''menu'' approach to quantifying Leakage Credits, including definitions of each of the technologies associated with the values in the menu.

In addition to the above ''menu'' for vehicles using the current high-GWP refrigerant (HFC–134a), EPA also proposes to continue to provide the leakage credit calculation for vehicles using an alternative, lower-GWP refrigerant. This provision was also a part of the MYs 2012–2016 rule. As with the earlier rule, the agency is including this provision because shifting to lower-GWP alternative refrigerants would significantly reduce the climate-change concern about HFC–134a refrigerant leakage by reducing the direct climate impacts. Thus, the credit a manufacturer could generate is a function of the degree to which the GWP of an alternative refrigerant is less than that of the current refrigerant (HFC–134a).

In recent years, the global industry has given serious attention primarily to three of the alternative refrigerants: HFO–1234yf, HFC–152a, and carbon dioxide (R–744). Work on additional low GWP alternatives continues. HFO1234yf, has a GWP of 4, HFC–152a has a GWP of 124 and CO_2 has a GWP of 1.[254] Both HFC–152a and CO_2 are produced commercially in large amounts and thus, supply of refrigerant is not a significant factor preventing adoption.[255] HFC–152a has been shown to be comparable to HFC–134a with respect to cooling performance and fuel use in A/C systems.[256]

In the MYs 2012–2016 GHG rule, a manufacturer using an alternative refrigerant would receive no credit for leakage-reduction technologies. At that time, EPA believed that from the perspective of primary climate effect, leakage of a very low GWP refrigerant is largely irrelevant. However, there is now reason to believe that the need for repeated recharging (top-off) of A/C systems with another, potentially costly refrigerant could lead some consumers and/or repair facilities to recharge a system designed for use with an alternative, low GWP refrigerant with either HFC–134a or another high GWP refrigerant. Depending on the refrigerant, it may still be feasible, although not ideal, for systems designed for a low GWP refrigerant to operate on HFC–134a; in particular, the A/C system operating pressures for HFO–1234yf and HFC–152a might allow their use. Thus, the need for repeated recharging in use could slow the transition away from the high-GWP refrigerant even though recharging with a refrigerant different from that already in the A/C system is not authorized under current regulations.[257]

For alternative refrigerant systems, EPA is proposing to add to the existing credit calculation approach for alternative-refrigerant systems a provision that would provide a disincentive for manufacturers if systems designed to operate with HFO–1234yf, HFC–152a, R744, or some other low GWP refrigerant incorporated fewer leakage-reduction technologies. A system with higher annual leakage could then be recharged with HFC–134a or another refrigerant with a GWP higher than that with which the vehicle was originally equipped (*e.g.,* HFO–1234yf, CO_2, or HFC–152a). Some stakeholders have suggested that EPA take precautions to address the potential for HFC–134a to replace HFO–1234yf, for example, in vehicles designed for use with the new refrigerant (*see* comment and response section of EPA's SNAP rule on HFO–1234yf*,* 76 FR 17509; March 29, 2011).[258] In EPA's proposed disincentive provision, manufacturers would avoid some or all of a deduction in their Leakage Credit of about 2 g/mi by maintaining the use of low-leak components after a transition to an alternative refrigerant.

ii. Issues Raised by a Potential Broad Transition to Alternative Refrigerants

As described previously, use of alternative, lower-GWP refrigerants for mobile use reduces the climate effects of leakage or release of refrigerant through the entire life-cycle of the A/C system. Because the impact of direct emissions of such refrigerants on climate is significantly less than that for the current refrigerant HFC–134a, release of these refrigerants into the atmosphere through direct leakage, as well as release due to maintenance or vehicle scrappage, is predictably less of a concern than with the current refrigerant. As discussed above, there remains a concern, even with a low-GWP refrigerant, that some repairs may repeatedly result in the replacement of the lower-GWP refrigerant from a leaky A/C system with a readily-available, inexpensive, high-GWP refrigerant.

For a number of years, the automotive industry has explored lower-GWP refrigerants and the systems required for them to operate effectively and efficiently, taking into account refrigerant costs, toxicity, flammability, environmental impacts, and A/C system costs, weight, complexity, and efficiency. European Union regulations require a transition to alternative refrigerants with a GWP of 150 or less for motor vehicle air conditioning. The European Union's Directive on mobile

[253] Society of Automotive Engineers, ''IMAC Team 1—Refrigerant Leakage Reduction, Final Report to Sponsors,'' 2006. This document is available in Docket EPA–HQ–OAR–2010–0799.

[254] IPCC 4th Assessment Report.

[255] The U.S. has one of the largest industrial quality CO_2 production facilities in the world (Gale Group, 2011). HFC–152a is used widely as an aerosol propellant in many commercial products and thus potentially available for refrigerant use in motor vehicle A/C. Production volume for non-confidential chemicals reported under the 2006 Inventory Update Rule. Chemical: Ethane, 1,1-difluoro-. Aggregated National Production Volume: 50 to <100 million pounds. [US EPA; Non-Confidential 2006 Inventory Update Reporting. National Chemical Information. Ethane, 1,1-difluoro- (75–37–6). Available from, as of September 21, 2009: *http://cfpub.epa.gov/iursearch/index.cfm?s=chem&err=t.*

[256] United Nations Environment Program, Technology and Economic Assessment Panel, ''Assessment of HCFCs and Environmentally Sound Alternatives,'' TEAP 2010 Progress Report, Volume 1, May 2010. *http://www.unep.ch/ozone/Assessment_Panels/TEAP/Reports/TEAP_Reports/teap-2010-progress-report-volume1-May2010.pdf.* This document is available in Docket EPA–HQ–OAR–2010–0799.

[257] See appendix D to 40 CFR part 82, subpart G.

[258] Regulations in Appendix D to Subpart G of 40 CFR part 82 prohibit topping off the refrigerant in a motor vehicle A/C system with a different refrigerant.

air-conditioning systems (MAC Directive [259]) aims at reducing emissions of specific fluorinated greenhouse gases in the air-conditioning systems fitted to passenger cars (vehicles under EU category M1) and light commercial vehicles (EU category N1, class 1).

The main objectives of the EU MAC Directive are: to control leakage of fluorinated greenhouse gases with a global warming potential (GWP) higher than 150 used in this sector; and to prohibit by a specified date the use of higher GWP refrigerants in MACs. The MAC Directive is part of the European Union's overall objectives to meet commitments made under the UNFCCC's Kyoto Protocol. This transition starts with new car models in 2011 and continues with a complete transition to manufacturing all new cars with low GWP refrigerant by January 1, 2017.

One alternative refrigerant has generated significant interest in the automobile manufacturing industry and it appears likely to be used broadly in the near future for this application. This refrigerant, called HFO–1234yf, has a GWP of 4. The physical and thermodynamic properties of this refrigerant are similar enough to HFC–134a that auto manufacturers would need to make relatively minor technological changes to their vehicle A/C systems in order to manufacture and market vehicles capable of using HFO–1234yf. Although HFO–1234yf is flammable, it requires a high amount of energy to ignite, and is expected to have flammability risks that are not significantly different from those of HFC–134a or other refrigerants found acceptable subject to use conditions (76 FR 17494–17496, 17507; March 29, 2011).

There are some drawbacks to the use of HFO–1234yf. Some technological changes, such as the addition of an internal heat exchanger in the A/C system, may be necessary to use HFO–1234yf. In addition, the anticipated cost of HFO–1234yf is several times that of HFC–134a. At the time that EPA's Significant New Alternatives Policy (SNAP) program issued its determination allowing the use of HFO–1234yf in motor vehicle A/C systems, the agency cited estimated costs of $40 to $60 per pound, and stated that this range was confirmed by an automobile manufacturer (76 FR 17491; March 29, 2011) and a component supplier.[260] By comparison, HFC–134a currently costs about $2 to $4 per pound.[261] The higher cost of HFO–1234yf is largely because of limited global production capability at this time. However, because it is more complicated to produce the molecule for HFO–1234yf, it is unlikely that it will ever be as inexpensive as HFC–134a is currently. In Chapter 5 of the TSD (see Section 5.1.4), the EPA has accounted for this additional cost of both the refrigerant as well as the hardware upgrades.

Manufacturers have seriously considered other alternative refrigerants in recent years. One of these, HFC–152a, has a GWP of 124.[262] HFC–152a is produced commercially in large amounts.[263] HFC–152a has been shown to be comparable to HFC–134a with respect to cooling performance and fuel use in A/C systems.[264] HFC–152a is flammable, listed as A2 by ASHRAE.[265] Air conditioning systems using this refrigerant would require engineering strategies or devices in order to reduce flammability risks to acceptable levels (*e.g.,* use of release valves or secondary-loop systems). In addition, CO_2 can be used as a refrigerant. It has a GWP of 1, and is widely available commercially.[266] Air conditioning systems using CO_2 would require different designs than other refrigerants, primarily due to the higher operating pressures that are required. Reesearch continues exploring the potential for these alternative refrigerants for automotive applications. Finally, EPA is aware that the chemical and automobile manufacturing industries continue to consider additional refrigerants with GWPs less than 150. For example, SAE International is currently running a cooperative research program looking at two low GWP refrigerant blends, with the program to complete in 2012.[267] The producers of these blends have not to date applied for SNAP approval. However, we expect that there may well be additional alternative refrigerants available to vehicle manufacturers in the next few years.

(1) Related EPA Actions to Date and Potential Actions Concerning Alternative Refrigerants

EPA is addressing potential environmental and human health concerns of low-GWP alternative refrigerants through a number of actions. The SNAP program has issued final rules regulating the use of HFC–152a and HFO–1234yf in order to reduce their potential risks (June 12, 2008, 73 FR 33304; March 29, 2010, 76 FR 17488). The SNAP rule for HFC–152a allows its use in new motor vehicle A/C systems where proper engineering strategies and/or safety devices are incorporated into the system. The SNAP rules for both HFC–152a and HFO–1234yf require meeting safety requirements of the industry standard SAE J639. With both refrigerants, EPA expects that manufacturers conduct and keep on file failure mode and effect analysis for the motor vehicle A/C system, as stated in SAE J1739. EPA has also proposed a rule that would allow use of carbon dioxide as a refrigerant subject to use conditions for motor vehicle A/C systems (September 21, 2006; 71 FR 55140). EPA expects to finalize a rule for use of carbon dioxide in motor vehicle A/C systems in 2012.

Under Section 612(d) of the Clean Air Act, any person may petition EPA to add alternatives to or remove them from the list of acceptable substitutes for ozone depleting substances. The National Resource Defense Council (NRDC) submitted a petition on behalf of NRDC, the Institute for Governance & Sustainable Development (IGSD), and the Environmental Investigation Agency-US (EIA–US) to EPA under Clean Air Act Section 612(d), requesting that the Agency remove HFC–134a from the list of acceptable substitutes and add it to the list of unacceptable (prohibited) substitutes for motor vehicle A/C, among other uses.[268] EPA has found this

[259] 2006/40/EC.

[260] Automotive News, April 18, 2011.21.

[261] Ibid.

[262] IPCC 4th Assessment Report.

[263] HFC–152a is used widely as an aerosol propellant in many commercial products and may potentially be available for refrigerant use in motor vehicle A/C systems. Aggregated national production volume is estimated to be between 50 and 100 million pounds. [US EPA; Non-Confidential 2006 Inventory Update Reporting. National Chemical Information.]

[264] May 2010 TEAP XXI/9 Task Force Report, *http://www.unep.ch/ozone/Assessment_Panels/TEAP/Reports/TEAP_Reports/teap-2010-progress-report-volume1–May2010.pdf*.

[265] A wide range of concentrations has been reported for HFC–152a flammability where the gas poses a risk of ignition and fire (3.7%–20% by volume in air) (Wilson, 2002). EPA finalized a rule in 2008 listing HFC–152a as acceptable subject to use conditions in motor vehicle air-conditioning, one of these restricting refrigerant concentrations in the passenger compartment resulting from leaks above the lower flammability limit of 3.7% (see 71 FR 33304; June 12, 2008).

[266] The U.S. has one of the largest industrial quality CO_2 production facilities in the world (Gale Group, 2011).

[267] ''Recent Experiences in MAC System Development: 'New Alternative Refrigerant Assessment' Technical Update. Enrique Peral-Antunez, Renault. Presentation at SAE Alternative Refrigerant and System Efficiency Symposium. September, 2011. Available online at *http://www.sae.org/events/aars/presentations/2011/Enrique%20Peral%20Renault%20Recent%20Experiences%20in%20MAC%20System%20Dev.pdf* .

[268] NRDC *et al.* Re: Petition to Remove HFC–134a from the List of Acceptable Substitutes under the Significant New Alternatives Policy Program (November 16, 2010).

petition complete specifically for use of HFC–134a in new motor vehicle A/C systems for use in passenger cars and light duty vehicles. EPA intends to initiate a separate notice and comment rulemaking in response to this petition in the future.

EPA expects to address potential toxicity issues with the use of CO_2 as a refrigerant in automotive A/C systems in the upcoming final SNAP rule mentioned above. CO_2 has a workplace exposure limit of 5000 pm on a 8-hour time-weighted average.[269] EPA has also addressed potential toxicity issues with HFO–1234yf through a significant new use rule (SNUR) under the Toxic Substances Control Act (TSCA) (October 27, 2010; 75 FR 65987). The SNUR for HFO–1234yf allows its use as an A/C refrigerant for light-duty vehicles and light-duty trucks, and found no significant toxicity issues with that use. As mentioned in the NPRM for a VOC exemption for HFO–1234yf, ''The EPA considered the results of developmental testing available at the time of the final SNUR action to be of some concern, but not a sufficient basis to find HFO–1234yf unacceptable under the SNUR determination. As a result, the EPA requested additional toxicity testing and issued the SNUR for HFO–1234yf. The EPA has received and is presently reviewing the results of the additional toxicity testing. The EPA continues to believe that HFO–1234yf, when used in new automobile air conditioning systems in accordance with the use conditions under the SNAP rule, does not result in significantly greater risks to human health than the use of other available substitutes.'' (76 FR 64063, October 17, 2011). HFC–152a is considered relatively low in toxicity and comparable to HFC–134a, both of which have a workplace environmental exposure limit from the American Industrial Hygiene Association of 1000 ppm on an 8-hour time-weighted average (73 FR 33304; June 12, 2008).

EPA has issued a proposed rule, proposing to exempt HFO–1234yf from the definition of ''volatile organic compound'' (VOC) for purposes of preparing State implementation Plans (SIPs) to attain the national ambient air quality standards for ozone under Title I of the Clean Air Act (October 17, 2011; 76 FR 64059). VOCs are a class of compounds that can contribute to ground level ozone, or smog, in the presence of sunlight. Some organic compounds do not react enough with sunlight to create significant amounts of smog. EPA has already determined that a number of compounds, including the current automotive refrigerant, HFC–134a as well as HFC–152a, are low enough in photochemical reactivity that they do not need to be regulated under SIPs. CO_2 is not considered a volatile organic compound (VOC) for purposes of preparing SIPs.

(2) Vehicle Technology Requirements for Alternative Refrigerants

As discussed above, significant hardware changes could be needed to allow use of HFC–152a or CO_2, because of the flammability of HFC–152a and because of the high operating pressure required for CO_2. In the case of HFO–1234yf, manufacturers have said that A/C systems for use with HFO–1234yf would need a limited amount of additional hardware to maintain cooling efficiency compared to HFC–134a. In particular, A/C systems may require an internal heat exchanger to use HFO–1234yf, because HFO–1234yf would be less effective in A/C systems not designed for its use. Because EPA's SNAP ruling allows only for its use in new vehicles, we expect that manufacturers would introduce cars using HFO–1234yf only during complete vehicle redesigns or when introducing new models.[270] EPA expects that the same would be true for other alternative refrigerants that are potential candidates (*e.g.,* HFC–152a and CO_2). This need for complete vehicle redesign limits the potential pace of a transition from HFC–134a to alternative refrigerants. In meetings with EPA, manufacturers have informed EPA that, in the case of HFO–1234yf, for example, they would need to upgrade their refrigerant storage facilities and charging stations on their assembly lines. During the transition period between the refrigerants, some of these assembly lines might need to have the infrastructure for both refrigerants simultaneously since many lines produce multiple vehicle models. Moreover, many of these plants might not immediately have the facilities or space for two refrigerant infrastructures, thus likely further increasing necessary lead time. EPA took these kinds of factors into account in estimating the penetration of alternative refrigerants, and the resulting estimated average credits over time shown in Table III–13.

Switching to alternative refrigerants in the U.S. market continues to be an attractive option for automobile manufacturers because vehicles with low GWP refrigerant could qualify for a significantly larger leakage credit. Manufacturers have expressed to EPA that they would plan to place a significant reliance on, or in some cases believe that they would need, alternative refrigerant credits for compliance with GHG fleet emission standards starting in MY 2017.

(3) Alternative Refrigerant Supply

EPA is aware that another practical factor affecting the rate of transition to alternative refrigerants is their supply. As mentioned above, both HFC–152a and CO_2 are being produced commercially in large quantities and thus, although their supply chain does not at this time include auto manufacturers, it may be easier to increase production to meet additional demand that would occur if manufacturers adopt either as a refrigerant. However, for the newest refrigerant listed under the SNAP program, HFO–1234yf, supply is currently limited. There are currently two major producers of HFO–1234yf, DuPont and Honeywell, that are licensed to produce this chemical for the U.S. market. Both companies will likely provide most of their production for the next few years from a single overseas facility, as well as some production from small pilot plants. The initial emphasis for these companies is to provide HFO–1234yf to the European market, where regulatory requirements for low GWP refrigerants are already in effect. These same companies have indicated that they plan to construct a new facility in the 2014 timeframe and intend to issue a formal announcement about that facility close to the end of this calendar year. This facility should be designed to provide sufficient production volume for a worldwide market in coming years. EPA expects that the speed of the transition to alternative refrigerants in the U.S. may depend on how rapidly chemical manufacturers are able to provide supply to automobile manufacturers sufficient to allow most or all vehicles sold in the U.S. to be built using the alternative refrigerant.

One manufacturer (GM) has announced its intention to begin introducing vehicle models using HFO–

[269] The 8-hour time-weighted average worker exposure limit for CO_2 is consistent with OSHA's PEL–TWA, and ACGIH'S TLV–TWA of 5,000 ppm (0.5%).

[270] Some suppliers and manufacturers have informed us that some vehicles may be able to upgrade A/C systems during a refresh of an existing model (between redesign years). However, this is highly dependent on the vehicle, space constraints behind the dashboard, and the manufacturing plant, so an upgrade may be feasible for only a select few models.

1234yf as early as MY 2013.[271] EPA is not aware of other companies that have made a public commitment to early adoption of HFO–1234yf or other alternative refrigerants. As described above, we expect that in most cases a change-over to systems designed for alternative refrigerants would be limited to vehicle product redesign cycles, typically about every 5 years. Because of this, the pace of introduction is likely to be limited to about 20% of a manufacturer's fleet per year. In addition, the current uncertainty about the availability of supply of the new refrigerant in the early years of introduction into vehicles in the U.S. vehicles, also discussed above, means that the change-over may not occur at every vehicle redesign point. Thus, even with the announced intention of this one manufacturer to begin early introduction of an alternative refrigerant, EPA's analysis of the overall industry trend will assume minimal penetration of the U.S. vehicle market before MY 2017.

Table III–13 shows that, starting from MY 2017, virtually all of the expected increase in generated credits would be due to a gradual increase in penetration of alternative refrigerants. In earlier model years, EPA attributes the expected increase in Leakage Credits to improvements in low-leak technologies.

(4) Projected Potential Scenarios for Auto Industry Changeover to Alternative Refrigerants

As discussed above, EPA is planning on issuing a proposed SNAP rulemaking in the future requesting comment on whether to move HFC–134a from the list of acceptable substitutes to the list of unacceptable (prohibited) substitutes. However, the agency has not determined the specific content of that proposal, and the results of any final action are unknowable at this time. EPA recognizes that a major element of that proposal will be the evaluation of the time needed for a transition for automobile manufacturers away from HFC–134a. Thus, there could be multiple scenarios for the timing of a transition considered in that future proposed rulemaking. Should EPA finalize a rule under the SNAP program that prohibits the use of HFC–134a in new vehicles, the agency plans to evaluate the impacts of such a SNAP rule to determine whether it would be necessary to consider revisions to the availability and use of the compliance credit for MY 2017–2025.

For purposes of this proposed GHG rule, EPA is assuming the current status, where there are no U.S. regulatory requirements for manufacturers to eliminate the use of HFC–134a for newly manufactured vehicles. Thus, the agency would expect that the market penetration of alternatives will proceed based on supply and demand and the strong incentives in this proposal. Given the combination of clear interest from automobile manufacturers in switching to an alternative refrigerant, the interest from HFO–1234yf alternative refrigerant manufacturers to expand their capacity to produce and market the refrigerant, and current commercial availability of HFC–152a and CO_2, EPA believes it is reasonable to project that supply would be adequate to support the orderly rate of transition to an alternative refrigerant described above. As mentioned earlier, at least one U.S. manufacturer already has plans to introduce models using the alternative refrigerant HFO–1234yf beginning in MY 2013. However, it is not certain how widespread the transition to a alternative refrigerants will be in the U.S., nor how quickly that transition will occur in the absence of requirements or strong incentives.

There are other situations that could lead to an overall fleet changeover from HFC–134a to alternative refrigerants. For example, the governments of the U.S., Canada, and Mexico have proposed to the Parties to the *Montreal Protocol on Substances that Deplete the Ozone Layer* that production of HFCs be reduced over time. The North American Proposal to amend the Montreal Protocol allows the global community to make near-term progress on climate change by addressing this group of potent greenhouse gases. The proposal would result in lower emissions in developed and developing countries through the phase-down of the production and consumption of HFCs. If an amendment were adopted by the Parties, then switching from HFC–134a to alternative refrigerants would likely become an attractive option for decreasing the overall use and emissions of high-GWP HFCs, and the Parties would likely initiate or expand policies to incentivize suppliers to ramp up the supply of alternative refrigerants. Options for reductions would include transition from HFCs, moving from high to lower GWP HFCs, and reducing charge sizes.

EPA requests comment on the implications for the program of the refrigerant transition scenario assumed for the analyses supporting this NPRM; that is, where there are no U.S. regulatory requirements for manufacturers to eliminate the use of HFC–134a for newly manufactured vehicles. EPA requests comment on factors that may affect the industry demand for refrigerant and its U.S. and international supply.

b. Air Conditioning Efficiency (''Indirect'') Emissions and Credits

In addition to the A/C leakage credits discussed above, EPA is proposing credits for improving the efficiency of—and thus reducing the CO_2 emissions from—A/C systems. Manufacturers have available a number of very cost-effective technology options that can reduce these A/C-related CO_2 emissions, which EPA estimates are currently on average 11.9 g/mi for cars and 17.1 for trucks nationally.[272] When manufacturers incorporate these technologies into vehicles that clearly result in reduced CO_2 emissions, EPA believes that A/C Efficiency Credits are warranted. Based on extensive industry testing and EPA analysis, the agency proposes that eligible efficiency-improving technologies be limited to up to a maximum 42% improvement,[273] which translates into a maximum credit value of 5.0 g/mi for cars and 7.2 g/mi for trucks.

As discussed further in Section III.C.1.b.iii below, under its EPCA authority, EPA is proposing, in coordination with NHTSA, to allow manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of A/C efficiency technologies. EPA is proposing that both the A/C efficiency credits under EPA's GHG program and the A/C efficiency fuel consumption improvement values under the CAFE program would be based on the same methodologies and test procedures, as further described below.

i. Quantifying A/C Efficiency Credits

In the 2012–2016 rule, EPA proposed that A/C Efficiency Credits be calculated based on the efficiency-improving

[271] General Motors Press Release, July 23, 2010. ''GM First to Market Greenhouse Gas-Friendly Air Conditioning Refrigerant in U.S''.

[272] EPA derived these estimates using a sophisticated new vehicle simulation tool that EPA has developed since the completion of the MYs 2012–2016 final rule. Although results are very similar to those in the earlier rule, EPA believes they represent more accurate estimates. Chapter 5 of the Joint TSD presents a detailed discussion of the development of the simulation tool and the resulting emissions estimates.

[273] The cooperative IMAC study mentioned above concluded that these emissions can be reduced by as much as 40% through the use of these technologies. In addition, EPA has concluded that improvements in the control software for the A/C system, including more precise control of such components as the radiator fan and compressor, can add another 2% to the emission reductions. In total, EPA believes that a total maximum improvement of 42% is available for A/C systems.

technologies included in the vehicle. The design-based approach, associating each technology with a specific credit value, was a surrogate for a using a performance test to determine credit values. Although EPA generally prefers measuring actual emissions performance to a design-based approach, measuring small differences in A/C CO_2 emissions is very difficult, and an accurate test procedure capable of determining such differences was not available.

In conjunction with the (menu or) design-based calculation, EPA continues to believe it is important to verify that the technologies installed to generate credits are improving the efficiency of the A/C system. In the 2012–2016 rule, EPA required that manufacturers submit data from an A/C CO_2 Idle Test as a prerequisite to accessing the design-based credit calculation method. Beginning in MY 2014, manufacturers wishing to generate the A/C Efficiency Credits need to meet a CO_2 emissions threshold on the Idle Test.

As manufacturers have begun to evaluate the Idle Test requirements, they have made EPA aware of an issue with the test's original design. In the MYs 2012–2016 rule, EPA received comments that the Idle Test did not properly capture the efficiency impact of some of the technologies on the Efficiency Credit menu list. EPA also received comments that idle operation is not typical of real-world driving. EPA acknowledges that both of these comments have merit. At the time of the MY 2012–2016 rule, we expected that many manufacturers would be able to demonstrate improved efficiency with technologies like forced cabin air recirculation or electronically-controlled, and variable-displacement compressors., But under idle conditions, testing by manufacturers has shown that the benefits from these technologies can be difficult to quantify. Also, recent data provided by the industry shows that some vehicles that incorporate higher-efficiency A/C technologies are not able to consistently reach the CO_2 threshold on the current Idle Test. The available data also indicates that meeting the threshold tends to be more difficult for vehicles with smaller-displacement engines.[274] EPA continues to believe that there are some technologies that do have their effectiveness demonstrated during idle and that idle is a significant fraction of real-world operation.[275]

Although EPA believes some adjustments in the Idle Test are warranted and is proposing such adjustments, the agency also believes that a reasonable degree of verification is still needed, to demonstrate that that A/C efficiency-improving technologies for which manufacturers are basing credits are indeed implemented properly and are reducing A/C-related fuel consumption. EPA continues to believe that the Idle Test is a reasonable measure of some A/C-related CO_2 emissions as there is significant real-world driving activity at idle, and it significantly exercises a number of the A/C technologies from the menu. Therefore, EPA proposes to maintain the use of Idle Test as a prerequisite for generating Efficiency Credits for MYs 2014–2016. However, in order to provide reasonable verification while encouraging the development and use of efficiency-improving technologies, EPA proposes to revise the CO_2 threshold. Specifically, the agency proposes to scale the magnitude of the threshold to the displacement of the vehicle's engine, with smaller-displacement engines having a higher ''grams per minute'' threshold than larger-displacement engines. Thus, for vehicles with smaller-displacement engines, the threshold would be less stringent. The revised threshold would apply for MYs 2014–2016, and can be used (optionally) instead of the flat gram per minute threshold that applies for MYs 2014, through 2016.[276] In addition to revising the threshold, EPA proposes to relax the average ambient temperature and humidity requirements, due to the difficulty in controlling the year-round humidity in test cells designed for FTP testing. EPA requests comment on the proposed continued use of the Idle Test as a tool to validate the function of a vehicle's A/C efficiency-improving technologies, and on the revised CO_2 threshold and ambient requirements.

As stated above, EPA still considers the Idle Test to be a reasonable measure of some A/C-related CO_2 emissions. However, there are A/C efficiency-improving technologies that cannot be fully evaluated with the Idle Test. In addition to proposing the revised Idle Test, EPA proposes that manufacturers have the option of reporting results from a new transient A/C test in place of the Idle Test, for MYs 2014–2016. In the year since the previous GHG rule was finalized, EPA, CARB, and a consortium of auto manufacturers (USCAR) have developed a new transient test procedure that can measure the effect of the operation of the overall A/C system on CO_2 emissions and fuel economy. The new test, known as ''AC17'' (for Air Conditioning, 2017), and described in detail in Chapter 5 of the Joint TSD, is essentially a combination of the existing SC03 and HWFET test procedures, which, with the proposed modifications, would exercise the A/C system (and new technologies) under conditions representing typical U.S. driving and climate.

Some aspects of the AC17 test are still being developed and improved, but the basic procedure is sufficiently complete for EPA to propose it as a reporting option alternative to the Idle Test threshold in 2014, and a replacement for the Idle Test in 2017, as a prerequisite for generating Efficiency Credits. In model years 2014 to 2016, the AC17 test would be used to demonstrate that a vehicle's A/C system is delivering the efficiency benefits of the new technologies, and the menu will still be utilized. Manufacturers would run the AC17 test procedure on each vehicle platform that incorporates the new technologies, with the A/C system off and then on, and then report these test results to the EPA. This reporting option would replace the need for the Idle Test. In addition to reporting the test results, EPA will require that manufactures provide detailed vehicle and A/C system information for each vehicle tested (*e.g.* vehicle class, model type, curb weight, engine size, transmission type, interior volume, climate control type, refrigerant type, compressor type, and evaporator/condenser characteristics).

For model years 2017 and beyond, the A/C Idle Test menu and threshold requirement would be eliminated and be replaced with the AC17 test, as a prerequisite for access to the credit menu. For vehicle models which manufacturers are applying for A/C efficiency credits, the AC17 test would be run to validate that the performance and efficiency of a vehicle's A/C technology is commensurate to the level of credit for which the manufacturer is applying. To determine whether the efficiency improvements of these technologies are being realized on the vehicle, the results of an AC17 test performed on a new vehicle model would be compared to a ''baseline'' vehicle which does not incorporate the efficiency-improving technologies. If the difference between the new vehicle's AC17 test result and the baseline vehicle test result is greater than or equal to the amount of menu credit for

[274] Chapter 5 of the Joint TDS provides details about the manufacturers' testing of these vehicles.

[275] More discussion of real world idle operation can be found below and in chapter 5 of the joint TSD in the description of stop-start off cycle credits.

[276] Chapter 5 of the Joint TSD describes the available data relevant to testing on the Idle Test and to the design of the displacement-weighted revised threshold in more detail.

which the manufacturer is applying, then the menu credit amount would be generated. However, if the difference in test results did not demonstrate the full menu-based potential of the technology, a partial credit could still be generated. This partial credit would be proportional to how far the difference in results was from the expected menu-based credit (*i.e.,* the sum of the individual technology credits). The baseline vehicle is defined as one with characteristics which are similar to the new vehicle, except that it is not equipped with the efficiency-improving technologies (or they are de-activated). EPA is seeking comment on this approach to qualifying for A/C efficiency credits.

The AC17 test requires a significant amount of time for each test (nearly 4 hours) and must be run in expensive SC03-capable facilities. EPA believes that the purpose of the test—to validate that A/C CO_2 reductions are indeed occurring and hence that the manufacturer is eligible for efficiency credits—would be met if the manufacturer performs the new test on a limited subset of test vehicles. EPA proposes that manufacturers wishing to use the AC17 test to validate a vehicle's A/C technology be required to test one vehicle from each platform. For this purpose, ''platform'' would be defined as a group of vehicles with common body floorplan, chassis, engine, and transmission.[277] EPA requests comment on the new test and its proposed use. EPA also requests comment on using the AC17 test to quantify efficiency credits, instead of the menu. EPA is also seeking comment on an option starting in MY 2017, to have the AC17 test be used in a similar fashion as the Idle Test, such that if the CO_2 measurements are below a certain threshold value, then credit would be quantified based on the menu. EPA also seeks comment on eliminating the idle test in favor of reporting only the AC17 test for A/C efficiency credits starting as early as MY 2014.

ii. Potential Future Use of the New A/C Test for Credit Quantification

As described above, EPA is proposing to use the AC17 test as a prerequisite to generating A/C Efficiency Credits. The test is well-suited for this purpose since it can accurately measure the difference in the increased CO_2 emissions that occur when the A/C system is turned on vs. when it is turned off. This difference in the ''off-on'' CO_2 emissions, along with details about the vehicle and its A/C system design, will help inform EPA as to how these efficiency-improving technologies perform on a wide variety of vehicle types.

However, the test is limited in its ability to accurately quantify the amount of credit that would be warranted by an improved A/C system on a particular vehicle. This is because to determine an absolute—rather than a relative—difference in CO_2 effect for an individual vehicle design would require knowledge of the A/C system CO_2 performance for that exact vehicle, but without those specific A/C efficiency improvements installed. This would be difficult and costly, since two test vehicles (or a single vehicle with the components removed and replaced) would be necessary to quantify this precisely. Even then, the inherent variability between such tests on such a small sample in such an approach might not be statistically robust enough to confidently determine a small absolute CO_2 emissions impact between the two vehicles.

As an alternative to comparing new vehicle AC17 test with a ''baseline'' (described above), in Chapter 5 of the Joint TSD, EPA discusses a potential method of more accurately quantifying the credit. This involves comparing the efficiencies of individual components outside the vehicles, through ''bench'' testing of components supplemented by vehicle simulation modeling to relate that component's performance to the complete vehicle. EPA believes that such approaches may eventually allow the AC17 test to be used as part of a more complicated series of test procedures and simulations, to accurately quantify the A/C CO_2 effect of an individual vehicle's A/C technology package. However, EPA believes that this issue is beyond the scope of this proposed rule since there are many challenges associated with measuring small incremental decreases in fuel consumption and CO_2 emissions compared to the relatively large overall fuel consumption rate and CO_2 emissions. The agency does encourage comment, including test data, on how the AC17 test could be enhanced in order to measure the individual and collective impact of different A/C efficiency-improving technologies on individual vehicle designs and thus to quantify Efficiency Credits. EPA especially seeks comment on a more complex procedure, also discussed in Chapter 5 of the Joint TSD, that uses a combination of bench testing of components, vehicle simulation models, and dynamometer testing to quantify Efficiency Credits. Specifically, the agencies request comment on how to define the baseline configuration for bench testing. The agencies also request comment on the use of the Lifecycle Climate Performance Model (LCCP), or alternatively, the use of an EPA simulation tool to convert the test bench results to a change in fuel consumption and CO_2 emissions.

iii. A/C Efficiency Fuel Consumption Improvement Values in the CAFE Program

As described in section II.F and above, EPA is proposing to use the AC17 test as a prerequisite to generating A/C Efficiency Credits starting in MY 2017. EPA is proposing, in coordination with NHTSA, for the first time under its EPCA authority to allow manufacturers to use this same test procedure to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of A/C efficiency technologies. As described above, the CO_2 credits would be determined from a comparison of the new vehicle compared to an older ''baseline vehicle.'' For CAFE, EPA proposes to convert the total CO_2 credits due to A/C efficiency improvements from metric tons of CO_2 to a fleetwide CAFE improvement value. The fuel consumption improvement values are presented to give the reader some context and explain the relationship between CO_2 and fuel consumption improvements. The fuel consumption improvement values would be the amount of fuel consumption reduction achieved by that vehicle, up to a maximum of 0.000563 gallons/mi fuel consumption improvement value for cars and a 0.000586 gallons/mi fuel consumption improvement value for trucks.[278] If the difference between the new vehicle and baseline results does not demonstrate the full menu-based potential of the technology, a partial credit could still be generated. This partial credit would be proportional to how far the difference in results was from the expected menu-based credit (*i.e.,* the sum of the individual technology credits). The table below presents the proposed CAFE fuel consumption improvement values for

[277] A single platform may encompass a larger group of fuel economy label classes or car lines (40 CFR § 600.002–93), such as passenger cars, compact utility vehicles, and station wagons The specific vehicle selection requirements for manufacturers using this testing are laid out in the regulations associated with this NPRM.

[278] Note that EPA's proposed calculation methodology in 40 CFR 600.510–12 does not use vehicle-specific fuel consumption adjustments to determine the CAFE increase due to the various incentives allowed under the proposed program. Instead, EPA would convert the total CO_2 credits due to each incentive program from metric tons of CO_2 to a fleetwide CAFE improvement value. The fuel consumption values are presented to give the reader some context and explain the relationship between CO_2 and fuel consumption improvements.

each of the efficiency-reducing air conditioning technologies considered in this proposal. More detail is provided on the calculation of indirect A/C CAFE fuel consumption improvement values in chapter 5 of the joint TSD. EPA is proposing definitions of each of the technologies in the table below which are discussed in Chapter 5 of the draft joint TSD to ensure that the air conditioner technology used by manufacturers seeking these values corresponds with the technology used to derive the fuel consumption improvement values.

Table III-14 Proposed Fuel Consumption Improvement Values for A/C Efficiency

Technology Description	Estimated reduction in A/C CO_2 Emissions and Fuel Consumption	Car A/C Efficiency Fuel Consumption Improvement (gallon / mi)	Truck A/C Efficiency Fuel Consumption Improvement (gallon / mi)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	0.000169	0.000248
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	0.000113	0.000158
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed based on additional analysis)	30%	0.000169	0.000248
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	20%	0.000113	0.000158

Blower motor control which limit wasted electrical energy (e.g. pulsewidth modulated power controller)	15%	0.000090	0.000124
Internal heat exchanger (or suction line heat exchanger)	20%	0.000113	0.000158
Improved evaporators and condensers (with engineering analysis on each component indicating a COP improvement greater than 10%, when compared to previous design)	20%	0.000113	0.000158
Oil Separator (internal or external to compressor)	10%	0.000090	0.000079

2. Incentive for Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Fuel Cell Vehicles

a. Rationale for Temporary Regulatory Incentives for Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Fuel Cell Vehicles

EPA has identified two vehicle powertrain-fuel combinations that have the future potential to transform the light-duty vehicle sector by achieving near-zero greenhouse gas (GHG) emissions and oil consumption in the longer term, but which face major near-term market barriers such as vehicle cost, fuel cost (in the case of fuel cell vehicles), the development of low-GHG fuel production and distribution infrastructure, and/or consumer acceptance.

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) which would operate exclusively or frequently on grid electricity that could be produced from very low GHG emission feedstocks or processes.

Fuel cell vehicles (FCVs) which would operate on hydrogen that could be produced from very low GHG emissions feedstocks or processes.

As in the 2012–2016 rule, EPA is proposing temporary regulatory incentives for the commercialization of EVs, PHEVs, and FCVs. EPA believes that these advanced technologies represent potential game-changers with respect to control of transportation GHG emissions as they can combine an efficient vehicle propulsion system with the potential to use motor fuels produced from low-GHG emissions feedstocks or from fossil feedstocks with carbon capture and sequestration. EPA recognizes that the use of EVs, PHEVs, and FCVs in the 2017–2025 timeframe, in conjunction with the incentives, will decrease the overall GHG emissions reductions associated with the program as the upstream emissions associated with the generation and distribution of electricity are higher than the upstream emissions associated with production and distribution of gasoline. EPA accounts for this difference in projections of the overall program's impacts and benefits (see Section III.F).[279]

The tailpipe GHG emissions from EVs, PHEVs operated on grid electricity, and hydrogen-fueled FCVs are zero, and traditionally the emissions of the vehicle itself are all that EPA takes into account for purposes of compliance with standards set under Clean Air Act section 202(a). Focusing on vehicle tailpipe emissions has not raised any issues for criteria pollutants, as upstream emissions associated with production and distribution of the fuel are addressed by comprehensive regulatory programs focused on the upstream sources of those emissions. At this time, however, there is no such comprehensive program addressing upstream emissions of GHGs, and the upstream GHG emissions associated with production and distribution of electricity are higher, on a national average basis, than the corresponding upstream GHG emissions of gasoline or other petroleum based fuels.[280] In the future, if there were a program to comprehensively control upstream GHG emissions, then the zero tailpipe levels from these vehicles have the potential to contribute to very large GHG reductions, and to transform the transportation sector's contribution to nationwide GHG emissions (as well as oil consumption). For a discussion of this issue in the 2012–2016 rule, see 75 FR at 25434–438.

EVs and FCVs also represent some of the most significant changes in automotive technology in the industry's history.[281] For example, EVs face major consumer barriers such as significantly

[279] Also see the Regulatory Impact Analysis.

[280] There is significant regional variation with upstream GHG emissions associated with electricity production and distribution. Based on EPA's eGRID2010 database, comprised of 26 regions, the average powerplant GHG emissions rates per kilowatt-hour for those regions with the highest GHG emissions rates are about 3 times higher than those with the lowest GHG emissions rates. See *http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html*.

[281] A PHEV is not such a big change since, if the owner so chooses, it can operate on gasoline.

higher vehicle cost and lower range. However, EVs also have attributes that could be attractive to some consumers: Lower and more predictable fuel price, no need for oil changes or spark plugs, and reducing one's personal contribution to local air pollution, climate change, and oil dependence.[282]

Original equipment manufacturers currently offer two EVs and one PHEV in the U.S. market.[283] Deliveries of the Nissan Leaf EV, which has a list price of about $33,000 (before tax credits) and an EPA label range of 73 miles, began in December 2010 in selected areas, and total sales through October 2011 are about 8000. The luxury Tesla Roadster EV, with a list price of $109,000, has been on sale since March 2008 with cumulative sales of approximately 1500. The Chevrolet Volt PHEV, with a list price of about $41,000 and an EPA label all-electric range of 35 miles, has sold over 5000 vehicles since it entered the market in December 2010 in selected markets. At this time, no original equipment manufacturer offers FCVs to the general public except for some limited demonstration programs.[284] Currently, combined EV, PHEV, and FCV sales represent about 0.1% of overall light-duty vehicle sales. Additional models, such as the Ford Focus EV, the Mitsubishi i EV, and the Toyota Prius PHEV, are expected to enter the U.S. market in the next few months.

The agency remains optimistic about consumer acceptance of EVs, PHEVs, and FCVs in the long run, but we believe that near-term market acceptance is less certain. One of the most successful new automotive powertrain technologies—conventional hybrid electric vehicles like the Toyota Prius—illustrates the challenges involved with consumer acceptance of new technologies, even those that do not involve vehicle attribute tradeoffs. Even though conventional hybrids have now been on the U.S. market for over a decade, their market share hovers around 2 to 3 percent or so[285] even though they offer higher vehicle range than their traditional gasoline vehicle counterparts, involve no significant consumer tradeoffs (other than cost), and have reduced their incremental cost to a few thousand dollars. The cost and consumer tradeoffs associated with EVs, PHEVs, and FCVs are more significant than those associated with conventional hybrids. Given the long leadtimes associated with major transportation technology shifts, there is value in promoting these potential game-changing technologies today if we want to retain the possibility of achieving major environmental and energy benefits in the future.

In terms of the relative relationship between tailpipe and upstream fuel production and distribution GHG emissions, EVs, PHEVs, and FCVs are very different than conventional gasoline vehicles. Combining vehicle tailpipe and fuel production/distribution sources, gasoline vehicles emit about 80 percent of these GHG emissions at the vehicle tailpipe with the remaining 20 percent associated with "upstream" fuel production and distribution GHG emissions.[286] On the other hand, vehicles using electricity and hydrogen emit no GHG (or other emissions) at the vehicle tailpipe, and therefore all GHG emissions associated with powering the vehicle are due to fuel production and distribution.[287] Depending on how the electricity and hydrogen fuels are produced, these fuels can have very high fuel production/distribution GHG emissions (for example, if coal is used with no GHG emissions control) or very low GHG emissions (for example, if renewable processes with minimal fossil energy inputs are used, or if carbon capture and sequestration is used). For example, as shown in the Regulatory Impact Analysis, today's Nissan Leaf EV would have an upstream GHG emissions value of 161 grams per mile based on national average electricity, and a value of 89 grams per mile based on the average electricity in California, one of the initial markets for the Leaf.

Because these upstream GHG emissions values are generally higher than the upstream GHG emissions values associated with gasoline vehicles, and because there is currently no national program in place to reduce GHG emissions from electric powerplants, EPA believes it is appropriate to consider the incremental upstream GHG emissions associated with electricity production and distribution. But, we also think it is appropriate to encourage the initial commercialization of EV/PHEV/FCVs as well, in order to retain the potential for game-changing GHG emissions and oil savings in the long term.

Accordingly, EPA proposes to provide temporary regulatory incentives for EVs, PHEVs (when operated on electricity) and FCVs that will be discussed in detail below. EPA recognizes that the use of EVs, PHEVs, and FCVs in the 2017–2025 timeframe, in conjunction with the incentives, will decrease the overall GHG emissions reductions associated with the program as the upstream emissions associated with the generation and distribution of electricity are higher than the upstream emissions associated with production and distribution of gasoline. EPA accounts for this difference in projections of the overall program's impacts and benefits (see Section III.F). EPA believes that the relatively minor impact on GHG emissions reductions in the near term is justified by promoting technologies that have significant transportation GHG emissions and oil consumption game-changing potential in the longer run, and that also face major market barriers in entering a market that has been dominated by gasoline vehicle technology and infrastructure for over 100 years.

EPA will review all of the issues associated with upstream GHG emissions, including the status of EV/PHEV/FCV commercialization, the status of upstream GHG emissions control programs, and other relevant factors.

b. MYs 2012–2016 Light-Duty Vehicle Greenhouse Gas Emissions Standards

The light-duty vehicle greenhouse gas emissions standards for model years 2012–2016 provide a regulatory incentive for electric vehicles (EVs), fuel cell vehicles (FCVs), and for the electric portion of operation of plug-in hybrid

[282] PHEVs and FCVs share many of these same challenges and opportunities.

[283] Smart has also leased approximately 100 Smart ED vehicles in the U.S.

[284] For example, Honda has leased up to 200 Clarity fuel cell vehicles in southern California (see Honda.com) and Toyota has announced plans for a limited fuel cell vehicle introduction in 2015 (see Toyota.com).

[285] Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010, EPA–420–R–10–023, November 2010, *www.epa.gov/otaq/fetrends.htm.*

[286] Fuel production and distribution GHG emissions have received much attention because there is the potential for more widespread commercialization of transportation fuels that have very different GHG emissions characteristics in terms of the relative contribution of GHG emissions from the vehicle tailpipe and those associated with fuel production and distribution. Other GHG emissions source categories include vehicle production, including the raw materials used to manufacture vehicle components, and vehicle disposal. These categories have not been included in EPA motor vehicle emissions regulations for several reasons: These categories are less important from an emissions inventory perspective, they raise complex accounting questions that go well beyond vehicle testing and fuel-cycle analysis, and in general there are fewer differences across technologies.

[287] The Agency notes that many other fuels currently used in light-duty vehicles, such as diesel from conventional oil, ethanol from corn, and compressed natural gas from conventional natural gas, have tailpipe GHG and fuel production/distribution GHG emissions characteristics fairly similar to that of gasoline from conventional oil. See 75 FR at 25437. The Agency recognizes that future transportation fuels may be produced from renewable feedstocks with lower fuel production/distribution GHG emissions than gasoline from oil.

electric vehicles (PHEVs). See generally 75 FR at 25434–438. This is designed to promote advanced technologies that have the potential to provide ''game changing'' GHG emissions reductions in the future. This incentive is a 0 grams per mile compliance value (*i.e.,* a compliance value based on measured vehicle tailpipe GHG emissions) up to a cumulative EV/PHEV/FCV production cap threshold for individual manufacturers. There is a two-tier cumulative EV/PHEV/FCV production cap for MYs 2012–2016: The cap is 300,000 vehicles for those manufacturers that sell at least 25,000 EVs/PHEVs/FCVs in MY 2012, and the cap is 200,000 vehicles for all other manufacturers. For manufacturers that exceed the cumulative production cap over MYs 2012–2016, compliance values for those vehicles in excess of the cap will be based on a full accounting of the net fuel production and distribution GHG emissions associated with those vehicles relative to the fuel production and distribution GHG emissions associated with comparable gasoline vehicles. For an electric vehicle, this accounting is based on the vehicle electricity consumption over the EPA compliance tests, eGRID2007 national average powerplant GHG emissions factors, and multiplicative factors to account for electricity grid transmission losses and pre-powerplant feedstock GHG related emissions.[288] The accounting for a hydrogen fuel cell vehicle would be done in a comparable manner.

Although EPA also proposed a vehicle incentive multiplier for MYs 2012–2016, the agency did not finalize a multiplier. At that time, the Agency believed that combining the 0 gram per mile and multiplier incentives would be excessive.

The 0 grams per mile compliance value decreases the GHG emissions reductions associated with the 2012–2016 standards compared to the same standards and no 0 grams per mile compliance value. It is impossible to know the precise number of vehicles that will take advantage of this incentive in MYs 2012–2016. In the preamble to the final rule, EPA projected the decrease in GHG emissions reductions that would be associated with a scenario of 500,000 EVs certified with a compliance value of 0 grams per mile. This scenario would result in a projected decrease of 25 million metric tons of GHG emissions reductions, or less than 3 percent of the total projected GHG benefits of the program of 962 million metric tons. This GHG emissions impact could be smaller or larger, of course, based on the actual number of EVs that would certify at 0 grams per mile.

In the preamble to the final rule, EPA stated that it would reassess this issue for rulemakings beginning in MY 2017 based on the status of advanced vehicle technology commercialization, the status of upstream GHG control programs, and other relevant factors.

c. Supplemental Notice of Intent

In our most recent Supplemental Notice of Intent,[289] EPA stated that: ''EPA intends to propose an incentive multiplier for all electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) sold in MYs 2017 through 2021. This multiplier approach means that each EV/PHEV/FCV would count as more than one vehicle in the manufacturer's compliance calculation. EPA intends to propose that EVs and FCVs start with a multiplier value of 2.0 in MY 2017, phasing down to a value of 1.5 in MY 2021. PHEVs would start at a multiplier value of 1.6 in MY 2017 and phase down to a value of 1.3 in MY 2021. These multipliers would be proposed for incorporation in EPA's GHG program * * *. As an additional incentive for EVs, PHEVs and FCVs, EPA intends to propose allowing a value of 0 g/mile for the tailpipe compliance value for EVs, PHEVs (electricity usage) and FCVs for MYs 2017–2021, with no limit on the quantity of vehicles eligible for 0 g/mi tailpipe emissions accounting. For MYs 2022–2025, 0 g/mi will only be allowed up to a per-company cumulative sales cap based on significant penetration of these advanced vehicles in the marketplace. EPA intends to propose an appropriate cap in the NPRM.''

d. Proposal for MYs 2017–2025

EPA is proposing the following temporary regulatory incentives for EVs, PHEVs, and FCVs consistent with the discussion in the August 2011 Supplemental Notice of Intent.

For MYs 2017 through 2021, EPA is proposing two incentives. The first proposed incentive is to allow all EVs, PHEVs (electric operation), and FCVs to use a GHG emissions compliance value of 0 grams per mile. There would be no cap on the number of vehicles eligible for the 0 grams per mile compliance value for MYs 2017 through 2021.

The second proposed incentive for MYs 2017 through 2021 is a multiplier for all EVs, PHEVs, and FCVs, which would allow each of these vehicles to ''count'' as more than one vehicle in the manufacturer's compliance calculation.[290] While the Agency rejected a multiplier incentive in the MYs 2012–2016 final rule, we are proposing a multiplier for MYs 2017–2021 because, while advanced technologies were not necessary for compliance in MYs 2012–2016, they are necessary, for some manufacturers, to comply with the GHG standards in the MYs 2022–2025 timeframe. A multiplier for MYs 2017–2021 can also promote the initial commercialization of these advanced technologies. In order for a PHEV to be eligible for the multiplier incentive, EPA proposes that PHEVs be required to be able to complete a full EPA highway test (10.2 miles), without using any conventional fuel, or alternatively, have a minimum equivalent all-electric range of 10.2 miles as measured on the EPA highway cycle. EPA seeks comment on whether this minimum range (all-electric or equivalent all-electric) should be lower or higher, or whether the multiplier should vary based on range or on another PHEV metric such as battery capacity or ratio of electric motor power to engine or total vehicle power. The specific proposed multipliers are shown in Table III–15.

[288] See 40 CFR 600.113–12(m).

[289] 76 **Federal Register** 48758 (August 9, 2011).

[290] In the unlikely case where a PHEV with a low electric range might have an overall GHG emissions compliance value that is higher than its compliance target, EPA proposes that the automaker can choose not to use the multiplier.

Table III-15 Proposed EV, FCV, and PHEV Per-Vehicle Multiplier Incentives for MY 2017-2021

Model Year(s)	EVs and FCVs	PHEVs
2017-2019	2.0	1.6
2020	1.75	1.45
2021	1.5	1.3

EPA also requests comments on the merits of providing similar multiplier incentives to dedicated and/or dual fuel compressed natural gas vehicles.

For MYs 2022 through 2025, EPA is proposing one incentive—the 0 grams per mile GHG emissions compliance incentive for EVs, PHEVs (electric operation), and FCVs up to a per-company cumulative production cap threshold for those model years. EPA is proposing a two-tier, per-company cap based on cumulative production in prior years, consistent with the general approach that was adopted in the rulemaking for MYs 2012–2016. For manufacturers that sell 300,000 or more EV/PHEV/FCVs combined in MYs 2019–2021, the proposed cumulative production cap would be 600,000 EV/PHEV/FCVs for MYs 2022–2025. Other automakers would have a proposed cumulative production cap of 200,000 EV/PHEV/FCVs in MYs 2022–2025.

This proposed cap design is appropriate as a way to encourage automaker investment in potential GHG emissions game-changing technologies that face very significant cost and consumer barriers. In addition, as with the rulemaking for MYs 2012–2016, EPA believes it is important to both recognize the benefit of early leadership in commercialization of these technologies, and encourage additional manufacturers to invest over time. Manufacturers are unlikely to do so if vehicles with these technologies are treated for compliance purposes to be no more advantageous than the best conventional hybrid vehicles. Finally, we believe that the proposed cap design provides a reasonable limit to the overall decrease in program GHG emissions reductions associated with the incentives, and EPA is being transparent about these GHG emissions impacts (see later in this section and also Section III.F).

EPA recognizes that a central tension in the design of a proposed cap relates to certainty and uncertainty with respect to both individual automaker caps and the overall number of vehicles that may fall under the cap, which determines the overall decrease in GHG emissions reductions. A per-company cap as described above would provide clear certainty for individual manufacturers at the time of the final rule, but would yield uncertainty about how many vehicles industry-wide would take advantage of the 0 grams per mile incentive and therefore the overall impact on GHG emissions. An alternative approach would be an industry-wide cap where EPA would establish a finite limit on the total number of vehicles eligible for the 0 grams per mile incentive, with a method for allocating this industry-wide cap to individual automakers. An industry-wide cap would provide certainty with respect to the maximum number of vehicles and GHG emissions impact and would reward those automakers who show early leadership. If EPA were to make a specific numerical allocation at the time of the final rule, automakers would have certainty, but EPA is concerned that we may not have sufficient information to make an equitable allocation for a timeframe that is over a decade away. If EPA were to adopt an allocation formula in the final rule that was dependent on future sales (as we are proposing above for the per-company cap), automakers would have much less certainty in compliance planning as they would not know their individual caps until some point in the future.

To further assess the merits of an industry-wide cap approach, EPA also seeks comment on the following alternative for an industry-wide cap. EPA would place an industry-wide cumulative production cap of 2 million EV/PHEV/FCVs eligible for the 0 grams per mile incentive in MYs 2022–2025. EPA has chosen 2 million vehicles because, as shown below, we project that this limits the maximum decrease in GHG emissions reductions to about 5 percent of total program GHG savings. EPA would allocate this 2 million vehicle cap to individual automakers in calendar year 2022 based on cumulative EV/PHEV/FCV sales in MYs 2019–2021, *i.e.,* if an automaker sold X percent of industry-wide EV/PHEV/FCV sales in MYs 2019–2021, that automaker would get X percent of the 2 million industry-wide cumulative production cap in MYs 2022–2025 (or possibly somewhat less than X percent, if EPA were to reserve some small volumes for those automakers that sold zero EV/PHEV/FCVs in MYs 2019–2021).

For both the proposed per-company cap and the alternative industry-wide cap, EPA proposes that, for production beyond the cumulative vehicle production cap for a given manufacturer in MY 2022 and later, compliance values would be calculated according to a methodology that accounts for the full net increase in upstream GHG emissions relative to that of a comparable gasoline vehicle. EPA also asks for comment on various approaches for phasing in from a 0 gram per mile value to a full net increase value, *e.g.,* an interim period when the compliance value might be one-half of the net increase.

EPA also seeks comments on whether any changes should be made for MYs 2012–2016, *i.e.,* whether the compliance value for production beyond the cap should be one-half of the net increase in upstream GHG emissions, or whether the current cap for MYs 2012–2016 should be removed.

EPA is not proposing any multiplier incentives for MYs 2022 through 2025. EPA believes that the 0 gram per mile compliance value, with cumulative vehicle production cap, is a sufficient incentive for MYs 2022–2025.

One key issue here is the appropriate electricity upstream GHG emissions factor or rate to use in future projections of EV/PHEV emissions based on the net upstream approach. In the following example, we use a 2025 nationwide average electricity upstream GHG emissions rate (powerplant plus feedstock extraction, transportation, and processing) of 0.574 grams GHG/watt-hour, based on simulations with the EPA Office of Atmospheric Program's Integrated Planning Model (IPM).[291] For the example below, EPA is using a projected national average value from the IPM model, but EPA recognizes that values appropriate for future vehicle use may be higher or lower than this value. EPA is considering running the IPM model with a more robust set of vehicle and vehicle charging-specific assumptions to generate a better electricity upstream GHG emissions factor for EVs and PHEVs for our final rulemaking, and, at minimum, intends to account for the likely regional sales variation for initial EV/PHEV/FCVs, and different scenarios for the relative frequency of daytime and nighttime charging. EPA seeks comment on whether there are additional factors that we should try to include in the IPM modeling for the final rulemaking.

EPA proposes a 4-step methodology for calculating the GHG emissions compliance value for vehicle production in excess of the cumulative production cap for an individual automaker. For example, for an EV in MY 2025, this methodology would include the following steps and calculations:

Measuring the vehicle electricity consumption in watt-hours/mile over the EPA city and highway tests (for example, a midsize EV in 2025 might have a 2-cycle test electricity consumption of 230 watt-hours/mile)

Adjusting this watt-hours/mile value upward to account for electricity losses during electricity transmission (dividing 230 watt-hours/mile by 0.93 to account for grid/transmission losses yields a value of 247 watt-hours/mile)

Multiplying the adjusted watt-hours/mile value by a 2025 nationwide average electricity upstream GHG emissions rate of 0.574 grams/watt-hour at the powerplant (247 watt-hours/mile multiplied by 0.574 grams GHG/watt-hour yields 142 grams/mile)

Subtracting the upstream GHG emissions of a comparable midsize gasoline vehicle of 39 grams/mile[292] to reflect a full net increase in upstream GHG emissions (142 grams/mile for the EV minus 39 grams/mile for the gasoline vehicle yields a net increase and EV compliance value of 103 grams/mile).[293]

The full accounting methodology for FCVs and the portion of PHEV operation on grid electricity would use this same approach. The proposed regulations contain EPA's proposed method to determine the compliance value for PHEVs, and EPA proposes to develop a similar methodology for FCVs if and when the need arises.[294] Given the uncertainty about how hydrogen would be produced, if and when it were used as a transportation fuel, EPA seeks comment on projections for the fuel production and distribution GHG emissions associated with hydrogen production for various feedstocks and processes.

EPA is fully accounting for the upstream GHG emissions associated with all electricity used by EVs and PHEVs (and any hydrogen used by FCVs), both in our regulatory projections of the impacts and benefits of the program, and in all GHG emissions inventory accounting.

EPA seeks public comment on the proposed incentives for EVs, PHEVs, and FCVs described above.

e. Projection of Impact on GHG Emissions Reductions Due to Incentives

EPA believes it is important to project the impact on GHG emissions that will be associated with the proposed incentives (both 0 grams per mile and the multiplier) for EV/PHEV/FCVs over the MYs 2017–2025 timeframe. Since it is impossible to know precisely how many EV/PHEV/FCVs will be sold in the MYs 2017–2025 timeframe that will utilize the proposed incentives, EPA presents projections for two scenarios: (1) The number of EV/PHEV/FCVs that EPA's OMEGA technology and cost model predicts based exclusively on its projections for the most cost-effective way for the industry to meet the proposed standards, and (2) a scenario with a greater number of EV/PHEV/FCVs, based not only on compliance with the proposed GHG and CAFE standards, but other factors such as the proposed cumulative production caps and manufacturer investments. For this analysis, EPA assumes that EVs and PHEVs each account for 50 percent of all EV/PHEV/FCVs. EPA seeks comment on whether there are other scenarios which should be evaluated for this purpose in the final rule.

[291] Technical Support Document, Chapter 4.

[292] A midsize gasoline vehicle with a footprint of 46 square feet would have a MY 2025 GHG target of about 140 grams/mile; dividing 8887 grams CO_2/gallon of gasoline by 140 grams/mile yields an equivalent fuel economy level of 63.5 mpg; and dividing 2478 grams upstream GHG/gallon of gasoline by 63.5 mpg yields a midsize gasoline vehicle upstream GHG value of 39 grams/mile. The 2478 grams upstream GHG/gallon of gasoline is calculated from 21,546 grams upstream GHG/million Btu (EPA value for future gasoline based on DOE's GREET model modified by EPA standards and data; see docket memo to MY 2012–2016 rulemaking titled "Calculation of Upstream Emissions for the GHG Vehicle Rule") and multiplying by 0.115 million Btu/gallon of gasoline.

[293] Manufacturers can utilize alternate calculation methodologies if shown to yield equivalent or superior results and if approved in advance by the Administrator.

[294] 40 CFR 600.113–12(m).

Table III-16 Projected Impact of EV/PHEV/FCV Incentives on GHG Emissions Reductions

Scenario	Cumulative EV/PHEV/FCV Sales 2017-2025	Cumulative EV/PHEV/FCV Sales 2022-2025	Cumulative Decrease in GHG Emissions Reductions 2017-2025[295]	Percentage Decrease in GHG Emissions Reductions 2017-2025[296]
EPA OMEGA model projection	1.9 million	1.3 million	80 million metric tons	3.6%
EPA alternative projection	2.8 million	2.0 million	110 million metric tons	5.4%

EPA projects that the cumulative GHG emissions savings of the proposed MYs 2017–2025 standards, on a model year lifetime basis, is approximately 2 billion metric tons. Table III–16 projects that the likely decrease in cumulative GHG emissions reductions due to the EV/PHEV/FCV incentives for MYs 2017–2025 vehicles is in the range of 80 to 110 million metric tons, or about 4 to 5 percent.

It is important to note that the above projection of the impact of the EV/PHEV/FCV incentives on the overall program GHG emissions reductions assumes that there would be no change to the standard even if the EV 0 gram per mile incentive were not in effect, *i.e.,* that EPA would propose exactly the same standard if the 0 gram per mile compliance value were not allowed for any EV/PHEV/FCVs. While EPA has not analyzed such a scenario, it is clear that not allowing a 0 gram per mile compliance value would change the technology mix and cost projected for the proposed standard.

It is also important to note that the projected impact on GHG emissions reductions in the above table are based on the 2025 nationwide average electricity upstream GHG emissions rate (powerplant plus feedstock) of 0.574 grams GHG/watt-hour discussed above (based on simulations with the EPA's Integrated Planning Model (IPM) for powerplants in 2025, and a 1.06 factor to account for feedstock-related GHG emissions).

EPA recognizes two factors which could significantly reduce the electricity upstream GHG emissions factor by calendar year 2025. First, there is a likelihood that early EV/PHEV/FCV sales will be much more concentrated in parts of the country with lower electricity GHG emissions rates and much less concentrated in regions with higher electricity GHG emissions rates. This has been the case with sales of hybrid vehicles, and is likely to be more so with EVs in particular. Second, there is the possibility of a future comprehensive program addressing upstream emissions of GHGs from the generation of electricity. Other factors which could also help in this regard include technology innovation and lower prices for some powerplant fuels such as natural gas.

On the other hand, EPA also recognizes factors which could increase the appropriate electricity upstream GHG emissions factor in the future, such as a consideration of marginal electricity demand rather than average demand and use of high-power charging. The possibility that EVs won't displace gasoline vehicle use on a 1:1 basis (*i.e.,* multi-vehicle households may use EVs for more shorter trips and fewer longer trips, which could lead to lower overall travel for typical EVs and higher overall travel for gasoline vehicles) could also reduce the overall GHG emissions benefits of EVs.

EPA seeks comment on information relevant to these and other factors which could both decrease or increase the proper electricity upstream GHG emissions factor for calendar year 2025 modeling.

[295] The number of metric tons represents the number of additional tons that would be reduced if the standards stayed the same and there was no 0 gram per mile compliance value.

[296] The percentage change represents the ratio of the cumulative decrease in GHG emissions reductions from the prior column to the total cumulative GHG emissions reductions associated with the proposed standards and the proposed 0 gram per mile compliance value.

3. Incentives for ''Game-Changing'' Technologies Including Use of Hybridization and Other Advanced Technologies for Full-Size Pickup Trucks

As explained in section II. C above, the agencies recognize that the standards under consideration for MY 2017–2025 will be challenging for large trucks, including full size pickup trucks that are often used for commercial purposes and have generally higher payload and towing capabilities, and cargo volumes than other light-duty vehicles. In Section II.C and Chapter 2 of the joint TSD, EPA and NHTSA describe how the slope of the truck curve has been adjusted compared to the 2012–2016 rule to reflect these disproportionate challenges. In Section III.B, EPA describes the progression of the truck standards. In this section, EPA describes a proposed incentive for full size pickup trucks, proposed by EPA under both section 202 (a) of the CAA and section 32904 (c) of EPCA, to incentivize advanced technologies on this class of vehicles. This incentive would be in the form of credits under the EPA GHG program, and fuel consumption improvement values (equivalent to EPA's credits) under the CAFE program.

The agencies' goal is to incentivize the penetration into the marketplace of ''game changing'' technologies for these pickups, including their hybridization. For that reason, EPA is proposing credits for manufacturers that hybridize a significant quantity of their full size pickup trucks, or use other technologies that significantly reduce CO_2 emissions and fuel consumption. This proposed credit would be available on a per-vehicle basis for mild and strong HEVs, as well as for use of other technologies that significantly improve the efficiency of the full sized pickup class. As described in section II.F. and III.B.10, EPA, in coordination with NHTSA, is also proposing that manufacturers be able to include ''fuel consumption improvement values'' equivalent to EPA CO_2 credits in the CAFE program. The gallon per mile values equivalent to EPA proposed CO_2 credits are also provided below, in addition to the proposed CO_2 credits.[297] These credits and fuel consumption improvement values provide the incentive to begin transforming this challenged category of vehicles toward use of the most advanced technologies.

Access to this credit is conditioned on a minimum penetration of the technologies in a manufacturer's full size pickup truck fleet. The proposed penetration rates can be found in Table 5–26 in the TSD. EPA is seeking comment on these penetration rates and how they should be applied to a manufacturer's truck fleet.

To ensure its use for only full sized pickup trucks, EPA is proposing a specific definition for a full sized pickup truck based on minimum bed size and minimum towing capability. The specifics of this proposed definition can be found in Chapter 5 of the draft joint TSD (see Section 5.3.1) and in the draft regulations at 86.1866–12(e). This proposed definition is meant to ensure that the larger pickup trucks which provide significant utility with respect to payload and towing capacity as well as open beds with large cargo capacity are captured by the definition, while smaller pickup trucks which have more limited hauling, payload and/or towing are not covered by the proposed definition. For this proposal, a full sized pickup truck would be defined as meeting requirements 1 and 2, below, as well as either requirement 3 or 4, below:

1. The vehicle must have an open cargo box with a minimum width between the wheelhouses of 48 inches measured as the minimum lateral distance between the limiting interferences (pass-through) of the wheelhouses. The measurement would exclude the transitional arc, local protrusions, and depressions or pockets, if present.[298] An open cargo box means a vehicle where the cargo bed does not have a permanent roof or cover. Vehicles sold with detachable covers are considered ''open'' for the purposes of these criteria.

2. Minimum open cargo box length of 60 inches defined by the lesser of the pickup bed length at the top of the body (defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate; this would be measured at the height of the top of the open pickup bed along vehicle centerline and the pickup bed length at the floor) and the pickup bed length at the floor (defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate; this would be measured at the cargo floor surface along vehicle centerline).[299]

3. Minimum Towing Capability—the vehicle must have a GCWR (gross combined weight rating) minus GVWR (gross vehicle weight rating) value of at least 5,000 pounds.[300]

4. Minimum Payload Capability—the vehicle must have a GVWR (gross vehicle weight rating) minus curb weight value of at least 1,700 pounds.

As discussed above, this proposed definition is intend to cover the larger pickup trucks sold in the U.S. today (and for 2017 and later) which have the unique attributes of an open bed, and larger towing and/or payload capacity. This proposed incentive will encourage the penetration of advanced, low CO_2 technologies into this market segment. The proposed definition would exclude a number of smaller-size pickup trucks sold in the U.S. today (examples are the Dodge Dakota, Nissan Frontier, Chevrolet Colorado, Toyota Tacoma and Ford Ranger). These vehicles generally have smaller boxes (and thus smaller cargo capacity), and lower payload and towing ratings. EPA is aware that some configurations of these smaller pickups trucks can offer towing capacity similar to the larger pickups. As discussed in the draft Joint TSD Section 5.3.1, EPA is seeking comment on expanding the scope of this credit to somewhat smaller pickups (with a minimum distance between the wheel wells of 42 inches, but still with a minimum box length of 60 inches), provided they have the towing capabilities of the larger full-size trucks (for example a minimum towing capacity of 6,000 pounds). EPA believes this could incentivize advanced technologies (such as HEVs) on pickups which offer some of the utility of the larger vehicles, but overall have lower CO_2 emissions due to the much lighter mass of the vehicle. Providing an advanced technology incentive credit for a vehicle which offers consumers much of the utility of a larger pickup truck but with overall lower CO_2 performance would promote the overall objective of the proposed standards.

[297] Note that EPA's proposed calculation methodology in 40 CFR 600.510–12 does not use vehicle-specific fuel consumption adjustments to determine the CAFE increase due to the various incentives allowed under the proposed program. Instead, EPA would convert the total CO_2 credits due to each incentive program from metric tons of CO_2 to a fleetwide CAFE improvement value. The fuel consumption values are presented to give the reader some context and explain the relationship between CO_2 and fuel consumption improvements.

[298] This dimension is also known as dimension W202 as defined in Society of Automotive Engineers Procedure J1100.

[299] The pickup body length at the top of the body is also known as dimension L506 in Society of Automotive Engineers Procedure J1100. The pickup body length at the floor is also known as dimension L505 in Society of Automotive Engineers Procedure J1100.

[300] Gross combined weight rating means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment. Gross vehicle weight rating means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment. Curb weight is defined in 40 CFR 86.1803, consistent with the provisions of 40 CFR 1037.140.

EPA proposes that mild HEV pickup trucks would be eligible for a per-truck 10 g/mi CO_2 credit (equal to 0.0011 gal/mi for a 25 mpg truck) during MYs 2017–2021 if the mild HEV technology is used on a minimum percentage of a company's full sized pickups. That minimum percentage would be 30 percent of a company's full sized pickup production in MY 2017 with a ramp up to at least 80 percent of production in MY 2021.

EPA is also proposing that strong HEV pickup trucks would be eligible for a per-truck 20 g/mi CO_2 credit (equal to 0.0023 gal/mi for a 25 mpg truck) during MYs 2017–2025 if the strong HEV technology is used on a minimum percentage of a company's full sized pickups. That minimum percentage would be 10 percent of a company's full sized pickup production in each year over the model years 2017–2025.

To ensure that the hybridization technology used by manufacturers seeking one of these credits meets the intent behind the incentives, EPA is proposing very specific definitions of what qualifies as a mild and a strong HEV for these purposes. These definitions are described in detail in Chapter 5 of the draft joint TSD (see section 5.3.3).

Because there are other technologies besides mild and strong hybrids which can significantly reduce GHG emissions and fuel consumption in pickup trucks, EPA is also proposing performance-based incentive credits, and equivalent fuel consumption improvement values for CAFE, for full size pickup trucks that achieve an emission level significantly below the applicable CO_2 target.[301] EPA proposes that this credit be either 10 g/mi CO_2 (equivalent to 0.0011 gal/mi for the CAFE program) or 20 g/mi CO_2 (equivalent to 0.0023 gal/mi for the CAFE program) for pickups achieving 15 percent or 20 percent, respectively, better CO_2 than their footprint based target in a given model year. Because the footprint target curve has been adjusted to account for A/C related credits, the CO_2 level to be compared with the target would also include any A/C related credits generated by the vehicles. EPA provides further details on this performance-based incentive in Chapter 5 of the draft joint TSD (see Section 5.3). The 10 g/mi (equivalent to 0.0011 gal/mi) performance-based credit would be available for MYs 2017 to 2021 and a vehicle meeting the requirements would receive the credit until MY 2021 unless its CO_2 level or fuel consumption increases. The 10 g/mi credit is not available after 2021 because the post-2021 standards quickly overtake a 15% overcompliance. Earlier in the program, an overcompliance lasts for more years, making the credit/value appropriate for a longer period. The 20 g/mi CO_2 (equivalent to 0.0023 gal/mi) performance-based credit would be available for a maximum of 5 consecutive years within the model years of 2017 to 2025 after it is first eligible, provided its CO_2 level and fuel consumption does not increase. Subsequent redesigns can qualify for the credit again. The credits would begin in the model year of introduction, and (as noted) could not extend past MY 2021 for the 10 g/mi credit (equivalent to 0.0011 gal/mi) and MY 2025 for the 20 g/mi credit (equivalent to 0.0023 gal/mi).

As with the HEV-based credit, the performance-based credit/value requires that the technology be used on a minimum percentage of a manufacturer's full-size pickup trucks. That minimum percentage for the 10 g/mi GHG credit (equivalent to 0.0011 gal/mi fuel consumption improvement value) would be 15 percent of a company's full sized pickup production in MY 2017 with a ramp up to at least 40 percent of production in MY 2021. The minimum percentage for the 20 g/mi credit (equivalent to 0.0011 gal/mi fuel consumption improvement value) would be 10 percent of a company's full sized pickup production in each year over the model years 2017–2025. These minimum percentages are set to encourage significant penetration of these technologies, leading to long-term market acceptance.

Importantly, the same vehicle could not receive credits (or equivalent fuel consumption improvement values) under both the HEV and the performance-based approaches. EPA requests comment on all aspects of this proposed pickup truck incentive credit, including the proposed definitions for full sized pickup truck and mild and strong HEV.

[301] The 15 and 20 percent thresholds would be based on CO_2 performance compared to the applicable CO_2 vehicle footprint target for both CO_2 credits and corresponding CAFE fuel consumption improvement values. As with A/C and off-cycle credits, EPA would convert the total CO_2 credits due to the pick-up incentive program from metric tons of CO_2 to a fleetwide equivalent CAFE improvement value.

4. Treatment of Plug-in Hybrid Electric Vehicles, Dual Fuel Compressed Natural Gas Vehicles, and Ethanol Flexible Fuel Vehicles for GHG Emissions Compliance

a. Greenhouse Gas Emissions

i. Introduction

This section addresses proposed approaches for determining the compliance values for greenhouse gas (GHG) emissions for those vehicles that can use two different fuels, typically referred to as dual fuel vehicles under the CAFE program. Three specific technologies are addressed: Plug-in hybrid electric vehicles (PHEVs), dual fuel compressed natural gas (CNG) vehicles, and ethanol flexible fuel vehicles (FFVs).[302] EPA's underlying principle is to base compliance values on demonstrated vehicle tailpipe CO_2 emissions performance. The key issue with vehicles that can use more than one fuel is how to weight the operation (and therefore GHG emissions performance) on the two different fuels. EPA proposes to do this on a technology-by-technology basis, and the sections below will explain the rationale for choosing a particular approach for each vehicle technology.

EPA is proposing no changes to the tailpipe GHG emissions compliance approach for dedicated vehicles, *i.e.,* those vehicles that can use only one fuel. As finalized for MY 2016 and later vehicles in the 2012–2016 rule, tailpipe CO_2 emissions compliance levels are those values measured over the EPA 2-cycle city/highway tests.[303] EPA is proposing provisions for how and when to also account for the upstream fuel production and distribution related GHG emissions associated with electric vehicles, fuel cell vehicles, and the electric portion of plug-in hybrid electric vehicles, and these provisions are discussed in Section III.C.2 above.

ii. Plug-In Hybrid Electric Vehicles

PHEVs can operate both on an on-board battery that can be charged by wall electricity from the grid, and on a conventional liquid fuel such as gasoline. Depending on how these vehicles are fueled and operated, PHEVs

[302] EPA recognizes that other vehicle technologies may be introduced in the future that can use two (or more) fuels. For example, the original FFVs were designed for up to 85% methanol/15% gasoline, rather than the 85% ethanol/15% gasoline for which current FFVs are designed. EPA has regulations that address methanol vehicles (both FFVs and dedicated vehicles), and, for GHG emissions compliance in MYs 2017–2025, EPA is proposing to treat methanol vehicles in the same way as ethanol vehicles.

[303] For dedicated alternative fuel vehicles. See 75 at FR 25434.

could operate exclusively on grid electricity, exclusively on the conventional fuel, or any combination of both fuels. EPA can determine the CO_2 emissions performance when operated on the battery and on the conventional fuel. But, in order to generate a single CO_2 emissions compliance value, EPA must adopt an approach for determining the appropriate weighting of the CO_2 emissions performance on grid electricity and the CO_2 emissions performance on gasoline.

EPA is proposing no changes to the Society of Automotive Engineers (SAE) cycle-specific utility factor approach for PHEV compliance and label emissions calculations first adopted by EPA in the joint EPA/DOT final rulemaking establishing new fuel economy and environment label requirements for MY 2013 and later vehicles.[304] This utility factor approach is based on several key assumptions. One, PHEVs are designed such that the first mode of operation is all-electric drive or electric assist. Every PHEV design with which EPA is familiar is consistent with this assumption. Two, PHEVs will be charged once per day. While this critical assumption is unlikely to be met by every PHEV driver every day, EPA believes that a large majority of PHEV owners will be highly motivated to re-charge as frequently as possible, both because the owner has paid a considerably higher initial vehicle cost to be able to operate on grid electricity, and because electricity is considerably cheaper, on a per mile basis, than gasoline. Three, it is reasonable to assume that future PHEV drivers will retain driving profiles similar to those of past drivers on which the utility factors were based. More detailed information on the development of this utility factor approach can be obtained from the Society of Automotive Engineers.[305] EPA will continue to reevaluate the appropriateness of these assumptions over time.

Based on this approach, and PHEV-specific specifications such as all-electric drive or equivalent all-electric range, the cycle-specific utility factor methodology yields PHEV-specific values for projected average percent of operation on grid electricity and average percent of operation on gasoline over both the city and highway test cycles. For example, the Chevrolet Volt PHEV, the only original equipment manufacturer (OEM) PHEV in the U.S. market today, which has an all-electric range of 35 miles on EPA's fuel economy label, has city and highway cycle utility factors of about 0.65, meaning that the average Volt driver is projected to drive about 65 percent of the miles on grid electricity and about 35 percent of the miles on gasoline. Each PHEV will have its own utility factor.

Based on this utility factor approach, EPA calculates the GHG emissions compliance value for an individual PHEV as the sum of (1) the GHG emissions value for electric operation (either 0 grams per mile or a non-zero value reflecting the net upstream GHG emissions accounting depending on whether automaker EV/PHEV/FCV production is below or above its cumulative production cap as discussed in Section III.C.2 above) multiplied by the utility factor, and (2) the tailpipe CO_2 emissions value on gasoline multiplied by (1 minus the utility factor).

iii. Dual Fuel Compressed Natural Gas Vehicles

Dual fuel CNG vehicles operate on either compressed natural gas or gasoline, but not both at the same time, and have separate tanks for the two fuels.[306] There are no OEM dual fuel CNG vehicles in the U.S. market today, but some manufacturers have expressed interest in bringing them to market during the rulemaking time frame. Under current EPA regulations through MY 2015, GHG emissions compliance values for dual fuel CNG vehicles are based on a methodology that provides significant GHG emissions incentives equivalent to the ''CAFE credit'' approach for dual and flexible fuel vehicles. For MY 2016, current EPA regulations utilize a methodology based on demonstrated vehicle emissions performance and real world fuels usage, similar to that for ethanol flexible fuel vehicles discussed below.

EPA proposes to develop a new approach for dual fuel CNG vehicle GHG emissions compliance that is very similar to the utility factor approach developed and described above for PHEVs, and for this new approach to take effect with MY 2016. As with PHEVs, EPA believes that owners of dual fuel CNG vehicles will preferentially seek to refuel and operate on CNG fuel as much as possible, both because the owner paid a much higher price for the dual fuel capability, and because CNG fuel is considerably cheaper than gasoline on a per mile basis. EPA notes that there are some relevant differences between dual fuel CNG vehicles and PHEVs, and some of these differences might weaken the case for using utility factors for dual fuel CNG vehicles. For example, a dual fuel CNG vehicle might be able to run on gasoline when both fuels are available on board (depending on how the vehicle is designed), it may be much more inconvenient for some private dual fuel CNG vehicle owners to fuel every day relative to PHEVs, and there are many fewer CNG refueling stations than electrical charging facilities.[307] On the other hand, there are differences that could strengthen the case as well, *e.g.,* many dual fuel CNG vehicles will likely have smaller gasoline tanks given the expectation that gasoline will be used only as an ''emergency'' fuel, and it may be easier for a dual fuel CNG vehicle to be refueled during the day than a PHEV (which is most conveniently refueled at night with a home charging unit).

Taking all these considerations into account, EPA believes that the merit of using a utility factor-based approach for dual fuel CNG vehicles is similar to that of doing so for PHEVs, and we propose to develop a similar methodology for dual fuel CNG vehicles. For example, applying the current SAE fleet utility factor approach developed for PHEVs to a dual fuel CNG vehicle with a 150-mile CNG range would result in a compliance assumption of about 95 percent operation on CNG and about 5 percent operation on gasoline.[308] EPA is proposing to directly extend the PHEV utility factor methodology to dual fuel CNG vehicles, using the same assumptions about daily refueling. EPA invites comment on this proposal, including the appropriateness of the assumptions described above for dual fuel CNG vehicles.

Further, for MYs 2012–2015, EPA is also proposing to allow the option, at the manufacturer's discretion, to use the proposed utility factor-based methodology for MYs 2016–2025 discussed above. The rationale for providing this option is that some manufacturers are likely to reach the maximum allowable GHG emissions credits (based on the statutory CAFE credits) through their production of

[304] 76 FR 39504–39505 (July 6, 2011) and 40 CFR 600.116–12(b).

[305] *http://www.SAE.org*, specifically SAE J2841 ''Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data,'' September 2010.

[306] EPA considers ''bi-fuel'' CNG vehicles to be those vehicles that can operate on a mixture of CNG and gasoline. Bi-fuel vehicles would not be eligible for this treatment, since they are not designed to allow the use of CNG only.

[307] EPA assumes that most PHEV owners will charge at home with electrical charging equipment that they purchase and install for their own use.

[308] See SAE J2841 ''Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data,'' September 2010, available at *http://www.SAE.org*, which we are proposing to use for dual fuel CNG vehicles as well.

ethanol FFVs, and therefore would not be able to gain any GHG emissions compliance benefit even if they produced dual fuel CNG vehicles that demonstrated superior GHG emissions performance.

In determining eligibility for the utility factor approach, EPA may consider placing additional constraints on the designs of dual fuel CNG vehicles to maximize the likelihood that consumers will routinely seek to use CNG fuel. Options include, but are not limited to, placing a minimum value on CNG tank size or CNG range, a maximum value on gasoline tank size or gasoline range, a minimum ratio of CNG-to-gasoline range, and requiring an onboard control system so that a dual fuel CNG vehicle is only able to access the gasoline fuel tank if the CNG tank is empty. EPA seeks comments on the merits of these additional eligibility constraints for dual fuel CNG vehicles.

iv. Ethanol Flexible Fuel Vehicles

Ethanol FFVs can operate on E85 (a blend of 15 percent gasoline and 85 percent ethanol, by volume), gasoline, or any blend of the two. There are many ethanol FFVs in the market today.

In the final rulemaking for MY 2012–2016, EPA promulgated regulations for MYs 2012–2015 ethanol FFVs that provided significant GHG emissions incentives equivalent to the long-standing ''CAFE credits'' for ethanol FFVs under EPCA, since many manufacturers had relied on the availability of these credits in developing their compliance strategies.[309] Beginning in MY 2016, EPA ended the GHG emissions compliance incentives and adopted a methodology based on demonstrated vehicle emissions performance. This methodology established a default value assumption where ethanol FFVs are operated 100 percent of the time on gasoline, but allows manufacturers to use a relative E85 and gasoline vehicle emissions performance weighting based either on national average E85 and gasoline sales data, or manufacturer-specific data showing the percentage of miles that are driven on E85 vis-à-vis gasoline for that manufacturer's ethanol FFVs.[310] EPA is not proposing any changes to this methodology for MYs 2017–2025.

EPA believes there is a compelling rationale for not adopting a utility factor-based approach, as discussed above for PHEVs and dual fuel CNG vehicles, for ethanol FFVs. Unlike with PHEVs and dual fuel CNG vehicles, owners of ethanol FFVs do not pay any more for the E85 fueling capability. Unlike with PHEVs and dual fuel CNG vehicles, operation on E85 is not cheaper than gasoline on a per mile basis, it is typically the same or somewhat more expensive to operate on E85. Accordingly, there is no direct economic motivation for the owner of ethanol FFVs to seek E85 refueling, and in some cases there is an economic disincentive. Because E85 has a lower energy content per gallon than gasoline, an ethanol FFV will have a lower range on E85 than on gasoline, which provides an additional disincentive. The data confirm that, on a national average basis in 2008, less than one percent of ethanol FFVs used E85 fuel.[311]

If, in the future, this situation were to change (*e.g.,* if E85 were less expensive, on a per mile basis), then EPA could reconsider its approach to this issue.

b. Procedures for CAFE Calculations for MY 2020 and Later

49 U.S.C. 32905 specifies how the fuel economy of dual fuel vehicles is to be calculated for the purposes of CAFE through the 2019 model year. The basic calculation is a 50/50 harmonic average of the fuel economy for the alternative fuel and the conventional fuel, irrespective of the actual usage of each fuel. In addition, the fuel economy value for the alternative fuel is significantly increased by dividing by 0.15 in the case of CNG and ethanol and by using a petroleum equivalency factor methodology that yields a similar overall increase in the CAFE mpg value for electricity.[312] In a related provision, 49 U.S.C. 32906, the amount by which a manufacturer's CAFE value (for domestic passenger cars, import passenger cars, or light-duty trucks) can be improved by the statutory incentive for dual fuel vehicles is limited by EPCA to 1.2 mpg through 2014, and then gradually reduced until it is phased out entirely starting in model year 2020.[313] With the expiration of the special calculation procedures in 49 U.S.C. 32905 for dual fueled vehicles, the CAFE calculation procedures for model years 2020 and later vehicles need to be set under the general provisions authorizing EPA to establish testing and calculation procedures.[314]

With the expiration of the specific procedures for dual fueled vehicles, there is less need to base the procedures on whether a vehicle meets the specific definition of a dual fueled vehicle in EPCA. Instead, EPA's focus is on establishing appropriate procedures for the broad range of vehicles that can use both alternative and conventional fuels. For convenience, this discussion uses the term dual fuel to refer to vehicles that can operate on an alternative fuel and on a conventional fuel.

EPA sees two potential approaches for dual fuel vehicle CAFE calculations for model years 2020 and later. EPA requests comment on the two options discussed here, and we welcome comments on other potential options as well.

Determining the fuel economy of the vehicle for purposes of CAFE requires a determination on how to weight the fuel economy performance on the alternative fuel and the fuel economy performance on the conventional fuel. For PHEVs, dual-fuel CNG vehicles, and FFVs, EPA proposes to apply the same weighting for CAFE purposes as for purposes of GHG emissions compliance values. EPA proposes that, for PHEVs and dual-fuel CNG vehicles, the fuel economy weightings will be determined using the SAE utility factor methodology, while for ethanol FFVs, manufacturers can choose to use a default based on 100% gasoline operation, or can choose to base the fuel economy weightings on national average E85 and gasoline use, or on manufacturer-specific data showing the percentage of miles that are driven on E85 vis-à-vis gasoline for that manufacturer's ethanol FFVs. Where the two options differ is whether the 0.15 divisor or similar adjustment factor is retained or not. EPA believes that there are legitimate arguments both for and against retaining the adjustment factors.

EPA proposes to continue to use the 0.15 divisor for CNG and ethanol, and the petroleum equivalency factor for electricity, both of which the statute requires to be used through 2019, for model years 2020 and later. EPA believes there are two primary arguments for retaining the 0.15 divisor and petroleum equivalency factor. One, this approach is directionally consistent with the overall petroleum reduction goals of EPCA and the CAFE program, because it continues to encourage manufacturers to build vehicles capable of operating on fuels other than petroleum. Two, the 0.15 divisor and petroleum equivalency factor are used under EPCA to calculate CAFE compliance values for dedicated alternative fuel vehicles, and retaining this approach for dual fuel vehicles would maintain consistency, for MY 2020 and later, between the approaches for dedicated alternative fuel vehicles and for the alternative fuel portion of

[309] 75 FR at 25432–433.

[310] 75 FR at 25433–434.

[311] 75 FR 14762 (March 26, 2010).

[312] 49 U.S.C. 32905.

[313] 49 U.S.C. 32906. NHTSA interprets section 32906(a) as not limiting the impact of duel fueled vehicles on CAFE calculations after MY2019.

[314] 49 U.S.C. 32904(a), (c).

dual fuel vehicle operation. Opting not to provide the 0.15 divisor or PEF for the alternative fuel portion of these vehicles' operation may discourage manufacturers from building vehicles capable of operating on both gasoline/diesel and alternative fuels, and thus potentially discourage important ''bridge'' technologies that may help consumers overcome current concerns about advanced technology vehicles.

EPA recognizes that this proposed calculation procedure would continue to provide, directionally, an increase in fuel economy values for the vehicles previously covered by the special calculation procedures in 49 U.S.C. 32905, and that Congress chose both to end the specific calculation procedures in that section and over time to reduce the benefit for CAFE purposes of the increase in fuel economy mandated by those special calculation procedures. However, the proposed provisions differ significantly in important ways from the special calculation provisions mandated by EPCA. Most importantly, they are changed to reflect actual usage rates of the alternative fuel and do not use the artificial 50/50 weighting previously mandated by 49 U.S.C. 32905. In practice this means the primary vehicles to benefit from the proposed provision will be PHEVs and dual-fuel CNG vehicles, and not FFVs, while the primary source of benefit to manufacturers under the statutory provisions came from FFVs. Changing the weighting to better reflect real world usage is a major change from that mandated by 49 U.S.C. 32905, and it orients the calculation procedure more to the real world impact on petroleum usage, consistent with the statute's overarching purpose of energy conservation. In addition, as noted above, Congress clearly continued the calculation procedures for dedicated alternative fuel vehicles that result in increased fuel economy values. This proposed approach is consistent with this, as it uses the same approach for calculating fuel economy on the alternative fuel when there is real world usage of the alternative fuel. Since the proposed provisions are quite different in effect from the specified provisions in 49 U.S.C. 32905, and are consistent with the calculation procures for dedicated vehicles that use the same alternative fuel, EPA believes this proposal would be an appropriate exercise of discretion under the general authority provided in 49 U.S.C. 32904.

An alternative option to the above proposal, and about which EPA seeks comment, is to not adopt the 0.15 divisor and petroleum equivalency factor for model years 2020 and later. The fuel economy for the CNG portion of a dual fuel CNG vehicle, E85 portion of FFVs, and the electric portion of a PHEV would be determined strictly on an energy-equivalent basis, without any adjustment based on the 0.15 divisor or petroleum equivalency factor. For E85 FFVs, the manufacturer would almost certainly use the gasoline fuel economy value only because gasoline has higher energy content and fuel economy than E85.[315] This approach would place less emphasis on conservation of petroleum and more on conservation of energy for dual fuel vehicles. It would also place more emphasis on Congress' decision to reduce over time the impact on CAFE from the increased fuel economy values derived from the specified calculation procedures in 49 U.S.C. 32905, and less emphasis on aligning the incentives for dual fuel alternative fuel vehicles with the incentives for dedicated alternative fuel vehicles.[316] EPA invites comment on both approaches.

5. Off-Cycle Technology Credits

For MYs 2012–2016, EPA provided an option for manufacturers to generate credits for employing new and innovative technologies that achieve CO_2 reductions which are not reflected on current 2-cycle test procedures. For this proposal, EPA, in coordination with NHTSA, is proposing to apply the off-cycle credits and equivalent fuel consumption improvement values to both the GHG and CAFE programs. This proposed expansion is a change from the 2012–16 final rule where EPA only provided the off-cycle credits for the GHG program. For MY 2017 and later, EPA is proposing that manufacturers may continue to use off-cycle credits for GHG compliance and begin to use fuel consumption improvement values (essentially equivalent to EPA credits) for CAFE compliance. In addition, EPA is proposing a set of defined (*e.g.* default) values for identified off-cycle technologies that would apply unless the manufacturer demonstrates to EPA that a different value for its technologies is appropriate. The proposed changes to incorporate off-cycle technologies for the GHG program are described in Section III.C.5.a–b below, and for the CAFE program are described in Section III.C.5.c below.

a. Off-Cycle Credit Program Adopted in MY 2012–2016 Rule

In the MY 2012–2016 Final Rule, EPA adopted an optional credit opportunity for new and innovative technologies that reduce vehicle CO_2 emissions, but for which the CO_2 reduction benefits are not significantly captured over the 2-cycle test procedure used to determine compliance with the fleet average standards (*i.e.,* ''off-cycle'').[317] EPA indicated that eligible innovative technologies are those that may be relatively newly introduced in one or more vehicle models, but that are not yet implemented in widespread use in the light-duty fleet, and which provide novel approaches to reducing greenhouse gas emissions. The technologies must have verifiable and demonstrable real-world GHG reductions.[318] EPA adopted the off-cycle credit option to provide an incentive to encourage the introduction of these types of technologies, believing that bona fide reductions from these technologies should be considered in determining a manufacturer's fleet average, and that a credit mechanism is an effective way to do this. This optional credit opportunity is currently available through the 2016 model year.

EPA finalized a two-tiered process for OEMs to demonstrate that CO_2 reductions of an innovative and novel technology are verifiable and measureable but are not captured by the 2-cycle test procedures. First, a manufacturer must determine whether the benefit of the technology could be captured using the 5-cycle methodology currently used to determine fuel economy label values. EPA established the 5-cycle test methods to better represent real-world factors impacting fuel economy, including higher speeds and more aggressive driving, colder temperature operation, and the use of air conditioning. If this determination is affirmative, the manufacture must follow the 5-cycle procedures.

If the manufacturer finds that the technology is such that the benefit is not adequately captured using the 5-cycle approach, then the manufacturer would have to develop a robust methodology, subject to EPA approval, to demonstrate the benefit and determine the appropriate CO_2 gram per mile credit. This case-by-case, non-5-cycle credits approach includes an opportunity for public comment as part of the approval

[315] Manufacturers can also choose to base the fuel economy weightings on national average E85 and gasoline use, or on manufacturer-specific data showing the percentage of miles that are driven on E85 vis-à-vis gasoline for that manufacturer's ethanol FFVs, but since E85 fuel economy ratings are based on miles per gallon of E85, not adjusted for energy equivalency with gasoline, E85 mpg values are lower than gasoline mpg values, which makes this a non-option.

[316] Incentives for dedicated alternative fuel vehicles would not be affected by changes to incentives for dual fueled vehicles. Dedicated alternative fuel vehicles would continue to use the 0.15 divisor or petroleum equivalency factor.

[317] 75 FR 25438–440,

[318] See 40 CFR 1866.12 (d); 75 FR at 25438.

process. The demonstration program must be robust, verifiable, and capable of demonstrating the real-world emissions benefit of the technology with strong statistical significance. Whether the approach involves on-road testing, modeling, or some other analytical approach, the manufacturer is required to present a proposed methodology to EPA. EPA will approve the methodology and credits only if certain criteria are met. Baseline emissions and control emissions must be clearly demonstrated over a wide range of real world driving conditions and over a sufficient number of vehicles to address issues of uncertainty with the data. Data must be on a vehicle model-specific basis unless a manufacturer demonstrated model specific data was not necessary. See generally 75 FR at 25438–40.

b. Proposed Changes to the Off-cycle Credits Program

EPA has been encouraged by automakers' interest in off-cycle credits since the program was finalized. Though it is early in the program, several manufacturers have shown interest in introducing off-cycle technologies which are in various stages of development and testing. EPA believes that continuing the option for off-cycle credits would further encourage innovative strategies for reducing CO_2 emissions beyond those measured by the 2-cycle test procedures. Continuing the program provides manufacturers with additional flexibility in reducing CO_2 to meet increasingly stringent CO_2 standards and to encourage early penetration of off-cycle technologies into the light duty fleet. Furthermore, extending the program may encourage automakers to invest in off-cycle technologies that could have the benefit of realizing additional reductions in the light-duty fleet over the longer-term. Therefore, EPA is proposing to extend the off-cycle credits program to 2017 and later model years.

In implementing the program, some manufacturers have expressed concern that a drawback to using the program is uncertainty over which technologies may be eligible for off-cycle credits plus uncertainties resulting from a case-by-case approval process. Current EPA eligibility criteria require technologies to be new, innovative, and not in widespread use in order to qualify for credits. Also, the MY 2012–2016 Final Rule specified that technologies must not be significantly measurable on the 2-cycle test procedures. As discussed below, EPA proposes to significantly modify the eligibility criteria, as the current criteria are not well defined and have been a source of uncertainty for manufacturers, thereby interfering with the goal of providing an incentive for the development and use of additional technologies to achieve real world reductions in CO_2 emissions. The focus will be on whether or not add-on technologies can be demonstrated to provide off-cycle CO_2 emissions reductions that are not sufficiently reflected on the 2-cycle tests.

In addition, as described below in section III.C.5.b.i, EPA is proposing that manufacturers would be able to generate credits by applying technologies listed on an EPA pre-defined and pre-approved technology list starting with MY 2017. These credits would be verified and approved as part of certification with no prior approval process needed. We believe this new option would significantly streamline and simplify the program for manufacturers choosing to use it and would provide manufacturers with certainty that credits may be generated through the use of pre-approved technologies. For credits not based on the pre-defined list, EPA is proposing to streamline and better define a step-by-step process for demonstrating emissions reductions and applying for credits. EPA is proposing that these procedural changes to the case-by-case approach would be effective for new credit applications for both the remaining years of the MY 2012–2016 program as well as for MY 2017 and later credits that are not based on the pre-defined list.

As discussed in section II.F and III.B.10, EPA, in coordination with NHTSA, is also proposing that manufacturers be able to include fuel consumption reductions resulting from the use of off-cycle technologies in their CAFE compliance calculations. Manufacturers would generate ''fuel consumption improvement values'' essentially equivalent to EPA credits, for use in the CAFE program. The proposed changes to the CAFE program to incorporate off-cycle technologies are discussed below in section III.5.c.

i. Pre-Defined Credit List for MY 2017 and Later

As noted above, EPA proposes to establish a list of off-cycle technologies from which manufacturers could select to earn a pre-defined level of CO_2 credits in MY 2017 and later. Both technologies and credit values based on the list would be pre-approved. The manufacturer would demonstrate in the certification process that their technology meets the definition of the technology in the list. Table III–17 provides an initial proposed list of the technologies and per vehicle credit levels for cars and light trucks. EPA has used a combination of available activity data from the MOVES model, vehicle and test data, and EPA's vehicle simulation tool to estimate a proposed credit value EPA believes to be appropriate. In particular, this vehicle simulation tool was used to determine the credit amount for electrical load reduction technologies (*e.g.* high efficiency exterior lighting, engine heat reconvery, and solar roof panels) and active aerodynamic improvements. Chapter 5 of the joint TSD provides a detailed description of how these technologies are defined and how the proposed credits levels were derived.

Table III-17 Off-cycle Technologies and Proposed Credits for Cars and Light Trucks

Technology	Credit for Cars	Credit for Light Trucks	Minimum Penetration Requirement
	g/mi	g/mi	percent
High Efficiency Exterior Lighting	1.1	1.1	10%
Engine Heat Recovery	0.7	0.7	--
Solar Roof Panels	3.0	3.0	--
Active Aerodynamic Improvements	0.6	1.0	10%
Engine Start-Stop	2.9	4.5	10%
Electric Heater Circulation Pump	1.0	1.5	--
Active Transmission Warm-Up	1.8	1.8	10%
Active Engine Warm-Up	1.8	1.8	10%
Solar Control	Up to 3.0	Up to 4.3	10%

Two technologies on the list—active aerodynamic improvements and stop start—are in a different category than the other technologies on the list. Both of these technologies are included in the agencies' modeling analysis of technologies projected to be available for use in achieving the reductions needed for the standards. We have information on their effectiveness, cost, and availability for purposes of considering them along with the various other technologies we consider in determining the appropriate CO_2 emissions standard. These technologies are among those listed in Chapter 3 of the joint TSD and have measureable benefit on the 2-cycle test. However in the context of off-cycle credits, stop start is any technology which enables a vehicle to automatically turn off the engine when the vehicle comes to a rest and restart the engine when the driver applies pressure to the accelerator or releases the brake. This includes HEVs and PHEVs (but not EVs). In addition, active grill shutters is just one of various technologies that can be used as part of aerodynamic design improvements (as part of the ''aero2'' technology). The modeling and other analysis developed for determining the appropriate emissions standard includes these technologies, using the effectiveness values on the 2-cycle test. This is consistent with our consideration of all of the other technologies included in these analyses. Including them on the list for off-cycle credit generation, for purposes of compliance with the standard, would recognize that these technologies have a higher degree of effectiveness in reducing real-world CO_2 emissions than is reflected in their 2-cycle effectiveness. EPA has taken into account the generation of off-cycle credits by these two technologies in determining the appropriateness of the proposed GHG standards, considering the amount of credit, the projected degree of penetration of these technologies, and other factors. Section III.D has a more detailed discussion on the feasibility of the standards within the context of the flexibilities (such as off-cycle credits) proposed in this rule. As discussed in section III.D, EPA plans to incorporate the off-cycle credits for these two technologies in the cost analysis for the final rule (which EPA anticipates would slightly reduce costs with no change to benefits). EPA requests comments on this approach for stop start and active aerodynamic improvements.

Although EPA believes that there is sufficient information to estimate performance of other listed technologies for purposes of a credit program, EPA does not believe it appropriate to reflect these technologies in setting the level of standards at this point. There remains significant uncertainty as to the extent listed technologies other than stop start and active aerodynamic improvements may be used across the light duty fleet and (in some instances) costs of the technologies. Including them in the standard setting, as is done with A/C control technology, calls for a reasonable projection of the penetration of these technologies across the fleet and over time, along with reasonable estimates of their cost. EPA does not have adequate data at this point in time to make such fleet wide projections for other technologies on the list, or for other technologies addressed by the case-by-case approach. As in the 2012–2016 rule, the use of these technologies continues to be not nearly so well developed and understood for purposes of consideration in setting the standards. See 75 FR at 25438. Technologies that are considered by EPA in setting the standard, as discussed in section III.D and in Chapter 3 of the TSD, may not generate off-cycle credits under this approach, except for active aerodynamic improvements and stop start.[319] This would amount to the double counting discussed at 75 FR 25438, as EPA has already considered these technologies and assigned them an emission reduction effectiveness for purposes of standard setting, and has enough information on effectiveness, cost, and applicability to project their use for purposes of standard setting. EPA will reassess the list above for the Final Rule, based on additional information that becomes available during the comment period. It may also be appropriate to reconsider this approach as part of the mid-term evaluation as information on these technologies' applicability, costs, and performance becomes more robust.

EPA proposes to cap the amount of credits a manufacturer could generate using the above list to 10 g/mile per year on a combined car and truck fleet-wide average basis. The cap would not apply on a vehicle model basis, allowing manufacturers the flexibility to focus off-cycle technologies on certain vehicle models and generate credits for that vehicle model in excess of 10 g/mile. EPA is proposing a fleet-wide cap because the proposed credits are based on limited data, and also EPA recognizes that some uncertainty is introduced when credits are provided based on a general assessment of off-cycle performance as opposed to testing on the individual vehicle models. Also, as discussed in Chapter 5 of the draft TSD, EPA believes the credits proposed are based on conservative estimates, providing additional assurance that the list would not result in an overall loss of CO_2 benefits. EPA proposes that manufacturers wanting to generate credits in excess of the 10 g/mile limit for these listed technologies could do so by generating necessary data and going through the credit approval process described below in Section III.C.5.b.iii and iv.

As noted above, EPA proposes to make the list available for credit generation starting in MY 2017. Prior to MY 2017, manufacturers would need to demonstrate off-cycle emissions reductions in order to generate credits for off-cycle technologies, including those on the list. Requirements for demonstrating off-cycle credits not based on the list are described below. Manufacturers may also opt to generate data for listed technologies in MY 2017 and later where they are able to demonstrate a credit value greater than that provided on the list.

Prior to MY 2017, EPA would continue to evaluate off-cycle technologies. Based on data provided by manufacturers for non-listed technologies, and other available data, EPA would consider adding technologies to the list through rulemaking. EPA could also issue guidance in the future for additional off-cycle technologies, indicating the level of credits that EPA expects could be approved for any manufacturer through the case-by-case approach, helping to streamline the case-by-case approach until a rulemaking was conducted to update the list. If the CO_2 reduction benefits of a technology have been established through manufacturer data and testing, EPA believes that it would be appropriate to list the technology and a conservative associated credit value.

Since one purpose of the off-cycle credits is to encourage market penetration of the technologies (see 75 FR at 25438), EPA also proposes to require minimum penetration rates for several of the listed technologies as a condition for generating credit from the list as a way to further encourage their widespread adoption by MY 2017 and later. The proposed minimum penetration rates for the various technologies are provided in Table III–17. At the end of the model year for which the off-cycle credit is claimed, manufacturers would need to demonstrate that production of vehicles equipped with the technologies for that model year exceeded the percentage thresholds in order to receive the listed credit. EPA proposes to set the threshold at 10 percent of a manufacturer's overall combined car and light truck production except for technologies specific to HEVs/PHEVs/EVs and exhaust heat recovery. EPA believes 10 percent is an appropriate threshold as it would encourage manufacturers to develop technologies for use on larger volume models and bring the technologies into the mainstream. On the other hand, EPA is not proposing a larger value because EPA does not want to discourage the use of technologies. For solar roof panels (solar control) and electric heater circulation pumps, which are HEV/PHEV/EV-specific, EPA is not proposing a minimum penetration rate threshold for credit generation. Hybrids and EVs may be a small subset of a manufacturer's fleet, less than 10 percent in some cases, and EPA does not believe establishing a threshold for hybrid-based technologies would be useful and could unnecessarily impede the introduction of these technologies. EPA is also not proposing to apply a minimum penetration threshold to exhaust heat recovery because the threshold could impede rather than encourage the development of the technology due to its relatively early stage of development and potentially high cost. EPA requests comments on applying this type of threshold, the appropriateness of 10 percent as the threshold for several of the listed technologies, and the proposed treatment of HEV/PHEV/EV specific technologies and exhaust heat recovery.

ii. Proposed Technology Eligibility Criteria

EPA proposes to remove the criteria in the 2012–2016 rule that off-cycle technologies must be 'new, innovative, and not widespread' because these terms are imprecise and have created implementation issues and uncertainty in the program. For example, it is unclear if technologies developed in the past but not used extensively would be considered new, if only the first one or two manufacturers using the technology would be eligible or if all manufacturers could use a technology to generate credits, or if credits for a technology would sunset after a period of time. It has also been unclear if a technology such as active aerodynamics would be eligible since it provides a small measurable reduction on the 2-cycle test but provides additional reductions off-cycle, especially during high speed driving. These criteria have interfered with the goal of providing an incentive for the development and use of off-cycle technology that reduces CO_2 emissions. EPA proposes this approach for new MY 2012–2016 credits as well as for MY 2017–2025.

EPA believes it is appropriate to provide credit opportunities for technologies that achieve real world

[319] Section III.D provides EPA projected technology penetration rates. Technologies projected to be used to meet the standards would not be eligible for off-cycle credits, with the exception of stop start and active aerodynamic improvements.

reductions beyond those measured under the two-cycle test without further making (somewhat subjective) judgments regarding the newness and innovativeness of the technology. Instead, EPA proposes to provide off-cycle credits for any technologies that are added to a vehicle model that are demonstrated to provide significant incremental off-cycle CO_2 reductions, like those on the list. The proposed technology demonstration and step-by-step application process is described in detail below in section III.C.5.b.ii. EPA is proposing to clarify that technologies providing small reductions on the 2-cycle tests but additional significant reductions off-cycle could be eligible to generate off-cycle credits. EPA thus proposes to remove the ''not significantly measurable over the 2-cycle test'' criteria. EPA proposes that, instead, manufacturers must be able to make a demonstration through testing with and without the off-cycle technology.

As noted above, EPA proposes that technologies included in EPA's assessment in this rulemaking of technology for purposes of developing the standard would not be allowed to generate off-cycle credits, as their cost and effectiveness and expected use are already included in the assessment of the standard. (As explained above, the agencies have done so with respect to stop start and active aerodynamic improvements by including the projected level of credits in determining the appropriateness of the proposed standards.) EPA proposes that technologies integral or inherent to the basic vehicle design including engine, transmission, mass reduction, passive aerodynamic design, and base tires would not be eligible for credits. For example, manufacturers would not be able to generate off-cycle credits by moving to an eight-speed transmission. EPA believes that it would be difficult to clearly establish an appropriate A/B test (with and without technologies) for technologies so integral to the basic vehicle design. EPA proposes to limit the off-cycle program to technologies that can be clearly identified as add-on technologies conducive to A/B testing. Further, EPA would not provide credits for a technology required to be used by Federal law, such as tire pressure monitoring systems, as EPA would consider such credits to be windfall credits (*i.e.* not generated as a result of the rule). The base versions of such technologies would be considered part of the base vehicle. However, if a manufacturer demonstrates that an improvement to such technologies provides additional off-cycle benefits above and beyond a system meeting minimum Federal requirements, those incremental improvements could be eligible for off-cycle credits, assuming an appropriate quantification of credits is demonstrated.

By proposing to remove the ''new, innovative, not widespread use'' criteria in the present rule, EPA is also making clear that once approved, EPA does not intend to sunset a technology's credit eligibility or deny credits to other vehicle applications using the technology, as may have been implied by those criteria under the MY 2012–2016 program. EPA believes, at this time, that it should encourage the wider use of technologies with legitimate off-cycle emissions benefits. Manufacturers demonstrating through the EPA approval process that the technology is effective on additional vehicle models would be eligible for credits. Limiting the application of a technology or sunsetting the availability of credits during the 2017–2025 time frame would be counterproductive because it would remove part of the incentive for manufacturers to invest in developing and deploying off-cycle technologies, some of which may be promising but have considerable development costs associated with them. Also, approving a technology only to later disallow it could lead to a manufacturer discontinuing the use of the technology even if it remained a cost effective way to reduce emissions. EPA also believes that this approach provides an incentive for manufacturers to continue to improve technologies without concern that they will become ineligible for credits at some future time. EPA requests comments on all aspects of the above approach for the off-cycle credits program criteria.

iii. Demonstrating Off-Cycle Emissions Reductions

5-Cycle Testing

EPA is retaining a two-tiered process for demonstrating the CO_2 reductions of off-cycle technologies (in those instances when a manufacturer is not using the default value provided by the rule), but is clarifying several of the requirements. The process described below would be used for all credits not based on the pre-defined list described in Section III.C.5.i, above. As noted above, the proposed approach would replace the requirement in the 2012–2016 rule that technology must not be ''significantly measurable'' over the 2-cycle test. See section 86. 1866–12 (d)(ii). This criterion has been problematic because several technologies provide some benefit on the 2-cycle test but much greater benefits off-cycle. Under today's proposal, technologies would need to be demonstrated to provide significant incremental off-cycle benefits above and beyond those provided over the 2-cycle test (examples are shown below). EPA proposes this approach for new MY 2012–2016 credits as well as for MY 2017–2025.

The 5-cycle test procedures would remain the starting point for demonstrating off-cycle emissions reductions. The MY 2012–2016 rulemaking established general 5-cycle testing requirements and EPA is proposing several provisions to delineate what EPA would expect as part of a 5-cycle based demonstration. Manufacturers requested clarification on the amount of 5-cycle testing that would be needed to demonstrate off-cycle credits, and EPA is proposing the following as part of the step-by-step methodology manufacturers would follow to generate credits. In addition to the general 5-cycle demonstration requirements of the MY 2012–2016 program, EPA proposes to specifically require model-based verification of 5-cycle results where off-cycle reductions are small and could be a product of testing variability. EPA is also proposing to specifically require that all applications include an engineering analysis for why the technology provides off-cycle emissions reductions. EPA proposes to specify that manufacturers would run an initial set of three 5-cycle tests with and without the technology providing the off-cycle CO_2 reduction. Testing must be conducted on a representative vehicle, selected using good engineering judgment, for each vehicle model. EPA proposes that manufacturers could bundle off-cycle technologies together for testing in order to reduce testing costs and improve their ability to demonstrate consistently measurable reductions over the tests. If these A/B 5-cycle tests demonstrate an off-cycle benefit of 3 percent or greater, comparing average test results with and without the off-cycle technology, the manufacturer would be able to use the data as the basis for credits. EPA has long used 3 percent as a threshold in fuel economy confirmatory testing for determining if a manufacturer's fuel economy test results are comparable to those run by EPA.[320]

If the initial three sets of 5-cycle results demonstrate a reduction of less than a 3 percent difference in the 5-cycle results with and without the off-cycle technology, the manufacturer

[320] 40 CFR 600.008 (b)(3).

would have to run two additional 5-cycle tests with and without the off-cycle technologies and verify the emission reduction using the EPA Light-duty Simulation Tool described below. If the simulation tool supports credits that are less than 3 percent of the baseline 2-cycle emissions, then EPA would approve the credits based on the test results. As outlined below, credits based on this methodology would be subject to a 60 day EPA review period starting when EPA receives a complete application, which would not include a public review.

EPA believes that small off-cycle credit claims (*i.e.,* less than 3 percent of the vehicle model 2-cycle CO_2 level) should be supported with modeling and engineering analysis. EPA is proposing the approach above for a number of reasons. Emissions reductions of only a few grams may not be statistically significant and could be the product of gaming. Also, manufacturers have raised test-to-test variability as an issue for demonstrating technologies through 5-cycle testing. Modeling and engineering analyses can help resolve these questions. EPA also requests comments on allowing manufacturers to use the EPA simulation tool and engineering analysis in lieu of additional 5-cycle testing. For some technologies providing very small incremental benefits, it may not be possible to accurately measure their benefit with vehicle testing.

Demonstrations Not Based on 5-Cycle Testing

In cases where the benefit of a technological approach to reducing CO_2 emissions cannot be adequately represented using 5-cycle testing, manufacturers will need to develop test procedures and analytical approaches to estimate the effectiveness of the technology for the purpose of generating credits. See 75 FR at 25440. EPA is not proposing to make significant changes to this aspect of the program. If the 5-cycle process is inadequate for the specific technology being considered by the manufacturer (*i.e.,* the 5-cycle test does not demonstrate any emissions reductions), then an alternative approach may be developed by the manufacturer and submitted to EPA for approval. The demonstration program must be robust, verifiable, and capable of demonstrating the real-world emissions benefit of the technology with strong statistical significance. The methodology developed and submitted to EPA would be subject to public review as explained at 75 FR 25440 and in 86.1866(d)(2)(ii).

EPA has identified two general situations where manufacturers would need to develop their own demonstration methodology. The first is a situation where the technology is active only during certain operating conditions that are not represented by any of the 5-cycle tests. To determine the overall emissions reductions, manufacturers must determine not only the emissions impacts during operation but also real-world activity data to determine how often the technology is utilized during actual, in-use driving on average across the fleet. EPA has identified some of these types of technologies and has calculated a default credit for them, including items such as high efficiency (*e.g.,* LED) lights and solar panels on hybrids. See Table III–17 above. In their demonstrations, manufacturers may be able to apply the same type of methodologies used by EPA as a basis for these default values (see TSD Chapter 5).

The second type of situation where manufacturers would need to develop their own demonstration data would be for technologies that involve action by the driver to make the technology effective in reducing CO_2 emissions. EPA believes that driver interactive technologies face the highest demonstration hurdle because manufacturers would need to provide actual real-world usage data on driver response rates. Such technologies would include ''eco buttons'' where the driver has the option of selecting more fuel efficient operating modes, traffic avoidance systems, and more advanced tire pressure monitor systems (*i.e.,* technologies that go beyond the minimum Federal requirements) notifying the driver to fill their tires more often.[321] EPA proposes that data would need to be from instrumented vehicle studies and not through driver surveys where results may be influenced by drivers failure to accurately recall their response behavior. Systems such as On-star could be one promising way to collect driver response data if they are designed to do so. Manufacturers might have to design extensive on-road test programs. Any such on-road testing programs would need to be statistically robust and based on average U.S. driving conditions, factoring in differences in geography, climate, and driving behavior across the U.S. EPA proposes this approach for new MY 2012–2016 credits as well as for MY 2017–2025.

EPA Light-Duty Vehicle Simulation Tool

As explained above and, EPA has developed full vehicle simulation capabilities in order to support regulations and vehicle compliance by quantifying the effectiveness of different technologies over a wide range of engine and vehicle operating conditions. This in-house simulation tool has been developed for modeling a wide variety of light, medium, and heavy duty vehicle applications over various driving cycles. In order to ensure transparency of the models and free public access, EPA has developed the tool in MATLAB/Simulink environment with a completely open source code. EPA's first application of the vehicle simulation tool was for purposes of heavy-duty vehicle compliance and certification. For the model years 2014 to 2017 final rule for medium and heavy duty trucks, EPA created the ''Greenhouse gas Emissions Model'' (GEM), which is used both to assess Class 2b–8 vocational vehicle and Class 7/8 combination tractor GHG emissions and fuel efficiency and to demonstrate compliance with the vocational vehicle and combination tractor standards. See 76 FR at 57146–147.[322] EPA will submit the simulation tool for peer review for the final rule. Chapter 2 of the Draft RIA has more details of this simulation tool.

As mentioned previously, the tool is based on MATLAB/Simulink and is a forward-looking full vehicle model that uses the same physical principles as other commercially available vehicle simulation tools (*e.g.* Autonomie, AVL–CRUISE, GT–Drive, etc.) to derive the governing equations. These governing equations describe steady-state and transient behaviors of each of electrical, engine, transmission, driveline, and vehicle systems, and they are integrated together to provide overall system behavior during transient conditions as well as steady-state operations. In the light-duty vehicle simulation tool, there are four key system elements that describe the overall vehicle dynamics behavior and the corresponding fuel efficiency: Electrical, engine, transmission, and vehicle. The electrical system model consists of parasitic electrical load and A/C blower fan, both of which were assumed to be constant. The engine system model is comprised

[321] A tire pressure monitor system that also automatically fills the tire without driver interaction would obviously not involve driver response data for the automatic system, but the demonstration may involve the driver response rates for the baseline system to determine an incremental credit.

[322] See also US EPA, ''Final Rule Making to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles,'' Heavy-Duty Regulatory Impact Analysis.give cite to where GEM is written up in the heavy duty RIA.

of engine torque and fueling maps. For the vehicle system, four vehicles were modeled: Small, mid, large size passenger vehicles, and a light-duty pick-up truck. The engine maps, transmission gear ratios and shifting schedules were appropriately sized and adjusted according to the vehicle type represented by the simulation. This tool is capable of simulating a wide range of conventional and advanced engines, transmissions, and vehicle technologies over various driving cycles. It evaluates technology package effectiveness while taking into account synergy (and dis-synergy) effects among vehicle components and estimates GHG emissions for various combinations of technologies. Chapter 2 of the Draft Regulatory Impact Analysis provides more details on this light-duty vehicle simulation tool.

As discussed in section III.C.1, EPA has used the light-duty vehicle simulation tool to estimate indirect A/C CO_2 emissions from conventional (non-hybrid) vehicles, helping to quantify the indirect A/C credit. In addition to A/C related CO_2 reductions, EPA believes this same simulation tool may be useful in estimating CO_2 reductions from off-cycle technologies. Currently, the model provides A/B relative comparisons with and without technologies that can help inform credits estimates. EPA has used it to estimate credits for some of the technologies in the proposed pre-defined list, including active aerodynamic improvements. As discussed above, EPA is proposing to require this simulation tool be used as an additional way to estimate emissions reductions in cases where the 5-cycle test results indicate the potential reductions to be small, and EPA is also requesting comments on using the simulation tool as a basis for estimating off-cycle credits in lieu of 5-cycle testing.

There are a number of technologies that could bring additional GHG reductions over the 5-cycle drive test (or in the real world) compared to the combined FTP/Highway (or two) cycle test. These are called off-cycle technologies and are described in chapter 5 of the Joint TSD in detail. Among them are technologies related to reducing vehicle's electrical loads, such as High Efficiency Exterior Lights, Engine Heat Recovery, and Solar Roof Panels. In an effort to streamline the process for approving off-cycle credits, we have set a relatively conservative estimate of the credit based on our efficacy analysis. EPA seeks comment on utilizing the model in order to quantify the credits more accurately, for example, if actual data of electrical load reduction and/or on-board electricity generation by one or more of these technologies is available through data submission from manufacturers. Similarly, there are technologies that would provide additional GHG reduction benefits in the 5-cycle test by actively reducing the vehicle's aerodynamic drag forces. These are referred to as active aerodynamic technologies, which include but are not limited to Active Grill Shutters and Active Suspension Lowering. Like the electrical load reduction technologies, the vehicle simulation tool can be used to more accurately estimate the additional GHG reductions (therefore the credits) provided by these active aerodynamic technologies over the 5-cycle drive test. EPA seeks comment on using the simulation tool in order to quantify these credits. In order to do this properly, manufacturers would be expected to submit two sets of coast-down coefficients (with and without the active aerodynamic technologies).

There are other technologies that would result in additional GHG reduction benefits that cannot be fully captured on the combined FTP/Highway cycle test. These technologies typically reduce engine loads by utilizing advanced engine controls, and they range from enabling the vehicle to turn off the engine at idle, to reducing cabin temperature and thus A/C compressor loading when the vehicle is restarted. Examples include Engine Start-Stop, Electric Heater Circulation Pump, Active Engine/Transmission Warm-Up, and Solar Control. For these types of technologies, the overall GHG reduction largely depends on the control and calibration strategies of individual manufacturers and vehicle types. Also, the current vehicle simulation tool does not yet have the capability to properly simulate the vehicle behaviors that depend on thermal conditions of the vehicle and its surroundings, such as Active Engine/Transmission Warm-Up and Solar Control. Therefore, the vehicle simulation may not provide full benefits of the technologies on the GHG reductions. For this reason, the agency is not proposing to use the simulation tool to generate the GHG credits for these technologies at this time, though future versions of the model may be more capable of quantifying the efficacy of these off-cycle technologies as well.

iv. In-Use Emissions Requirements

EPA requires off-cycle components to be durable in-use and continues to believe that this is an important aspect of the program. See 86.1866–12 (d)(1)(iii). The technologies upon which the credits are based are subject to full useful life compliance provisions, as with other emissions controls. Unless the manufacturer can demonstrate that the technology would not be subject to in-use deterioration over the useful life of the vehicle, the manufacturer must account for deterioration in the estimation of the credits in order to ensure that the credits are based on real in-use emissions reductions over the life of the vehicle. In-use requirements would apply to technologies generating credits based on the pre-defined list as well as to those based on a manufacturer's demonstration.

Manufacturers have requested clarification of these provisions and guidance on how to demonstrate in-use performance. EPA is proposing to clarify that off-cycle technologies are considered emissions related components and all in-use requirements apply including defect reporting, warranty, and recall. OBD requirements do not apply under the MY 2012–2016 program and EPA is not proposing any OBD requirements at this time for off-cycle technologies. Manufacturers may establish maintenance intervals for these components in the same way they would for other emissions related components. The performance of these components would be considered in determining compliance with the applicable in-use CO_2 standards. Manufacturers may demonstrate in-use emissions durability at time of certification by submitting an engineering analysis describing why the technology is durable and expected to last for the full useful life of the vehicle. This demonstration may also include component durability testing or through whole vehicle aging if the manufacturer has such data. The demonstration would be subject to EPA approval prior to credits being awarded.[323] EPA believes these provisions are important to ensure that promised emissions reductions and fuel economy benefit to the consumer are delivered in-use. EPA requests comments on the above approach for in-use emissions durability.

v. Step-by-Step EPA Review Process

EPA proposes to provide a step-by-step process and timeline for reviewing credit applications and providing a decision to manufacturers. EPA requests comments on the process described below including comments on how to further improve or streamline it while maintaining its effectiveness. EPA

[323] Listed technologies are pre-approved assuming the manufacturer demonstrates durability.

proposes these clarifications and further detailed step-by-step instructions for new MY 2012–2016 credits as well as for MY 2017–2025. EPA believes these additional details are consistent with the general off-cycle requirements adopted in the MY 2012–2016 rule. Starting in MY 2017, EPA is proposing that manufacturers may generate credits using technologies on a pre-defined list, and these technologies would not be required to go through the approval process described below.

Step 1: Manufacturer Conducts Testing and Prepares Application

5-cycle—Manufacturers would conduct the testing and/or simulation described above

Non 5-cycle—Manufacturers would develop a methodology for non 5-cycle based demonstration and carry-out necessary testing and analysis

- Manufacturers may opt to meet with EPA to discuss their plans for demonstrating technologies and seek EPA input prior to conducting testing or analysis

Manufacturers conduct engineering analysis and/or testing to demonstrate in-use durability

Step 2: Manufacturer Submits Application

The manufacturer application must contain the following:

Description of the off-cycle technologies and how they function to reduce off-cycle emissions

The vehicle models on which the technology will be applied

Test vehicles selection and supporting engineering analysis for their selection

5-cycle test data, and/or including simulation results using EPA Light-duty Simulation Tool, as applicable

For credits not based on 5-cycle testing, a complete description of methodology used to estimate credits and supporting data (vehicle test data and activity data)

- Manufacturer may seek EPA input on methodology prior to conducting testing or analysis

An estimate of off-cycle credits by vehicle model, and fleetwide based on projected vehicle sales

Engineering analysis and/or component durability testing or whole vehicle test data (as necessary) demonstrating in-use durability of components

Step 3: EPA Review

Once EPA receives an application, EPA would do the following:

EPA will review the application for completeness and within 30 days will notify the manufacturer if additional information is needed

EPA will review the data and information provided to determine if the application supports the level of credits estimated by manufacturers

EPA will consult with NHTSA on the application and the data received in cases where the manufacturer intends to generate fuel consumption improvement values for CAFE in MY 2017 and later

For applications where the rule specifies public participation in the review process, EPA will make the applications available to the public within 60 days of receiving a complete application

- The public review period will be 30 day review of the methodology used by the manufacturer to estimate credits, during which time the public may submit comments.
- Manufacturers may submit a written rebuttal of comments for EPA consideration or may revise their application in response to comments following the end of the public review period.

Step 4: EPA Decision

For applications where the rule does not specify public participation and review, EPA, after consultation with NHTSA in cases where the manufacturer intends to generate fuel consumption improvement values for CAFE in MY 2017 and later, will notify the manufacturer of its decision within 60 days of receiving a complete application.

For applications where the rule does specify public participation and review, EPA will notify the manufacturer of its decision on the application after reviewing public comments.

EPA will notify manufacturers in writing of its decision to approve or deny the credits application, and provide a written explanation for its action (supported by the administrative record for the application proceeding).

c. Off-Cycle Technology Fuel Consumption Improvement Values in the CAFE Program

EPA proposes, in coordination with NHTSA, that manufacturers would be able to generate fuel consumption improvement values equivalent to CO_2 off-cycle credits for use in the CAFE program. EPA is proposing that a CAFE improvement value for off-cycle improvements be determined at the fleet level by converting the CO_2 credits determined under the EPA program (in metric tons of CO_2) for each fleet (car and truck) to a fleet fuel consumption improvement value. This improvement value would then be used to adjust the fleet's CAFE level upward. See the proposed regulations at 40 CFR 600.510–12. Note that while the following table presents fuel consumption values equivalent to a given CO_2 credit value, these consumption values are presented for informational purposes and are not meant to imply that these values will be used to determine the fuel economy for individual vehicles. For off-cycle CO_2 credits not based on the list, manufacturers would go though the steps described above in Section III.C.5.b. Again, all off-cycle CO_2 credits would be converted to a gallons per mile fuel consumption improvement value at a fleet level for purposes of the CAFE program. EPA would approve credit generation, and corresponding equivalent fuel consumption improvement values, in consultation with NHTSA.

III-18 Fuel Consumption Improvement Values Equivalent to Proposed CO_2 Off-cycle Credits

Technology	Cars	Light Trucks
	gallons/mi	gallons/mi
High Efficiency Exterior Lighting	0.000124	0.000124
Engine Heat Recovery	0.000778	0.000778
Solar Roof Panels	0.000338	0.000338
Active Aerodynamic Improvements	0.0000675	0.000113
Engine Start-Stop	0.000326	0.000506
Electric Heater Circulation Pump	0.000123	0.000169
Active Transmission Warm-Up	0.000203	0.000203
Active Engine Warm-Up	0.000203	0.000203
Solar Control	Up to 0.000338	Up to 0.000484

D. Technical Assessment of the Proposed CO_2 Standards

This proposed rule is based on the need to obtain significant GHG emissions reductions from the transportation sector, and the recognition that there are cost-effective technologies available in this timeframe to achieve such reductions for MY 2017–2025 light duty vehicles. As in many prior mobile source rulemakings, the decision on what standard to set is largely based on the effectiveness of the emissions control technology, the cost and other impacts of implementing the technology, and the lead time needed for manufacturers to employ the control technology. The standards derived from assessing these factors are also evaluated in terms of the need for reductions of greenhouse gases, the degree of reductions achieved by the standards, and the impacts of the standards in terms of costs, quantified benefits, and other impacts of the standards. The availability of technology to achieve reductions and the cost and other aspects of this technology are therefore a central focus of this rulemaking.

EPA is taking the same basic approach in this rulemaking as that taken in the MYs 2012–2016 rulemaking. EPA is evaluating emissions control technologies which reduce CO_2 and other greenhouse gases. CO_2 emissions from automobiles are largely the product of fuel combustion. Vehicles combust fuel to perform two basic functions: (1) to transport the vehicle, its passengers and its contents (and any towed loads), and (2) to operate various accessories during the operation of the vehicle such as the air conditioner. Technology can reduce CO_2 emissions by either making more efficient use of the energy that is produced through combustion of the fuel or reducing the energy needed to perform either of these functions.

This focus on efficiency calls for looking at the vehicle as an entire system, and as in the MYs 2012–2016 rule, the proposed standards reflect this basic paradigm. In addition to fuel delivery, combustion, and aftertreatment technology, any aspect of the vehicle that affects the need to produce energy must also be considered. For example, the efficiency of the transmission system, which takes the energy produced by the engine and transmits it to the wheels, and the resistance of the tires to rolling both have major impacts on the amount of fuel that is combusted while operating the vehicle. The braking system, the aerodynamics of the vehicle, and the efficiency of accessories, such as the air conditioner, all affect how much fuel is combusted as well.

In evaluating vehicle efficiency, we have excluded fundamental changes in vehicles' utility.[324] For example, we did not evaluate converting minivans and SUVs to station wagons, converting vehicles with four wheel drive to two wheel drive, or reducing headroom in order to lower the roofline and reduce aerodynamic drag. We have limited our assessment of technical feasibility and resultant vehicle cost to technologies which maintain vehicle utility as much as possible (and, in our assessment of the costs of the rule, included the costs to manufacturers of preserving vehicle utility). Manufacturers may decide to alter the utility of the vehicles which they sell, but this would not be a

[324] EPA recognizes that electric vehicles, a technology considered in this analysis, have unique attributes and discusses these considerations in Section III.H.1.b. There is also a fuller discussion of the utility of Atkinson engine hybrid vehicles in EPA DRIA Chapter 1.

necessary consequence of the rule but rather a matter of automaker choice.

This need to focus on the efficient use of energy by the vehicle as a system leads to a broad focus on a wide variety of technologies that affect vehicle design. As discussed below, there are many technologies that are currently available which can reduce vehicle energy consumption. Several of these are ''game-changing'' technologies and are already being commercially utilized to a limited degree in the current light-duty fleet. Examples include hybrid technologies that use high efficiency batteries and electric motors as the power source in combination with or instead of internal combustion engines, plug-in hybrid electric vehicles, and battery-electric vehicles. While already commercialized, these technologies continue to be developed and offer the potential for even more significant efficiency improvements. There are also other advanced technologies under development and not yet on production vehicles, such as high BMEP engines with cooled EGR, which offer the potential of improved energy generation taking the gasoline combustion process nearly to its thermodynamic limit. In addition, the available technologies are not limited to powertrain improvements but also include a number of technologies that are expected to continually improve incrementally, such as engine friction reduction, rolling resistance reduction, mass reduction, electrical system efficiencies, and aerodynamic improvements.

The large number of possible technologies to consider and the breadth of vehicle systems that are affected mean that consideration of the manufacturer's design, product development and manufacturing process plays a major role in developing the proposed standards. Vehicle manufacturers typically develop many different models by basing them on a limited number of vehicle platforms. The platform typically consists of a common set of vehicle architecture and structural components.[325] This allows for efficient use of design and manufacturing resources. Given the very large investment put into designing and producing each vehicle model, manufacturers typically plan on a major redesign for the models approximately every 5 years.[326] At the redesign stage, the manufacturer will upgrade or add all of the technology and make most other changes supporting the manufacturer's plans for the next several years, including plans to comply with emissions, fuel economy, and safety regulations.[327] This redesign often involves significant engineering, development, manufacturing, and marketing resources to create a new product with multiple new features. In order to leverage this significant upfront investment, manufacturers plan vehicle redesigns with several model years' of production in mind. Vehicle models are not completely static between redesigns as limited changes are often incorporated for each model year. This interim process is called a refresh of the vehicle and generally does not allow for major technology changes although more minor ones can be done (*e.g.,* small aerodynamic improvements, valve timing improvements, etc). More major technology upgrades that affect multiple systems of the vehicle thus occur at the vehicle redesign stage and not in the time period between redesigns.

This proposal affects nine years of vehicle production, model years 2017–2025. Given the now-typical five year redesign cycle, many vehicles will be redesigned three times between MY 2012 and MY 2025 and are expected to be redesigned twice during the 2017–2025 timeframe. Due to the relatively long lead time before 2017, there are fewer lead time concerns with regard to product redesign in this proposal than with the MYs 2012–2016 rule (or the MY 2014–2018 rule for heavy duty vehicles and engines). However, there are still some technologies that require significant lead time, and are not projected to be heavily utilized in the first years of this proposal. An example is the advanced high BMEP, cooled EGR engines. As these engines are not yet in vehicles today, a research and development period is required, even if there are a number of demonstration projects complete (as discussed in Chapter 3 of the joint TSD).

In developing the proposed MY 2021 and 2025 car and truck curves (discussed in Section III.B), EPA used the OMEGA model to evaluate technologies that manufacturers could use to comply with the targets which those curves would establish. These curves correspond to sales-weighted fleetwide CO_2 average targets of 200 g/mile in MY 2021 and 163 g/mile in MY 2025. As discussed later in this section, we believe that this level of technology application to the light-duty vehicle fleet can be achieved in this time frame, the standards will produce significant reductions in GHG emissions, and the costs for both the industry and the costs to the consumer are reasonable and that consumer savings due to improved fuel economy will more than pay for the increased vehicle cost over the life of the vehicles. EPA also estimated costs for the intermediate model years 2017 through 2020 based on the OMEGA analyses in MYs 2016 and 2021 as well as the intermediate model years 2022–2024 based on the OMEGA analyses in MYs 2021 and 2025.

EPA's technical assessment of the proposed MY2017–2025 standards is described below. EPA has also evaluated a set of alternative standards for these model years, two of which are more stringent and two of which are less stringent than the standards proposed. The technical assessment of these alternative standards in relation to the ones proposed is discussed at the end of this section.

Evaluating the appropriateness of these standards includes a core focus on identifying available technologies and assessing their effectiveness, cost, and impact on relevant aspects of vehicle performance and utility. The wide number of technologies which are available and likely to be used in combination requires a sophisticated assessment of their combined cost and effectiveness. An important factor is also the degree that these technologies are already being used in the current vehicle fleet and thus, unavailable for use to improve energy efficiency beyond current levels. Finally, the challenge for manufacturers to design the technology into their products within the constraints of the redesign cycles, and the appropriate lead time needed to employ the technology over the product line of the industry must be considered.

Applying these technologies efficiently to the wide range of vehicles produced by various manufacturers is a challenging task involving dozens of technologies and hundreds of vehicle platforms. In order to assist in this task, EPA is again using a computerized program called the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). Broadly, OMEGA starts with a description of the future vehicle fleet (*i.e.* the 'reference fleet'; see section II.B above), including manufacturer, sales, base CO_2 emissions, footprint and the extent to which emission control technologies are already employed. For the purpose of this analysis, EPA uses OMEGA to analyze over 200 vehicle platforms comprising approximately 1300 vehicle models in order o capture the important differences in vehicle and engine design and utility of future vehicle sales of roughly 16–18 million

[325] Examples of shared vehicle platforms include the Ford Taurus and Ford Explorer or the Chrysler Sebring and Dodge Journey.

[326] See TSD Chapter 3.

[327] TSD 3 discusses redesign schedules in greater detail.

units annually in the 2017–2025 timeframe. The model is then provided with a list of technologies which are applicable to various types of vehicles, along with the technologies' cost and effectiveness and the percentage of vehicle sales which can receive each technology during the redesign cycle of interest. The model combines this information with economic parameters, such as fuel prices and a discount rate, to project how various manufacturers would apply the available technology in order to meet increasing levels of emission control. The result is a description of which technologies are added to each vehicle platform, along with the resulting cost. While OMEGA can apply technologies which reduce CO_2 efficiency related emissions and refrigerant leakage emissions associated with air conditioner use, this task is currently handled outside of the OMEGA model. A/C improvements are relatively cost-effective, and would always be added to vehicles by the model, thus they are simply added into the results at the projected penetration levels. The model can also be set to account for the various proposed compliance flexibilities (and to accommodate compliance flexibilities in general.

The remainder of this section describes the technical feasibility analysis in greater detail. Section III.D.1 describes the development of our reference and control case projections of the MY 2017–2025 fleet. Section III.D.2 describes our estimates of the effectiveness and cost of the control technologies available for application in the 2017–2025 timeframe. Section III.D.3 describes how these technologies are combined into packages likely to be applied at the same time by a manufacturer. In this section, the overall effectiveness of the technology packages vis-à-vis their effectiveness when adopted individually is described. Section III.D.4 describes EPA's OMEGA model and its approach to estimating how manufacturers will add technology to their vehicles in order to comply with potential CO_2 emission standards. Section III.D.5 presents the results of the OMEGA modeling, namely the level of technology added to manufacturers' vehicles and the cost of adding that technology. Section III.D.6 discusses the appropriateness (or lack of appropriateness) of the alternative standards in relation to those proposed. Further technical detail on all of these issues can be found in the Draft Joint Technical Support Document as well as EPA's Regulatory Impact Analysis.

1. How did EPA develop a reference and control fleet for evaluating standards?

In order to calculate the impacts of this proposal, it is necessary to project the GHG emissions characteristics of the future vehicle fleet absent the proposed regulation. EPA and NHTSA develop this projection using a three step process. (1) Develop a set of detailed vehicle characteristics and sales for a specific model year (in this case, 2008).[328] This is called the baseline fleet. (2) Adjust the sales of this baseline fleet using projections made by the Energy Information Administration (EIA) and CSM to account for projected sales volumes in future MYs absent future regulation.[329] (3) Apply fuel saving and emission control technology to these vehicles to the extent necessary for manufacturers to comply with the existing 2016 standards and the proposed standards.

Thus, the analyzed fleet differs from the MY 2008 baseline fleet in both the level of technology utilized and in terms of the sales of any particular vehicle. A similar method is used to analyze both reference and control cases, with the major distinction being the stringency of the standards.

EPA and NHTSA perform steps one and two above in an identical manner. The development of the characteristics of the baseline 2008 fleet and the sales adjustment to match AEO and CSM forecasts is described in Section II.B above and in greater detail in Chapter 1 of the joint TSD. The two agencies perform step three in a conceptually identical manner, but each agency utilizes its own vehicle technology and emission model to project the technology needed to comply with the reference and proposed standards. Further, each agency evaluates its own proposed and MY 2016 standards; neither NHTSA nor EPA evaluated the other agency's standard in this proposal.[330]

The use of MY 2008 vehicles in our fleet projections includes vehicle models which already have or will be discontinued by the time this rule takes effect and will be replaced by more advanced vehicle models. However, we believe that the use of MY 2008 vehicle designs is still the most appropriate approach available for this proposal.[331] First, as discussed in Section II.B above, the designs of these MYs 2017–2025 vehicles at the level of detail required for emission and cost modeling are not publically available, and in many cases, do not yet exist. Even manufacturers' confidential descriptions of these vehicle designs are usually not of sufficient detail to facilitate the level of technology and emission modeling performed by both agencies. Second, steps two and three of the process used to create the reference case fleet adjust both the sales and technology of the 2008 vehicles. Thus, our reference fleet reflects the extent that completely new vehicles are expected to shift the light vehicle market in terms of both segment and manufacturer. Also, by adding technology to facilitate compliance with the MY 2016 standards, we account for the vast majority of ways in which these new vehicles will differ from their older counterparts.

a. Reference Fleet Scenario Modeled

EPA projects that in the absence of the proposed GHG and CAFE standards, the reference case fleet in MY 2017–2025 would have fleetwide GHG emissions performance no better than that projected to be necessary to meet the MY 2016 standards. While it is not possible to know with certainty the future fleetwide GHG emissions performance in the absence of more stringent standards, EPA believes that this approach is the most reasonable projection for developing the reference case fleet for MYs 2017–2025. One important element supporting the proposed approach is that AEO2011 projects relatively stable gasoline prices over the next 15 years. The average actual price in the U.S. for the first nine months of 2011 for gasoline was $3.57 per gallon ($3.38 in 2009 dollars).[332] However, the AEO2011 reference case projects a price of $2.80 per gallon (in 2009 dollars) AEO2011 projects prices to be $3.25 in 2017, rising slightly to $3.54 per gallon in 2025 (which is less than a 4 cent per year increase on average). Based on these fuel price projections, the reference fleet for MYs 2017–2025 should correspond to a time period where there is a stable, unchanging GHG standard, and essentially stable gasoline prices.

EPA reviewed the historical record for similar periods when we had stable fuel economy standards and stable gasoline

[328] As discussed in TSD Chapter 1, and in Section II.B.2, the agencies will consider using Model Year 2010 for the final rule, based on availability and an analysis of the data representativeness.

[329] See generally Chapter 1 of the Joint TSD for details on development of the baseline fleet, and Section III.H.1 for a discussion of the potential sales impacts of this proposal.

[330] While the MY 2012–2016 standards are largely similar, some important differences remain. See 75 FR at 25342.

[331] See section II.B.2 concerning the selection of MY 2008 as the appropriate baseline.

[332] The Energy Information Administration estimated the average regular unleaded gasoline price in the U.S. for the first nine months of 2011 was $3.57.

prices. EPA maintains, and publishes every year, the seminal reference on new light-duty vehicle CO_2 emissions and fuel economy.[333] This report contains very detailed data from MYs 1975–2010. There was an extended 18-year period from 1986 through 2003 during which CAFE standards were essentially unchanged,[334] and gasoline prices were relatively stable and remained below $1.50 per gallon for almost the entire period. The 1975–1985 and 2004–2010 timeframes are not relevant in this regard due to either rising gasoline prices, rising CAFE standards, or both. Thus, the 1986–2003 time frame is an excellent analogue to the period out to MY 2025 during which AEO projects relatively stable gasoline prices. EPA staff have analyzed the fuel economy trends data from the 1986–2003 timeframe (during which CAFE standards did not vary by footprint) and have drawn three conclusions: (1) there was a small, industry-wide, average over-compliance with CAFE on the order of 1–2 mpg or 3–4%, (2) almost all of this industry-wide over-compliance was from 3 companies (Toyota, Honda, and Nissan) that routinely over-complied with the universal CAFE standards simply because they produced smaller and lighter vehicles relative to the industry average, and (3) full line car and truck manufacturers, such as General Motors, Ford, and Chrysler, which produced larger and heavier vehicles relative to the industry average and which were constrained by the universal CAFE standards, rarely over-complied during the entire 18-year period.[335]

Since the MY 2012–2016 standards are footprint-based, every major manufacturer is expected to be constrained by the new standards in 2016 and manufacturers of small vehicles will not routinely over-comply as they had with the past universal standards.[336] Thus, the historical evidence and the footprint-based design of the 2016 GHG emissions and CAFE standards strongly support the use of a reference case fleet where there are no further fuel economy improvements beyond those required by the MY 2016 standards. There are additional factors that reinforce the historical evidence. While it is possible that one or two companies may over-comply, any voluntary over-compliance by one company would generate credits that could be sold to other companies to substitute for their more expensive compliance technologies; this ability to buy and sell credits could eliminate any over-compliance for the overall fleet.[337] NHTSA also evaluated EIA assumptions and inputs employed in the version of NEMS used to support AEO 2011 and found, based on this analysis, that when fuel economy standards were held constant after MY 2016, EIA appears to forecast market-driven levels of over- and under-compliance generally consistent with a CAFE model analysis using a flat, 2016-based reference case fleet. From a consumer market driven perspective, while there is considerable evidence that many consumers now care more about fuel economy than in past decades, the 2016 compliance level is projected to be several mpg higher than that being demanded in the market today.[338] On the other hand, some manufacturers have already announced plans to introduce technology well beyond that required by the 2016 MY GHG standards.[339] However, it is difficult, if not impossible, to separate future fuel economy improvements made for marketing purposes from those designed to efficiently plan for compliance with anticipated future CAFE or CO_2 emission standards, *i.e.,* some manufacturers may have made public statements about higher mpg levels in the future in part because of the expectation of higher future standards.

All estimates of actual GHG emissions and fuel economy performance in 2016 or other future years are projections, and it is plausible that actual GHG emissions and fuel economy performance in 2016 and later years, absent more stringent standards, could be worse than projected if there are shifts from car market share to truck market share, or to higher footprint levels. For example, average fuel economy performance levels decreased over the period from 1986–2003 even as car CAFE standards were stable and truck CAFE levels rose slightly.[340] On the other hand, it is also possible that future GHG emissions and fuel economy performance could be better than MY2016 levels if there are shifts from trucks to cars, or to lower footprint levels. While EPA has not performed a quantified sensitivity assessment for this proposal, EPA believes that a reasonable range for a sensitivity analysis would evaluate over or under compliance on the order of a few percent which EPA projects would have, at most, a small impact on projected program costs and benefits.

Based on this assessment, the EPA reference case fleet is estimated through the target curves defined in the MY 2016 rulemaking applied to the projected MYs 2017–2025 fleet.[341] As in the previous rulemaking, EPA assumes that manufacturers make use of 10.2 grams of air conditioning credits on cars and 11.5 on light trucks, or an average of approximately 11 grams on the U.S. fleet and the technology for doing so is included in the reference case (Section III.C).

b. Control Scenarios Modeled

For the control scenario, EPA modeled the proposed standard curves discussed in Section III.B, as well as the alternative scenarios discussed in III.D.6. Other flexibilities are accounted for in the analysis. The air conditioning credits modeled are discussed in III.D.2. Air conditioning credits (both leakage and efficiency) are included in the cost and technology analysis described below. The compliance value of 0 g/mi for PHEVs and EVs are also included. However, off-cycle credits, PH/EV multipliers through MY 2021, pickup truck credits, flexible fuel, and carry forward/back credits are not included explicitly in the cost analysis. These flexibilities will offer the manufacturers more compliance options. Moreover, the overall cost analysis includes small volume manufacturers in the fleet, which would have company specific standards assuming this part of the proposal is finalized (see section III.C). As we expect all of these flexibilities together to only have a small impact on the fleet compliance costs on average, we will re-evaluate including them in the final rule analysis.

c. Vehicle Groupings Used

In order to create future technology projections and enable compliance with the modeled standards, EPA aggregates vehicle sales by a combination of manufacturer, vehicle platform, and engine design for the OMEGA model. As

[333] Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2010, November 2010, available at *http://www.epa.gov/otaq/fetrends.htm*.

[334] There are no EPA LD GHG emissions regulations prior to MY 2012.

[335] See Regulatory Impact Analysis, Chapter 3.

[336] With the notable exception of manufacturers who only market electric vehicles or other limited product lines.

[337] Oates, Wallace E., Paul R. Portney, and Albert M. McGartland. ''The Net Benefits of Incentive-Based Regulation: A Case Study of Environmental Standard Setting.'' American Economic Review 79(5) (December 1989): 1233–1242.

[338] The average, fleetwide ''laboratory'' or ''unadjusted'' fuel economy value for MY 2010 is 28.3 mpg (see Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010, November 2010, available at *http://www.epa.gov/otaq/fetrends.htm*), 6–7 mpg less than the 34–35 mpg levels necessary to meet the EPA GHG and NHTSA CAFE levels in MY 2016.

[339] For example, Hyundai has made a public commitment to achieve 50 mpg by 2025.

[340] See Regulatory Impact Analysis, Chapter 3.

[341] 75 FR at 25686.

discussed above, manufacturers implement major design changes at vehicle redesign and tend to implement these changes across a vehicle platform (such as large SUV, mid-size SUV, large automobile, etc) at a given manufacturing plant. Because the cost of modifying the engine depends on the valve train design (such as SOHC, DOHC, etc.), the number of cylinders and in some cases head design, the vehicle sales are broken down beyond the platform level to reflect relevant engine differences. The vehicle groupings are shown in Table III–19.

Table III-19 Vehicle Groupings [a]

Vehicle Description	Vehicle Type	Vehicle Description	Vehicle Type
Large SUV (Car) V8+ OHV	13	Large Pickup V8+ DOHC	19
Large SUV (Car) V6 4v	16	Large Pickup V8+ SOHC 3v	14
Large SUV (Car) V6 OHV	12	Large Pickup V8+ OHV	13
Large SUV (Car) V6 2v SOHC	9	Large Pickup V8+ SOHC	10
Large SUV (Car) I4 and I5	7	Large Pickup V6 DOHC	18
Large SUV V8+ DOHC	17	Large Pickup V6 OHV	12
Large SUV V8+ SOHC 3v	14	Large Pickup V6 SOHC 2v	11
Large SUV V8+ OHV	13	Large Pickup I4 S/DOHC	7
Large SUV V8+ SOHC	10	Small Pickup V6 OHV	12
Large SUV V6 S/DOHC 4v	16	Small Pickup V6 2v SOHC	8
Large SUV V6 OHV	12	Small Pickup I4	7
Large SUV V6 SOHC 2v	9	Cargo Van V8+ OHV	13
Large SUV I4/	7	Cargo Van V8+ SOHC	10
Midsize SUV (Car) V6 2v SOHC	8	Cargo Van V6 OHV	12
Midsize SUV (Car) V6 S/DOHC 4v	5	Minivan V6 S/DOHC	16
Midsize SUV (Car) I4	7	Minivan V6 OHV	12
Midsize SUV V6 OHV	12	Minivan I4	7
Midsize SUV V6 2v SOHC	8		
Midsize SUV V6 S/DOHC 4v	5		
Midsize SUV I4 S/DOHC	7		
Small SUV (Car) V6 OHV	12		
Small SUV (Car) V6 S/DOHC	4		
Small SUV (Car) I4	3		
Small SUV V6 OHV	12		

Large Auto V8+ OHV	15	Compact Auto V7+ S/DOHC	6
Large Auto V8+ SOHC	10	Compact Auto V6 OHV	12
Large Auto V8+ DOHC, 4v SOHC	6	Compact Auto V6 S/DOHC 4v	4
Large Auto V6 OHV	12	Compact Auto I5	7
Large Auto V6 SOHC 2/3v	5	Compact Auto I4	2
Midsize Auto V8+ OHV	15	Subcompact Auto V8+ OHV	15
Midsize Auto V8+ SOHC	10	Subcompact Auto V8+ S/DOHC	6
Midsize Auto V7+ DOHC, 4v SOHC	6	Subcompact Auto V6 2v SOHC	8
Midsize Auto V6 OHV	12	Subcompact Auto I5/V6 S/DOHC 4v	4
Midsize Auto V6 2v SOHC	8	Subcompact Auto I4	1
Midsize Auto V6 S/DOHC 4v	5		
Midsize Auto I4	3		

[a]I4 = 4 cylinder engine, I5 = 5 cylinder engine, V6, V7, and V8 = 6, 7, and 8 cylinder engines, respectively, DOHC = Double overhead cam, SOHC = Single overhead cam, OHV = Overhead valve, v = number of valves per cylinder, "/" = and, "+" = or larger.

2. What are the Effectiveness and Costs of CO_2-Reducing Technologies?

EPA and NHTSA worked together to develop information on the effectiveness and cost of most CO_2-reducing and fuel economy-improving technologies. This joint work is reflected in Chapter 3 of the draft Joint TSD and in Section II.D of this preamble. The work on technology cost and effectiveness also includes maximum penetration rates, or ''caps'' for the OMEGA model. These caps are an important input to OMEGA that capture the agencies' analysis concerning the rate at which technologies can be added to the fleet (see Chapter 3.5 of the draft joint TSD for more detail). This preamble section, rather than repeating those details, focuses upon EPA-only technology assumptions, specifically, those relating to air conditioning refrigerant.

EPA expects all manufacturers will choose to use AC improvement credit opportunities as a strategy for complying with the CO_2 standards, and has set the stringency of the proposed standards accordingly (see section II.F above). EPA estimates that the level of the credits earned will increase from 2017 (13 grams/mile) to 2021 (21 grams/mile) as more vehicles in the fleet convert to use of the new alternative refrigerant.[342] By 2021, we project that 100% of the MY 2021 fleet will be using alternative refrigerants, and that credits will remain constant on a car and truck basis until 2025. Note from the table below that costs then decrease from 2021 to 2025 due to manufacturer learning as discussed in Section II of this preamble and in Chapter 3 of the draft joint TSD. A more in-depth discussion of feasibility and availability of low GWP alternative refrigerants, can be found in Section III.C of the Preamble.

[342] See table in III.B.

Table III-20 Total CO_2 Reduction Potential and Costs for A/C Technologies Related to Alternative Refrigerants (Costs in 2009 dollars)

	Technology	2017	2021	2025
Car	Leakage reduction (continued from the 2012-2016 rule)	$3	$3	$3
	Low GWP refrigerant	$17	$57	$49
	Low GWP refrigerant hardware	$4	$16	$15
	Total	$23	$76	$67
Truck	Leakage reduction (continued from the 2012-2016 rule)	$1	$3	$3
	Low GWP refrigerant	$0	$57	$49
	Low GWP refrigerant hardware	$0	$16	$15
	Total	$1	$76	$67
Fleet	Total	$24	$76	$67

Note that the costs shown in Table III-20 do not include maintenance savings that would be expected from the new AC systems. Further, EPA does not include AC-related maintenance savings in our cost and benefit analysis presented in Section III.H. EPA discusses the likely maintenance savings in Chapter 5 of the draft joint TSD, though these savings are not included in our final cost estimates for the final rule. EPA requests comment on and information regarding maintenance costs (and savings) due to new technologies included in this proposal.

Additionally, by MY 2019, EPA estimates that 100% of the A/C efficiency improvements will by fully phased-in. However 85% of these costs are already in the reference fleet, as this is the level of penetration assumed in the 2012–2016 final rule. The penetration of A/C costs for this proposal can be found in Chapter 5 of the draft joint TSD.

3. How were technologies combined into ''Packages'' and what is the cost and effectiveness of packages?

Individual technologies can be used by manufacturers to achieve incremental CO_2 reductions. However, as discussed extensively in the MYs 2012–2016 Rule, EPA believes that manufacturers are more likely to bundle technologies into ''packages'' to capture synergistic aspects and reflect progressively larger CO_2 reductions with additions or changes to any given package. In this manner, and consistent with the concept of a redesign cycle, manufacturers can optimize their available resources, including engineering, development, manufacturing and marketing activities to create a product with multiple new features. Therefore, the approach taken here is to group technologies into packages of increasing cost and effectiveness.

EPA built unique technology packages for each of 19 ''vehicle types,'' which, as in the MYs 2012–2016 rule and the Interim Joint TAR, provides sufficient resolution to represent the technology of the entire fleet. This was the result of analyzing the existing light duty fleet with respect to vehicle size and powertrain configurations. All vehicles, including cars and trucks, were first distributed based on their relative size, starting from compact cars and working upward to large trucks. Next, each vehicle was evaluated for powertrain, specifically the engine size (I4, V6, and V8) then by valvetrain configuration (DOHC, SOHC, OHV), and finally by the number of valves per cylinder. For purposes of calculating some technology costs and effectiveness values, each of these 19 vehicle types is mapped into one of seven classes of vehicles: Subcompact, Small car, Large car, Minivan, Minivan with towing, Small truck, and Large truck.[343] We believe that these seven vehicle classes, along with engine cylinder count, provide adequate representation for the cost basis associated with most technology application. Note also that these 19 vehicle types span the range of vehicle footprints—smaller footprints for smaller vehicles and larger footprints for larger vehicles—which served as the basis for the 2012–2016 GHG standards and the standards in this proposal. A detailed table showing the 19 vehicle types, their baseline engines and their

[343] Note that, for the current assessment and representing an update since the 2010 TAR, EPA has created a new vehicle class called ''minivan with towing'' which allows for greater differentiation of costs for this popular class of vehicles (such as the Ford Edge, Honda Odyssey, Jeep Grand Cherokee).

descriptions is contained in Table III–19 and in Chapter 1 of EPA's draft RIA.

Within each of the 19 vehicle types, multiple technology packages were created in increasing technology content resulting in increasing effectiveness. As stated earlier, with few exceptions, each package is meant to provide equivalent driver-perceived performance to the baseline package. Note that we refer throughout this discussion of package building to a ''baseline'' vehicle or a ''baseline'' package. This should not be confused with the baseline fleet, which is the fleet of roughly 16 million 2008MY individual vehicles comprised of over 1,100 vehicle models. In this discussion, when we refer to ''baseline'' vehicle we refer to the ''baseline'' configuration of the given vehicle type. So, we have 19 baseline vehicles in the context of building packages. Each of those 19 baseline vehicles is equipped with a port fuel injected engine and a 4 speed automatic transmission. The valvetrain configuration and the number of cylinders changes for each vehicle type in an effort to encompass the diversity in the 2008 baseline fleet as discussed above. In short, while the baseline vehicle that defines the vehicle type is relevant when discussing the package building process, the baseline and reference case fleets of real vehicles are not relevant to the discussion here. We describe this in more detail in Chapter 1 of EPA's draft RIA.

To develop a set of packages as OMEGA inputs, EPA builds packages consisting of every legitimate permutation of technology available, subject to constraints.[344] This ''preliminary-set'' of packages consists of roughly 2,000 possible packages of technologies for each of 19 vehicle types, or nearly 40,000 packages in all. The cost of each package is determined by adding the cost of each individual technology contained in the package for the given year of interest. The effectiveness of each package is determined in a more deliberate manner; one cannot simply add the effectiveness of individual technologies to arrive at a package-level effectiveness because of the synergistic effects of technologies when grouped with other technologies that seek to improve the same or similar efficiency loss mechanism. As an example, the benefits of the engine and transmission technologies can usually be combined multiplicatively,[345] but in some cases, the benefit of the transmission-related technologies overlaps with the engine technologies. This occurs because the transmission technologies shift operation of the engine to more efficient locations on the engine map by incorporating more ratio selections and a wider ratio span into the transmissions. Some of the engine technologies have the same goal, such as cylinder deactivation, advanced valvetrains, and turbocharging. In order to account for this overlap and avoid over-estimating emissions reduction effectiveness, EPA uses an engineering approach known as the lumped-parameter technique. The results from this approach were then applied directly to the vehicle packages. The lumped-parameter technique is well documented in the literature, and the specific approach developed by EPA is detailed in Chapter 3 (Section 3.3.2) of the draft joint TSD as well as Chapter 1 of EPA's draft RIA.

Table III–21 presents technology costs for a subset of the more prominent technologies in our analysis (note that all technology costs are presented in Chapter 3 of the draft Joint TSD and in Chapter 1.2 of EPA's draft RIA). Table III–21 includes technology costs for a V6 dual overhead cam midsize or large car and a V8 overhead valve large pickup truck. This table is meant to illustrate how technology costs are similar and/or different for these two large selling vehicle classes and how the technology costs change over time due to learning and indirect cost changes as described in section II.D of this preamble and at length in Chapter 3.2 of the draft Joint TSD. Note that these costs are not package costs but, rather, individual technology costs. We present package costs for the V6 midsize or large car in Table III–22, below.

[344] Example constraints include the requirement for stoichiometric gasoline direct injection on every turbocharged and downsized engine and/or any 27 bar BMEP turbocharged and downsized engine must also include cooled EGR. Some constraints are the result of engineering judgment while others are the result of effectiveness value estimates which are tied to specific combinations of technologies.

[345] For example, if an engine technology reduces CO_2 emissions by five percent and a transmission technology reduces CO_2 emissions by four percent, the benefit of applying both technologies is 8.8 percent (100% − (100% − 4%) * (100% − 5%)).

Table III-21 Total Costs of Select Technologies for V6 Midsize or Large Car and V8 Large Pickup Truck (2009 dollars)

Vehicle Class & Base Engine	Technology	2017 MY	2021 MY	2025 MY
Midsize/Large car V6 DOHC 4 valves/cylinder Port fuel injected 4 speed auto trans	Dual cam phasing on V6	$201	$175	$165
	Dual cam phasing on I4 (used when downsized)	$94	$81	$77
	Stoichiometric gasoline direct injection on V6	$413	$359	$338
	Stoichiometric gasoline direct injection on I4 (used when downsized)	$274	$238	$224
	18-bar BMEP with downsize from V6 DOHC to I4 DOHC	$248	$163	$170
	24-bar BMEP with downsize from V6 DOHC to I4 DOHC	$509	$448	$382
	Cooled EGR on I-configuration (used when downsized)	$303	$285	$247
	Advanced diesel	$3,595	$3,120	$2,936
	8 speed dual clutch transmission (wet)	$47	$44	$38
	High efficiency gearbox	$248	$225	$200
	Aerodynamic treatments (active, Aero2)	$210	$195	$173
	Stop-start (12 Volt)	$446	$376	$343
	P2 hybrid electric technology[a]	$4,196	$3,521	$3,121
	Plug-in hybrid technology with 20 mile range[a]	$15,448	$11,719	$9,657
	Electric vehicle technology with 75 mile range[a]	$20,727	$15,458	$11,430
Large pickup truck V8 OHV 2 valves/cylinder Port fuel injected	Dual cam phasing on V6 (used when downsized)	$201	$175	$165
	Stoichiometric gasoline direct injection on V8	$497	$431	$406
	Stoichiometric gasoline direct injection on V6 (used when downsized)	$413	$359	$338

4 speed auto trans	18-bar BMEP with downsize from V8 OHV to V6 DOHC	$1,323	$1,138	$1,067
	24-bar BMEP with downsize from V8 OHV to V6 DOHC	$1,762	$1,618	$1,426
	Cooled EGR on V-configuration	$303	$285	$247
	Advanced diesel	$4,114	$3,570	$3,359
	8 speed automatic transmission	$61	$53	$50
	High efficiency gearbox	$248	$225	$200
	Aerodynamic treatments (active, Aero2)	$210	$195	$173
	Stop-start (12 Volt)	$490	$413	$376
	P2 hybrid electric technology[a]	$4,417	$3,717	$3,282

[a] Assumes application of weight reduction technology resulting in 10% weight reduction before adding back the weight of batteries and motors resulting in a net weight reduction less than 10% (see Chapter 3.4.3.8 of the draft Joint TSD for more details).

Table III–22 presents the cost and effectiveness values from a 2025MY master-set of packages used in the OMEGA model for EPA's vehicle type 5, a midsize or large car class equipped with a V6 engine. Similar packages were generated for each of the 19 vehicle types and the costs and effectiveness estimates for each of those packages are discussed in detail in Chapter 1 of EPA's draft RIA.

As detailed in Chapter 1 of EPA's draft RIA, this preliminary-set of packages is then ranked according to technology application ranking factors (TARFs) to eliminate packages that are not as cost-effective as others.[346] The result of this TARF ranking process is a ''ranked-set'' of roughly 500 packages for use as OMEGA inputs, or roughly 25 per vehicle type. EPA prepares a ranked set of packages for any MY in which OMEGA is run,[347] the initial packages represent what we believe a manufacturer will most likely implement on all vehicles, including lower rolling resistance tires, low friction lubricants, engine friction reduction, aggressive shift logic, early torque converter lock-up, improved electrical accessories, and low drag brakes (to the extent not reflected in the baseline vehicle).[348] Subsequent packages include gasoline direct injection, turbocharging and downsizing, and more advanced transmission technologies such as six and eight speed dual-clutch transmissions and 6 and 8 speed automatic transmissions. The most technologically advanced packages within a vehicle type include the hybrids, plug-in hybrids and electric vehicles. Note that plug-in hybrid and electric vehicle packages are only modeled for the non-towing vehicle types, in order to better maintain utility. We request comment on this decision and whether or not we should perhaps consider plug-in hybrids for towing vehicle types.

[346] The Technology Application Ranking Factor (TARF) is discussed further in III.D.5.

[347] Note that a ranked-set of package is generated for any year for which OMEGA is run due to the changes in costs and maximum penetration rates. EPA's draft RIA chapter 3 contains more details on the OMEGA modeling and draft Joint TSD Chapter 3 has more detail on both costs changes over time and the maximum penetration limits of certain technologies.

[348] When making reference to low friction lubricants, the technology being referred to is the engine changes and possible durability testing that would be done to accommodate the low friction lubricants, not the lubricants themselves.

Table III-22 CO_2 Reducing Technology Vehicle Packages for a V6 Midsize or Large Car Effectiveness and Costs in the 2025MY (Costs in 2009 dollars)

Pkg#	Engine & Vehicle technologies	Trans	Elec-trical	Mass Rdxn	Cost	Effect-iveness
500	3.3L 4V DOHC V6	4sp AT	12V	base	$0	0.0%
501	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC +EPS +Aero1 +LRRT1 +HEG	6sp DCT-wet	12V	5%	$646	27.3%
502	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC +EPS +Aero1 +LRRT1 +HEG	8sp DCT-wet	12V	5%	$760	30.2%
503	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS18	6sp DCT-wet	12V	5%	$1,058	37.4%
504	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	5%	$1,172	39.4%
505	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	5%	$1,386	42.6%
506	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	10%	$1,507	44.2%
509	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	15%	$1,741	45.8%
507	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24	8sp DCT-wet	12V	10%	$1,719	46.1%
511	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	20%	$2,048	47.4%
513	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS18	8sp DCT-wet	12V	20%	$2,128	47.7%
508	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR	8sp DCT-wet	12V	10%	$1,966	48.0%
515	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS18	8sp DCT-wet	12V	20%	$2,259	48.2%
516	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS18	8sp DCT-wet	12V S-S	20%	$2,602	48.7%

519	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DSL-Adv +SAX	8sp DCT-wet	12V	20%	$4,673	49.4%
510	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR	8sp DCT-wet	12V	15%	$2,200	49.5%
512	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR	8sp DCT-wet	12V	20%	$2,507	51.0%
514	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS24 +EGR	8sp DCT-wet	12V	20%	$2,588	51.3%
517	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR	8sp DCT-wet	12V S-S	20%	$2,931	51.8%
518	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS27 +EGR	8sp DCT-wet	12V S-S	20%	$3,356	52.2%
520	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +HEV	8sp DCT-wet	HEV	20%	$5,353	59.3%
521	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +HEV +SAX	8sp DCT-wet	HEV	20%	$5,433	59.6%
522	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20	8sp DCT-wet	EV	20%	$12,485	75.2%
523	4V DOHC V6 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40	8sp DCT-wet	EV	20%	$15,670	84.7%
524	EV75 mile +IACC2 +Aero2 +LRRT2 +EPS	N/A	EV	20%	$12,908	100%
525	EV100 mile +IACC2 +Aero2 +LRRT2 +EPS	N/A	EV	20%	$14,643	100%
526	EV150 mile +IACC2 +Aero2 +LRRT2 +EPS	N/A	EV	20%	$20,280	100%

Aero=aerodynamic treatments;ASL=aggressive shift logic; AT=auto trans; ATKCS=Atkinson-cycle; DCP=dual cam phasing; DCT=dual clutch trans; DSL-Adv=advanced diesel; DOHC=dual overhead cam; EFR=engine friction reduction; EGR=exhaust gas recirculation; EPS=electric power steering; EV=electric vehicle; GDI=stoich gasoline direct injection; HEG=high efficiency gearbox; HEV=hybrid EV; IACC=improved accessories; LDB=low drag brakes; LRRT=lower rolling resistance tires; REEV=range extended EV or plug-in HEV; SAX=secondary axle disconnect; S-S=stop-start; TDS18/24/27=turbocharged & downsized 18 bar BMEP/24 bar BMEP/27 bar BMEP.

"1" and "2" suffixes to certain technologies indicate the first level versus the second level of the technology as described in Chapter 3 of the draft joint TSD.

4. How does EPA project how a manufacturer would decide between options to improve CO_2 performance to meet a fleet average standard?

As discussed, there are many ways for a manufacturer to reduce CO_2-emissions from its vehicles. A manufacturer can choose from a myriad of CO_2 reducing technologies and can apply one or more of these technologies to some or all of its vehicles. Thus, for a variety of levels of CO_2 emission control, there are an almost infinite number of technology combinations which produce a desired CO_2 reduction. As noted earlier, EPA used the same model used in the MYs 2012–2016 Rule, the OMEGA model, in order to make a reasonable estimate of how manufacturers will add technologies to vehicles in order to meet a fleet-wide CO_2 emissions level. EPA has described OMEGA's specific methodologies and algorithms previously in the model documentation,[349] makes the model publically available on its Web site,[350] and has recently peer reviewed the model.[351]

The OMEGA model utilizes four basic sets of input data. The first is a description of the vehicle fleet. The key pieces of data required for each vehicle are its manufacturer, CO_2 emission level, fuel type, projected sales and footprint. The model also requires that each vehicle be assigned to one of the 19 vehicle types, which tells the model which set of technologies can be applied to that vehicle. (For a description of how the 19 vehicle types were created, see Section III.D.3 above.) In addition, the degree to which each baseline vehicle already reflects the effectiveness and cost of each available technology must also be input. This avoids the situation, for example, where the model might try to add a basic engine improvement to a current hybrid vehicle. Except for this type of information, the development of the required data regarding the reference fleet was described in Section III.D.1 above and in Chapter 1 of the Joint TSD.

The second type of input data used by the model is a description of the technologies available to manufacturers, primarily their cost and effectiveness. This information was described above as well as in Chapter 3 of the draft Joint TSD and Chapter 1 of EPA's draft RIA. In all cases, the order of the technologies or technology packages for a particular vehicle type is determined by the model user prior to running the model. The third type of input data describes vehicle operational data, such as annual vehicle scrappage rates and mileage accumulation rates, and economic data, such as fuel prices and discount rates. These estimates are described in Section II.E above, Section III.H below and Chapter 4 of the Joint TSD.

The fourth type of data describes the CO_2 emission standards being modeled. These include the MY 2016 standards, proposed MY 2021 and proposed MY 2025 standards. As described in more detail below, the application of A/C technology is evaluated in a separate analysis from those technologies which impact CO_2 emissions over the 2-cycle test procedure. Thus, for the percent of vehicles that are projected to achieve A/C related reductions, the CO_2 credit associated with the projected use of improved A/C systems is used to adjust the final CO_2 standard which will be applicable to each manufacturer to develop a target for CO_2 emissions over the 2-cycle test which is assessed in our OMEGA modeling. As an example, on an industry wide basis, EPA projects that manufacturers will generate 11 g/mi of A/C credit in 2016. Thus, the 2016 CO_2 target in OMEGA was approximately eleven grams less stringent for each manufacturer than predicted by the curves. Similar adjustments were made for the control cases (*i.e.*, the A/C credits allowed by the rule are accounted for in the standards), but for a larger amount of A/C credit (approximately 25 grams).

As mentioned above for the market data input file utilized by OMEGA, which characterizes the vehicle fleet, our modeling accounts for the fact that many 2008 MY vehicles are already equipped with one or more of the technologies discussed in Section III.D.2 above. Because of the choice to apply technologies in packages, and because 2008 vehicles are equipped with individual technologies in a wide variety of combinations, accounting for the presence of specific technologies in terms of their proportion of package cost and CO_2 effectiveness requires careful, detailed analysis.

Thus, EPA developed a method to account for the presence of the combinations of applied technologies in terms of their proportion of the technology packages. This analysis can be broken down into four steps

The first step in the updated process is to break down the available GHG control technologies into five groups: (1) Engine-related, (2) transmission-related, (3) hybridization, (4) weight reduction and (5) other. Within each group, each individual technology was given a ranking which generally followed the degree of complexity, cost and effectiveness of the technologies within each group. More specifically, the ranking is based on the premise that a technology on a 2008 baseline vehicle with a lower ranking would be replaced by one with a higher ranking which was contained in one of the technology packages which we included in our OMEGA modeling. The corollary of this premise is that a technology on a 2008 baseline vehicle with a higher ranking would be not be replaced by one with an equal or lower ranking which was contained in one of the technology packages which we chose to include in our OMEGA modeling. This ranking scheme can be seen in an OMEGA pre-processor (the TEB/CEB calculation macro), available in the docket.

In the second step of the process, these rankings were used to estimate the complete list of technologies which would be present on each baseline vehicle after the application of a technology package. In other words, this step indicates the specific technology on each baseline vehicle after a package has been applied to it. EPA then used the lumped parameter model to estimate the total percentage CO_2 emission reduction associated with the technology present on the baseline vehicle (termed package 0), as well as the total percentage reduction after application of each package. A similar approach was used to determine the total cost of all of the technology present on the baseline vehicle and after the application of each applicable technology package.

The third step in this process is to account for the degree of each technology package's incremental effectiveness and incremental cost is affected by the technology already present on the baseline vehicle. In this step, we calculate the degree to which a technology package's effectiveness is already present on the baseline vehicle, and produce a value for each package termed the technology effectiveness basis, or TEB. The degree to which a technology package's incremental cost is reduced by technology already present on the baseline vehicle is termed the cost effectiveness basis, or CEB, in the OMEGA model. The equations for calculating these values can be seen in RIA chapter 3.

As described in Section III.D.3 above, technology packages are applied to groups of vehicles which generally represent a single vehicle platform and which are equipped with a single engine size (*e.g.,* compact cars with four cylinder engine produced by Ford). These groupings are described in Table

[349] Previous OMEGA documentation for versions used in MYs 2012–2016 Final Rule (EPA–420–B–09–035), Interim Joint TAR (EPA–420–B–10–042).

[350] *http://www.epa.gov/oms/climate/models.htm.*

[351] EPA–420–R–09–016, September 2009.

III–19. Thus, the fourth step is to combine the fractions of the CEB and TEB of each technology package already present on the individual MY 2008 vehicle models for each vehicle grouping. For cost, percentages of each package already present are combined using a simple sales-weighting procedure, since the cost of each package is the same for each vehicle in a grouping. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO_2 emission level. This appropriately weights vehicle models with either higher sales or CO_2 emissions within a grouping. Once again, this process prevents the model from adding technology which is already present on vehicles, and thus ensures that the model does not double count technology effectiveness and cost associated with complying with the modeled standards.

Conceptually, the OMEGA model begins by determining the specific CO_2 emission standard applicable for each manufacturer and its vehicle class (*i.e.,* car or truck). Since the proposal allows for averaging across a manufacturer's cars and trucks, the model determines the CO_2 emission standard applicable to each manufacturer's car and truck sales from the two sets of coefficients describing the piecewise linear standard functions for cars and trucks (*i.e.*, the respective car and truck curves) in the inputs, and creates a combined car-truck standard. This combined standard considers the difference in lifetime VMT of cars and trucks, as indicated in the proposed regulations which govern credit trading between these two vehicle classes (which reflect the final 2012–2016 rules on this point).[352]

As noted above, EPA estimated separately the cost of the improved A/C systems required to generate the credit. In the reference case fleet that complies with the MY 2016 standards, 85% of vehicles are modeled with improved A/C efficiency and leakage prevention technology.

The model then works with one manufacturer at a time to add technologies until that manufacturer meets its applicable proposed standard. The OMEGA model can utilize several approaches to determining the order in which vehicles receive technologies. For this analysis, EPA used a ''manufacturer-based net cost-effectiveness factor'' to rank the technology packages in the order in which a manufacturer is likely to apply them. Conceptually, this approach estimates the cost of adding the technology from the manufacturer's perspective and divides it by the mass of CO_2 the technology will reduce. One component of the cost of adding a technology is its production cost, as discussed above. However, it is expected that new vehicle purchasers value improved fuel economy since it reduces the cost of operating the vehicle. Typical vehicle purchasers are assumed to value the fuel savings accrued over the period of time which they will own the vehicle, which is estimated to be roughly five years. It is also assumed that consumers discount these savings at the same rate as that used in the rest of the analysis (3 or 7 percent).[353] Any residual value of the additional technology which might remain when the vehicle is sold is not considered. The CO_2 emission reduction is the change in CO_2 emissions multiplied by the percentage of vehicles surviving after each year of use multiplied by the annual miles travelled by age.

Given this definition, the higher priority technologies are those with the lowest manufacturer-based net cost-effectiveness value (relatively low technology cost or high fuel savings leads to lower values). Because the order of technology application is set for each vehicle, the model uses the manufacturer-based net cost-effectiveness primarily to decide which vehicle receives the next technology addition. Initially, technology package #1 is the only one available to any particular vehicle. However, as soon as a vehicle receives technology package #1, the model considers the manufacturer-based net cost-effectiveness of technology package #2 for that vehicle and so on. In general terms, the equation describing the calculation of manufacturer-based cost effectiveness is as follows:

$$CostEffManuf_t = \frac{\Delta TechCost - \Delta FS}{\Delta CO_2 x\ VMT_{regulatory}}$$

Where:

$CostEffManuf_t$ = Manufacturer-Based Cost Effectiveness (in dollars per kilogram CO_2),

TechCost = Marked up cost of the technology (dollars),

FS = Difference in fuel consumption due to the addition of technology times fuel price and discounted over the payback period, or the number of years of vehicle use over which consumers value fuel savings when evaluating the value of a new vehicle at time of purchase

dCO_2 = Difference in CO_2 emissions (g/mile) due to the addition of technology

$VMT_{regulatory}$ = the statutorily defined VMT

EPA describes the technology ranking methodology and manufacturer-based cost effectiveness metric in greater detail in the OMEGA documentation.[354]

When calculating the fuel savings in the TARF equation, the full retail price of fuel, including taxes is used. While taxes are not generally included when calculating the cost or benefits of a regulation, the net cost component of the manufacturer-based net cost-effectiveness equation is not a measure of the social cost of this proposed rule, but a measure of the private cost, (*i.e.,* a measure of the vehicle purchaser's willingness to pay more for a vehicle with higher fuel efficiency). Since vehicle operators pay the full price of fuel, including taxes, they value fuel costs or savings at this level, and the manufacturers will consider this when choosing among the technology options.[355]

The values of manufacturer-based net cost-effectiveness for specific

[352] The analysis for the control cases in this proposal was run with slightly different lifetime VMT estimates than those proposed in the regulation. The impact on the cost estimates is small and varies by manufacturer.

[353] While our costs and benefits are discounted at 3% or 7%, the decision algorithm (TARF) used in OMEGA was run at a discount rate of 3%. Given that manufacturers must comply with the standard regardless of the discount rate used in the TARF, this has little impact on the technology projections shown here.

[354] OMEGA model documentation. EPA–420–B–10–042.

[355] This definition of manufacturer-based net cost-effectiveness ignores any change in the residual value of the vehicle due to the additional technology when the vehicle is five years old. Based on historic used car pricing, applicable sales taxes, and insurance, vehicles are worth roughly 23% of their original cost after five years, discounted to year of vehicle purchase at 7% per annum. It is reasonable to estimate that the added technology to improve CO_2 level and fuel economy will retain this same percentage of value when the vehicle is five years old. However, it is less clear whether first purchasers, and thus, manufacturers consider this residual value when ranking technologies and making vehicle purchases, respectively. For this proposal, this factor was not included in our determination of manufacturer-based net cost-effectiveness in the analyses.

technologies will vary from vehicle to vehicle, often substantially. This occurs for three reasons. First, both the cost and fuel-saving component cost, ownership fuel-savings, and lifetime CO_2 effectiveness of a specific technology all vary by the type of vehicle or engine to which it is being applied (*e.g.,* small car versus large truck, or 4-cylinder versus 8-cylinder engine). Second, the effectiveness of a specific technology often depends on the presence of other technologies already being used on the vehicle (*i.e.,* the dis-synergies). Third, the absolute fuel savings and CO_2 reduction of a percentage an incremental reduction in fuel consumption depends on the CO_2 level of the vehicle prior to adding the technology. Chapter 1 of EPA's draft RIA contains further detail on the values of manufacturer-based net cost-effectiveness for the various technology packages.

5. Projected Compliance Costs and Technology Penetrations

The following tables present the projected incremental costs and technology penetrations for the proposed program. Overall projected cost increases are $734 in MY 2021 and $1946 in MY 2025. Relative to the reference fleet complying with of MY 2016 standards, we see significant increases in advanced transmission technologies such as the high efficiency gear box and 8 speed transmissions, as well as more moderate increase in turbo downsized, cooled EGR 24 bar BMEP engines. In the control case, 15 percent of the MY 2025 fleet is projected to be a strong P2 hybrid as compared to 5% in the 2016 reference case. Similarly, 3 percent of the MY 2025 fleet are projected to be electric vehicles while less than 1 percent are projected to be electric vehicles in the reference case. EPA notes that we have projected one potential compliance path for each company and the industry as a whole—this does not mean other potential technology penetrations are not possible, in fact, it is likely that each firm will of course plot their own future course on how to comply. For example, while we show relatively low levels of EV and PHEV technologies may be used to meet the proposed standards, several firms have announced plans to aggressively pursue EV and PHEV technologies and thus the actual penetration of those technologies may turn out to be much higher than the prediction we present here.

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Table III-23 Total Costs per Vehicle by Company, Incremental to the 2016 Standards (2009$)

Company	2021			2025		
	Cars	Trucks	Fleet	Cars	Trucks	Fleet
BMW	$945	$915	$937	$2,251	$1,959	$2,174
Chrysler/Fiat	$569	$853	$698	$1,914	$2,212	$2,043
Daimler	$1,949	$956	$1,702	$2,931	$1,952	$2,707
Ferrari[356]	$6,351	$0	$6,351	$7,109	$0	$7,109
Ford	$655	$776	$696	$2,051	$2,463	$2,178
Geely-Volvo	$2,035	$1,086	$1,741	$3,228	$2,040	$2,876
GM	$502	$680	$590	$2,209	$1,834	$2,030
Honda	$467	$756	$556	$1,452	$1,937	$1,595
Hyundai	$614	$884	$669	$1,677	$1,988	$1,739
Kia	$483	$927	$582	$1,442	$1,675	$1,491
Mazda	$924	$897	$919	$2,196	$1,806	$2,131
Mitsubishi	$813	$998	$877	$2,114	$2,171	$2,133
Nissan	$759	$662	$729	$1,997	$2,212	$2,060
Porsche	$5,455	$1,328	$4,482	$5,827	$2,054	$5,012
Spyker-Saab	$3,335	$898	$2,986	$4,001	$1,468	$3,670
Subaru	$1,017	$922	$994	$2,236	$2,087	$2,202
Suzuki	$1,160	$1,000	$1,132	$2,307	$1,832	$2,225
Tata-JLR	$2,220	$1,648	$1,935	$3,255	$2,653	$2,976
Toyota	$332	$713	$481	$1,399	$1,631	$1,483
VW	$1,624	$797	$1,457	$2,618	$2,048	$2,506
Fleet	$718	$764	$734	$1,942	$1,954	$1,946

Costs for Aston Martin, Lotus and Tesla are not included here but can be found in EPA's draft RIA.

Costs include stranded capital and A/C-related costs.

[356] Note that Ferrari is shown as a separate entity in the table above but could be combined with other Fiat-owned companies for purposes of GHG compliance at the manufacturer's discretion. Also, in Section III.B., EPA is requesting comment on the concept of allowing companies that are able to demonstrate "operational independence" to be eligible for SVM alternative standards. However, the costs shown above are based on Ferrari meeting the primary program standards.

Table III-24 Technology Penetrations for the 2021 MY Reference Case – Combined Fleet

	Mass	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	GDI	DSL
BMW	-8%	51%	15%	0%	28%	8%	36%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/ Fiat	-7%	45%	11%	0%	27%	12%	31%	17%	3%	0%	4%	0%	0%	0%	0%	0%	18%	0%	56%	0%
Daimler	-8%	48%	14%	0%	16%	19%	39%	21%	5%	0%	14%	15%	0%	0%	57%	0%	30%	0%	69%	16%
Ferrari	-8%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-7%	52%	12%	0%	30%	12%	29%	16%	6%	0%	10%	2%	0%	0%	0%	0%	21%	0%	63%	0%
Geely- Volvo	-8%	54%	15%	0%	37%	12%	32%	17%	2%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
GM	-7%	37%	8%	0%	38%	18%	20%	11%	3%	0%	6%	0%	0%	0%	0%	0%	21%	0%	46%	0%
Honda	-3%	6%	0%	0%	24%	6%	41%	19%	8%	0%	0%	2%	0%	0%	0%	0%	8%	0%	6%	0%
Hyundai	-3%	28%	0%	0%	24%	11%	32%	17%	6%	0%	0%	0%	0%	0%	0%	0%	4%	0%	28%	0%
Kia	-3%	9%	0%	0%	22%	9%	35%	19%	7%	0%	0%	0%	0%	0%	0%	0%	8%	0%	9%	0%
Mazda	-5%	26%	11%	0%	22%	7%	34%	19%	14%	0%	4%	0%	0%	0%	0%	0%	24%	0%	37%	0%
Mitsubishi	-7%	68%	15%	0%	17%	7%	39%	22%	6%	0%	15%	2%	0%	0%	0%	0%	27%	0%	85%	0%
Nissan	-5%	33%	8%	0%	20%	8%	39%	21%	4%	0%	3%	1%	0%	0%	0%	0%	21%	0%	41%	0%
Porsche	-5%	48%	15%	0%	20%	7%	19%	10%	43%	0%	15%	15%	0%	0%	57%	0%	30%	0%	78%	13%
Spyker- Saab	-8%	57%	15%	0%	19%	4%	41%	23%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-7%	46%	5%	0%	6%	2%	39%	22%	22%	0%	3%	0%	0%	0%	0%	0%	17%	0%	50%	0%
Suzuki	-1%	67%	15%	0%	11%	4%	42%	23%	9%	0%	15%	3%	0%	0%	0%	0%	26%	0%	85%	0%
Tata-JLR	-8%	48%	15%	0%	33%	10%	37%	20%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Toyota	-2%	5%	0%	0%	26%	10%	28%	15%	5%	0%	0%	12%	0%	0%	0%	0%	12%	0%	12%	0%
VW	-7%	50%	15%	0%	22%	6%	40%	21%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%

Fleet	-5%	30%	7%	0%	27%	11%	31%	16%	6%	0%	5%	5%	0%	0%	7%	0%	18%	0%	40%	2%

Mass=true mass reduction; TDS18/24/27=turbocharged & downsized at 18/24/27 bar BMEP; AT=automatic transmission; DCT=dual clutch transmission; MT=manual transmission; HEG=high efficiency gearbox; EGR=cooled exhaust gas recirculation; HEV=hybrid electric vehicle; EV=full electric vehicle; PHEV=plug-in HEV; SS=12V stop-start; LRRT2=lower rolling resistance tires level 2; IACC2=Improved accessories level 2; EFR2=engine friction reduction level 2; GDI=stoichiometric gasoline direct injection; DSL=advanced diesel

Note that technology penetrations for Aston Martin, Lotus and Tesla are not included here but can be found in EPA's draft RIA.

Negative values for Mass Reduction represent percentage of mass removed.

Table III-25 Technology Penetrations for the 2025 MY Reference Case – Combined Fleet

	Mass	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	GDI	DSL
BMW	-8%	51%	15%	0%	28%	8%	36%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/ Fiat	-7%	38%	11%	0%	26%	12%	33%	18%	3%	0%	4%	0%	0%	0%	0%	0%	20%	0%	49%	0%
Daimler	-8%	48%	14%	0%	15%	18%	40%	22%	5%	0%	14%	15%	0%	0%	57%	0%	30%	0%	70%	16%
Ferrari	-8%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-7%	53%	12%	0%	29%	12%	29%	16%	6%	0%	10%	2%	0%	0%	0%	0%	21%	0%	64%	0%
Geely-Volvo	-8%	53%	15%	0%	36%	12%	33%	18%	2%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
GM	-7%	40%	9%	0%	37%	18%	21%	11%	3%	0%	6%	0%	0%	0%	0%	0%	21%	0%	49%	0%
Honda	-3%	4%	0%	0%	23%	5%	42%	19%	8%	0%	0%	2%	0%	0%	0%	0%	8%	0%	4%	0%
Hyundai	-3%	27%	0%	0%	24%	11%	32%	18%	6%	0%	0%	0%	0%	0%	0%	0%	4%	0%	27%	0%
Kia	-3%	6%	0%	0%	21%	8%	36%	20%	7%	0%	0%	0%	0%	0%	0%	0%	9%	0%	6%	0%
Mazda	-5%	25%	11%	0%	22%	7%	34%	19%	15%	0%	4%	0%	0%	0%	0%	0%	25%	0%	36%	0%
Mitsubishi	-7%	68%	15%	0%	16%	6%	40%	22%	6%	0%	15%	2%	0%	0%	0%	0%	27%	0%	85%	0%

Nissan	-5%	33%	7%	0%	20%	8%	39%	21%	4%	0%	3%	1%	0%	0%	0%	0%	21%	0%	40%	0%
Porsche	-5%	48%	15%	0%	19%	6%	20%	11%	44%	0%	15%	15%	0%	0%	57%	0%	30%	0%	78%	13%
Spyker-Saab	-8%	57%	15%	0%	18%	4%	42%	23%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-7%	52%	5%	0%	6%	2%	39%	21%	23%	0%	3%	0%	0%	0%	0%	0%	15%	0%	55%	0%
Suzuki	-1%	67%	15%	0%	11%	4%	42%	23%	9%	0%	15%	3%	0%	0%	0%	0%	26%	0%	85%	0%
Tata-JLR	-8%	48%	15%	0%	32%	9%	38%	21%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Toyota	-2%	3%	0%	0%	25%	9%	36%	9%	5%	0%	0%	12%	0%	0%	0%	0%	12%	0%	11%	0%
VW	-7%	50%	15%	0%	21%	6%	40%	21%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%
Fleet	-5%	30%	6%	0%	26%	11%	33%	15%	6%	0%	5%	5%	0%	0%	7%	0%	18%	0%	39%	2%

Mass=true mass reduction; TDS18/24/27=turbocharged & downsized at 18/24/27 bar BMEP; AT=automatic transmission; DCT=dual clutch transmission; MT=manual transmission; HEG=high efficiency gearbox; EGR=cooled exhaust gas recirculation; HEV=hybrid electric vehicle; EV=full electric vehicle; PHEV=plug-in HEV; SS=12V stop-start; LRRT2=lower rolling resistance tires level 2; IACC2 = improved accessories level 2; EFR2=engine friction reduction level 2; GDI=stoichiometric gasoline direct injection; DSL=advanced diesel

Note that technology penetrations for Aston Martin, Lotus and Tesla are not included here but can be found in EPA's draft RIA.

Negative values for Mass Reduction represent percentage of mass removed.

Table III-26 Technology Penetrations for the 2021 MY Control Case – Combined Fleet

	Mass	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	GDI	DSL
BMW	-9%	49%	25%	2%	5%	21%	13%	52%	8%	59%	28%	30%	1%	0%	0%	75%	80%	59%	99%	0%
Chrysler/ Fiat	-7%	64%	15%	2%	8%	32%	11%	45%	3%	60%	14%	0%	0%	0%	0%	75%	80%	60%	81%	0%
Daimler	-10%	48%	20%	4%	5%	20%	13%	52%	4%	57%	24%	30%	6%	0%	0%	75%	80%	57%	91%	3%
Ferrari	-7%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-8%	75%	16%	3%	8%	32%	10%	42%	6%	59%	18%	2%	0%	0%	0%	74%	79%	59%	94%	0%
Geely- Volvo	-10%	52%	18%	6%	8%	32%	10%	42%	1%	57%	24%	30%	6%	0%	11%	75%	80%	57%	94%	0%
GM	-8%	41%	14%	3%	12%	49%	7%	29%	3%	60%	14%	0%	0%	0%	0%	75%	80%	60%	58%	0%
Honda	-5%	33%	0%	0%	4%	15%	14%	56%	8%	59%	0%	2%	0%	0%	0%	73%	78%	59%	33%	0%
Hyundai	-6%	45%	6%	0%	7%	29%	12%	46%	6%	60%	6%	0%	0%	0%	0%	75%	80%	60%	51%	0%
Kia	-4%	37%	0%	0%	6%	23%	13%	51%	7%	60%	0%	0%	0%	0%	0%	41%	44%	60%	37%	0%
Mazda	-6%	78%	22%	0%	5%	19%	12%	50%	14%	60%	11%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-10%	64%	30%	0%	5%	18%	14%	58%	5%	60%	30%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	68%	14%	1%	5%	21%	14%	56%	4%	60%	15%	1%	0%	0%	0%	75%	80%	60%	83%	0%
Porsche	-5%	24%	25%	4%	5%	19%	9%	36%	21%	54%	29%	30%	11%	11%	16%	75%	80%	54%	86%	3%
Spyker- Saab	-8%	34%	24%	3%	3%	11%	14%	55%	7%	54%	27%	30%	10%	3%	10%	75%	80%	54%	90%	0%
Subaru	-9%	69%	30%	0%	1%	5%	14%	58%	22%	60%	30%	1%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-2%	49%	30%	0%	3%	11%	16%	63%	7%	60%	30%	21%	0%	0%	0%	75%	80%	60%	100%	0%
Tata-JLR	-9%	54%	9%	11%	7%	26%	12%	48%	0%	56%	19%	30%	7%	0%	4%	75%	80%	56%	93%	0%

Toyota	-3%	40%	0%	1%	7%	26%	10%	41%	5%	53%	1%	12%	0%	0%	0%	38%	40%	53%	41%	0%
VW	-8%	42%	27%	1%	4%	16%	13%	54%	8%	57%	29%	30%	5%	0%	0%	75%	80%	57%	95%	0%
Fleet	-6%	50%	11%	2%	7%	28%	11%	44%	6%	58%	12%	7%	1%	0%	0%	66%	71%	58%	65%	0%

Mass=true mass reduction; TDS18/24/27=turbocharged & downsized at 18/24/27 bar BMEP; AT=automatic transmission; DCT=dual clutch transmission; MT=manual transmission; HEG=high efficiency gearbox; EGR=cooled exhaust gas recirculation; HEV=hybrid electric vehicle; EV=full electric vehicle; PHEV=plug-in HEV; SS=12V stop-start; LRRT2=lower rolling resistance tires level 2; IACC2=Improved accessories level 2; EFR2=engine friction reduction level 2; GDI=stoichiometric gasoline direct injection; DSL=advanced diesel

Note that technology penetrations for Aston Martin, Lotus and Tesla are not included here but can be found in EPA's draft RIA.

Negative values for Mass Reduction represent percentage of mass removed.

Table III-27 Technology Penetrations for the 2025 MY Control Case – Combined Fleet

	Mass	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	GDI	DSL
BMW	-10%	8%	58%	6%	0%	26%	0%	59%	7%	92%	64%	34%	8%	0%	0%	100%	100%	92%	92%	0%
Chrysler/ Fiat	-11%	16%	66%	5%	0%	38%	0%	58%	2%	99%	71%	15%	1%	0%	0%	100%	100%	99%	99%	0%
Daimler	-11%	11%	41%	11%	0%	23%	0%	62%	4%	88%	53%	36%	12%	0%	0%	100%	100%	88%	86%	2%
Ferrari	-6%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-11%	18%	56%	9%	0%	39%	0%	51%	4%	95%	65%	19%	4%	0%	0%	99%	99%	95%	95%	0%
Geely- Volvo	-10%	11%	42%	13%	0%	39%	0%	50%	1%	89%	54%	44%	11%	0%	0%	100%	100%	89%	89%	0%
GM	-11%	21%	60%	8%	0%	59%	0%	37%	2%	98%	68%	10%	2%	0%	0%	100%	100%	98%	98%	0%
Honda	-8%	24%	73%	0%	0%	18%	0%	71%	8%	98%	73%	3%	0%	0%	0%	98%	98%	98%	98%	0%
Hyundai	-10%	25%	75%	0%	0%	35%	0%	58%	6%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-7%	39%	61%	0%	0%	27%	0%	66%	7%	100%	42%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Mazda	-8%	6%	73%	0%	0%	23%	0%	65%	11%	98%	73%	19%	2%	0%	0%	100%	100%	98%	98%	0%

Mitsubishi	-12%	8%	70%	0%	0%	21%	0%	69%	4%	95%	70%	17%	5%	0%	0%	100%	100%	95%	95%	0%
Nissan	-7%	13%	69%	3%	0%	25%	0%	69%	3%	98%	72%	20%	2%	0%	0%	100%	100%	98%	98%	0%
Porsche	-5%	8%	35%	7%	0%	21%	0%	42%	19%	83%	41%	34%	17%	10%	1%	100%	100%	83%	83%	0%
Spyker-Saab	-10%	5%	47%	3%	0%	13%	0%	66%	6%	84%	50%	32%	16%	5%	2%	100%	100%	84%	84%	0%
Subaru	-10%	6%	71%	0%	0%	6%	0%	72%	19%	96%	71%	19%	4%	0%	0%	100%	100%	96%	96%	0%
Suzuki	-3%	3%	67%	0%	0%	14%	0%	72%	6%	92%	67%	22%	8%	0%	0%	100%	100%	92%	92%	0%
Tata-JLR	-9%	15%	16%	29%	0%	31%	0%	58%	0%	88%	45%	43%	12%	0%	0%	100%	100%	88%	88%	0%
Toyota	-7%	23%	60%	4%	0%	30%	0%	53%	5%	88%	64%	13%	0%	0%	0%	88%	88%	88%	88%	0%
VW	-8%	6%	60%	3%	0%	20%	0%	63%	8%	90%	62%	31%	10%	1%	0%	100%	100%	90%	90%	0%
Fleet	-9%	19%	62%	5%	0%	34%	0%	55%	5%	94%	66%	15%	3%	0%	0%	97%	97%	94%	94%	0%

Mass=true mass reduction; TDS18/24/27=turbocharged & downsized at 18/24/27 bar BMEP; AT=automatic transmission; DCT=dual clutch transmission; MT=manual transmission; HEG=high efficiency gearbox; EGR=cooled exhaust gas recirculation; HEV=hybrid electric vehicle; EV=full electric vehicle; PHEV=plug-in HEV; SS=12V stop-start; LRRT2=lower rolling resistance tires level 2; IACC2=Improved accessories level 2; EFR2=engine friction reduction level 2; GDI=stoichiometric gasoline direct injection; DSL=advanced diesel

Note that technology penetrations for Aston Martin, Lotus and Tata are not included here but can be found in EPA's draft RIA.

Negative values for Mass Reduction represent percentage of mass removed.

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6. How does the technical assessment support the proposed CO_2 standards as compared to the alternatives has EPA considered?

a. What are the targets and achieved levels for the fleet in this proposal?

In this section EPA analyzes the proposed standards alongside several potential alternative GHG standards.

Table III–28 includes a summary of the proposed standards and the four alternatives considered by EPA for this notice. In this table and for the majority of the data presented in this section, EPA focuses on two specific model years in the 2017–2025 time frame addressed by this proposal. For the purposes of considering alternatives, EPA assessed these two specific years as being reasonably separated in time in order to evaluate a range of meaningfully different standards, rather than analyzing alternatives for each individual model year. After discussing the reasons for selecting the proposed standards rather than any of the alternatives, EPA will describe the specific standard phase-in schedule for the proposal. Table III–28 presents the projected reference case targets for the fleet in 2021 and 2025, that is the estimated industry wide targets that would be required for the projected fleet in those years by the MY 2016 standards.[357] The alternatives, like the proposed standards, account for projected use of A/C related credits. They represent the average targets for cars and trucks projected for the proposed standards and four alternative standards. They do not represent the manner in which manufacturers are projected to achieve compliance with these targets, which includes the ability to transfer credits to and from the car and truck fleets. That is discussed later.

[357] The reference case targets for 2021 and 2025 may be different even though the footprint based standards are identical (the 2016 curves). This is because the fleet distribution of cars and trucks may change in the intervening years thus changing the targets in 2021 and 2025.

Table III-28 2021 and 2025 Fleet Targets for the Proposal and Alternative Standards

(grams/mile CO_2)

	Car Target	Truck Target	Fleet Target
2021 Proposal	173	249	199
Alternative 1: 2021 Trucks+20	173	270	207
Alternative 2: 2021 Trucks-20	173	230	193
Alternative 3: 2021 Cars+20	193	250	213
Alternative 4: 2021 Cars-20	153	250	187
2021 Reference Case	*225*	*297*	*250*
2025 Proposal	144	203	163
Alternative 1: 2025 Trucks+20	144	223	170
Alternative 2: 2025 Trucks-20	144	183	157
Alternative 3: 2025 Cars+20	164	203	177
Alternative 4: 2025 Cars-20	124	203	150
2025 Reference Case	*225*	*295*	*248*

Alternative 1 and 2 are focused on changes in the level of stringency for just light-duty trucks: Alternative 1 is 20 grams/mile CO_2 less stringent (higher) in 2021 and 2025, and Alternative 2 is 20 grams/mile CO_2 more stringent (lower) in 2021 and 2025. Alternative 3 and 4 are focused on changes in the level of stringency for just passenger cars: Alternative 3 is 20 grams/mile CO_2 less stringent (higher) in 2021 and 2025, and Alternative 4 is 20 grams/mile CO_2 more stringent (lower) in 2021 and 2025. When combined with the sales projections for 2021 and 2025, these alternatives span fleet wide targets with a range of 187–213 g/mi CO_2 in 2021 (equivalent to a range of 42–48 mpge if all improvements were made with fuel economy technologies) and a range of 150–177 g/mi CO_2 in 2025 in 2025 (equivalent to a range of 50–59 mpg if all improvements were made with fuel economy technologies).

Using the OMEGA model, EPA evaluated the proposed standards and each of the alternatives in 2021 and in 2025. It is worth noting that although Alternatives 1 and 2 consider different truck footprint curves compared to the proposal and Alternatives 3 and 4 evaluate different car footprint curves compared to the proposal, in all cases EPA evaluated the alternatives by modeling both the car and truck footprint curves together (which achieve the fleet targets shown in Table III–28) as this is how manufacturers would view the future standards given the opportunity to transfer credits between cars and trucks under the GHG program.[358] A manufacturer's ability to transfer GHG credits between its car and truck fleets without limit does have the effect of muting the "truck" focused and "car" focused nature of the alternatives EPA is evaluating. For example, while Alternative 1 has truck standards

[358] The curves for the alternatives were developed using the same methods as the proposed curves, however with different targets. Thus, just as in the proposed curves, the car and truck curves described in TSD 2 were "fanned" up or down to determine the curves of the alternatives.

projected in 2021 and 2025 to be 20 grams/mile less stringent than the proposed truck standards and the same car standards as the proposed car standards, individual firms may over comply on trucks and under-comply on cars (or vice versa) in order to meet Alternative 1 in a cost effective manner from each company's perspective. EPA's modeling of single manufacturer fleets reflects this flexibility, and appropriately so given that it reflects manufacturers' expected response.

Table III–29 shows the projected target and projected achieved levels in 2025 for the proposed standards. This accounts for a manufacturer's ability to transfer credits to and from cars and trucks to meet a manufacturer's car and truck targets.

Table III-29 2025 Projected Target and Achieved Levels for the Proposal for Individual Firms (grams/mile CO2)

	Target			Achieved			Car Target-Achieved	Truck Target-Achieved
Company	Cars	Trucks	Fleet	Cars	Trucks	Fleet		
BMW	146	194	159	145	196	158	1	-2
Chrysler/Fiat	146	201	170	148	199	170	-2	2
Daimler	153	208	166	146	230	165	8	-22
Ferrari	150	n/a	150	159	n/a	159	-9	n/a
Ford	147	213	167	153	200	167	-6	13
Geely-Volvo	148	189	160	141	204	159	8	-15
GM	146	213	178	146	212	178	0	1
Honda	142	191	156	143	186	156	-2	5
Hyundai	142	188	151	145	178	152	-3	11
Kia	143	199	155	146	189	155	-3	10
Mazda	142	186	149	145	172	150	-3	14
Mitsubishi	139	180	153	144	171	153	-5	8
Nissan	145	202	162	143	204	161	1	-2
Porsche	131	195	144	119	231	143	12	-36
Spyker-Saab	141	188	148	133	231	146	8	-43
Subaru	137	177	146	147	149	147	-10	28
Suzuki	132	181	140	132	179	140	-1	3
Tata-JLR	161	182	171	134	208	168	27	-26
Toyota	141	200	163	140	201	162	1	-1
VW	139	203	152	133	225	151	6	-22
Fleet	144	203	163	144	202	163	-0.1	1.6

Note: This table and the remainder in this section do not include projections for Aston Martin and Lotus. These two firms would qualify for consideration of the unique Small Volume Manufacturer alternative standards discussed in Section III.B, and thus while we have included modeling for these companies in the Draft RIA, we do not present the results in this section. In addition, we do not present in this section results for the firm Tesla, as our forecast assumes they only make all electric vehicles, and thus under any standard we analyzed the firm always complies without the addition of any technology.

Similar tables for each of the alternatives for 2025 and for the alternatives and the proposal for 2021 are contained in Chapter 3 of EPA's draft RIA. With the proposed standards and for Alternatives 1 and 2, all companies are projected to be able to comply both in 2021 and 2025, with the with the exception of Ferrari, which in each case falls 9 g/mi short of its projected fleet wide obligation in 2025.[359] In Alternatives 3 and 4, where the car stringency varies, all companies are again projected to comply with the exception of Ferrari, which complies under Alternative 3, but has a 30 gram shortfall under Alternative 4. This level of compliance was not the case for the 2016 standards from the previous rule. The primary reason for this result is the penetration of more efficient technologies beyond 2016. As described earlier, many technologies projected as not to be available by MY 2016 or whose penetration was limited due to lead time issues are projected to be available or available at greater penetration rates in the 2017–2025 timeframe, especially given two more redesign cycles for the industry on average.

b. Why is the Relative Rate of Car Truck Stringency Appropriate?

Table III–29 illustrates the importance of car-truck credit transfer for individual firms. For example, the OMEGA model projects for the proposed standards that in 2025, Daimler would under comply for trucks by 22 g/mile but over comply in their car fleet by 8 g/mi in order to meet their overall compliance obligation, while for Kia the OMEGA model projects that under the proposed standards Kia's truck fleet would over comply by 10 g/mi and under comply in their car fleet by 3 g/mi in order to meet their compliance obligations. However, for the fleet as a whole, we project only a relatively small degree of net credit transfers from the truck fleet to the car fleet.

Table III–23 shows that the average costs for cars and trucks are also nearly equivalent for 2021 and 2025. For MY 2021, the average cost to comply with the car standards is $718, while it is $764 for trucks. For MY 2025, the average cost to comply with the car standards is $1,942, while it is $1,954 for trucks. These results are highly consistent with the small degree of net projected credit transfer between cars and trucks.

The average cost for complying with the truck and car standards are similar, even though the level of stringency for trucks is increasing at a slower rate than for cars. As described in Section I.B.2 of the preamble, the proposed car standards are decreasing (in CO_2) at a rate of 5% per year from MYs 2017–2025, while the proposed truck standards are decreasing at a rate of 3.5% per year on average from MYs 2017–2021, then 5% per year thereafter till 2025. Given this difference in percentage rates, the close similarity in average cost stems from the fact that it is more costly to add the technologies to trucks (in general) than to cars as described in Chapter 1 of the draft RIA. Moreover, some technologies are not even available for towing trucks. These include EVs, PHEVs, Atkinson Cycle engines (matched with HEVs), and DCTs—the latter two are relatively cost effective. Together these result in a decrease in effectiveness potential for the heavier towing trucks compared to non-towing trucks and cars. In addition,, there is more mass reduction projected for these vehicles, but this comes at higher cost as well, as the cost per pound for mass reduction goes up with higher levels of mass reduction (that is, the cost increase curves upward rather than being linear). As described in greater detail in Chapter 2 of the joint TSD, these factors help explain the reason EPA and NHTSA are proposing to make the truck curve steeper relative to the 2016 curve, thus resulting in a truck curve that is ''more parallel'' to cars than the 2016 truck curve.

Taken together, our analysis shows that under the proposed standards, there is relatively little net trading between car and trucks; average costs for compliance with cars is similar to that of trucks in MY 2021 as well as MY 2025; and it is more costly to add technologies to trucks than to cars. These facts corroborate the reasonableness for increasing the slope of the truck curve. These observations also lead us to the conclusion that (at a fleet level) starting from MYs 2017–2021, the slower rate of increase for trucks compared to cars (3.5% compared to 5% per year), and the same rate of increase (5% per year) for both cars and trucks for MY 2022–2025 results in car and truck standards that reflect increases in stringency over time that are comparable and consistent. There are no indications that either the truck or car standards are leading manufacturers to choose technology paths that lead to significant over or under compliance for cars or trucks, on an industry wide level. *E.g.,* there is no indication that on average the proposed car standards would lead manufacturers to consistently under or over comply with the car standard in light of the truck standard, or vice versa. A consistent pattern across the industry of manufacturers choosing to under or over comply with a car or trucks standard could indicate that the car or truck standard should be evaluated further to determine if one was more or less stringent than might be appropriate in light of the technology choices available to manufacturers and their costs. As shown above, that is not the case for the proposed car and truck standards. However, EPA did evaluate a set of alternative standards that reflect separately increasing or decreasing the stringency of the car and truck standards, as discussed below.

c. What are the costs and advanced technology penetration rates for the alternative standards in relation to the proposed standards?

Below we discuss results for the proposed car and truck standards compared to the truck alternatives evaluated (Alternatives 1 and 2), and then discuss the proposed car and truck standards compared to the car alternatives (Alternatives 3 and 4).

Table III–30 presents our projected per-vehicle cost for the average car, truck and for the fleet in model year 2021 and 2025 for the proposal and for Alternatives 1 and 2. All costs are relative to the reference case (*i.e.* the fleet with technology added to meet the 2016 MY standards). As can be seen, even though only the truck standards vary among these three scenarios, in each case the projected average car and truck costs vary as a result of car-truck credit transfer by individual companies. Table III–30 shows that compared to the proposal, Alternative 1 (with a 2021 and 2025 truck target 20 g/mile less stringent, or 20 g/mile greater, than the proposal) is $281 per vehicle less than the proposal in 2021 and $430 per vehicle less than the proposal in 2025. Alternative 2 (with a 2021 and 2025 truck target 20g/mile more stringent, or 20 g/mile less, than the proposal) is $343 per vehicle more than the proposal in 2021 and $516 per vehicle more than the proposal in 2025.

Note that while the car and truck costs are nearly equivalent for Alternative 2 in 2021 and 2025, cars are over complying on average by 7 g/mi, while trucks are under complying by 11 g/mi, thus indicating significant flow of credits from cars to trucks.[360] The situation is reversed in Alternative 1, where cars are under complying on average by 9 g/mi and trucks are over

[359] Note that Ferrari is shown as a separate entity in the table above but could be combined with other Fiat-owned companies for purposes of GHG compliance at the manufacturer's discretion. Also, in Section III.B., EPA is requesting comment on the concept of allowing companies that are able to demonstrate ''operational independence'' to be eligible for SVM alternative standards. However, the costs shown above are based on Ferrari meeting the primary program standards.

[360] These detailed tables are in Chapter 3 of EPA's draft RIA.

complying by 16 g/mi, implying significant flow of credits from truck to cars.

significant flow of credits from truck to cars.

Table III-30 2021 and 2025 Fleet Average Projected Per-Vehicle Costs for Proposal and Alternatives 1 and 2 ($/vehicle)

	Cars	Trucks	Fleet
2021 Proposal	$718	$764	$734
Alternative 1: 2021 Trucks+20	$436	$487	$453
Alternative 2: 2021 Trucks-20	$1,055	$1,121	$1,077
2025 Proposal	$1,942	$1,954	$1,946
Alternative 1: 2025 Trucks+20	$1,484	$1,580	$1,516
Alternative 2: 2025 Trucks-20	$2,443	$2,501	$2,462

Table III–31 presents the per-vehicle cost estimates in MY 2021 by company for the proposal, Alternative 1 and Alternative 2. In general, for most of the companies our projected results show the same trends as for the industry as a whole.

Table III-31 2021 Projected Per-Vehicle Costs for the Proposal and Alternatives 1 and 2 by Company

(cars & trucks, $/vehicle)

	Proposal	Alternative 1 (trucks+20)	Alternative 2 (trucks-20)
BMW	$937	$427	$1,354
Chrysler/Fiat	$698	$280	$1,125
Daimler	$1,702	$1,255	$2,208
Ferrari	$6,351	$6,351	$6,351
Ford	$696	$368	$1,131
Geely-Volvo	$1,741	$1,190	$2,437
GM	$590	$202	$1,123
Honda	$556	$411	$758
Hyundai	$669	$559	$829
Kia	$582	$479	$704
Mazda	$919	$763	$1,113
Mitsubishi	$877	$507	$1,384
Nissan	$729	$462	$985
Porsche	$4,482	$4,070	$5,148
Spyker-Saab	$2,986	$2,696	$3,342
Subaru	$994	$766	$1,319
Suzuki	$1,132	$890	$1,370
Tata-JLR	$1,935	$1,097	$2,821
Toyota	$481	$320	$678
VW	$1,457	$1,034	$1,812
Fleet	$734	$453	$1,077

Table III–32 presents the per-vehicle cost estimates in MY 2025 by company for the proposal, Alternative 1 and Alternative 2. In general, for most of the companies our projected results show the same trends as for the industry as a whole, with Alternative 1 on the order of $200 to $600 per vehicle less expensive then the proposal, and Alternative 2 on the order of $200 to $800 per vehicle more expensive. For the fleet as a whole, the average cost for Alternative 1 is $430 less costly, while Alternative 2 is $516 more costly. Thus the incremental average cost is higher for the more stringent alternative than for an equally less stringent alternative standard. This is not a surprise as more technologies must be added to vehicles to meet tighter standards, and these technologies increase in cost in a non-linear fashion.

Table III-32 2025 Projected Per-Vehicle Costs for Proposal and Alternatives 1 and 2 by Company

(cars & trucks, $/vehicle)

	Proposal	Alternative 1 (trucks+20)	Alternative 2 (trucks-20)
BMW	$2,174	$1,780	$2,607
Chrysler/Fiat	$2,043	$1,455	$2,673
Daimler	$2,707	$2,345	$3,127
Ferrari	$7,109	$7,109	$7,109
Ford	$2,178	$1,671	$2,670
Geely-Volvo	$2,876	$2,374	$3,546
GM	$2,030	$1,355	$2,877
Honda	$1,595	$1,327	$1,987
Hyundai	$1,739	$1,509	$2,004
Kia	$1,491	$1,282	$1,715
Mazda	$2,131	$1,895	$2,347
Mitsubishi	$2,133	$1,758	$2,574
Nissan	$2,060	$1,616	$2,487
Porsche	$5,012	$4,555	$5,477
Spyker-Saab	$3,670	$3,338	$3,887
Subaru	$2,202	$1,925	$2,452
Suzuki	$2,225	$2,051	$2,436
Tata-JLR	$2,976	$2,337	$3,787
Toyota	$1,483	$1,133	$2,014
VW	$2,506	$2,168	$2,871
Fleet	$1,946	$1,516	$2,462

The previous tables present the costs for the proposal and alternatives 1 and 2 at both the industry and company level. In addition to costs, another key is the technology required to meet potential future standards. The EPA assessment of the proposal, as well as Alternatives 1 and 2 predict the penetration into the fleet of a large number of technologies at various rates of penetration. A subset of these technologies are discussed below, while EPA's draft RIA Chapter 3 includes the details on this much longer list for the passenger car fleet, light-duty truck fleet, and the overall fleet at both the industry and individual company level. Table III–33 and Table III–34 present only a sub-set of the technologies EPA estimates could be used to meet the proposed standards as well as alternative 1 and 2 in MY 2021. Table III–35 and Table III–36 show the same for 2025. The technologies listed in these tables are those for which there is a large difference in penetration rates between the proposal and the alternatives. We have not included here, for example, the penetration rates for improved high efficiency gear boxes because in 2021 our modeling estimates a 58% penetration of this technology across the total fleet for the proposal as well as for alternatives 1 and 2, or 8 speed automatic transmissions which in 2021 we estimate at a 28% penetration rate for the proposed standards as well as for alternatives 1 and 2. There are several other technologies (shown in the Chapter 3 of the DRIA) where there is little differentiation between the proposal and alternatives 1 and 2.

Table III–33 shows that in 2021, for several technologies the proposal requires higher levels of penetration for trucks than alternative 1. For example, for trucks, compared to the proposal, alternative 1 leads to an 8% decrease in the 24 bar turbo-charged/downsized engines, a 10% decrease in the penetration of cooled EGR, and a 12% decrease in the penetration of gasoline direct injection fuel systems. We also see that due to credit transfer between cars and trucks, the lower level of stringency considered for trucks in alternative 1 also impacts the penetration of technology to the car fleet—with alternative 1 leading to a 14% decrease in penetration of 18 bar turbo-downsized engines, 5% decrease in penetration of 24 bar turbo-downsize engines, 8% decrease in penetration of 8 speed dual clutch transmissions, and a 19% decrease in penetration of gasoline direct injection fuel systems in the car fleet. For the more stringent alternative 2, we see increases in the penetration of many of these technologies projected for 2021, for the truck fleet as well as for the car fleet. Table III–34 shows these same overall trends but at the sales weighted fleet level in 2021.

Table III-33: 2021 Projected Technology Penetrations for Proposal and Alternatives 1 and 2 for all Cars and Trucks

	Cars			Trucks		
Technology	Proposal	Alt. 1	Alt. 2	Proposal	Alt. 1	Alt. 2
Turbo-downsize(18 bar)	45%	31%	50%	59%	57%	66%
Turbo-downsize (24 bar)	10%	5%	17%	14%	6%	19%
8 speed DCT	61%	53%	61%	13%	12%	13%
Cooled EGR*	9%	6%	18%	17%	7%	23%
Hybrid Electric Vehicle	8%	7%	9%	4%	4%	7%
LRRT2	62%	53%	72%	74%	62%	74%
IACC2	67%	57%	77%	79%	66%	79%
GDI	60%	41%	73%	76%	64%	91%

* In EPA packages TDS27 engines have cooled EGR, nearly all TDS24 engines also have cooled EGR, virtually none of the TDS18 bar engines have cooled EGR (See Chapter 1 of the draft RIA)

Table III-34: 2021 Projected Technology Penetrations for Proposal and Alternatives 1 and 2 for Fleet

	Proposal	Alt. 1	Alt. 2
Turbo-downsize (18 bar)	50%	40%	55%
Turbo-downsize (24 bar)	11%	5%	18%
8 speed DCT	44%	39%	44%
Cooled EGR	12%	6%	20%
Hybrid Electric Vehicle	7%	6%	8%
LRRT2	66%	56%	73%
IACC2	71%	60%	78%
GDI	65%	49%	79%

Table III–35 shows that in 2025, there is only a small change in many of these technology penetration rates when comparing the proposal to alternative 1 for trucks, and most of the change shows up in the car fleet. One important exception is hybrid electric vehicles, where the less stringent alternative 1 is projected to be met with a 4% decrease in penetration of HEVs compared to the proposal. As in 2021, we see that due to credit transfer between cars and trucks, the lower level of stringency considered for trucks in alternative 1 also impacts the car fleet penetration—with alternative 1 leading to a 8% decrease in penetration of 24 bar turbo-downsized engines, 12% decrease in penetration of cooled EGR, 6% decrease in penetration of HEVs, and a 2% decrease in penetration of electric vehicles. For the more stringent alternative 2, we see only small increases in the penetration of many of these technologies projected for 2025, with a major exception being a significant 14% increase in the penetration of HEVs for trucks compared to the proposal, a 6% increase in the penetration of HEVs for cars compared to the proposal, and a 3% increase in the penetration of EVs for cars compared to the proposal.

Table III-35 2025 Projected Technology Penetrations for Proposal and Alternatives 1 and 2 for all Cars and Trucks

	Cars			Trucks		
	Proposal	Alt. 1	Alt. 2	Proposal	Alt. 1	Alt. 2
Turbo-downsize (18 bar)	14%	23%	8%	27%	24%	26%
Turbo-downsize (24 bar)	65%	57%	63%	57%	57%	56%
8 speed DCT	75%	76%	73%	15%	16%	15%
Cooled EGR	66%	54%	64%	67%	68%	67%
Hybrid Electric Vehicle	15%	9%	21%	13%	9%	27%
EV	4%	2%	7%	1%	0%	1%
LRRT2	96%	96%	96%	99%	99%	99%
IACC2	96%	96%	96%	99%	99%	99%
GDI	93%	88%	90%	97%	94%	97%

Table III-36 2025 Projected Technology Penetrations for Proposal and Alternatives 1 and 2 for Fleet

	Proposal	Alt. 1	Alt. 2
Turbo-downsize (18 bar)	19%	24%	14%
Turbo-downsize (24 bar)	62%	57%	60%
8 speed DCT	55%	56%	54%
Cooled EGR	66%	59%	65%
Hybrid Electric Vehicle	15%	9%	23%
EV	3%	2%	5%
LRRT2	97%	97%	97%
IACC2	97%	97%	97%
GDI	94%	90%	92%

The results are similar for Alternatives 3 and 4, where the truck standard stays at the proposal level and the car stringency varies, +20 g/mi and -20 g/mi respectively. Table III–37 presents our projected per-vehicle cost for the average car, truck and for the fleet in model year 2021 and 2025 for the proposal and for Alternatives 3 and

4. Compared to the proposal, Alternative 3 (with a 2021 and 2025 car target 20 g/mile less stringent then the proposal) is $442 per vehicle less on average than the proposal in 2021 and $708 per vehicle less than the proposal in 2025. Alternative 4 (with a 2021 and 2025 car target 20g/mile more stringent then the proposal) is $635 per vehicle more on average than the proposal in 2021 and $923 per vehicle more than the proposal in 2025. These differences are even more pronounced than Alternatives 1 and 2. As in the analysis above, the costs increases are greater for more stringent alternatives than the reduced costs from the less stringent alternatives.

Note that although the car and truck costs are not too dissimilar for cars and trucks for Alternative 3 in 2025, what is not shown is that cars are over complying by 5 g/mi, while trucks are under complying by 7 g/mi, thus indicating significant flow of credits from cars to trucks. The situation is reversed in Alternative 4, where cars are under complying by 6 g/mi and trucks are over complying by 12 g/mi implying significant flow of credits from truck to cars.

Table III-37 2021 and 2025 Fleet Average Projected Per-Vehicle Costs for Proposal and Alternatives 3 and 4 ($/vehicle)

	Cars	Trucks	Fleet
2021 Proposal	$718	$764	$734
Alternative 3: 2021 Cars+20	$244	$390	$292
Alternative 4: 2021 Cars-20	$1,415	$1,275	$1,369
2025 Proposal	$1,942	$1,954	$1,946
Alternative 3: 2025 Cars+20	$1,161	$1,394	$1,238
Alternative 4: 2025 Cars-20	$2,923	$2,760	$2,869

Table III–38 presents the per-vehicle cost estimates in MY 2021 by company for the proposal, Alternative 3 and Alternative 4. In general, for most of the companies our projected results show the same trends as for the industry as a whole, with Alternative 3 being a several hundred dollars per vehicle less expensive then the proposal, and Alternative 4 being several hundred dollars per vehicle more expensive (with larger increment for more stringent than less stringent alternatives). In some case the differences exceed $1,000 (*e.g.* BMW, Daimler, Geely/Volvo, Mazda, Spyker/Saab, and Tata).

Table III-38 2021 Projected Per-Vehicle Costs for Proposal and Alternatives 3 and 4 by Company

(cars & trucks combined, $/vehicle)

	Proposal	Alt. 3 (cars+20)	Alt. 4 (cars-20)
BMW	$937	-$218	$2,143
Chrysler/Fiat	$698	$272	$1,142
Daimler	$1,702	$567	$3,114
Ferrari	$6,351	$6,351	$6,351
Ford	$696	$240	$1,501
Geely-Volvo	$1,741	$662	$3,215
GM	$590	$245	$1,042
Honda	$556	$292	$993
Hyundai	$669	$318	$1,356
Kia	$582	$326	$1,066
Mazda	$919	$355	$1,957
Mitsubishi	$877	$326	$1,803
Nissan	$729	$287	$1,469
Porsche	$4,482	$3,131	$5,473
Spyker-Saab	$2,986	$1,588	$4,817
Subaru	$994	$478	$1,906
Suzuki	$1,132	$331	$2,128
Tata-JLR	$1,935	$1,097	$2,862
Toyota	$481	$298	$758
VW	$1,457	$186	$2,854
Fleet	$734	$292	$1,369

Table III–39 presents the per-vehicle cost estimates in MY 2025 by company for the proposal, Alternative 3 and Alternative 4. In general, for most of the companies our projected results show the same trends as for the industry as a whole, with Alternative 3 on the order of $500 to $1,400 per vehicle less expensive then the proposal, and Alternative 4 on the order of $700 to $1,600 per vehicle more expensive. Again these differences are more pronounced for the car alternatives than the truck alternatives.

Table III-39 2025 Projected Per-Vehicle Costs for Proposal and Alternatives 3 and 4 by Company (cars & trucks, $/vehicle)

	NPRM	Alt. 3 (cars+20)	Alt. 4 (cars-20)
BMW	$2,174	$1,164	$3,428
Chrysler/Fiat	$2,043	$1,424	$2,757
Daimler	$2,707	$1,616	$4,087
Ferrari	$7,109	$6,292	$7,109
Ford	$2,178	$1,299	$3,214
Geely-Volvo	$2,876	$1,790	$4,307
GM	$2,030	$1,400	$2,843
Honda	$1,595	$1,064	$2,387
Hyundai	$1,739	$1,044	$2,771
Kia	$1,491	$908	$2,408
Mazda	$2,131	$1,229	$3,279
Mitsubishi	$2,133	$1,414	$3,050
Nissan	$2,060	$1,246	$2,957
Porsche	$5,012	$3,685	$6,320
Spyker-Saab	$3,670	$2,296	$5,261
Subaru	$2,202	$1,400	$3,040
Suzuki	$2,225	$1,383	$3,274
Tata-JLR	$2,976	$2,246	$3,953
Toyota	$1,483	$982	$2,252
VW	$2,506	$1,391	$4,001
Fleet	$1,946	$1,238	$2,869

Table III–40 shows that in 2021, for several technologies Alternative 3 leads to lower levels of penetration for cars as well as trucks compared to the proposal. For example (on cars) there is an 13% decrease in the 18 bar turbo-charged/downsized engines, a 5% decrease in the penetration of cooled EGR, and a 22% decrease in the penetration of gasoline direct injection fuel systems. We also see that due to credit transfer between cars and trucks, the lower level of stringency considered for cars in alternative 3 also impacts the penetration of technology to the truck fleet—with alternative 3 leading to 12% decrease in penetration of 24 bar turbo-downsized engines, 13% decrease in penetration of cooled EGR, and a 17% decrease in penetration of gasoline direct injection fuel systems in the car fleet. For the more stringent alternative 4, we see increases in the penetration of many of these technologies projected for 2021, for the truck fleet as well as for the car fleet. Table III–41 shows these same overall trends but at the sales weighted fleet level in 2021.

Table III-40 2021 Projected Technology Penetrations for Proposal and Alternatives 3 and 4 for all Cars and Trucks

Technology	Cars			Trucks		
	Proposal	Alt. 3	Alt. 4	Proposal	Alt. 3	Alt. 4
Turbo-downsize (18 bar)	45%	32%	51%	59%	55%	62%
Turbo-downsize (24 bar)	10%	4%	21%	14%	2%	22%
8 speed DCT	61%	46%	61%	13%	11%	13%
Cooled EGR	9%	4%	20%	17%	4%	26%
Hybrid Electric Vehicle	8%	5%	12%	4%	3%	9%
LRRT2	62%	43%	72%	74%	54%	74%
IACC2	67%	46%	77%	79%	58%	79%
GDI	60%	38%	82%	76%	59%	91%

Table III-41 2021 Projected Technology Penetrations for Proposal and Alternatives 3 and 4 for Fleet

Technologies	Proposal	Alt. 3	Alt. 4
Turbo-downsize (18 bar)	50%	40%	55%
Turbo-downsize (24 bar)	11%	3%	21%
8 speed DCT	44%	34%	44%
Cooled EGR	12%	4%	22%
Hybrid Electric Vehicle	7%	4%	11%
LRRT2	66%	47%	73%
IACC2	71%	50%	78%
GDI	65%	46%	85%

Table III–42 shows that in 2025, there is only a small change in many of these technology penetration rates when comparing the proposal to alternative 3 for cars, and most of the change shows up in the car fleet. There are a few exceptions: There is a 15% decrease in the penetrate rate of 24 bar bmep engines (made up somewhat by a 4% increase in 18 bar engines); there is 20% less EGR boost and GDI, and 9% less hybrid electric vehicles compared to the proposal. As in 2021, we see that due to credit transfer between cars and trucks at the lower level of stringency considered for cars in alternative 3 also impacts the truck fleet penetration—with alternative 3 leading to 7% decrease in penetration of HEVs. For the more stringent alternative 4, we see only small increases in the penetration of many of these technologies projected for 2025, with a major exception being a significant 9% increase in the penetration of HEVs for cars compared to the proposal (along with a drop in advanced engines), and a 20% increase in the penetration of HEVs for trucks compared to the proposal.

Table III-42 2025 Projected Technology Penetrations for Proposal and Alternatives 3 and 4 for all Cars and Trucks

Technologies	Cars			Trucks		
	Proposal	Alt. 3	Alt. 4	Proposal	Alt.3	Alt. 4
Turbo-downsize (18 bar)	14%	18%	6%	27%	25%	26%
Turbo-downsize (24 bar)	65%	50%	59%	57%	58%	55%
8 speed DCT	75%	76%	71%	15%	16%	14%
Cooled EGR	66%	46%	61%	67%	68%	66%
Hybrid Electric Vehicle	15%	6%	24%	13%	6%	33%
EV	4%	1%	9%	1%	0%	2%
LRRT2	96%	96%	96%	99%	98%	99%
IACC2	96%	96%	96%	99%	98%	99%
GDI	93%	73%	88%	97%	94%	97%

Table III-43 2025 Projected Technology Penetrations for Proposal and Alternatives 3 and 4 for Fleet

Technologies	Proposal	Alt. 3	Alt. 4
Turbo-downsize (18 bar)	19%	20%	12%
Turbo-downsize (24 bar)	62%	53%	58%
8 speed DCT	55%	56%	53%
Cooled EGR	66%	54%	63%
Hybrid Electric Vehicle	15%	6%	27%
EV	3%	1%	7%
LRRT2	97%	97%	97%
IACC2	97%	97%	97%
GDI	94%	80%	91%

The trend for Alternatives 3 and 4 have thus far been that the impacts have been more extreme than Alternatives 1 and 2 compared to the proposal. Thus we will focus the discussion of feasibility on Alternatives 1 and 2 (as the same will also then apply to 3 and 4 respectively).

As stated above, EPA's OMEGA analysis indicates that there is a technology pathway for all manufacturers to build vehicles that would meet the proposed standards as well as the alternative standards.[361] The differences lie in the per-vehicle costs and the associated technology penetrations. With the proposed standards, we estimate that the average per-vehicle cost is $734 in 2021 and $1,946 in 2025. We have also shown that the relative rate of increase in the stringencies of cars and trucks are at an appropriate level such that there is greater balance amongst the manufacturers where the distribution of the burden is relatively evenly spread. In Section I.C of the Preamble, we also showed that the benefits of the program are significant, and that this cost can be recovered within the first four years of vehicle ownership.

EPA's analysis of the four alternatives indicates that under all of the alternatives the projected response of the manufacturers is to change both their car and truck fleets. Whether the car or truck standard is being changed, and whether it is being made more or less stringent, the response of the manufacturers is to make changes across their fleet, in light of their ability to transfer credits between cars and trucks. For example, Alternatives 1 and 3 make either the car or trucks standard less stringent, and keep the other standard as is. For both alternatives, manufacturers increase their projected CO_2 g/mile level achieved by their car fleet, and to a lesser extent their truck fleet. For alternatives 2 and 4, where either the truck or car fleet is made more stringent, and the other standard is kept as is, manufacturers reduce the projected CO_2 g/mile level achieved by both their car and trucks fleets, in a generally comparable fashion. This is summarized in Table III–44 for MY 2025.

Table III-44 A Comparison of the Achieved CO2 levels in Relation to the Proposed Achieved Levels for all Alternative Scenarios in MY 2025

Alternative	Change in car achieved level compared to proposal achieved level	Change in truck achieved level compared to proposal achieved level
1: truck +20	+8	+6
2: truck -20	-8	-7
3: car +20	+15	+9
4: car -20	-14	-10

This demonstrates that the four alternatives are indicative of what would happen if EPA increased the stringency of both the car and truck fleet at the same time, or decreased the stringency of the car and truck fleet at the same time. *E.g.,* Alternative 4 would be comparable to an alternative where EPA made the car standard more stringent by 14 gm/mi and the truck standard by 10 gm/mile. Under such an alternative, there would logically be little if any net transfer of credits between cars and trucks. In that context, the results from alternatives 1 and 3 can be considered as indicative of what would be expected if EPA decreased the stringency of both the car and truck standards, and alternatives 2 and 4 as indicative of what would happen if EPA increased the stringency of both the car and truck standards. In general, it appears that decreasing the stringency of the standards would lead the manufacturers to focus more on increasing the CO_2 gm/mile of cars than trucks (alternatives 1 and 3). Increasing the stringency of the car and truck standards would generally lead to comparable increases in gm/mi for both cars and trucks.

Alternatives 1 and 3 would achieve significantly lower reductions, and would therefore forego important benefits that the proposed standards would achieve at reasonable costs and

[361] Except Ferrari.

penetrations of technology. EPA judges that there is not a good reason to forego such benefits, and is not proposing less stringent standards such as alternatives 1 and 3.

Alternatives 2 and 4 increase the per vehicle estimates to $1,077 and $1,369 respectively in 2021 and $2,462 and $2,869 respectively in 2025. This increase in cost from the proposal originates from the dramatic increases in the costlier electrification technologies, such as HEVs and EVs. The following tables and charts show the technology penetrations by manufacturer in greater detail.

Table III–45 and later tables describe the projected penetration rates for the OEMs of some key technologies in MY 2021 and MY2025 under the proposed standards. TDS27, HEV, and PHEV+EV technologies represent the most costly technologies added in the package generation process, and the OMEGA model generally adds them as one of the last technology choices for compliance. They are therefore an indicator of the extent to which the stringency of the standard is pushing the manufacturers to the most costly technology. Cost (as shown above) is a similar indicator.

Table III–45 describes technology penetration for MY2021 under the proposal.

Table III-45 Percent Penetration of Technologies in MY 2021 for the Proposed Standards

(Ferrari has been removed from this table)

	2021 CAR				2021 TRUCK				2021 Fleet			
	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV
BMW	26%	2%	30%	2%	24%	3%	30%	0%	25%	2%	30%	1%
Chrysler/Fiat	7%	1%	0%	0%	25%	3%	0%	0%	15%	2%	0%	0%
Daimler	21%	4%	30%	8%	14%	6%	30%	0%	20%	4%	30%	6%
Ford	15%	1%	2%	0%	17%	6%	2%	0%	16%	3%	2%	0%
Geely/Volvo	15%	8%	30%	9%	27%	2%	30%	0%	18%	6%	30%	6%
GM	9%	1%	0%	0%	19%	5%	0%	0%	14%	3%	0%	0%
Honda	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	2%	0%
Hyundai	0%	0%	0%	0%	30%	0%	0%	0%	6%	0%	0%	0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mazda	20%	0%	0%	0%	30%	0%	0%	0%	22%	0%	0%	0%
Mitsubishi	30%	0%	6%	0%	30%	0%	4%	0%	30%	0%	6%	0%
Nissan	9%	0%	1%	0%	24%	3%	0%	0%	14%	1%	1%	0%
Porsche	25%	3%	30%	29%	24%	8%	30%	0%	25%	4%	30%	22%
Spyker/Saab	25%	3%	30%	16%	19%	6%	30%	0%	24%	3%	30%	13%
Subaru	30%	0%	2%	0%	30%	0%	0%	0%	30%	0%	1%	0%
Suzuki	30%	0%	24%	0%	30%	0%	6%	0%	30%	0%	21%	0%
Tata/JLR	7%	11%	30%	10%	10%	10%	30%	4%	9%	11%	30%	7%
Toyota	0%	0%	15%	0%	0%	3%	5%	0%	0%	1%	12%	0%
VW	29%	1%	30%	6%	23%	3%	30%	0%	27%	1%	30%	5%
Fleet	10%	1%	8%	1%	14%	4%	4%	0%	11%	2%	7%	1%

TDS24 = 24 bar bmep Turbo downsized GDI Engines, where most of these are EGR boosted, TDS27 = EGR boosted turbo downsized GDI 24 bar bmep, HEV= Hybrid Electric Vehicle, EV = Electric Vehicle, PHEV = Plug-in Hybrid Electric Vehicle

It can be seen from this table that the larger volume manufacturers have levels of advanced technologies that are below the phase in caps (described in the next table). On the other hand, smaller "luxury" volume manufacturers tend to require higher levels of these technologies. BMW, Daimler, Volvo, Porsche, Saab, Jaguar/LandRover, and VW all reach the maximum penetration cap for HEVs (30%) in 2021. Suzuki is the only other company with greater than 20% penetration of HEVs and only two manufacturers have greater than 10% penetration of PH/EVs: Porsche and Saab. Together these seven ''luxury'' vehicle manufacturers represent 12% of vehicle sales and their estimated cost of compliance with 2021 proposed standards is $2,178 compared to $744 for the others.

It is important to review some of the caps or limits on the technology phase in rates described in Chapter 3.5.2.3 of the joint TSD as it relates to the remainder of this discussion. These are upper limits on the penetration rates allowed under our modeling, and reflect an estimate of the physical limits for such penetration. It is not a judgment that rates below that cap are practical or reasonable, and is intended to be more of a physical limit of technical capability in light of conditions such as supplier capacity, up-front investment capital requirements, manufacturability, and other factors. For example, in MY 2010, there are presently 3% HEVs in the new vehicle fleet. In MYs 2015, 2021 and 2025 we project that this cap on technology penetration rate increases to 15%, 30% and 50% respectively. For PH/EVs in MY 2010, there is practically none of these technologies. In MYs 2015, 2021 and 2025 we project that this cap on technology penetration rate increases to approximately 5%, 10% and 15% respectively for EVs and PHEVs separately. These highly complex technologies also have the slowest penetration phase-in rates to reflect the relatively long lead time required to implement into substantial fractions of the fleet subject to the manufacturers' product redesign schedules. In contrast, an advanced technology still under development based on an improved engine design, TDS27, has a cap on penetration phase in rate in MYs 2015, 2021, and 2025 of 0%, 15%, and 50% indicative of a longer lead time to develop the technology, but a relatively faster phase in rate once the technology is ''ready'' (consistent with other ''conventional'' evolutionary improvements). Table III–46 summarizes the caps on the phase in rates of some of the key technologies. A penetration rate result from the analysis that approaches the caps for these technologies for a given manufacturer is an indication of how much that manufacturer is being ''pushed'' to technical limits by the standards. This will be in direct correlation to the cost of compliance for that same manufacturer.

Table III-46 Phase-in Rates for Some Key Advanced Technologies

Technology	Abbr.	2016	2021	2025
Turbocharging & downsizing with EGR Level 1 (w/ cooled EGR, 24 bar)	EGRB1 or TDS24	15%	30%	75%
Turbocharging & downsizing with EGR Level 2 (w/ cooled EGR, 27 bar)	EGRB2 or TDS27	0%	15%	50%
Strong Hybrid	HEV	15%	30%	50%
Plug-in Hybrid	PHEV	5%	10%	14%
Electric Vehicle	EV 1	6%	11%	15%

Table III–47 shows the technology penetrations for Alternative 2. Immediately striking is the penetration rates of truck HEVs in the fleet: Even in 2021, it nearly doubles in comparison to the proposal. The Ford truck fleet (to take one of the largest volume manufacturers as an example) increases from 2% HEVs in the proposal trucks to 16% in Alternative 2, an eightfold increase.

There are other significant increases in the larger manufacturers and even more dramatic increases in the HEV penetration in smaller manufacturers' fleets. For example, Suzuki cars now reach the maximum technology penetration cap of 30% for HEVs and Mitsubishi now has 20% HEVs. Also, there are now four manufacturers with total fleet PH/EV penetration rates equal to 10% or greater.

The larger volume manufacturers have an estimated per vehicle cost of compliance with 2021 alternative standards of $1,044, which is $555 higher than the proposed standards. The seven ''luxury'' vehicle manufacturers now have estimated costs of $2,733, which is $300 higher than the proposed standards (See Table III–12 above).

Table III-47 Percent Penetration of Technologies in MY 2021 for Alternative 2

	2021 CAR				2021 TRUCK				2021 Fleet			
	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV
BMW	26%	2%	30%	6%	24%	3%	30%	0%	25%	2%	30%	4%
Chrysler/Fiat	28%	1%	1%	0%	25%	3%	2%	0%	27%	2%	2%	0%
Daimler	21%	4%	30%	12%	14%	6%	30%	0%	20%	4%	30%	9%
Ford	27%	1%	4%	0%	17%	6%	16%	0%	23%	3%	8%	0%
Geely/Volvo	15%	8%	30%	15%	27%	2%	30%	0%	18%	6%	30%	10%
GM	28%	1%	1%	0%	20%	5%	2%	0%	24%	3%	2%	0%
Honda	0%	0%	3%	0%	22%	0%	0%	0%	7%	0%	2%	0%
Hyundai	7%	0%	0%	0%	30%	0%	0%	0%	12%	0%	0%	0%
Kia	0%	0%	0%	0%	9%	0%	0%	0%	2%	0%	0%	0%
Mazda	30%	0%	1%	0%	30%	0%	1%	0%	30%	0%	1%	0%
Mitsubishi	30%	0%	25%	0%	30%	0%	11%	1%	30%	0%	20%	0%
Nissan	30%	0%	1%	0%	24%	3%	0%	0%	28%	1%	1%	0%
Porsche	25%	3%	30%	31%	27%	8%	30%	0%	25%	4%	30%	24%
Spyker/Saab	25%	3%	30%	19%	19%	6%	30%	0%	24%	3%	30%	16%
Subaru	30%	0%	17%	0%	30%	0%	0%	0%	30%	0%	13%	0%
Suzuki	30%	0%	30%	0%	30%	0%	6%	1%	30%	0%	26%	0%
Tata/JLR	7%	11%	30%	13%	10%	10%	30%	11%	9%	11%	30%	12%
Toyota	0%	0%	15%	0%	13%	3%	5%	0%	5%	1%	12%	0%
VW	29%	1%	30%	8%	23%	3%	30%	0%	27%	1%	30%	7%
Fleet	17%	1%	9%	2%	19%	4%	7%	0%	18%	2%	8%	1%

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Table III–48 shows the technology penetrations for Alternative 4 for MY 2021. The large volume manufacturer, Ford now has a 25% penetration rate of truck HEVs (a 23% increase compared to the proposed standards) and the fleet penetration has gone up 11 fold for this company in comparison to the proposed standards.

Mitsubishi, and Suzuki cars now reach the maximum technology penetration cap of 30% for HEVs, and Mazda, Subaru cars as well as Ford trucks now have greater than 20% HEVs. Also, there are now six manufacturers with PH/EV penetration rates greater than 10%.

The larger volume manufacturers now have an estimated per vehicle cost of compliance with 2021 alternative standards of $1,428, which is $683 higher than the proposed standards. The seven ''luxury'' vehicle manufacturers now have estimated costs of $3,499, which is $1,320 higher than the proposed standard (See Table III–32 above). For the seven luxury manufacturers, this per vehicle cost exceeds the costs under the proposal for complying with the considerably more stringent 2025 standards.

Table III-48 Percent Penetration of Technologies in MY 2021 for Alternative 4

	2021 CAR					2021 TRUCK					2021 Fleet			
	TDS24	TDS27	HEV	PHEV +EV		TDS24	TDS27	HEV	PHEV +EV		TDS24	TDS27	HEV	PHEV +EV
BMW	26%	2%	30%	12%		24%	3%	30%	0%		25%	2%	30%	9%
Chrysler/Fiat	28%	1%	1%	0%		25%	3%	2%	0%		27%	2%	2%	0%
Daimler	21%	4%	30%	19%		14%	6%	30%	0%		20%	4%	30%	14%
Ford	27%	1%	14%	0%		17%	6%	25%	1%		23%	3%	18%	0%
Geely/Volvo	15%	8%	30%	21%		27%	2%	30%	0%		18%	6%	30%	15%
GM	28%	1%	0%	0%		20%	5%	2%	0%		24%	3%	1%	0%
Honda	14%	0%	3%	0%		30%	0%	0%	0%		19%	0%	2%	0%
Hyundai	30%	0%	3%	0%		30%	0%	3%	0%		30%	0%	3%	0%
Kia	12%	0%	0%	0%		30%	0%	0%	0%		16%	0%	0%	0%
Mazda	30%	0%	26%	1%		30%	0%	11%	1%		30%	0%	23%	1%
Mitsubishi	30%	0%	30%	3%		30%	0%	11%	2%		30%	0%	23%	2%
Nissan	30%	0%	14%	0%		24%	3%	13%	0%		28%	1%	14%	0%
Porsche	12%	15%	30%	31%		25%	15%	30%	0%		15%	15%	30%	24%
Spyker/Saab	25%	3%	30%	28%		19%	6%	30%	0%		24%	3%	30%	24%
Subaru	30%	0%	27%	1%		30%	0%	23%	0%		30%	0%	26%	1%
Suzuki	30%	0%	30%	7%		30%	0%	6%	2%		30%	0%	26%	6%
Tata/JLR	7%	11%	30%	14%		10%	10%	30%	11%		9%	11%	30%	12%
Toyota	1%	0%	15%	0%		21%	3%	5%	0%		9%	1%	12%	0%
VW	29%	1%	30%	16%		29%	3%	30%	0%		29%	1%	30%	13%
Fleet	21%	1%	12%	3%		22%	4%	9%	0%		21%	2%	11%	2%

Table III–49 shows the technology penetrations for the proposed standards in 2025. The larger volume manufacturers have levels of advanced technologies that are below the phase in caps (described in the next table), though there are some notably high penetration rates for truck HEVs for Ford and Nissan.[362] For the fleet in general, we note a 3% penetration rate of PHEV+EVs—it is interesting to note that this is the penetration rate of HEVs today. EPA believes that there is sufficient lead time to have this level of penetration of these vehicles by 2025. Case in point, it has taken approximately 10 years for HEV penetration to get to the levels that we see today, and that was without an increase in the stringency of passenger car CAFE standards.

[362] EPA has not conducted an analysis of pickup truck HEV penetration rates compared to the remainder of the truck fleet. This may be conducted for the final rule.

Table III-49 Percent Penetration of Technologies in MY 2025 for the Proposed Standards

	2025 CAR				2025 TRUCK				2025 Fleet			
	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV
BMW	56%	5%	28%	10%	61%	10%	50%	0%	58%	6%	34%	8%
Chrysler/Fiat	70%	2%	19%	1%	61%	8%	10%	1%	66%	5%	15%	1%
Daimler	43%	9%	32%	15%	35%	19%	50%	0%	41%	11%	36%	12%
Ford	64%	4%	13%	4%	40%	20%	31%	3%	56%	9%	19%	4%
Geely/Volvo	31%	16%	41%	15%	66%	6%	50%	0%	42%	13%	44%	11%
GM	68%	2%	15%	3%	51%	15%	3%	1%	60%	8%	10%	2%
Honda	73%	0%	3%	0%	75%	0%	2%	0%	73%	0%	3%	0%
Hyundai	75%	0%	0%	0%	74%	0%	2%	1%	75%	0%	0%	0%
Kia	57%	0%	0%	0%	75%	0%	0%	0%	61%	0%	0%	0%
Mazda	73%	0%	21%	2%	74%	0%	8%	0%	73%	0%	19%	2%
Mitsubishi	69%	0%	21%	6%	71%	0%	9%	4%	70%	0%	17%	5%
Nissan	73%	0%	18%	1%	59%	9%	24%	2%	69%	3%	20%	2%
Porsche	35%	1%	29%	35%	34%	28%	50%	0%	35%	7%	34%	27%
Spyker/Saab	47%	1%	29%	23%	46%	19%	50%	0%	47%	3%	32%	20%
Subaru	70%	0%	20%	5%	74%	0%	19%	1%	71%	0%	19%	4%
Suzuki	66%	0%	25%	9%	72%	0%	5%	3%	67%	0%	22%	8%
Tata/JLR	14%	26%	44%	15%	18%	33%	41%	8%	16%	29%	43%	12%
Toyota	61%	1%	17%	0%	59%	8%	7%	0%	60%	4%	13%	0%
VW	60%	1%	26%	13%	58%	11%	50%	0%	60%	3%	31%	11%
Fleet	65%	2%	15%	4%	57%	11%	13%	1%	62%	5%	15%	3%

Six of the seven luxury vehicle manufacturers reach the maximum penetration cap on their truck portion of their fleet; however, no company reaches 50% for their combined fleet. The seven do have over 30%

penetration rate of HEVs, while Suzuki is the only company to have between 20 and 30% HEVs. Six of the 7 luxury vehicle manufacturers also have greater than 10% penetration of PH/EVs (which has a total cap of 29%). The only company to have large penetration rates (>15%) of TDS27 is Jaguar/LandRover at 29%.

The estimated per vehicle cost of compliance with 2025 proposed standards is $1,943 for the larger volume manufacturers and $3,133 for the seven ''luxury'' vehicle manufacturers.

Table III–50 shows the technology penetrations for Alternative 2 in 2025. In this alternative Chrysler trucks nearly double their penetration rate of HEVs along with dramatic increases in car and truck PH/EVs. GM has a very large increase in truck HEVs as well: From 3% in the proposed to 39% in the alternative standards along with a doubling of PH/EVs. Toyota also has double the number of HEVs. In this alternative there are many more companies with 20–30% HEVs: Chrysler, Ford, GM, Mitsubishi, Nissan, Subaru, Suzuki, and Toyota. Suzuki (in addition to the seven) now also has 10% or greater penetration of PH/EVs. Ford, GM, Chrysler, and Nissan now have more than 20% penetration of HEVs in trucks.

The estimated per vehicle cost of compliance with 2025 alternative 2 standards is $2,354, which is $410 higher than the proposed standards. The seven luxury vehicle manufacturers now have costs of $3,616, which is $483 higher than the proposed standards. See Table III–32 above.

Table III-50 Percent Penetration of Technologies in MY 2025 for Alternative 2

	2025 CAR				2025 TRUCK				2025 Fleet			
	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV
BMW	52%	4%	28%	15%	61%	10%	50%	0%	55%	6%	34%	11%
Chrysler/Fiat	64%	2%	20%	8%	59%	8%	21%	3%	62%	5%	20%	6%
Daimler	42%	6%	32%	19%	35%	19%	50%	0%	41%	9%	36%	15%
Ford	61%	4%	19%	7%	38%	20%	38%	5%	54%	9%	25%	7%
Geely/Volvo	30%	11%	41%	21%	66%	6%	50%	0%	41%	10%	44%	15%
GM	64%	2%	20%	7%	51%	15%	39%	1%	58%	8%	29%	4%
Honda	71%	0%	13%	1%	73%	0%	10%	2%	72%	0%	12%	1%
Hyundai	73%	0%	9%	2%	74%	0%	2%	1%	74%	0%	7%	1%
Kia	75%	0%	0%	0%	75%	0%	0%	0%	75%	0%	0%	0%
Mazda	70%	0%	21%	5%	74%	0%	8%	1%	71%	0%	19%	4%
Mitsubishi	64%	0%	25%	11%	71%	0%	9%	4%	66%	0%	20%	9%
Nissan	69%	0%	24%	5%	59%	9%	27%	2%	66%	3%	25%	4%
Porsche	30%	1%	29%	40%	34%	28%	50%	0%	31%	7%	34%	31%
Spyker/Saab	45%	1%	29%	25%	46%	19%	50%	0%	45%	3%	32%	22%
Subaru	68%	0%	22%	7%	74%	0%	19%	1%	69%	0%	22%	6%
Suzuki	63%	0%	25%	12%	72%	0%	5%	3%	65%	0%	22%	10%
Tata/JLR	14%	22%	44%	19%	10%	33%	41%	15%	13%	27%	43%	18%
Toyota	58%	1%	30%	3%	58%	8%	17%	0%	58%	4%	25%	2%
VW	57%	0%	26%	17%	58%	11%	50%	0%	57%	3%	31%	13%
Fleet	63%	2%	21%	7%	56%	11%	27%	2%	60%	5%	23%	5%

Table III–51 shows the technology penetrations for Alternative 4 in 2025. In this alternative every company except Honda, Hyundai, Kia have greater than 20% HEVs. Many of the large volume manufacturers have even more dramatic increases in the volumes of P/H/EVs than in Alternative 2. Ford, GM, Nissan, and Toyota have greater than 20 or 30% penetration rates of HEVs on trucks. Mazda, Mitsubishi, Subaru, Suzuki (in addition to the seven) now also have 10% or greater penetration of PH/EVs, while Daimler, Volvo, Porsche, Saab, and VW have over 20%.

The estimated per vehicle cost of compliance with 2025 alternative standards is $2,853, which is $910 higher than the proposed standards. The seven luxury vehicle manufacturers now have costs of $4,481, which is $1,348 higher than the proposed standards. Much of this non-linear increase in cost is due to increased penetration of PHEVs and EVs (more so than HEVs).

Table III-51 Percent Penetration of Technologies in MY 2025 for Alternative 4

	2025 CAR				2025 TRUCK				2025 Fleet			
	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV	TDS24	TDS27	HEV	PHEV +EV
BMW	48%	1%	28%	23%	61%	10%	50%	0%	51%	3%	34%	17%
Chrysler/Fiat	64%	2%	24%	8%	59%	8%	21%	3%	62%	5%	23%	6%
Daimler	38%	2%	32%	28%	35%	19%	50%	0%	37%	6%	36%	22%
Ford	58%	4%	28%	11%	38%	20%	44%	6%	52%	9%	33%	9%
Geely/Volvo	26%	6%	41%	30%	66%	6%	50%	0%	38%	6%	44%	21%
GM	64%	2%	20%	7%	51%	15%	39%	1%	58%	8%	29%	4%
Honda	68%	0%	16%	4%	71%	0%	17%	4%	69%	0%	16%	4%
Hyundai	67%	0%	20%	8%	74%	0%	7%	1%	69%	0%	17%	6%
Kia	71%	0%	20%	4%	75%	0%	0%	0%	72%	0%	16%	3%
Mazda	62%	0%	22%	13%	72%	0%	42%	3%	64%	0%	25%	11%
Mitsubishi	61%	0%	25%	14%	70%	0%	25%	5%	64%	0%	25%	11%
Nissan	66%	0%	25%	9%	57%	9%	39%	4%	63%	3%	29%	7%
Porsche	0%	14%	41%	45%	11%	50%	50%	0%	2%	22%	43%	35%
Spyker/Saab	34%	1%	29%	36%	46%	19%	50%	0%	36%	3%	32%	31%
Subaru	63%	0%	25%	12%	69%	0%	25%	6%	65%	0%	25%	10%
Suzuki	55%	0%	25%	20%	72%	0%	45%	3%	58%	0%	28%	17%
Tata/JLR	14%	20%	44%	21%	10%	33%	41%	15%	13%	26%	43%	18%
Toyota	57%	1%	30%	5%	57%	8%	26%	1%	57%	4%	28%	3%
VW	47%	0%	26%	27%	58%	11%	50%	0%	49%	2%	31%	21%
Fleet	59%	1%	24%	10%	55%	11%	33%	2%	58%	4%	27%	8%

d. Summary of the Technology Penetration Rates and Costs From the Alternative Scenarios in Relation to the Proposed Standards

As described above, alternatives 2 and 4 would lead to significant increases in the penetration of advanced technologies into the fleet during the time frame of these standards. In general, both alternatives would lead to an increase in the average penetration rate for advanced technologies in 2021, in effect accelerating some of the technology penetration that would otherwise occur in the 2022–2025 timeframe. For the fleet as a whole, in 2021 alternative 2 would lead to a significant increase in cooled EGR use and a limited increase in HEV use, while alternative 4 would lead to an even larger increase in cooled EGR as well as a significant increase in HEV use. In 2025 these alternatives would dramatically affect penetration rates of HEVs, EVs, and PHEVs, in each case leading to very significant increases on average for the fleet. Again, Alternative 4 would lead to greater penetration rates than Alternative 2. When one considers the technology penetration rates for individual manufacturers, in 2021 the alternatives lead to much higher increases than average for some individual large volume manufacturers. Smaller volume manufacturers start out with higher penetration rates and are pushed to even higher levels. This result is even more pronounced in 2025.

This increase in technology penetration rates raises serious concerns about the ability and likelihood manufacturers can smoothly implement the increased technology penetration in a fleet that has so far seen limited usage of these technologies, especially for trucks—and for towing trucks in particular. While this is more pronounced for 2025, there are still concerns for the 2021 technology penetration rates. Although EPA believes that these penetration rates are, in the narrow sense, technically achievable, it is more a question of judgment whether we are confident at this time that these increased rates of advanced technology usage can be practically and smoothly implemented into the fleet—a reason the agencies are attempting to encourage more utilization of this technology with the proposed HEV pickup truck credits but being reasonably prudent in proposing standards that could de facto force high degrees of penetration of this technology on towing trucks.[363]

EPA notes that the same concerns support the proposed decision to steepen the slope of the truck curve in acknowledgement of the special challenges these larger footprint trucks (which in many instances are towing vehicles) would face. Without the steepening, the penetration rates of these challenging technologies would have been even greater.

From a cost point of view, the impacts on cost track fairly closely with the technology penetration rates discussed above. The average cost increases under Alternatives 2 and 4 are significant for 2021 (approximately $300 and $600), and for some manufacturers they result in very large cost increases. For 2025 the cost increases are even higher (approximately $500 and $900). Alternative 4, as expected, is significantly more costly than alternative 2. From another perspective, the average cost of compliance to the industry on average is $23 and $44 billion for the 2021 and 2025 proposed standards respectively. Alternative 2 will cost the industry on average $7 and $9 billion in excess, while Alternative 4 will cost the industry on average $10 and $16 billion in excess of the costs for the proposed standards. These are large increases in percentage terms, ranging from approximately 25% to 45% in 2021, and from approximately 20% to 35% in 2025.

Per vehicle costs will also increase dramatically including for some of the largest, full-line manufacturers. Under Alternative 2, per vehicle costs for Chrysler, Ford, GM, Honda and Nissan increase by an estimated one-third to nearly double (200%) to meet 2021 standards and from roughly 25% to 45% to meet 2025 standards (see Table III–31 and Table III–32 above). The per-vehicle costs to meet Alternative 4 for these manufacturers is significantly greater and in the same proportions, see Table III–38 and Table III–39.

As noted, these cost increases are associated especially with increased utilization of advanced technologies. As shown in Figure below, HEV+PHEV+EV penetration are projected to increase in 2025 from 17% in the proposed standards to 28% and to nearly 35% under Alternatives 2 and 4 respectively for manufacturers with annual sales above 500,000 vehicles (including Chrysler, Ford, GM, Honda, Hyundai, Nissan, Toyota and VW). The differences are less pronounced for 2021, but still (in alternative 4) over double the penetration level of the proposal. EPA regards these differences as significant, given the factors of expense, consumer cost, consumer acceptance, and potentially (for 2021) lead time.

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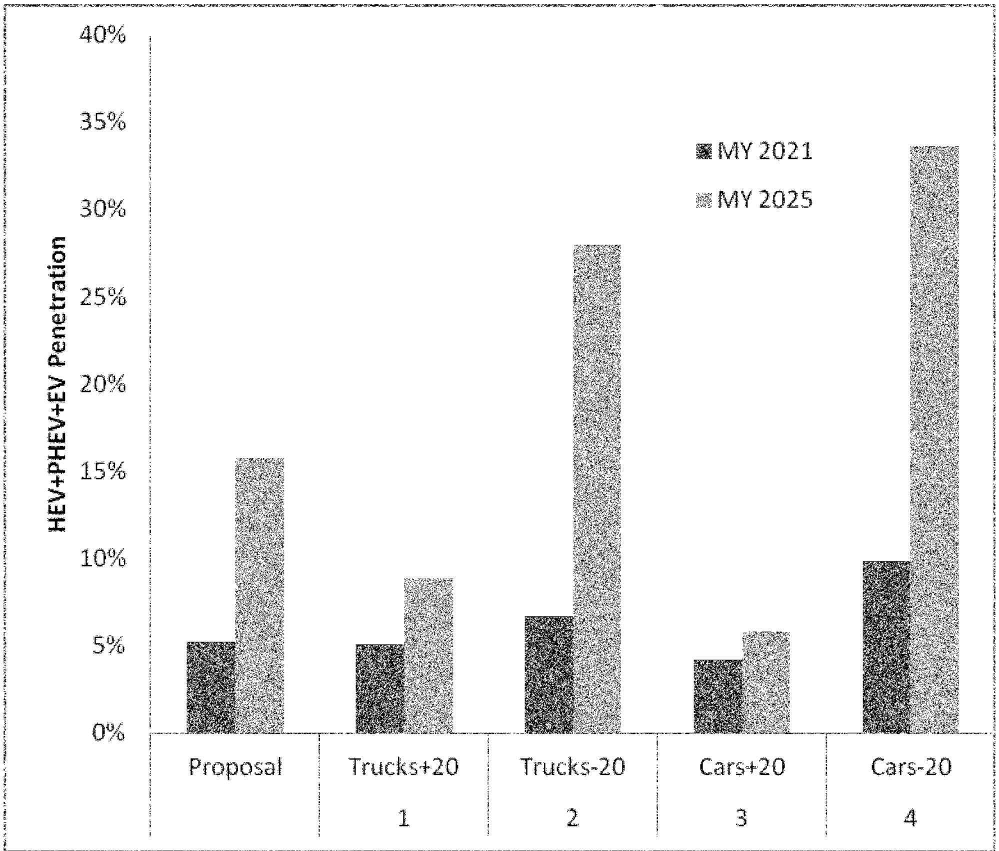
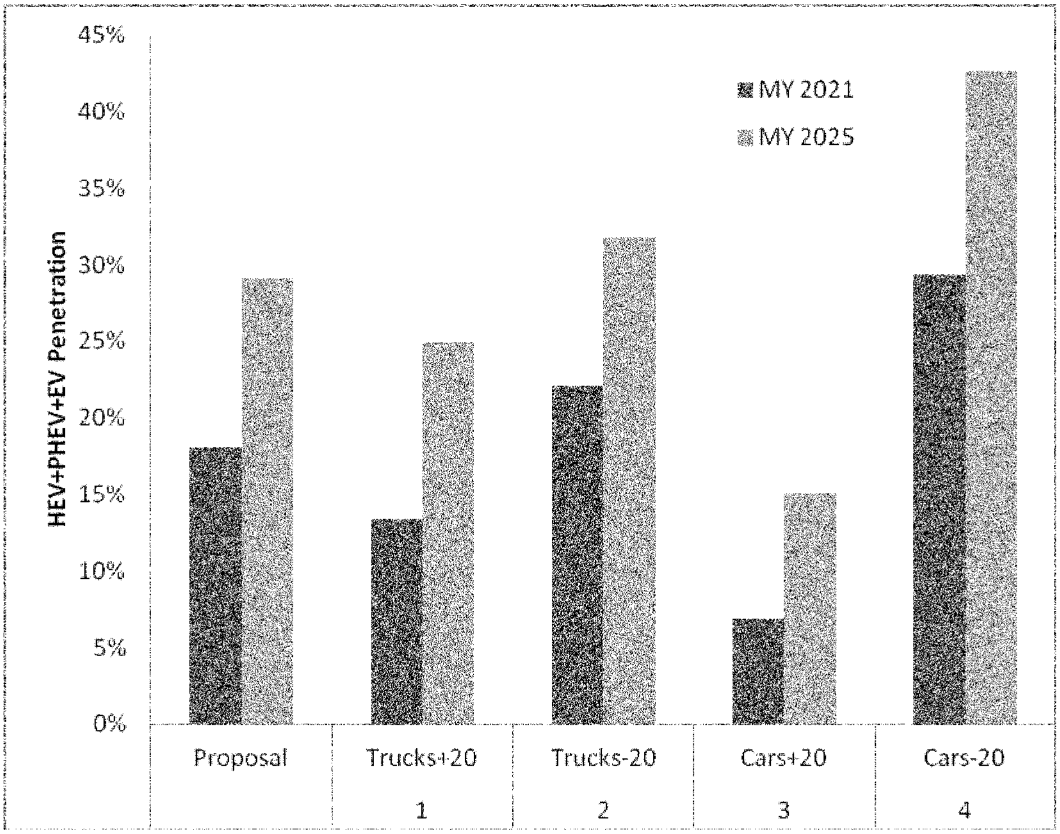
[363] See 76 FR at 57220 discussing a similar issue in the context of the standards for heavy duty pickups and vans: ‘‘Hybrid electric technology likewise could be applied to heavy-duty vehicles, and in fact has already been so applied on a limited basis. However, the development, design, and tooling effort needed to apply this technology to a vehicle model is quite large, and seems less likely to prove cost-effective in this time frame, due to the small sales volumes relative to the light-duty sector. Here again, potential customer acceptance would need to be better understood because the smaller engines that facilitate much of a hybrid's benefit are typically at odds with the importance pickup truck buyers place on engine horsepower and torque, whatever the vehicle's real performance''.

Figure 5- HEV + PHEV + EV Penetration for Manufacturers above 500,000 Sales



The Figure below shows the HEV+PHEV+EV penetration for manufacturers with sales below 500,000 but exceeding 30,000 (including BMW, Daimler, Volvo, Kia, Mazda, Mitsubishi, Porsche, Subaru, Suzuki, and Jaguar/LandRover while excluding Aston Martin, Ferrari, Lotus, Saab, and Tesla). While the penetration rates of these advanced technologies also increase, the distribution within these are shifting to the higher cost EVs and PHEVs as noted above.

Figure 6- HEV + PHEV + EV Penetration for Manufacturers below 500,000 (but above 30,000 Sales)



EPA did not model a number of flexibilities when conducting the analysis for the NPRM. For example, PHEV, EV and fuel cell vehicle incentive multipliers for 2017–2021, full size pickup truck HEV incentive credits, full size pickup truck performance based incentive credits, and off-cycle credits, were not explicitly captured. We plan on modeling these flexibilities for the final rule. For this proposal, while we have not been able to explicitly model the impacts on the program costs, the impact will only be to reduce the estimated costs of the program for most manufacturers. From an industry wide perspective, EPA expects that their overall impact on costs, technology penetration, and emissions reductions and other benefits will be limited. They will provide some additional, important flexibility in achieving the proposed levels and promoting more advanced technology, on a case by case basis, but their impact is not expected to be of enough significance to warrant a change to the standards proposed. Instead they are expected to support the reasonableness of the proposed standards.

Overall, EPA believes that the characteristics and impacts of these and other alternative standards generally reflect a continuum in terms of technical feasibility, cost, lead time, consumer impacts, emissions reductions and oil savings, and other factors evaluated under section 202 (a). In determining the appropriate standard to propose in this context, EPA judges that the proposed standards are appropriate and preferable to more stringent alternatives based largely on consideration of cost—both to manufacturers and to consumers—and the potential for overly aggressive penetration rates for advanced technologies relative to the penetration rates seen in the proposed standards, especially in the face of unknown degree of consumer acceptance of both the increased costs and the technologies themselves. At the same time, the proposal helps to address these issues by providing incentives to promote early and broader deployment of advanced technologies, and so provides a means of encouraging their further penetration while leaving manufacturers alternative technology choices. EPA thus judges that the increase in technology penetration rates and the increase in costs under the increased stringency for the car and truck fleets reflected in alternatives 2 and 4 are such that it would not be appropriate to propose standards that would increase the stringency of the car and truck fleets in this manner.

The two tables below shows the year on year costs as described in greater detail in Chapter 5 of the RIA. These projections show a steady increase in costs from 2017 thru 2025 (as interpolated).

Table III-52 Costs by Manufacturer by MY– Combined Fleet (2009$)

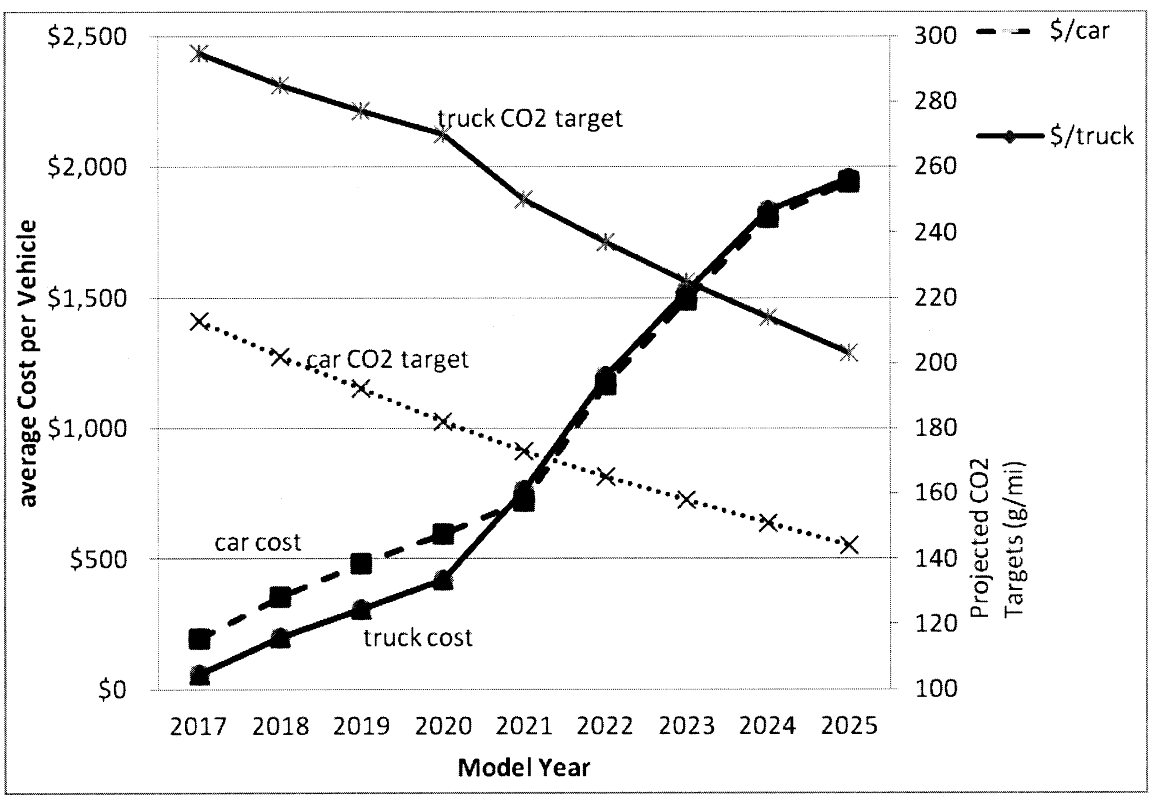
Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
BMW	$154	$370	$531	$696	$937	$1,413	$1,746	$2,058	$2,174
Chrysler/Fiat	$137	$266	$367	$475	$698	$1,179	$1,541	$1,893	$2,043
Daimler	$287	$671	$980	$1,297	$1,702	$2,226	$2,478	$2,704	$2,707
Ferrari	$1,634	$3,080	$4,170	$5,267	$6,351	$7,367	$7,487	$7,598	$7,109
Ford	$147	$293	$403	$501	$696	$1,208	$1,614	$2,003	$2,178
Geely-Volvo	$345	$746	$1,039	$1,339	$1,741	$2,297	$2,585	$2,858	$2,876
GM	$138	$247	$332	$410	$590	$1,080	$1,473	$1,850	$2,030
Honda	$55	$182	$281	$382	$556	$922	$1,201	$1,472	$1,595
Hyundai	$97	$253	$372	$492	$669	$1,062	$1,347	$1,622	$1,739
Kia	$75	$198	$303	$411	$582	$910	$1,155	$1,391	$1,491
Mazda	$134	$362	$534	$696	$919	$1,377	$1,697	$2,012	$2,131
Mitsubishi	$91	$304	$455	$614	$877	$1,349	$1,687	$2,007	$2,133
Nissan	$151	$312	$437	$558	$729	$1,204	$1,565	$1,910	$2,060
Porsche	$1,052	$2,077	$2,840	$3,618	$4,482	$5,262	$5,321	$5,377	$5,012
Spyker-Saab	$755	$1,431	$1,936	$2,444	$2,986	$3,582	$3,721	$3,851	$3,670
Subaru	$178	$410	$582	$755	$994	$1,470	$1,790	$2,096	$2,202
Suzuki	$239	$498	$692	$885	$1,132	$1,592	$1,881	$2,153	$2,225
Tata-JLR	$178	$644	$972	$1,333	$1,935	$2,494	$2,752	$2,994	$2,976
Toyota	$71	$174	$253	$324	$481	$820	$1,096	$1,358	$1,483
Volkswagen	$316	$644	$898	$1,153	$1,457	$1,947	$2,218	$2,472	$2,506
Fleet	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946

Table III-53 Industry Average Vehicle Costs Associated with the Proposed Standards (2009$)

Model Year	2017	2018	2019	2020	2021	2022	2023	2024	2025
$/car	$194	$353	$479	$595	$718	$1,165	$1,492	$1,806	$1,942
$/truck	$55	$198	$305	$417	$764	$1,200	$1,525	$1,834	$1,954
Combined	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946

Figure 7 below shows graphically the year on year average costs presented in Table III–53 with the per vehicle costs on the left axis and the projected CO_2 target standards on the right axis. It is quite evident and intuitive that as the stringency of the standard gets tighter, the average per vehicle costs increase. It is also clear that the costs for cars exceed that of trucks for the early years of the program, but then progress upwards together starting in MY 2021. It is interesting to note that the slower rate of progression of the standards for trucks seems to result in a slower rate of increase in costs for both cars and trucks. This initial slower rate of stringency for trucks is appropriate due primarily concerns over technology penetration rates and disproportionately higher costs for adding technologies to trucks than cars, as described in Section III.D.6.b above. The figure below corroborates these conclusions and further demonstrates that based on the smooth progression of average costs (from 2017–2025), the year on year increase in stringency of the standards is also reasonable. Though there are undoubtedly a range of minor modifications that could be made to the progression of standards, EPA believes that the progression proposed is reasonable and appropriate. Also, EPA believes that any progression of standards that significantly deviates from the proposed standards (such as those in Alternatives 1 through 4) are much less appropriate for the reasons provided in the discussion above.

Figure 7. Year on Year Progression of Projected (Target) CO2 Standards and Average Cost Per Vehicle



7. To what extent do any of today's vehicles meet or surpass the proposed MY 2017–2025 CO_2 footprint-based targets with current powertrain designs?

In addition to the analysis discussed above regarding what technologies could be added to vehicles in order to achieve the projected CO_2 obligation for each automotive company under the proposed MY 2017 to 2025 standards, EPA performed an assessment of the light-duty vehicles available in the market today to see how such vehicles compare to the proposed MY 2017–2025 footprint-based standard curves. This analysis supports EPA's overall assessment that there are a broad range of effective and available technologies that could be used to achieve the proposed standards, as well as illustrating the need for the lead-time between today and MY 2017 to MY 2025 in order for continued refinement of today's technologies and their broader penetration across the fleet for the industry as a whole as well as individual companies. In addition, this assessment supports EPA's view that the proposed standards would not interfere with consumer utility—footprint-attribute standards provide manufacturers with the ability to offer consumers a full range of vehicles with the utility customers want, and does not require or encourage companies to just produce small passenger cars with very low CO_2 emissions.

Using publicly available data, EPA compiled a list of available vehicles and their 2-cycle CO_2 emissions performance (that is, the performance over the city and highway test cycles required by this proposal). Data is currently available for all MY 2011 vehicles and some MY 2012 vehicles. EPA gathered vehicle footprint data from EPA reports, manufacturer submitted CAFE reports, and manufacturer Web sites.

EPA evaluated these vehicles against the proposed CO_2 footprint-based standard curves to determine which vehicles would meet or exceed the proposed MY 2017–MY 2025 footprint-based CO_2 targets assuming air conditioning credit generation consistent with today's proposal. Under the proposed 2017–2025 greenhouse gas emissions standards, each vehicle will have a unique CO_2 target based on the vehicle's footprint. However, it is important to note that the proposed CO_2 standard is a company-specific sales weighted fleet-wide standard for each company's passenger cars and truck fleets calculated using the proposed footprint-based standard curves. No individual vehicle is required to achieve a specific CO_2 target. In this analysis, EPA assumed usage of air conditioner credits because air conditioner improvements are considered to be among the cheapest and easiest technologies to reduce greenhouse gas emissions, manufacturers are already investing in air conditioner improvements, and air conditioner changes do not impact engine, transmission, or aerodynamic designs so assuming such credits does not affect consideration of cost and leadtime for use of these other technologies. In this analysis, EPA assumed increasing air conditioner credits over time with a phase-in of alternative refrigerant for the generation of HFC leakage reduction credits consistent with the assumed phase-in schedule discussed in Section III.C.I. of this preamble. No adjustments were made to vehicle CO_2 performance other then this assumption of air conditioning credit generation. Under this analysis, a wide range of existing vehicles would meet the MY 2017 proposed CO_2 targets, and a few meet even the proposed MY 2025 CO_2 targets. The details regarding this assessment are in Chapter 3 of the EPA Draft RIA.

This assessment shows that a significant number of vehicles models sold today (nearly 40 models) would meet or be lower than the proposed MY 2017 footprint-based CO_2 targets with current powertrain designs, assuming air conditioning credit generation consistent with our proposal. The list of vehicles includes a full suite of vehicle sizes and classes, including midsize cars, minivans, sport utility vehicles, compact cars, small pickup trucks and full size pickup trucks—all of which meet the proposed MY 2017 target values with no technology improvements other than air conditioning system upgrades. These vehicles utilize a wide variety of powertrain technologies and operate on a variety of different fuels including gasoline, diesel, electricity, and compressed natural gas. Nearly every major manufacturer currently produces vehicles that would meet or exceed the proposed MY 2017 footprint CO_2 target with only improvements in air conditioning systems. For all of these vehicle classes the MY 2017 targets are achieved with conventional gasoline powertrains, with the exception of the full size (or ''standard'') pickup trucks. In the case of full size pickups trucks, only HEV versions of the Chevrolet Silverado and the GMC Sierra fall into this category (though the HEV Silverado and Sierra meet not just the MY 2017 footprint-based CO_2 targets with A/C improvements, but their respective targets through MY 2022). As the CO_2 targets become more stringent each model year, fewer MY 2011 and MY 2012 vehicles achieve or surpass the proposed CO_2 targets, in particular for gasoline powertrains. While approximately 15 unique gasoline vehicle models achieve or surpass the MY 2017 targets, this number falls to approximately 11 for the MY 2018 targets, 9 for the model year 2019 targets, and only 2 unique gasoline vehicle models can achieve the MY 2020 proposed CO_2 targets with A/C improvements.

EPA also assessed the subset of these vehicles that have emissions within 5%, of the proposed CO_2 targets. As detailed in Chapter 3 of the EPA Draft RIA, the analysis shows that there are more than twenty additional vehicle models (primarily with gasoline and diesel powertrains) that are within 5% of the proposed MY 2017 CO_2 targets, including compact cars, midsize cars, large cars, SUVs, station wagons, minivans, small and standard pickup trucks. EPA also receives projected sales data prior to each model year from each manufacturer. Based on this data, approximately 7% of MY 2011 sales will be vehicles that would meet or be better than the proposed MY 2017 targets for those vehicles, requiring only improvements in air conditioning systems. In addition, nearly 15% of projected MY 2011 sales would be within 5% of the proposed MY 2017 footprint CO_2 target with only simple improvements to air conditioning systems, a full six model years before the proposed standard takes effect. With improvements to air conditioning systems, the most efficient gasoline internal combustion engines would meet the MY 2020 proposed footprint targets. After MY 2020, the only current vehicles that continue to meet the proposed footprint-based CO_2 targets (assuming improvements in air conditioning) are hybrid-electric, plug-in hybrid-electric, and fully electric vehicles. However, the proposed MY 2021 standards, if finalized, would not need to be met for another 9 years. Today's Toyota Prius, Ford Fusion Hybrid, Chevrolet Volt, Nissan Leaf, Honda Civic Hybrid, and Hyundai Sonata Hybrid all meet or surpass the proposed footprint-based CO_2 targets through MY 2025. In fact, the current Prius, Volt, and Leaf meet the proposed 2025 CO_2 targets without air conditioning credits.

This assessment of MY 2011 and MY 2012 vehicles makes it clear that HEV technology (and of course EVs and PHEVs) is capable of achieving the MY 2025 standards. However, as discussed earlier in this section, EPA's modeling projects that the MY 2017–2025 standards can primarily be achieved by advanced gasoline vehicles—for example, in MY 2025, we project more than 80 percent of the new vehicles could be advanced gasoline powertrains. The assessment of MY 2011 and MY 2012 vehicles available in the market today indicates advanced gasoline vehicles (as well as diesels) can achieve the targets for the early model years of the proposed standards (*i.e.,* model years 2017–2020) with only improvements in air conditioning systems. However, significant improvements in technologies are needed and penetrations of those technologies must increase substantially in order for individual manufacturers (and the fleet overall) to achieve the proposed standards for the early years of the program, and certainly for the later years (*i.e.,* model years 2021–2025). These technology improvements are the very technologies EPA and NHTSA describe in detail in Chapter 3 of the draft Joint Technical Support Document and which we forecasted penetration rates earlier in this section III.D, and they include for example: gasoline direct injection fuel systems; downsized and turbocharged gasoline engines (including in some cases with the application of cooled exhaust gas recirculation); continued improvements in engine friction reduction and low friction lubricants; transmissions with an increased number of forward gears (*e.g.,* 8 speeds); improvements in transmission shifting logic; improvements in transmission gear box efficiency; vehicle mass reduction; lower rolling resistance tires, and improved vehicle aerodynamics. In many (though not all) cases these technologies are beginning to penetrate the U.S. light-duty vehicle market.

In general, these technologies must go through the automotive product development cycle in order to be introduced into a vehicle. In some cases additional research is needed before the technologies' CO_2 benefits can be fully realized and large-scale manufacturing can be achieved. The subject of technology penetration phase-in rates is discussed in more detail in Chapter 3.5 of the draft Joint Technical Support Document. In that Chapter, we explain that why many CO_2 reducing technologies should be able to penetrate the new vehicle market at high levels between now and MY 2016. There are also many of the key technologies we project as being needed to achieve the proposed 2017–2025 standards which will only be able to penetrate the market at relatively low levels (*e.g.,* a maximum level of 30% or less) by MY 2016, and even by MY 2021. These include important powertrain technologies such as 8-speed transmissions and second or third generation downsized engines with turbocharging,

The majority of these technologies must be integrated into vehicles during the product redesign schedule, which is typically on a 5-year cycle. EPA discussed in the MY 2012–2016 rule the significant costs and potential risks associated with requiring major technologies to be added in-between the typical 5-year vehicle redesign schedule (see 75 FR at 25467–68, May 7, 2010). In addition, engines and transmissions generally have longer lifetimes then 5 years, typically on the order of 10 years. Thus major powertrain technologies generally take longer to penetrate the new vehicle fleet then can be done in a 5-year redesign cycle. As detailed in Chapter 3.5 of the draft Joint TSD, EPA projects that 8-speed transmissions could increase their maximum penetration in the fleet from 30% in MY 2016 to 80% in 2021 and to 100% in MY 2025. Similarly, we project that second generation downsized and turbocharged engines (represented in our assessment as engines with a brake-mean effective pressure of 24 bars) could penetrate the new vehicle fleet at a maximum level of 15% in MY 2016, 30% in MY 2021, and 75% in MY 2025. When coupled with the typical 5-year vehicle redesign schedule, EPA projects that it is not possible for all of the advanced gasoline vehicle technologies we have assessed to penetrate the fleet in a single 5-year vehicle redesign schedule.

Given the status of the technologies we project to be used to achieve the proposed MY2017–2025 standards and the product development and introduction process which is fairly standard in the automotive industry today, our assessment of the MY2011 and MY2012 vehicles in comparison to the proposed standards supports our overall feasibility assessment, and reinforces our assessment of the lead time needed for the industry to achieve the proposed standards.

E. Certification, Compliance, and Enforcement

1. Compliance Program Overview

This section summarizes EPA's comprehensive program to ensure compliance with emission standards for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), as described in Section III.B. An effective compliance program is essential to achieving the environmental and public health benefits promised by these mobile source GHG standards. EPA's GHG compliance program is designed around two overarching priorities: (1) to address Clean Air Act (CAA) requirements and policy objectives; and (2) to streamline the compliance process for both manufacturers and EPA by building on existing practice wherever possible, and by structuring the program such that manufacturers can use a single data set to satisfy both GHG and Corporate Average Fuel Economy (CAFE) testing and reporting requirements. The EPA and NHTSA programs replicate the compliance protocols established in the MY 2012–2016 rule.[364] The certification, testing, reporting, and associated compliance activities track current practices and are thus familiar to manufacturers. As is the case under the 2012–2016 program, EPA and NHTSA have designed a coordinated compliance approach for 2017–2025 such that the compliance mechanisms for both GHG and CAFE standards are consistent and non-duplicative. Readers are encouraged to review the MY 2012–2016 final rule for background and a detailed description of these certification, compliance, and enforcement requirements.

Vehicle emission standards established under the CAA apply throughout a vehicle's full useful life. Today's rule establishes fleet average greenhouse gas standards where compliance with the fleet average is determined based on the testing performed at time of production, as with the current CAFE fleet average. EPA is also establishing in-use standards that apply throughout a vehicle's useful life, with the in-use standard determined by adding an adjustment factor to the emission results used to calculate the fleet average. EPA's program will thus not only assess compliance with the fleet average standards described in Section III.B, but will also assess compliance with the in-use standards. As it does now, EPA will use a variety of compliance mechanisms to conduct these assessments, including pre-production certification and post-production, in-use monitoring once vehicles enter customer service. Under this compliance program manufacturers will also be afforded numerous flexibilities to help achieve compliance, both stemming from the program design itself in the form of a manufacturer-specific CO_2 fleet average standard, as well as in various credit banking and trading opportunities, as described in

[364] 75 FR 25468.

Section III.C. The compliance program is summarized in further detail below.

2. Compliance With Fleet-Average CO_2 Standards

Fleet average emission levels can only be determined when a complete fleet profile becomes available at the close of the model year. Therefore, EPA will determine compliance with the fleet average CO_2 standards when the model year closes out, based on actual production figures for each model and on model-level emissions data collected through testing over the course of the model year. Manufacturers will submit this information to EPA in an end-of-year report which is discussed in detail in Section II*I.E*.5.h of the MY 2012–2016 final rule preamble (see 75 FR 25481).

a. Compliance Determinations

As described in Section III.B above, the fleet average standards will be determined on a manufacturer by manufacturer basis, separately for cars and trucks, using the footprint attribute curves. EPA will calculate the fleet average emission level using actual production figures and, for each model type, CO_2 emission test values generated at the time of a manufacturer's CAFE testing. EPA will then compare the actual fleet average to the manufacturer's footprint standard to determine compliance, taking into consideration use of averaging and credits.

Final determination of compliance with fleet average CO_2 standards may not occur until several years after the close of the model year due to the flexibilities of carry-forward and carry-back credits and the remediation of deficits (see Section III.B). A failure to meet the fleet average standard after credit opportunities have been exhausted could ultimately result in penalties and injunctive orders under the CAA as described in Section II*I.E*.6 below.

b. Required Minimum Testing For Fleet Average CO_2

EPA will require and use the same test data to determine a manufacturer's compliance with both the CAFE standard and the fleet average CO_2 emissions standard. Please see Section II*I.E*.2.b of the MY 2012–2016 final rule preamble (75 FR 25469) for details.

3. Vehicle Certification

CAA section 203(a)(1) prohibits manufacturers from introducing a new motor vehicle into commerce unless the vehicle is covered by an EPA-issued certificate of conformity. Section 206(a)(1) of the CAA describes the requirements for EPA issuance of a certificate of conformity, based on a demonstration of compliance with the emission standards established by EPA under section 202 of the Act. The certification demonstration requires emission testing, and must be done for each model year.[365]

Since compliance with a fleet average standard depends on actual production volumes, it is not possible to determine compliance with the fleet average at the time the manufacturer applies for and receives a certificate of conformity for a test group. Instead, EPA will continue to condition each certificate of conformity for the GHG program upon a manufacturer's demonstration of compliance with the manufacturer's fleet-wide average CO_2 standard. Please see Section II*I.E*.3 of the MY 2012–2016 final rule preamble (75 FR 25470) for a discussion of how EPA will certify vehicles under the GHG standards.

4. Useful Life Compliance

Section 202(a)(1) of the CAA requires emission standards to apply to vehicles throughout their statutory useful life, as further described in Section III.A. The in-use CO_2 standard under the greenhouse gas program would apply to individual vehicles and is separate from the fleet-average standard. The in-use CO_2 standard for each model would be the model specific CO_2 level used in calculating the fleet average, adjusted to be 10% higher to account for test-to-test and production variability that might affect in-use test results. Please see Section II*I.E*.4 of the MY 2012–2016 final rule preamble (75 FR 25473 for a detailed discussion of the in-use standard, in-use testing requirements, and deterioration factors for CO_2, N_2O, and CH_4.

5. Credit Program Implementation

As described in Section III.C, several credit programs are available under this rulemaking. Please see Section II*I.E*.5 of the MY 2012–2016 final rule preamble (75 FR 25477) for a detailed explanation of credit program implementation, sample credit and deficit calculations, and end-of-year reporting requirements.

6. Enforcement

The enforcement structure EPA promulgated under the MY 2012–2016 rulemaking remains in place. Please see Section II*I.E*.6 of the MY 2012–2016 final rule preamble (75 FR 25482) for a discussion of these provisions.

[365] CAA section 206(a)(1).

Prohibited Acts in the CAA

Section 203 of the Clean Air Act describes acts that are prohibited by law. This section and associated regulations apply equally to the greenhouse gas standards as to any other regulated emission. Acts that are prohibited by section 203 of the Clean Air Act include the introduction into commerce or the sale of a vehicle without a certificate of conformity, removing or otherwise defeating emission control equipment, the sale or installation of devices designed to defeat emission controls, and other actions. This proposal includes a section that details these prohibited acts, as did the 2012 greenhouse gas regulations.

7. Other Certification Issues

a. Carryover/Carry Across Certification Test Data

EPA's certification program for vehicles allows manufacturers to carry certification test data over and across certification testing from one model year to the next, when no significant changes to models are made. EPA would continue to apply this policy to CO_2, N_2O and CH_4 certification test data and would allow manufacturers to use carryover and carry across data to demonstrate CO_2 fleet average compliance if they have done so for CAFE purposes.

b. Compliance Fees

The CAA allows EPA to collect fees to cover the costs of issuing certificates of conformity for the classes of vehicles covered by this rule.

At this time the extent of any added costs to EPA as a result of this rule is not known. EPA will assess its compliance testing and other activities associated with the rule and may amend its fees regulations in the future to include any warranted new costs.

c. Small Entity Exemption

EPA would exempt small entities, and these entities (necessarily) would not be subject to the certification requirements of this rule.

As discussed in Section III.B.7, businesses meeting the Small Business Administration (SBA) criterion of a small business as described in 13 CFR 121.201 would not be subject to the GHG requirements, pending future regulatory action. Small entities are currently covered by a number of EPA motor vehicle emission regulations, and they routinely submit information and data on an annual basis as part of their compliance responsibilities.

As discussed in detail in Section III.B.5, small volume manufacturers with annual sales volumes of less than 5,000 vehicles would be required to meet primary GHG standards or to petition the Agency for alternative standards.

d. Onboard Diagnostics (OBD) and CO_2 Regulations

As under the current program, EPA would not require CO_2, N_2O, and CH_4 emissions as one of the applicable standards required for the OBD monitoring threshold.

e. Applicability of Current High Altitude Provisions to Greenhouse Gases

As under the current program, vehicles covered by this rule would be required to meet the CO_2, N_2O and CH_4 standard at altitude but would not normally be required to submit vehicle CO_2 test data for high altitude. Instead, they would submit an engineering evaluation indicating that common calibration approaches will be utilized at high altitude.

f. Applicability of Standards to Aftermarket Conversions

With the exception of the small entity and small business exemptions, EPA's emission standards, including greenhouse gas standards, will continue to apply as stated in the applicability sections of the relevant regulations. EPA expects that some aftermarket conversion companies will qualify for and seek the small entity and/or small business exemption, but those that do not qualify will be required to meet the applicable emission standards, including the greenhouse gas standards to qualify for a tampering exemption under 40 CFR subpart F. Fleet average standards are not generally appropriate for fuel conversion manufacturers because the ''fleet'' of vehicles to which a conversion system may be applied has already been accounted for under the OEM's fleet average standard. Therefore, EPA is proposing to retain the process promulgated in 40 CFR subpart F anti-tampering regulations whereby conversion manufacturers demonstrate compliance at the vehicle rather than the fleet level. Fuel converters will continue to show compliance with greenhouse gas standards by submitting data to demonstrate that the conversion EDV N_2O, CH_4 and CREE results are less than or equal to the OEM's in-use standard for that subconfiguration.. EPA is also proposing to continue to allow conversion manufacturers, on a test group basis, to convert CO_2 overcompliance into CO_2 equivalents of N_2O and/or CH_4 that can be subtracted from the CH_4 and N_2O measured values to demonstrate compliance with CH_4 and/or N_2O standards.

g. Geographical Location of Greenhouse Gas Fleet Vehicles

EPA emission certification regulations require emission compliance [366] in the 50 states, the District of Columbia, the Puerto Rico, the Virgin Islands, Guam, American Samoa and the Commonwealth of the Northern Mariana Islands.

8. Warranty, Defect Reporting, and Other Emission-Related Components Provisions

This rulemaking would retain warranty, defect reporting, and other emission-related component provisions promulgated in the MY 2012–2016 rulemaking. Please see Section II*I.E.*10 of the MY 2012–2016 final rule preamble (75 FR 25486) for a discussion of these provisions.

9. Miscellaneous Technical Amendments and Corrections

EPA is proposing a number of noncontroversial amendments and corrections to the existing regulations. Because the regulatory provisions for the EPA greenhouse gas program, NHTSA's CAFE program, and the joint fuel economy and environment labeling program are all intertwined in 40 CFR Part 600, this proposed rule presents an opportunity to make corrections and clarifications to all or any of these programs. Consequently, a number of minor and non-substantive corrections are being proposed to the regulations that implement these programs.

Amendments include the following:

In section 86.135–12, we have removed references to the model year applicability of N_2O measurement. This applicability is covered elsewhere in the regulations, and we believe that—where possible—testing regulations should be limited to the specifics of testing and measurement.

The definition of ''Footprint'' in 86.1803–01 is revised to clarify measurement and rounding. The previous definition stated that track width is ''measured in inches,'' which may inadvertently imply measuring and recording to the nearest inch. The revised definition clarifies that measurements should be to the nearest one tenth of an inch, and average track width should be rounded to the nearest tenth of an inch.

We are also proposing a solution to a situation in which a manufacturer of a clean alternative fuel conversion is attempting to comply with the fuel conversion regulations (see 40 CFR part 85 subpart F) at a point in time before which certain data is available from the original manufacturer of the vehicle. Clean alternative fuel conversions are subject to greenhouse gas standards if the vehicle as originally manufactured was subject to greenhouse gas standards, unless the conversion manufacturer qualifies for exemption as a small business. Compliance with light-duty vehicle greenhouse gas emission standards is demonstrated by complying with the N_2O and CH_4 standards and the in-use CO_2 exhaust emission standard set forth in 40 CFR 86.1818–12(d) as determined by the original manufacturer for the subconfiguration that is identical to the fuel conversion emission data vehicle (EDV). However, the subconfiguration data may not be available to the fuel conversion manufacturer at the time they are seeking EPA certification. Several compliance options are currently provided to fuel conversion manufacturers that are consistent with the compliance options for the original equipment manufacturers. EPA is proposing to add another option that would be applicable starting with the 2012 model year. The new option would allow clean alternative fuel conversion manufacturers to satisfy the greenhouse gas standards if the sum of CH_4 plus N_2O plus CREE emissions from the vehicle pre-conversion is less than the sum post-conversion, adjusting for the global warming potential of the constituents.

10. Base Tire Definition

One of the factors in a manufacturer's calculation of vehicle footprint is the base tire. Footprint is based on a vehicle's wheel base and track width, and track width in turn is ''the lateral distance between the centerlines of the base tires at ground, including the camber angle.'' [367] EPA's current definition of base tire is the ''tire specified as standard equipment by the

[366] Section 216 of the Clean Air Act defines the term commerce to mean ''(A) commerce between any place in any State and any place outside thereof; and (B) commerce wholly within the District of Columbia.''

Section 302(d) of the Clean Air Act reads ''The term ''State'' means a State, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, and American Samoa and includes the Commonwealth of the Northern Mariana Islands.'' In addition, 40 CFR 85.1502 (14) regarding the importation of motor vehicles and motor vehicle engines defines the United States to include ''the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, and the U.S. Virgin Islands.''

[367] See 40 CFR 86.1803–01.

manufacturer.'' [368] EPA understands that some manufacturers may be applying this base tire definition in different ways, which could lead to differences across manufacturers in how they are ultimately calculating footprints. EPA invites public comment on whether the base tire definition should be clarified to ensure a more uniform application across manufacturers. For example, NHTSA is proposing a specific change to the base tire definition for the CAFE program (see Section IV.I.5.g, and proposed 49 CFR 523.2). Because the calculation of footprint is a fundamental aspect of both the greenhouse gas standards and the CAFE standards, EPA welcomes comments on whether the existing base tire definition should be clarified, and specific changes to the definition that would address this issue.

11. Treatment of Driver-Selectable Modes and Conditions

EPA is requesting comments on whether there is a need to clarify in the regulations how EPA treats driver-selectable modes (such as multi-mode transmissions and other user-selectable buttons or switches) that may impact fuel economy and GHG emissions. New technologies continue to arrive on the market, with increasing complexity and an increasing array of ways a driver can make choices that affect the fuel economy and greenhouse gas emissions. For example, some start-stop systems may offer the driver the option of choosing whether or not the system is enabled. Similarly, vehicles with ride height adjustment or grill shutters may allow drivers to override those features.

Under the current regulations, EPA draws a distinction between vehicles tested for purposes of CO_2 emissions performance and fuel economy and vehicles tested for non-CO_2 emissions performance. When testing emission data vehicles for certification under Part 86 for non-CO_2 emissions standards, a vehicle that has multiple operating modes must meet the applicable emission standards in all modes, and on all fuels. Sometimes testing may occur in all modes, but more frequently the worst-case mode is selected for testing to represent the emission test group. For example, a vehicle that allows the user to disengage the start-stop capability must meet the standards with and without the start-stop system operating (in some cases EPA has determined that the operation of start-stop is the worst case for emissions controlled by the catalyst because of the spike in emissions associated with each start). Similarly, a plug-in hybrid electric vehicle is tested in charge-sustaining (*i.e.,* gasoline-only) operation. Current regulations require the reporting of CO_2 emissions from certification tests conducted under Part 86, but EPA regulations also recognize that these values, from emission data vehicles that represent a test group, are ultimately not the values that are used to establish in-use CO_2 standards (which are established on much more detailed sub-configuration-specific level) or the model type CO_2 and fuel economy values used for fleet averaging under Part 600.

When EPA tests vehicles for fuel economy and CO_2 emissions performance, user-selectable modes are treated somewhat differently, where the goals are different and where worst-case operation may not be the appropriate method. For example, EPA does not believe that the fuel economy and CO_2 emissions value for a PHEV should ignore the use of grid electricity, or that other dual fuel vehicles should ignore the real-world use of alternative fuels that reduce GHG emissions. The regulations address the use of utility factors to properly weight the CO_2 performance on the conventional fuel and the alternative fuel. Similarly, non-CO_2 emission certification testing may be done in a transmission mode that is not likely to be the predominant mode used by consumers. Testing under Part 600 must determine a single fuel economy value for each model type for the CAFE program and a single CO_2 value for each model type for EPA's program. With respect to transmissions, Part 600 refers to 86.128, which states the following:

> All test conditions, except as noted, shall be run according to the manufacturer's recommendations to the ultimate purchaser, *Provided,* That: Such recommendations are representative of what may reasonably be expected to be followed by the ultimate purchaser under in-use conditions.

For multi-mode transmissions EPA relies on guidance letter CISD–09–19 (December 3, 2009) to guide the determination of what is ''representative of what may reasonably be expected to be followed by the ultimate purchaser under in-use conditions.'' If EPA can make a determination that one mode is the ''predominant'' mode (meaning nearly total usage), then testing may be done in that mode. However, if EPA cannot be convinced that a single mode is predominant, then fuel economy and GHG results from each mode are typically averaged with equal weighting. There are also detailed provisions that explain how a manufacturer may conduct surveys to support a statement that a given mode is predominant. However, CISD–09–19 only addresses transmissions, and states the following regarding other technologies:

> ''Please contact EPA in advance to request guidance for vehicles equipped with future technologies not covered by this document, unusual default strategies or driver selectable features, *e.g.,* hybrid electric vehicles where the multimode button or switch disables or modifies any fuel saving features of the vehicle (such as the stop-start feature, air conditioning compressor operation, electric-only operation, etc.).''

The unique operating characteristics of these technologies essentially often requires that EPA determine fuel economy and CO_2 testing and calculations on a case-by-case basis. Because the CAFE and CO_2 programs require a single value to represent a model type, EPA must make a decision regarding how to account for multiple modes of operation. When a manufacturer brings such a technology to us for consideration, we will evaluate the technology (including possibly requiring that the manufacturer give us a vehicle to test) and provide the manufacturer with instructions on how to determine fuel economy and CO_2 emissions. In general we will evaluate these technologies in the same way and following the same principles we use to evaluate transmissions under CISD–09–19, making a determination as to whether a given operating mode is predominant or not (using the criteria for predominance described in CISD–09–19). These instructions are provided to the manufacturer under the authority for special test procedures described in 40 CFR 600.111–08. EPA would apply the same approach to testing for compliance with the in-use CO_2 standard, so testing for the CO_2 fleet average and testing for compliance with the in-use CO_2 standard would be consistent. EPA requests comment on whether the current approach and regulatory provisions are sufficient, or whether additional regulations or guidance should be developed to describe EPA's process. EPA recognizes that ultimately no regulation can anticipate all options, devices, and operator controls that may arrive in the future, and adequate flexibility to address future situations is an important attribute for fuel economy and CO_2 emissions testing.

[368] See 40 CFR 86.1803–01, and 40 CFR 600.002. Standard equipment means those features or equipment which are marketed on a vehicle over which the purchaser can exercise no choice.

F. How would this proposal reduce GHG emissions and their associated effects?

This action is an important step towards curbing growth of GHG emissions from cars and light trucks. In the absence of control, GHG emissions worldwide and in the U.S. are projected to continue steady growth. Table III–54 shows emissions of CO_2, methane (CH_4), nitrous oxide (N_2O) and air conditioning refrigerant (HFC–134a) on a CO_2-equivalent basis for calendar years 2010, 2020, 2030, 2040 and 2050. As shown below, U.S. GHGs are estimated to make up roughly 15 percent of total worldwide emissions in 2010. Further, the contribution of direct emissions from cars and light-trucks to this U.S. share reaches an estimated 17 percent of U.S. emissions by 2030 in the absence of control. As discussed later in this section, this steady rise in GHG emissions is associated with numerous adverse impacts on human health, food and agriculture, air quality, and water and forestry resources.

Table III-54 GHG Emissions by Calendar Year without the Proposed Standards ($MMTCO_2eq$)[369]

	2010	2020	2030	2040	2050
All Sectors (Worldwide)[a]	45,000	53,000	61,000	69,000	76,000
All Sectors (U.S. Only)[b]	6,800	7,300	7,600	8,000	8,100
U.S. Cars/Light Truck Only[c]	1,300	1,200	1,300	1,500	1,700

[a] GCAM model[370]

[b] ADAGE model,[371]

[c] OMEGA model, Tailpipe CO_2 and HFC134a only (includes impacts of MYs 2012-2016 rule)

This rule will result in significant reductions as newer, cleaner vehicles come into the fleet. As discussed in Section I, this GHG rule is part of a joint National Program such that a large part of the projected benefits, but by no means all, would be achieved jointly with NHTSA's CAFE standards, which are described in detail in Section IV. EPA estimates the reductions attributable to the GHG program over time assuming the model year 2025 standards continue indefinitely post-2025, compared to a reference scenario in which the 2016 model year GHG standards continue indefinitely beyond 2016.

EPA estimated greenhouse impacts from several sources including: (a) The impact of the standards on tailpipe CO_2 emissions, (b) projected improvements in the efficiency of vehicle air conditioning systems, [372] (c) reductions in direct emissions of the refrigerant and potent greenhouse gas HFC–134a from air conditioning systems, (d) ''upstream'' emission reductions from gasoline extraction, production and distribution processes as a result of reduced gasoline demand associated with this rule, and (e) ''upstream'' emission increases from power plants as electric powertrain vehicles increase in prevalence as a result of this rule. EPA additionally accounted for the greenhouse gas impacts of additional vehicle miles travelled (VMT) due to the ''rebound'' effect discussed in Section III.H.

Using this approach EPA estimates the proposed standards would cut annual fleetwide car and light truck tailpipe CO_2 emissions by approximately 230 MMT or 18 percent by 2030, when 85 percent of car and light truck miles will be travelled by vehicles meeting the MY 2017 or later standards. An additional 65 $MMTCO_2eq$ of reduced emissions are attributable to reductions in gasoline production, distribution and transport. 15 $MMTCO_2eq$ of additional emissions will be attributable to increased electricity production. In total, EPA estimates that compared to a baseline of indefinite 2016 model year standards, net GHG emission reductions from the program would be approximately 300 million metric tons CO_2-equivalent ($MMTCO_2eq$) annually by 2030, which represents a reduction of 4% of total U.S. GHG emissions and 0.5% of total worldwide GHG emissions projected in that year. These GHG savings would result in savings of approximately 26 billion gallons of petroleum-based gasoline.[373]

EPA projects the total reduction of the program over the full life of model year 2017–2025 vehicles to be about 1,970 $MMTCO_2eq$, with fuel savings of 170 billion gallons (3.9 billion barrels) of gasoline over the life of these vehicles.

The impacts on atmospheric CO_2 concentrations, global mean surface temperature, sea level rise, and ocean pH resulting from these emission reductions are discussed in Section III.F.3.

[369] ADAGE and GCAM model projections of worldwide and U.S. GHG emissions are provided for context only. The baseline data in these models differ in certain assumptions from the baseline used in this proposal. For example, the ADAGE baseline is calibrated to AEO 2010, which includes the EISA 35 MPG by 2020 provision, but does not explicitly include the MYs 2012–2016 rule. All emissions data were rounded to two significant digits.

[a] GCAM model.

[370] Based on the Representative Concentration Pathway scenario in GCAM available at *http://www.globalchange.umd.edu/gcamrcp*. See section III.F.3 and DRIA Chapter 6.4 for additional information on GCAM.

[b] ADAGE model.

[371] Based on the ADAGE reference case used in U.S. EPA (2010). ''EPA Analysis of the American Power Act of 2010'' U.S. Environmental Protection Agency, Washington, DC, USA (*http:www.epagov/climatechange/economics/economicanalyses.html).*

[c] OMEGA model, Tailpipe CO_2 and HFC134a only (includes impacts of MYs 2012–2016 rule).

[372] While EPA anticipates that the majority of mobile air conditioning systems will be improved in response to the MY 2012–2016 rulemaking, the agency expects that the remainder will be improved as a result of this action.

[373] All estimates of fuel savings presented here assume that manufacturers use air conditioning leakage credits as part of their compliance strategy. If these credits were not used, the fuel savings would be larger.

1. Impact on GHG Emissions

The modeling of fuel savings and greenhouse gas emissions is substantially similar to that which was conducted in the 2012–2016 Final Rulemaking and the MY 2017–2025 Interim Joint Technical Assessment Report (TAR). As detailed in Draft RIA chapter 4, EPA estimated calendar year tailpipe CO_2 reductions based on pre- and post-control CO_2 gram per mile levels from EPA's OMEGA model, coupled with VMT projections derived from AEO 2011 Final Release. These estimates reflect the real-world CO_2 emissions reductions projected for the entire U.S. vehicle fleet in a specified calendar year. EPA also estimated full lifetime reductions for model years 2017–2025 using pre- and post-control CO_2 levels projected by the OMEGA model, coupled with projected vehicle sales and lifetime mileage estimates. These estimates reflect the real-world CO_2 emissions reductions projected for model years 2017 through 2025 vehicles over their entire life. Upstream impacts from power plant emissions came from OMEGA estimates of EV/penetration into the fleet (approximately 3%). For both calendar year and model year assessments, EPA estimated the environmental impact of the advanced technology multiplier, pickup truck hybrid electric vehicle (HEV) and performance based incentives and air conditioning credits. The impact of the off-cycle credits were not explicitly estimated, as these credits are assumed to be inherently environmentally neutral (Section III.B). EPA also did not assess the impact of the credit banking carry-forward programs.

As in the MY 2012–2016 rulemaking, this proposal allows manufacturers to earn credits for improvements to controls for both direct and indirect AC emissions. Since these improvements are relatively low cost, EPA again projects that manufacturers will take advantage of this flexibility, leading to reductions from emissions associated with vehicle air conditioning systems. As explained above, these reductions will come from both direct emissions of air conditioning refrigerant over the life of the vehicle and tailpipe CO_2 emissions produced by the increased load of the A/C system on the engine. In particular, EPA estimates that direct emissions of HFC–134a, one of the most potent greenhouse gases, would be fully removed from light-duty vehicles through the phase-in of alternative refrigerants. More efficient air conditioning systems would also lead to fuel savings and additional reductions in upstream emissions from fuel production and distribution. Our estimated reductions from the A/C credit program assume that manufacturers will fully utilize the program by MY 2021.

Upstream greenhouse gas emission reductions associated with the production and distribution of fuel were estimated using emission factors from DOE's GREET1.8 model, with modifications as detailed in Chapter 5 of the DRIA. These estimates include both international and domestic emission reductions, since reductions in foreign exports of finished gasoline and/or crude would make up a significant share of the fuel savings resulting from the GHG standards. Thus, significant portions of the upstream GHG emission reductions will occur outside of the U.S.; a breakdown of projected international versus domestic reductions is included in the DRIA.

Electricity emission factors were derived from EPA's Integrated Planning Model (IPM). EPA uses IPM to analyze the projected impact of environmental policies on the electric power sector in the 48 contiguous states and the District of Columbia. IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector. It provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental, transmission, dispatch, and reliability constraints. EPA derived average national CO_2 emission factors from the IPM version 4.10 base case run for the ''Proposed Transport Rule.'' [374] As discussed in Draft TSD Chapter 4, for the Final Rulemaking, EPA may consider emission factors other than national power generation, such as marginal power emission factors, or regional emission factors.

a. Calendar Year Reductions for Future Years

Table III–55 shows reductions estimated from these GHG standards assuming a pre-control case of 2016 MY standards continuing indefinitely beyond 2016, and a post-control case in which 2025 MY GHG standards continue indefinitely beyond 2025. These reductions are broken down by upstream and downstream components, including air conditioning improvements, and also account for the offset from a 10 percent VMT ''rebound'' effect as discussed in Section III.H. Including the reductions from upstream emissions, total reductions are estimated to reach 297 $MMTCO_2eq$ annually by 2030, and grow to over 540 $MMTCO_2eq$ in 2050 as cleaner vehicles continue to come into the fleet.

[374] EPA. IPM. *http://www.epa.gov/airmarkt/progsregs/epa-ipm/BaseCasev410.html*. ''Proposed Transport Rule/NODA version'' of IPM. TR_SB_Limited Trading v.4.10.

Table III-55 Projected GHG Deltas ($MMTCO_2eq$ per year)

Calendar Year:	2020	2030	2040	2050
Net Delta*	**-29**	**-297**	**-462**	**-547**
Net CO_2	*-24*	*-268*	*-420*	*-497*
Net other GHG	*-4*	*-29*	*-42*	*-50*
Downstream	**-24**	**-249**	**-389**	**-461**
CO_2 (excluding A/C)	*-19*	*-224*	*-355*	*-421*
A/C – indirect CO_2	*-1*	*-3*	*-4*	*-4*
A/C – direct HFCs	*-4*	*-21*	*-30*	*-36*
CH_4 (rebound effect)	*0*	*0*	*0*	*0*
N_2O (rebound effect)	*0*	*0*	*0*	*0*
Gasoline Upstream	***-6***	***-63***	***-100***	***-119***
CO_2	*-5*	*-55*	*-87*	*-103*
CH_4	*-1*	*-8*	*-12*	*-15*
N_2O	*0*	*0*	*0*	*0*
Electricity Upstream	**1**	**15**	**27**	**32**
CO_2	*1*	*15*	*26*	*32*
CH_4	*0*	*0*	*0*	*0*
N_2O	*0*	*0*	*0*	*0*

* includes impacts of 10% VMT rebound rate presented in Table III-57

The total program emission reductions yield significant emission decreases relative to worldwide and national total emissions.

Table III-56 Projected GHG Deltas ($MMTCO_2eq$ per year)

Emission Reduction Relative to:	2020	2030	2040	2050
Worldwide reference	-0.1%	-0.5%	-0.7%	-0.7%
U.S. reference (all sectors)	-0.4%	-3.9%	-5.8%	-6.8%
U.S. reference (cars + light trucks)*	-2.4%	-22.9%	-30.8%	-32.2%

*Note that total emission reductions include sectors (such as fuel refineries) that are not part of this reference.

b. Lifetime Reductions for 2017–2025 Model Years

EPA also analyzed the emission reductions over the full life of the 2017–2025 model year cars and light trucks that would be affected by this program.[375] These results, including both upstream and downstream GHG contributions, are presented in Table III–57, showing lifetime reductions of about 2,065 $MMTCO_2eq$.

Table III-57 Projected Net GHG Deltas ($MMTCO_2eq$ per year)

MY	Downstream	Upstream (Gasoline)	Electricity	Total CO2e
2017	-24	-6	1	**-29**
2018	-58	-14	2	**-70**
2019	-90	-21	3	**-108**
2020	-125	-30	4	**-151**
2021	-181	-44	5	**-220**
2022	-226	-56	9	**-273**
2023	-268	-68	13	**-322**
2024	-311	-79	18	**-372**
2025	-354	-91	23	**-422**
Total	-1,637	-408	77	**-1,967**

c. Impacts of VMT Rebound Effect

As noted above and discussed more fully in Section III.H., the effect of a decrease in fuel cost per mile on vehicle use (VMT "rebound") was accounted for in our assessment of economic and environmental impacts of this proposed rule. A 10 percent rebound case was used for this analysis, meaning that VMT for affected model years is modeled as increasing by 10 percent as much as the decrease in fuel cost per mile; *i.e.*, a 10 percent decrease in fuel cost per mile from our proposed standards would result in a 1 percent increase in VMT. Results are shown in Table III–58. This increase is accounted for in the reductions presented in Table III–55 and Table III–56). The table below compares the reductions under two different scenarios; one in which the VMT estimate is entirely insensitive to the cost of travel, and one in which both control and reference scenario VMT are affected by the rebound effect. This topic is further discussed in DRIA chapter 4.

[375] As detailed in DRIA Chapter 4 and TSD Chapter 4, for this analysis the full life of the vehicle is represented by average lifetime mileages for cars (197,000 miles [MY 2017] and 211,000 miles [MY 2025]) and trucks (235,000 miles [MY 2017] and 249,000 miles [MY 2025]). These estimates are a function of how far vehicles are driven per year and scrappage rates.

[376] This assessment assumes that owners of grid-electric powered vehicles react similarly to changes int eh cost of driving s owners of conventional gasoline vehicles. We seek comment on this approach in Section III.H.4c.

Table III-58 Delta GHG Impact Of 10% VMT Rebound[a]

($MMTCO_2eq$ per year)

CY	Downstream	Upstream Gasoline	Electricity[376]	Total CO2e
2020	4	1	0	**5**
2030	43	12	0	**55**
2040	75	20	0	**94**
2050	102	27	1	**128**

[a] These impacts are included in the reductions shown in Table III-55 and Table III-56.

d. Analysis of Alternatives

EPA analyzed four alternative scenarios for this proposal (Table III–59). EPA assumed that manufacturers would use air conditioning improvements and the HEV and performance based pickup incentives in identical penetrations as in the primary scenario. EPA re-estimated the impact of the electric vehicle multiplier under each alternative. Under these assumptions, EPA expects achieved fleetwide average emission levels of 150 g/mile CO_2 to 177 g/mile CO_2eq (6%) in 2025. As in the primary scenario, EPA assumed that the fleet complied with the standards. For full details on modeling assumptions, please refer to DRIA Chapter 4. EPA's assessment of these alternative standards is discussed in Section III.D.6

Table III-59 GHG g/mile Targets of Alternative Scenarios

	2021 CO_2 g/mile Targets			2025 CO_2 g/mile Targets		
Title	**Cars**	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Primary	173	250	200	144	203	164
A - Cars +20 g/mile	193	250	213	164	203	177
B - Cars -20 g/mile	153	250	187	124	203	150
C - Trucks +20 g/mile	173	270	207	144	223	170
D - Trucks -20 g/mile	173	230	193	144	183	157

Table III-60 Calendar Year Impacts of Alternative Scenarios

	GHG Delta (MMT2 CO2eq)				Fuel Savings (B. Gallons petroleum gasoline)			
Scenario	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Primary	-29	-297	-462	-547	-2.3	-25.6	-40.4	-47.9
A - Cars +20 g/mile	-20	-248	-396	-471	-1.4	-20.3	-33.0	-39.2
B - Cars -20 g/mile	-35	-335	-511	-604	-2.9	-30.8	-48.1	-56.9
C - Trucks +20 g/mile	-28	-275	-431	-510	-2.2	-23.0	-36.5	-43.3
D - Trucks -20 g/mile	-39	-322	-492	-582	-3.2	-28.6	-44.4	-52.7

Table III-61 Model Year Lifetime Impacts of Alternative Scenarios (Summary of MY 2017-MY2025)

	Total CO2e	Fuel Delta (b gal petroleum gasoline)	Fuel Delta (b. barrels petroleum gasoline)
Primary	-1,967	-165	-3.9
A - Cars +20 g/mile	-1,567	-125	-3.0
B - Cars -20 g/mile	-2,283	-202	-4.8
C - Trucks +20 g/mile	-1,788	-146	-3.5
D - Trucks -20 g/mile	-2,254	-194	-4.6

2. Climate Change Impacts From GHG Emissions

The impact of GHG emissions on the climate has been reviewed in the 2012–2016 light-duty rulemaking and recent heavy-duty GHG rulemaking. See 75 FR at 25491; 76 FR at 57294. This section briefly discusses again some of the climate impact context for transportation emissions. These previous discussions noted that once emitted, GHGs that are the subject of this regulation can remain in the atmosphere for decades to millennia, meaning that 1) their concentrations become well-mixed throughout the global atmosphere regardless of emission origin, and 2) their effects on climate are long lasting. GHG emissions come mainly from the combustion of fossil fuels (coal, oil, and gas), with additional contributions from the clearing of forests, agricultural activities, cement production, and some industrial activities. Transportation activities, in aggregate, were the second largest contributor to total U.S. GHG emissions in 2009 (27 percent of total emissions).[377]

The Administrator relied on thorough and peer-reviewed assessments of climate change science prepared by the Intergovernmental Panel on Climate Change (''IPCC''), the United States Global Change Research Program (''USGCRP''), and the National Research Council of the National Academies (''NRC'') [378] as the primary scientific and technical basis for the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act (74 FR 66496, December 15, 2009). These assessments comprehensively address the scientific issues the Administrator had to examine, providing her both data and information on a wide range of issues pertinent to the Endangerment Finding. These assessments have been rigorously reviewed by the expert community, and also by United States government agencies and scientists, including by EPA itself.

Based on these assessments, the Administrator determined, in essence, that greenhouse gases cause warming; that levels of greenhouse gases are increasing in the atmosphere due to human activity; the climate is warming; recent warming has been attributed to the increase in greenhouse gases; and that warming of the climate threatens human health and welfare. The Administrator further found that emissions of well-mixed greenhouse gases from new motor vehicles and engines contribute to the air pollution for which the endangerment finding was made. Specifically, the Administrator found under section 202(a) of the Act that six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) taken in combination endanger both the public health and the public welfare of current and future generations, and further found that the combined emissions of these greenhouse gases from new motor vehicles and engines contribute to the greenhouse gas air pollution that endangers public health and welfare.

More recent assessments have produced similar conclusions to those of the assessments upon which the Administrator relied. In May 2010, the NRC published its comprehensive assessment, ''Advancing the Science of Climate Change.'' [379] It concluded that ''climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems.'' Furthermore, the NRC stated that this conclusion is based on findings that are ''consistent with the conclusions of recent assessments by the U.S. Global Change Research Program, the Intergovernmental Panel on Climate Change's Fourth Assessment Report, and other assessments of the state of scientific knowledge on climate change.'' These are the same assessments that served as the primary scientific references underlying the Administrator's Endangerment Finding. Another NRC assessment, ''Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia,'' was published

[377] U.S. EPA (2011) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009. EPA 430–R–11–005. (Docket EPA–HQ–OAR–2010–0799).

[378] For a complete list of core references from IPCC, USGCRP/CCSP, NRC and others relied upon for development of the TSD for EPA's Endangerment and Cause or Contribute Findings see section 1(b), specifically, Table 1.1 of the TSD. (Docket EPA–HQ–OAR–2010–0799).

[379] National Research Council (NRC) (2010). Advancing the Science of Climate Change. National Academy Press. Washington, DC. (Docket EPA–HQ–OAR–2010–0799).

in 2011. This report found that climate change due to carbon dioxide emissions will persist for many centuries. The report also estimates a number of specific climate change impacts, finding that every degree Celsius (C) of warming could lead to increases in the heaviest 15% of daily rainfalls of 3 to 10%, decreases of 5 to 15% in yields for a number of crops (absent adaptation measures that do not presently exist), decreases of Arctic sea ice extent of 25% in September and 15% annually averaged, along with changes in precipitation and streamflow of 5 to 10% in many regions and river basins (increases in some regions, decreases in others). The assessment also found that for an increase of 4 degrees C nearly all land areas would experience summers warmer than all but 5% of summers in the 20th century, that for an increase of 1 to 2 degrees C the area burnt by wildfires in western North America will likely more than double, that coral bleaching and erosion will increase due both to warming and ocean acidification, and that sea level will rise 1.6 to 3.3 feet by 2100 in a 3 degree C scenario. The assessment notes that many important aspects of climate change are difficult to quantify but that the risk of adverse impacts is likely to increase with increasing temperature, and that the risk of abrupt climate changes can be expected to increase with the duration and magnitude of the warming.

In the 2010 report cited above, the NRC stated that some of the largest potential risks associated with future climate change may come not from relatively smooth changes that are reasonably well understood, but from extreme events, abrupt changes, and surprises that might occur when climate or environmental system thresholds are crossed. Examples cited as warranting more research include the release of large quantities of GHGs stored in permafrost (frozen soils) across the Arctic, rapid disintegration of the major ice sheets, irreversible drying and desertification in the subtropics, changes in ocean circulation, and the rapid release of destabilized methane hydrates in the oceans.

On ocean acidification, the same report noted the potential for broad, ''catastrophic'' impacts on marine ecosystems. Ocean acidity has increased 25 percent since pre-industrial times, and is projected to continue increasing. By the time atmospheric CO_2 content doubles over its preindustrial value, there would be virtually no place left in the ocean that can sustain coral reef growth. Ocean acidification could have dramatic consequences for polar food webs including salmon, the report said.

Importantly, these recent NRC assessments represent another independent and critical inquiry of the state of climate change science, separate and apart from the previous IPCC and USGCRP assessments.

3. Changes in Global Climate Indicators Associated With the Proposal's GHG Emissions Reductions

EPA examined [380] the reductions in CO_2 and other GHGs associated with this rulemaking and analyzed the projected effects on atmospheric CO_2 concentrations, global mean surface temperature, sea level rise, and ocean pH which are common variables used as indicators of climate change.[381] The analysis projects that the proposed rule, if adopted, will reduce atmospheric concentrations of CO_2, global climate warming, ocean acidification, and sea level rise relative to the reference case. Although the projected reductions and improvements are small in comparison to the total projected climate change, they are quantifiable, directionally consistent, and will contribute to reducing the risks associated with climate change. Climate change is a global phenomenon and EPA recognizes that this one national action alone will not prevent it: EPA notes this would be true for any given GHG mitigation action when taken alone or when considered in isolation. EPA also notes that a substantial portion of CO_2 emitted into the atmosphere is not removed by natural processes for millennia, and therefore each unit of CO_2 not emitted into the atmosphere due to this rule avoids essentially permanent climate change on centennial time scales.

EPA determines that the projected reductions in atmospheric CO_2, global mean temperature and sea level rise are meaningful in the context of this proposed action. In addition, EPA has conducted an analysis to evaluate the projected changes in ocean pH in the context of the changes in emissions from this rulemaking. The results of the analysis demonstrate that relative to the reference case, projected atmospheric CO_2 concentrations are estimated by 2100 to be reduced by 3.29 to 3.68 part per million by volume (ppmv), global mean temperature is estimated to be reduced by 0.0076 to 0.0184 C, and sea-level rise is projected to be reduced by approximately 0.074–0.166 cm, based on a range of climate sensitivities. The analysis also demonstrates that ocean pH will increase by 0.0018 pH units by 2100 relative to the reference case.

a. Estimated Reductions in Atmospheric CO_2 Concentration, Global Mean Surface Temperatures, Sea Level Rise, and Ocean pH

EPA estimated changes in the atmospheric CO_2 concentration, global mean temperature, and sea level rise out to 2100 resulting from the emissions reductions in this rulemaking using the Global Change Assessment Model (GCAM, formerly MiniCAM), integrated assessment model [382] coupled with the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC, version 5.3v2).[383] GCAM was used to create the globally and temporally consistent set of climate relevant variables required for running MAGICC. MAGICC was then used to estimate the projected change in these variables over time. Given the magnitude of the estimated emissions reductions associated with this action, a simple climate model such as MAGICC is reasonable for estimating the atmospheric and climate response. This widely used, peer reviewed modeling tool was also used to project temperature and sea level rise under different emissions scenarios in the Third and Fourth Assessments of the IPCC.

The integrated impact of the following pollutant and greenhouse gas emissions changes are considered: CO_2, CH_4, N_2O, HFC–134a, NO_X, CO, SO_2, and volatile organic compounds (VOC). For these pollutants an annual time-series of (upstream + downstream) emissions

[380] Using the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) 5.3v2, *http://www.cgd.ucar.edu/cas/wigley/magicc/*), EPA estimated the effects of this rulemaking's greenhouse gas emissions reductions on global mean temperature and sea level. Please refer to Chapter 6.4 of the DRIA for additional information.

[381] Due to timing constraints, this analysis was conducted with preliminary estimates of the emissions reductions projected from this proposal, which were similar to the final estimates.

[382] GCAM is a long-term, global integrated assessment model of energy, economy, agriculture and land use, that considers the sources of emissions of a suite of GHGs, emitted in 14 globally disaggregated regions, the fate of emissions to the atmosphere, and the consequences of changing concentrations of greenhouse related gases for climate change. GCAM begins with a representation of demographic and economic developments in each region and combines these with assumptions about technology development to describe an internally consistent representation of energy, agriculture, land-use, and economic developments that in turn shape global emissions. Brenkert A, S. Smith, S. Kim, and H. Pitcher, 2003: Model Documentation for the MiniCAM. PNNL–14337, Pacific Northwest National Laboratory, Richland, Washington. (Docket EPA–HQ–OAR–2010–0799).

[383] Wigley, T.M.L. 2008. MAGICC 5.3.v2 User Manual. UCAR—Climate and Global Dynamics Division, Boulder, Colorado. *http://www.cgd.ucar.edu/cas/wigley/magicc/* (Docket EPA–HQ–OAR–2010–0799).

reductions estimated from the rulemaking were applied as net reductions to a global reference case (or baseline) emissions scenario in GCAM to generate an emissions scenario specific to this proposed rule.[384] The emissions reductions past 2050 for all gases were scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. Road transport fuel consumption past 2050 does not change significantly and thus emissions reductions remain relatively constant from 2050 through 2100. Specific details about the GCAM reference case scenario can be found in Chapter 6.4 of the DRIA that accompanies this proposal.

MAGICC calculates the forcing response at the global scale from changes in atmospheric concentrations of CO_2, CH_4, N_2O, HFCs, and tropospheric ozone (O_3). It also includes the effects of temperature changes on stratospheric ozone and the effects of CH_4 emissions on stratospheric water vapor. Changes in CH_4, NO_X, VOC, and CO emissions affect both O_3 concentrations and CH_4 concentrations. MAGICC includes the relative climate forcing effects of changes in sulfate concentrations due to changing SO_2 emissions, including both the direct effect of sulfate particles and the indirect effects related to cloud interactions. However, MAGICC does not calculate the effect of changes in concentrations of other aerosols such as nitrates, black carbon, or organic carbon, making the assumption that the sulfate cooling effect is a proxy for the sum of all the aerosol effects. Therefore, the climate effects of changes in $PM_{2.5}$ emissions and precursors (besides SO_2) which are presented in the DRIA Chapter 6 were not included in the calculations in this chapter. MAGICC also calculates all climate effects at the global scale. This global scale captures the climate effects of the long-lived, well-mixed greenhouse gases, but does not address the fact that short-lived climate forcers such as aerosols and ozone can have effects that vary with location and timing of emissions. Black carbon in particular is known to cause a positive forcing or warming effect by absorbing incoming solar radiation, but there are uncertainties about the magnitude of that warming effect and the interaction of black carbon (and other co-emitted aerosol species) with clouds. While black carbon is likely to be an important contributor to climate change, it would be premature to include quantification of black carbon climate impacts in an analysis of these proposed standards. See generally, EPA, Response to Comments to the Endangerment Finding Vol. 9 section 9.1.6.1 and the discussion of black carbon in the endangerment finding at 74 FR at 66520. Additionally, the magnitude of $PM_{2.5}$ emissions changes (and therefore, black carbon emission changes) related to these proposed standards are small in comparison to the changes in the pollutants which have been included in the MAGICC model simulations.

Changes in atmospheric CO_2 concentration, global mean temperature, and sea level rise for both the reference case and the emissions scenarios associated with this action were computed using MAGICC. To calculate the reductions in the atmospheric CO_2 concentrations as well as in temperature and sea level resulting from this proposal, the output from the policy scenario associated with EPA's proposed standards was subtracted from an existing Global Change Assessment Model (GCAM, formerly MiniCAM) reference emission scenario. To capture some key uncertainties in the climate system with the MAGICC model, changes in atmospheric CO_2, global mean temperature and sea level rise were projected across the most current IPCC range of climate sensitivities, from 1.5 C to 6.0 C.[385] This range reflects the uncertainty for equilibrium climate sensitivity for how much global mean temperature would rise if the concentration of carbon dioxide in the atmosphere were to double. The information for this range come from constraints from past climate change on various time scales, and the spread of results for climate sensitivity from ensembles of models.[386] Details about this modeling analysis can be found in the DRIA Chapter 6.4.

The results of this modeling, summarized in Table III–62, show small, but quantifiable, reductions in atmospheric CO_2 concentrations, projected global mean temperature and sea level resulting from this action, across all climate sensitivities. As a result of the emission reductions from the proposed standards, relative to the reference case the atmospheric CO_2 concentration is projected to be reduced by 3.29–3.68 ppmv by 2100, the global mean temperature is projected to be reduced by approximately 0.0076–0.0184 C by 2100, and global mean sea level rise is projected to be reduced by approximately 0.074–0.166 cm by 2100. The range of reductions in global mean temperature and sea level rise is larger than that for CO_2 concentrations because CO_2 concentrations are only weakly coupled to climate sensitivity through the dependence on temperature of the rate of ocean absorption of CO_2, whereas the magnitude of temperature change response to CO_2 changes (and therefore sea level rise) is more tightly coupled to climate sensitivity in the MAGICC model.

[384] Due to timing constraints, this analysis was conducted with preliminary estimates of the emissions reductions projected from this proposal, which were similar to the final estimates.

[385] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The IPCC states that climate sensitivity is ''likely'' to be in the range of 2 C to 4.5 C, ''very unlikely'' to be less than 1.5 C, and ''values substantially higher than 4.5 C cannot be excluded.'' IPCC WGI, 2007, *Climate Change 2007—The Physical Science Basis,* Contribution of Working Group I to the Fourth Assessment Report of the IPCC, *http://www.ipcc.ch/* (Docket EPA–HQ–OAR–2010–0799).

[386] Meehl, G.A. et al. (2007) Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (Docket EPA–HQ–OAR–2010–0799).

Table III-62 Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with EPA's Proposed Rulemaking (Based on a range of climate sensitivities from 1.5-6°C)

VARIABLE	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-3.29 to -3.68
Global Mean Surface Temperature	°C	2100	-0.0076 to -0.0184
Sea Level Rise	cm	2100	-0.074 to -0.166
Ocean pH	pH units	2100	+0.0018[a]

[a] The value for projected change in ocean pH is based on a climate sensitivity of 3.0.

The projected reductions are small relative to the change in temperature (1.8–4.8 C), sea level rise (23–55 cm), and ocean acidity (−0.30 pH units) from 1990 to 2100 from the MAGICC simulations for the GCAM reference case. However, this is to be expected given the magnitude of emissions reductions expected from the program in the context of global emissions. This uncertainty range does not include the effects of uncertainty in future emissions. It should also be noted that the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica: the recent NRC report estimated a likely sea level increase for a business-as-usual scenario of 0.5 to 1.0 meters.[387] Further discussion of EPA's modeling analysis is found in the DRIA, Chapter 6.

EPA used the computer program CO2SYS,[388] version 1.05, to estimate projected changes in ocean pH for tropical waters based on the atmospheric CO_2 concentration change (reduction) resulting from this proposal. The program performs calculations relating parameters of the CO_2 system in seawater. EPA used the program to calculate ocean pH as a function of atmospheric CO_2 concentrations, among other specified input conditions. Based on the projected atmospheric CO_2 concentration reductions resulting from this proposal, the program calculates an increase in ocean pH of 0.0018 pH units in 2100 relative to the reference case (compared to a decrease of 0.3 pH units from 1990 to 2100 in the reference case). Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from the program will result in an increase in ocean pH. For additional validation, results were generated using different known constants from the literature. A comprehensive discussion of the modeling analysis associated with ocean pH is provided in the DRIA, Chapter 6.

As discussed in III.F.2, the 2011 NRC assessment on ''Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia'' determined how a number of climate impacts—such as heaviest daily rainfalls, crop yields, and Arctic sea ice extent—would change with a temperature change of 1 degree Celsius (C) of warming. These relationships of impacts with temperature change could be combined with the calculated reductions in warming in Table III–56 to estimate changes in these impacts associated with this rulemaking.

b. Program's Effect on Climate

As a substantial portion of CO_2 emitted into the atmosphere is not removed by natural processes for millennia, each unit of CO_2 not emitted into the atmosphere avoids essentially permanent climate change on centennial time scales. Reductions in emissions in the near-term are important in determining long-term climate stabilization and associated impacts experienced not just over the next decades but in the coming centuries and millennia.[389] Though the magnitude of the avoided climate change projected here is small in comparison to the total projected changes, these reductions represent a reduction in the adverse risks associated with climate change (though these risks were not formally estimated for this action) across a range of equilibrium climate sensitivities.

EPA's analysis of the program's impact on global climate conditions is intended to quantify these potential reductions using the best available science. EPA's modeling results show repeatable, consistent reductions relative to the reference case in changes of CO_2 concentration, temperature, sea-level rise, and ocean pH over the next century.

G. How would the proposal impact non-GHG emissions and their associated effects?

Although this rule focuses on GHGs, it will also have an impact on non-GHG pollutants. Sections G.1 of this preamble details the criteria pollutant and air toxic inventory changes of this proposed rule. The following sections, G.2 and G.3, discuss the health and environmental effects associated with

[387] National Research Council (NRC), 2011. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. Washington, DC: National Academies Press. (Docket EPA–HQ–OAR–2010–0799).

[388] Lewis, E., and D. W. R. Wallace. 1998. Program Developed for CO_2 System Calculations. ORNL/CDIAC–105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee. (Docket EPA–HQ–OAR–2010–0799).

[389] National Research Council (NRC) (2011). Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National Academy Press. Washington, DC. (Docket EPA–HQ–OAR–2010–0799).

the criteria and toxic air pollutants that are being impacted by this proposed rule. In Section G.4 we discuss the potential impact of this proposal on concentrations of criteria and air toxic pollutants in the ambient air. The tools and methodologies used in this analysis are substantially similar to those used in the MYs 2012–2016 light duty rulemaking.

1. Inventory

a. Impacts

In addition to reducing the emissions of greenhouse gases, this rule would influence ''non-GHG'' pollutants, *i.e.,* ''criteria'' air pollutants and their precursors, and air toxics. The proposal would affect emissions of carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_X), volatile organic compounds (VOC), nitrogen oxides (NO_X), benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Our estimates of these non-GHG emission impacts from the GHG program are shown by pollutant in Table III.G–1 and Table III.G–2 both in total and broken down by the three drivers of these changes: a) ''downstream'' emission changes, reflecting the estimated effects of VMT rebound (discussed in Sections III.F and III.H) and decreased consumption of fuel; b) ''upstream'' emission reductions due to decreased extraction, production and distribution of motor vehicle gasoline; c) ''upstream'' emission increases from power plants as electric powertrain vehicles increase in prevalence as a result of this rule. Program impacts on criteria and toxics emissions are discussed below, followed by individual discussions of the methodology used to calculate each of these three sources of impacts.

As shown in Table III–63, EPA estimates that the proposed light duty vehicle program would result in reductions of NO_X, VOC, $PM_{2.5}$ and SO_X, but would increase CO emissions.[390] For NO_X, VOC, and $PM_{2.5}$, we estimate net reductions because the net emissions reductions from reduced fuel refining, distribution and transport is larger than the emission increases due to increased VMT and increased electricity production. In the case of CO, we estimate slight emission increases, because there are relatively small reductions in upstream emissions, and thus the projected emission increases due to VMT rebound and electricity production are greater than the projected emission decreases due to reduced fuel production. For SO_X, downstream emissions are roughly proportional to fuel consumption, therefore a decrease is seen in both downstream and fuel refining sources.

For all criteria pollutants the overall impact of the proposed program would be small compared to total U.S. inventories across all sectors. In 2030, EPA estimates that the program would reduce total NO_X, PM and SO_X inventories by 0.1 to 0.8 percent and reduce the VOC inventory by 1.1 percent, while increasing the total national CO inventory by 0.5 percent.

As shown in Table III–64, EPA estimates that the proposed program would result in similarly small changes for air toxic emissions compared to total U.S. inventories across all sectors. In 2030, EPA estimates the proposed program would increase total 1,3 butadiene and acetaldehyde emissions by 0.1 to 0.4 percent. Total acrolein, benzene and formaldehyde emissions would decrease by similarly small amounts.

[390] While estimates for CY 2020 and 2030 are shown here, estimates through 2050 are shown in RIA Ch. 4.

Table III-63 Annual Criteria Emission Impacts of Program (short tons)

		CY 2020		CY 2030	
	Pollutant	Impacts (Short Tons)	% of Total US Inventory	Impacts (Short Tons)	% of Total US Inventory
Total	VOC	-12,467	-0.1%	-135,566	-1.1%
	CO	21,242	0.0%	397,861	0.7%
	NO_X	-2,449	0.0%	-16,008	-0.2%
	PM2.5	-351	0.0%	-3,123	-0.1%
	SO_X	-1,650	0.0%	-9,443	-0.1%
Downstream	VOC	379	0.0%	8,623	0.1%
	CO	22,212	0.0%	405,260	0.7%
	NO_X	779	0.0%	14,872	0.1%
	PM2.5	63	0.0%	1,023	0.0%
	SO_X	-449	0.0%	-5,051	-0.1%
Fuel Production and Distribution	VOC	-12,860	-0.1%	-144,503	-1.1%
	CO	-1,229	0.0%	-13,810	0.0%
	NO_X	-3,846	0.0%	-43,215	-0.4%
	PM2.5	-524	0.0%	-5,890	-0.1%
	SO_X	-2,353	0.0%	-26,443	-0.3%
Electricity	VOC	14	0.0%	6,411	0.1%
	CO	259	0.0%	6,411	0.0%
	NO_X	617	0.0%	12,335	0.1%
	PM2.5	110	0.0%	1,743	0.0%
	SO_X	1,153	0.0%	22,051	0.3%

Table III-64 Annual Air Toxic Emission Impacts of Program (short tons)

		CY 2020		CY 2030	
	Pollutant	Impacts (Short Tons)	% of Total US Inventory	Impacts (Short Tons)	% of Total US Inventory
Total	1,3- Butadiene	2	0.02%	47	0.4%
	Acetaldehyde	4	0.00%	112	0.2%
	Acrolein	0	0.01%	-6	0.0%
	Benzene	-15	-0.01%	-26	0.0%
	Formaldehyde	-5	0.00%	3	0.0%
Downstream	1,3- Butadiene	2	0.02%	49	0.4%
	Acetaldehyde	6	0.01%	124	0.2%
	Acrolein	0	0.01%	5	0.0%
	Benzene	13	0.01%	285	0.1%
	Formaldehyde	5	0.00%	118	0.1%
Fuel Production and Distribution	1,3- Butadiene	0	0.00%	-3	0.0%
	Acetaldehyde	-1	0.00%	-15	0.0%
	Acrolein	0	-0.01%	-15	0.0%
	Benzene	-28	-0.01%	-313	-0.1%
	Formaldehyde	-10	0.00%	-115	-0.1%
Electricity	1,3- Butadiene	0	0.00%	2	0.0%
	Acetaldehyde	0	0.00%	3	0.0%
	Acrolein	0	0.01%	4	0.0%
	Benzene	0	0.00%	2	0.0%
	Formaldehyde	0	0.00%	1	0.0%

b. Methodology

As in the MYs 2012–2016 rulemaking, for the downstream analysis, the current version of the EPA motor vehicle emission simulator (MOVES2010a) was used to estimate base VOC, CO, NO_X, PM and air toxics emission rates. Additional emissions from light duty cars and trucks attributable to the rebound effect were then calculated using the OMEGA model post-processor. A more complete discussion of the inputs, methodology, and results is contained in RIA Chapter 4.

This proposal assumes that MY 2017 and later vehicles are compliant with the agency's Tier 2 emission standards. This proposal does not model any future Tier 3 emission standards, because these standards have not yet been proposed (see Section III.A). We intend for the analysis assessing the impacts of both the final Tier 3 emission standards and the final 2017–2025 LD GHG to be included in the final Tier 3 rule. For the proposals, we are taking care to coordinate the modeling of each rule to properly assess the air quality impact of each action independently without double counting.

As in the MYs 2012–2016 GHG rulemaking, for this analysis we attribute decreased fuel consumption from this program to petroleum-based fuels only, while assuming no effect on volumes of ethanol and other renewable fuels because they are mandated under the Renewable Fuel Standard (RFS2). For the purposes of this emission analysis, we assume that all gasoline in the timeframe of the analysis is blended with 10 percent ethanol (E10). However, as a consequence of the fixed volume of renewable fuels mandated in the RFS2 rulemaking and the decreasing petroleum consumption predicted here, we anticipate that this proposal would in fact increase the fraction of the U.S. fuel supply that is made up by renewable fuels. Although we are not modeling this effect in our analysis of this proposal, the Tier 3 rulemaking will make more refined assumptions about future fuel properties, including (in a final Tier 3 rule) accounting for the impacts of the LD GHG rule. In this rulemaking EPA modeled the three impacts on criteria pollutant emissions (rebound driving, changes in fuel production, and changes in electricity production) discussed above.

While electric vehicles have zero tailpipe emissions, EPA assumes that manufacturers will plan for these vehicles in their regulatory compliance strategy for non-GHG emissions standards, and will not over-comply with those standards. Since the Tier 2 emissions standards are fleet-average standards, we assume that if a manufacturer introduces EVs into its fleet, that it would correspondingly compensate through changes to vehicles elsewhere in its fleet, rather than meet an overall lower fleet-average emissions level.[391] Consequently, EPA assumes neither tailpipe pollutant benefit (other than CO_2) nor an evaporative emission benefit from the introduction of electric vehicles into the fleet. Other factors which may impact downstream non-GHG emissions, but are not estimated in this analysis, include: The potential for decreased criteria pollutant emissions due to increased air conditioner efficiency; reduced refueling emissions due to less frequent refueling events and reduced annual refueling volumes resulting from the GHG standards; and increased hot soak evaporative emissions due to the likely increase in number of trips associated with VMT rebound modeled in this proposal. In all, these additional analyses would likely result in small changes relative to the national inventory.

To determine the upstream fuel production impacts, EPA estimated the impact of reduced petroleum volumes on the extraction and transportation of crude oil as well as the production and distribution of finished gasoline. For the purpose of assessing domestic-only emission reductions it was necessary to estimate the fraction of fuel savings attributable to domestic finished gasoline, and of this gasoline what fraction is produced from domestic crude. For this analysis EPA estimated that 50 percent of fuel savings is attributable to domestic finished gasoline and that 90 percent of this gasoline originated from imported crude. Emission factors for most upstream emission sources are based on the GREET1.8 model, developed by DOE's Argonne National Laboratory,[392] but in some cases the GREET values were modified or updated by EPA to be consistent with the National Emission Inventory (NEI).[393] The primary updates for this analysis were to incorporate newer information on gasoline distribution emissions for VOC from the NEI, which were significantly higher than GREET estimates; and the incorporation of upstream emission factors for the air toxics estimated in this analysis: benzene, 1,3-butadiene, acetaldehyde, acrolein, and formaldehyde. The development of these emission factors is detailed in a memo to the docket. These emission factors were incorporated into the OMEGA post-processor.

As with the GHG emission analysis discussed in section III.F, electricity emission factors were derived from EPA's Integrated Planning Model (IPM). EPA uses IPM to analyze the projected impact of environmental policies on the electric power sector in the 48 contiguous states and the District of Columbia. IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector. It provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental, transmission, dispatch, and reliability constraints. EPA derived average national CO_2 emission factors from the IPM version 4.10 run for the ''Proposed Transport Rule.'' [394] As discussed in Draft TSD Chapter 4, for the Final Rulemaking, EPA may consider emission factors other than national power generation, such as marginal power emission factors, or regional emission factors.

2. Health Effects of Non-GHG Pollutants

In this section we discuss health effects associated with exposure to some of the criteria and air toxic pollutants impacted by the proposed vehicle standards.

a. Particulate Matter

i. Background

Particulate matter is a generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. Since 1987, EPA has delineated that subset of inhalable particles small enough to penetrate to the thoracic region (including the tracheobronchial and alveolar regions) of the respiratory tract (referred to as thoracic particles).[395] Current National Ambient Air Quality Standards (NAAQS) use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ generally referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 micrometers (μm), and use PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 μm and less than or equal to 10 μm, or $PM_{10-2.5}$). Ultrafine particles are a subset of fine particles, generally less than 100 nanometers (0.1 μm) in diameter.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (*e.g.,* sulfur oxides (SO_X), nitrogen oxides (NO_X), and volatile organic compounds (VOC)) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology, and source

[391] Historically, manufacturers have reduced precious metal loading in catalysts in order to reduce costs. See *http://www.platinum.matthey.com/media-room/our-view-on-.-.-./thrifting-of-precious-metals-in-autocatalysts/* Accessed 11/08/2011. Alternatively, manufacturers could also modify vehicle calibration.

[392] Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation model (GREET), U.S. Department of Energy, Argonne National Laboratory, *http://www.transportation.anl.gov/modeling_simulation/GREET/*.

[393] U.S. EPA. 2002 National Emissions Inventory (NEI) Data and Documentation, *http://www.epa.gov/ttn/chief/net/2002inventory.html*.

[394] EPA. IPM. *http://www.epa.gov/airmarkt/progsregs/epa-ipm/BaseCasev410.html*. ''Proposed Transport Rule/NODA version'' of IPM. TR_SB_Limited Trading v.4.10.

[395] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR parts 50, 53, and 58.

category. Thus, $PM_{2.5}$ may include a complex mixture of different components including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel hundreds to thousands of kilometers.

ii. Health Effects of Particulate Matter

Scientific studies show ambient PM is associated with a series of adverse health effects. These health effects are discussed in detail in EPA's Integrated Science Assessment (ISA) for Particulate Matter.[396] Further discussion of health effects associated with PM can also be found in the draft RIA. The ISA summarizes health effects evidence associated with both short-term and long-term exposures to $PM_{2.5}$, $PM_{10-2.5}$, and ultrafine particles.

The ISA concludes that health effects associated with short-term exposures (hours to days) to ambient $PM_{2.5}$ include mortality, cardiovascular effects, such as altered vasomotor function and hospital admissions and emergency department visits for ischemic heart disease and congestive heart failure, and respiratory effects, such as exacerbation of asthma symptoms in children and hospital admissions and emergency department visits for chronic obstructive pulmonary disease and respiratory infections.[397] The ISA notes that long-term exposure (months to years) to $PM_{2.5}$ is associated with the development/progression of cardiovascular disease, premature mortality, and respiratory effects, including reduced lung function growth, increased respiratory symptoms, and asthma development.[398] The ISA concludes that the currently available scientific evidence from epidemiologic, controlled human exposure, and toxicological studies supports a causal association between short- and long-term exposures to $PM_{2.5}$ and cardiovascular effects and mortality. Furthermore, the ISA concludes that the collective evidence supports likely causal associations between short- and long-term $PM_{2.5}$ exposures and respiratory effects. The ISA also concludes that the scientific evidence is suggestive of a causal association for reproductive and developmental effects and cancer, mutagenicity, and genotoxicity and long-term exposure to $PM_{2.5}$.[399]

For $PM_{10-2.5}$, the ISA concludes that the current evidence is suggestive of a causal relationship between short-term exposures and cardiovascular effects. There is also suggestive evidence of a causal relationship between short-term $PM_{10-2.5}$ exposure and mortality and respiratory effects. Data are inadequate to draw conclusions regarding the health effects associated with long-term exposure to $PM_{10-2.5}$.[400]

For ultrafine particles, the ISA concludes that there is suggestive evidence of a causal relationship between short-term exposures and cardiovascular effects, such as changes in heart rhythm and blood vessel function. It also concludes that there is suggestive evidence of association between short-term exposure to ultrafine particles and respiratory effects. Data are inadequate to draw conclusions regarding the health effects associated with long-term exposure to ultrafine particles.[401]

b. Ozone

i. Background

Ground-level ozone pollution is typically formed by the reaction of VOC and NO_X in the lower atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources, such as highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone can be transported hundreds of miles downwind from precursor emissions, resulting in elevated ozone levels even in areas with low local VOC or NO_X emissions.

ii. Health Effects of Ozone

The health and welfare effects of ozone are well documented and are assessed in EPA's 2006 Air Quality Criteria Document and 2007 Staff Paper.[402][403] People who are more susceptible to effects associated with exposure to ozone can include children, the elderly, and individuals with respiratory disease such as asthma. Those with greater exposures to ozone, for instance due to time spent outdoors (*e.g.,* children and outdoor workers), are of particular concern. Ozone can irritate the respiratory system, causing coughing, throat irritation, and breathing discomfort. Ozone can reduce lung function and cause pulmonary inflammation in healthy individuals. Ozone can also aggravate asthma, leading to more asthma attacks that require medical attention and/or the use of additional medication. Thus, ambient ozone may cause both healthy and asthmatic individuals to limit their outdoor activities. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. In a report on the estimation of ozone-related premature mortality published by NRC, a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[404] Animal toxicological evidence indicates that with repeated exposure, ozone can inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue and irreversible reductions in lung function. The respiratory effects observed in controlled human exposure studies and animal studies are coherent with the evidence from epidemiologic studies supporting a causal relationship between acute ambient ozone exposures and increased respiratory-related emergency room visits and

[396] U.S. EPA (2009) Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, Docket EPA–HQ–OAR–2010–0799.

[397] *See* U.S. EPA, 2009 Final PM ISA, Note 396, at Section 2.3.1.1.

[398] *See* U.S. EPA 2009 Final PM ISA, Note 396, at page 2–12, Sections 7.3.1.1 and 7.3.2.1.

[399] *See* U.S. EPA 2009 Final PM ISA, Note 396, at Section 2.3.2.

[400] *See* U.S. EPA 2009 Final PM ISA, Note 396, at Section 2.3.4, Table 2–6.

[401] *See* U.S. EPA 2009 Final PM ISA, Note 396, at Section 2.3.5, Table 2–6.

[402] U.S. EPA. (2006). Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). EPA/600/R–05/004aF–cF. Washington, DC: U.S. EPA. Docket EPA–HQ–OAR–2010–0799.

[403] U.S. EPA. (2007). Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. EPA–452/R–07–003. Washington, DC, U.S. EPA. Docket EPA–HQ–OAR–2010–0799.

[404] National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution.* The National Academies Press: Washington, DC Docket EPA–HQ–OAR–2010–0799.

hospitalizations in the warm season. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and non-accidental and cardiopulmonary mortality.

c. Nitrogen Oxides and Sulfur Oxides

i. Background

Nitrogen dioxide (NO_2) is a member of the NO_X family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. Sulfur Dioxide (SO_2) a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (*e.g.,* coal or oil derived), extracting gasoline from oil, or extracting metals from ore.

SO_2 and NO_2 can dissolve in water droplets and further oxidize to form sulfuric and nitric acid which react with ammonia to form sulfates and nitrates, both of which are important components of ambient PM. The health effects of ambient PM are discussed in Section III.G.3.a.ii of this preamble. NO_X and NMHC are the two major precursors of ozone. The health effects of ozone are covered in Section III.G.3.b.ii.

ii. Health Effects of NO_2

Information on the health effects of NO_2 can be found in the EPA Integrated Science Assessment (ISA) for Nitrogen Oxides.[405] The EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of asthmatic subjects. Small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

Although the weight of evidence supporting a causal relationship is somewhat less certain than that associated with respiratory morbidity, NO_2 has also been linked to other health endpoints. These include all-cause (nonaccidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

iii. Health Effects of SO_2

Information on the health effects of SO_2 can be found in the EPA Integrated Science Assessment for Sulfur Oxides.[406] SO_2 has long been known to cause adverse respiratory health effects, particularly among individuals with asthma. Other potentially sensitive groups include children and the elderly. During periods of elevated ventilation, asthmatics may experience symptomatic bronchoconstriction within minutes of exposure. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. Separately, based on an evaluation of the epidemiologic evidence of associations between short-term exposure to SO_2 and mortality, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

d. Carbon Monoxide

Information on the health effects of CO can be found in the EPA Integrated Science Assessment (ISA) for Carbon Monoxide.[407] The ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[408] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[409]

Human clinical studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report inconsistent neural and behavioral effects following low-level CO exposures. The ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of epidemiologic and animal toxicological studies cited in the ISA have evaluated associations between CO exposure and birth outcomes such as preterm birth or cardiac birth defects. The epidemiologic studies provide limited evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal

[405] U.S. EPA (2008). *Integrated Science Assessment for Oxides of Nitrogen—Health Criteria (Final Report).* EPA/600/R–08/071. Washington, DC: U.S. EPA. Docket EPA–HQ–OAR–2010–0799.

[406] U.S. EPA. (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides—Health Criteria (Final Report).* EPA/600/R–08/047F. Washington, DC: U.S. Environmental Protection Agency. Docket EPA–HQ–OAR–2010–0799.

[407] U.S. EPA, 2010. Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–09/019F, 2010. Available at *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.* Docket EPA–HQ–OAR–2010–0799.

[408] The ISA evaluates the health evidence associated with different health effects, assigning one of five ''weight of evidence'' determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[409] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and nonambient components; and both components may contribute to adverse health effects.

toxicological studies have found associations between perinatal CO exposure and decrements in birth weight, as well as other developmental outcomes. The ISA concludes these studies are suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of effects on respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions associated with ambient CO concentrations. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50–100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term exposures to CO and mortality. Epidemiologic studies provide evidence of an association between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in copollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

e. Air Toxics

Light-duty vehicle emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to the class of pollutants known collectively as ''air toxics.''[410] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter, and naphthalene. These compounds were identified as national or regional risk drivers or contributors in the 2005 National-Scale Air Toxics Assessment and have significant inventory contributions from mobile sources.[411]

i. Benzene

The EPA's Integrated Risk Information System (IRIS) database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[412] [413] [414] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[415] [416]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[417] [418] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[419] [420] In addition, published work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[421] [422] [423] [424] EPA's IRIS program has not yet evaluated these new data.

ii. 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[425] [426] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[427] [428] There

[410] U.S. EPA. (2011) Summary of Results for the 2005 National-Scale Assessment. *http://www.epa.gov/ttn/atw/nata2005/05pdf/sum_results.pdf*. Docket EPA–HQ–OAR–2010–0799.

[411] U.S. EPA (2011) 2005 National-Scale Air Toxics Assessment. *http://www.epa.gov/ttn/atw/nata2005*. Docket EPA–HQ–OAR–2010–0799.

[412] U.S. EPA. 2000. Integrated Risk Information System File for Benzene. This material is available electronically at *http://www.epa.gov/iris/subst/0276.htm*. Docket EPA–HQ–OAR–2010–0799.

[413] International Agency for Research on Cancer. 1982. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29. Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France, p. 345–389. Docket EPA–HQ–OAR–2010–0799.

[414] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. 1992. Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691–3695. Docket EPA–HQ–OAR–2010–0799.

[415] See IARC, Note 413, above.

[416] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: *http://ntp.niehs.nih.gov/go/16183*. Docket EPA–HQ–OAR–2010–0799.

[417] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193–197. Docket EPA–HQ–OAR–2010–0799.

[418] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541–554. Docket EPA–HQ–OAR–2010–0799.

[419] Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes (1996) Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236–246. Docket EPA–HQ–OAR–2010–0799.

[420] U.S. EPA (2002) Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at *http://www.epa.gov/iris/subst/0276.htm*. Docket EPA–HQ–OAR–2010–0799.

[421] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003) HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China. Docket EPA–HQ–OAR–2010–0799.

[422] Qu, Q., R. Shore, G. Li, X. Jin, L.C. Chen, B. Cohen, et al. (2002) Hematological changes among Chinese workers with a broad range of benzene exposures. Am. J. Industr. Med. 42: 275–285. Docket EPA–HQ–OAR–2010–0799.

[423] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004) Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774–1776. Docket EPA–HQ–OAR–2010–0799.

[424] Turtletaub, K.W. and Mani, C. (2003) Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No. 113. Docket EPA–HQ–OAR–2010–0799.

[425] U.S. EPA (2002) Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600–P–98–001F. This document is available electronically at *http://www.epa.gov/iris/supdocs/buta-sup.pdf*. Docket EPA–HQ–OAR–2010–0799.

[426] U.S. EPA (2002) Full IRIS Summary for 1,3-butadiene (CASRN 106–99–0). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC *http://www.epa.gov/iris/subst/0139.htm*. Docket EPA–HQ–OAR–2010–0799.

[427] International Agency for Research on Cancer (1999) Monographs on the evaluation of

are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[429]

iii. Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[430] EPA is currently reviewing epidemiological data published since that time. For instance, research conducted by the National Cancer Institute found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[431, 432] In an analysis of the lymphohematopoietic cancer mortality from an extended follow-up of these workers, the National Cancer Institute confirmed an association between lymphohematopoietic cancer risk and peak exposures.[433] A National Institute of Occupational Safety and Health study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[434] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[435] In 2006, the IARC re-classified formaldehyde as a human carcinogen (Group 1).[436]

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation—including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma—particularly in the young.[437 438]

iv. Acetaldehyde

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[439] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[440 441] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[442] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[443 444] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[445] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

v. Acrolein

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal

carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide and Volume 97 (in preparation), World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2010–0799.

428 U.S. Department of Health and Human Services (2005) National Toxicology Program 11th Report on Carcinogens available at: *ntp.niehs.nih.gov/index.cfm?objectid=32BA9724–F1F6–975E–7FCE50709CB4C932*. Docket EPA–HQ–OAR–2010–0799.

429 Bevan, C.; Stadler, J.C.; Elliot, G.S.; et al. (1996) Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1–10. Docket EPA–HQ–OAR–2010–0799.

430 U.S. EPA (1987) Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde, Office of Pesticides and Toxic Substances, April 1987. Docket EPA–HQ–OAR–2010–0799.

431 Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615–1623. Docket EPA–HQ–OAR–2010–0799.

432 Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117–1130. Docket EPA–HQ–OAR–2010–0799.

433 Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751–761. Docket EPA–HQ–OAR–2010–0799.

434 Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193–200. Docket EPA–HQ–OAR–2010–0799.

435 Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608–1615. Docket EPA–HQ–OAR–2010–0799.

436 International Agency for Research on Cancer. 2006. Formaldehyde, 2–Butoxyethanol and 1-tert-Butoxypropan-2-ol. Volume 88. (in preparation), World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2010–0799;

437 Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. *http://www.atsdr.cdc.gov/toxprofiles/tp111.html* Docket EPA–HQ–OAR–2010–0799.

438 WHO (2002) Concise International Chemical Assessment Document 40: Formaldehyde. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva. Docket EPA–HQ–OAR–2010–0799.

439 U.S. EPA. 1991. Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. *Available at http://www.epa.gov/iris/subst/0290.htm*. Docket EPA–HQ–OAR–2010–0799.

440 U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: *http://ntp.niehs.nih.gov/index.cfm?objectid=32BA9724–F1F6–975E–7FCE50709CB4C932*. Docket EPA–HQ–OAR–2010–0799.

441 International Agency for Research on Cancer. 1999. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France. Docket EPA–HQ–OAR–2010–0799.

442 See Integrated Risk Information System File of Acetaldehyde, Note 439, above.

443 Appleman, L. M., R. A. Woutersen, V. J. Feron, R. N. Hooftman, and W. R. F. Notten. 1986. Effects of the variable versus fixed exposure levels on the toxicity of acetaldehyde in rats. *J. Appl. Toxicol.* 6: 331–336. Docket EPA–HQ–OAR–2010–0799.

444 Appleman, L.M., R.A. Woutersen, and V.J. Feron. 1982. Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. *Toxicology.* 23: 293–297. Docket EPA–HQ–OAR–2010–0799.

445 Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. 1993. Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. *Am. Rev. Respir.*Dis.148(4 Pt 1): 940–3. Docket EPA–HQ–OAR–2010–0799.

sensory reactions within minutes of exposure.[446] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[447] Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms.[448] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[449] Acute exposure effects in animal studies report bronchial hyper-responsiveness.[450] In one study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease by comparison to non-diseased mice which also showed decreases in respiratory rate.[451] Based on these animal data and demonstration of similar effects in humans (*e.g.,* reduction in respiratory rate), individuals with compromised respiratory function (*e.g.,* emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[452] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[453]

vi. Polycyclic Organic Matter

The term polycyclic organic matter (POM) defines a broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). One of these compounds, naphthalene, is discussed separately below. POM compounds are formed primarily from combustion and are present in the atmosphere in gas and particulate form. Cancer is the major concern from exposure to POM. Epidemiologic studies have reported an increase in lung cancer in humans exposed to diesel exhaust, coke oven emissions, roofing tar emissions, and cigarette smoke; all of these mixtures contain POM compounds.[454] [455] Animal studies have reported respiratory tract tumors from inhalation exposure to benzo[a]pyrene and alimentary tract and liver tumors from oral exposure to benzo[a]pyrene. In 1997 EPA classified seven PAHs (benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene) as Group B2, probable human carcinogens.[456] Since that time, studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development in preschool children (3 years of age).[457] [458] EPA has not yet evaluated these studies.

vii. Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[459] The draft reassessment completed external peer review.[460] Based on external peer review comments received, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as ''reasonably anticipated to be a human carcinogen'' in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[461] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[462] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[463]

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[446] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R–03/003. p. 10. Available online at: *http://www.epa.gov/ncea/iris/toxreviews/0364tr.pdf.* Docket EPA–HQ–OAR–2010–0799.

[447] See U.S. EPA 2003 Toxicological review of acrolein, Note 446, above.

[448] *See* U.S. EPA 2003 Toxicological review of acrolein, Note 446, at p. 11.

[449] Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *http://www.epa.gov/iris/subst/0364.htm* Docket EPA–HQ–OAR–2010–0799.

[450] See U.S. 2003 Toxicological review of acrolein, Note 446, at p. 15.

[451] Morris JB, Symanowicz PT, Olsen JE, et al. 2003. Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563–1571. Docket EPA–HQ–OAR–2010–0799.

[452] U.S. EPA. 2003. Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *http://www.epa.gov/iris/subst/0364.htm* Docket EPA–HQ–OAR–2010–0799.

[453] International Agency for Research on Cancer. 1995. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 63. Dry cleaning, some chlorinated solvents and other industrial chemicals, World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2010–0799.

[454] Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological profile for Polycyclic Aromatic Hydrocarbons (PAHs). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available electronically at *http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=122&tid=25.*

[455] U.S. EPA (2002). *Health Assessment Document for Diesel Engine Exhaust.* EPA/600/8–90/057F Office of Research and Development, Washington, DC. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.* Docket EPA–HQ–OAR–2010–0799

[456] U.S. EPA (1997). Integrated Risk Information System File of indeno(1,2,3-cd)pyrene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/ncea/iris/subst/0457.htm.*

[457] Perera, F.P.; Rauh, V.; Tsai, W–Y.; et al. (2002) Effect of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. Environ Health Perspect. 111: 201–205.

[458] Perera, F.P.; Rauh, V.; Whyatt, R.M.; Tsai, W.Y.; Tang, D.; Diaz, D.; Hoepner, L.; Barr, D.; Tu, Y.H.; Camann, D.; Kinney, P. (2006) Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ Health Perspect 114: 1287–1292.

[459] U.S. EPA. 2004. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/iris/subst/0436.htm.* Docket EPA–HQ–OAR–2010–0799.

[460] Oak Ridge Institute for Science and Education. (2004). External Peer Review for the IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene. August 2004. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=84403* Docket EPA–HQ–OAR–2010–0799.

[461] National Toxicology Program (NTP). (2004). 11th Report on Carcinogens. Public Health Service, U.S. Department of Health and Human Services, Research Triangle Park, NC. Available from: *http://ntp-server.niehs.nih.gov.* Docket EPA–HQ–OAR–2010–0799.

[462] International Agency for Research on Cancer. (2002). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France. Docket EPA–HQ–OAR–2010–0799.

[463] U. S. EPA. 1998. Toxicological Review of Naphthalene, Environmental Protection Agency, Integrated Risk Information System, Research and

viii. Other Air Toxics

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from light-duty vehicles will be affected by this proposal. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[464]

f. Exposure and Health Effects Associated With Traffic-Related Air Pollution

Populations who live, work, or attend school near major roads experience elevated exposure to a wide range of air pollutants, as well as higher risks for a number of adverse health effects. While the previous sections of this preamble have focused on the health effects associated with individual criteria pollutants or air toxics, this section discusses the mixture of different exposures near major roadways, rather than the effects of any single pollutant. As such, this section emphasizes traffic-related air pollution, in general, as the relevant indicator of exposure rather than any particular pollutant.

Concentrations of many traffic-generated air pollutants are elevated for up to 300–500 meters downwind of roads with high traffic volumes.[465] Numerous sources on roads contribute to elevated roadside concentrations, including exhaust and evaporative emissions, and resuspension of road dust and tire and brake wear. Concentrations of several criteria and hazardous air pollutants are elevated near major roads. Furthermore, different semi-volatile organic compounds and chemical components of particulate matter, including elemental carbon, organic material, and trace metals, have been reported at higher concentrations near major roads.

Populations near major roads experience greater risk of certain adverse health effects. The Health Effects Institute published a report on the health effects of traffic-related air pollution.[466] It concluded that evidence is "sufficient to infer the presence of a causal association" between traffic exposure and exacerbation of childhood asthma symptoms. The HEI report also concludes that the evidence is either "sufficient" or "suggestive but not sufficient" for a causal association between traffic exposure and new childhood asthma cases. A review of asthma studies by Salam et al. (2008) reaches similar conclusions.[467] The HEI report also concludes that there is "suggestive" evidence for pulmonary function deficits associated with traffic exposure, but concluded that there is "inadequate and insufficient" evidence for causal associations with respiratory health care utilization, adult-onset asthma, chronic obstructive pulmonary disease symptoms, and allergy. A review by Holguin (2008) notes that the effects of traffic on asthma may be modified by nutrition status, medication use, and genetic factors.[468]

The HEI report also concludes that evidence is "suggestive" of a causal association between traffic exposure and all-cause and cardiovascular mortality. There is also evidence of an association between traffic-related air pollutants and cardiovascular effects such as changes in heart rhythm, heart attack, and cardiovascular disease. The HEI report characterizes this evidence as "suggestive" of a causal association, and an independent epidemiological literature review by Adar and Kaufman (2007) concludes that there is "consistent evidence" linking traffic-related pollution and adverse cardiovascular health outcomes.[469]

Some studies have reported associations between traffic exposure and other health effects, such as birth outcomes (*e.g.,* low birth weight) and childhood cancer. The HEI report concludes that there is currently "inadequate and insufficient" evidence for a causal association between these effects and traffic exposure. A review by Raaschou-Nielsen and Reynolds (2006) concluded that evidence of an association between childhood cancer and traffic-related air pollutants is weak, but noted the inability to draw firm conclusions based on limited evidence.[470]

There is a large population in the United States living in close proximity of major roads. According to the Census Bureau's American Housing Survey for 2007, approximately 20 million residences in the United States, 15.6% of all homes, are located within 300 feet (91 m) of a highway with 4+ lanes, a railroad, or an airport.[471] Therefore, at current population of approximately 309 million, assuming that population and housing are similarly distributed, there are over 48 million people in the United States living near such sources. The HEI report also notes that in two North American cities, Los Angeles and Toronto, over 40% of each city's population live within 500 meters of a highway or 100 meters of a major road. It also notes that about 33% of each city's population resides within 50 meters of major roads. Together, the evidence suggests that a large U.S. population lives in areas with elevated traffic-related air pollution.

People living near roads are often socioeconomically disadvantaged. According to the 2007 American Housing Survey, a renter-occupied property is over twice as likely as an owner-occupied property to be located near a highway with 4+ lanes, railroad or airport. In the same survey, the median household income of rental housing occupants was less than half that of owner-occupants ($28,921/$59,886). Numerous studies in individual urban areas report higher levels of traffic-related air pollutants in areas with high minority or poor populations.[472] [473] [474]

Students may also be exposed in situations where schools are located

Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/iris/subst/0436.htm* Docket EPA–HQ–OAR–2010–0799.

[464] U.S. EPA Integrated Risk Information System (IRIS) database is available at: *http://www.epa.gov/iris.*

[465] Zhou, Y.; Levy, J.I. (2007) Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. BMC Public Health 7: 89. doi:10.1186/1471–2458–7–89 Docket EPA–HQ–OAR–2010–0799.

[466] HEI Panel on the Health Effects of Air Pollution. (2010) Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. [Online at *http://www.healtheffects.org*] Docket EPA–HQ–OAR–2010–0799.

[467] Salam, M.T.; Islam, T.; Gilliland, F.D. (2008) Recent evidence for adverse effects of residential proximity to traffic sources on asthma. Current Opin Pulm Med 14: 3–8. Docket EPA–HQ–OAR–2010–0799.

[468] Holguin, F. (2008) Traffic, outdoor air pollution, and asthma. Immunol Allergy Clinics North Am 28: 577–588. Docket EPA–HQ–OAR–2010–0799.

[469] Adar, S.D.; Kaufman, J.D. (2007) Cardiovascular disease and air pollutants: evaluating and improving epidemiological data implicating traffic exposure. Inhal Toxicol 19: 135–149. Docket EPA–HQ–OAR–2010–0799.

[470] Raaschou-Nielsen, O.; Reynolds, P. (2006) Air pollution and childhood cancer: a review of the epidemiological literature. Int J Cancer 118: 2920–2929. Docket EPA–HQ–OAR–2010–0799.

[471] U.S. Census Bureau (2008) American Housing Survey for the United States in 2007. Series H–150 (National Data), Table 1A–7. [Accessed at *http://www.census.gov/hhes/www/housing/ahs/ahs07/ahs07.html* on January 22, 2009] Docket EPA–HQ–OAR–2010–0799.

[472] Lena, T.S.; Ochieng, V.; Carter, M.; Holguín-Veras, J.; Kinney, Public Law (2002) Elemental carbon and $PM^{2.5}$ levels in an urban community heavily impacted by truck traffic. Environ Health Perspect 110: 1009–1015. Docket EPA–HQ–OAR–2010–0799.

[473] Wier, M.; Sciammas, C.; Seto, E.; Bhatia, R.; Rivard, T. (2009) Health, traffic, and environmental justice: collaborative research and community action in San Francisco, California. Am J Public Health 99: S499–S504. Docket EPA–HQ–OAR–2010–0799.

[474] Forkenbrock, D.J. and L.A. Schweitzer, *Environmental Justice and Transportation Investment Policy.* Iowa City: University of Iowa, 1997. Docket EPA–HQ–OAR–2010–0799.

near major roads. In a study of nine metropolitan areas across the United States, Appatova et al. (2008) found that on average greater than 33% of schools were located within 400 m of an Interstate, U.S., or state highway, while 12% were located within 100 m.[475] The study also found that among the metropolitan areas studied, schools in the Eastern United States were more often sited near major roadways than schools in the Western United States.

Demographic studies of students in schools near major roadways suggest that this population is more likely than the general student population to be of non-white race or Hispanic ethnicity, and more often live in low socioeconomic status locations.[476, 477, 478] There is some inconsistency in the evidence, which may be due to different local development patterns and measures of traffic and geographic scale used in the studies.

3. Environmental Effects of Non-GHG Pollutants

In this section we discuss some of the environmental effects of PM and its precursors such as visibility impairment, atmospheric deposition, and materials damage and soiling, as well as environmental effects associated with the presence of ozone in the ambient air, such as impacts on plants, including trees, agronomic crops and urban ornamentals, and environmental effects associated with air toxics.

a. Visibility

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[479] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2009 p.m. ISA.[480]

EPA is pursuing a two-part strategy to address visibility impairment. First, EPA developed the regional haze program (64 FR 35714) which was put in place in July 1999 to protect the visibility in Mandatory Class I Federal areas. There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas (62 FR 38680–38681, July 18, 1997). These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977. Second, EPA has concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not protected by the Regional Haze Rule, depending on $PM_{2.5}$ concentrations and other factors that control their visibility impact effectiveness such as dry chemical composition and relative humidity (*i.e.,* an indicator of the water composition of the particles), and has set secondary $PM_{2.5}$ standards to address these areas. The existing annual primary and secondary $PM_{2.5}$ standards have been remanded and are being addressed in the currently ongoing PM NAAQS review.

b. Plant and Ecosystem Effects of Ozone

Elevated ozone levels contribute to environmental effects, with impacts to plants and ecosystems being of most concern. Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation. Ozone damage to plants includes visible injury to leaves and impaired photosynthesis, both of which can lead to reduced plant growth and reproduction, resulting in reduced crop yields, forestry production, and use of sensitive ornamentals in landscaping. In addition, the impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to a subsequent reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.

These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on forest and other natural vegetation can potentially lead to species shifts and loss from the affected ecosystems, resulting in a loss or reduction in associated ecosystem goods and services. Lastly, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas. The final 2006 Ozone Air Quality Criteria Document presents more detailed information on ozone effects on vegetation and ecosystems.

c. Atmospheric Deposition

Wet and dry deposition of ambient particulate matter delivers a complex mixture of metals (*e.g.,* mercury, zinc, lead, nickel, aluminum, cadmium), organic compounds (*e.g.,* polycyclic organic matter, dioxins, furans) and inorganic compounds (*e.g.,* nitrate, sulfate) to terrestrial and aquatic ecosystems. The chemical form of the compounds deposited depends on a variety of factors including ambient conditions (*e.g.,* temperature, humidity, oxidant levels) and the sources of the material. Chemical and physical transformations of the compounds occur in the atmosphere as well as the media onto which they deposit. These transformations in turn influence the fate, bioavailability and potential toxicity of these compounds. Atmospheric deposition has been identified as a key component of the environmental and human health hazard posed by several pollutants including mercury, dioxin and PCBs.[481]

Adverse impacts on water quality can occur when atmospheric contaminants deposit to the water surface or when material deposited on the land enters a waterbody through runoff. Potential impacts of atmospheric deposition to waterbodies include those related to both nutrient and toxic inputs. Adverse effects to human health and welfare can occur from the addition of excess nitrogen via atmospheric deposition. The nitrogen-nutrient enrichment

[475] Appatova, A.S.; Ryan, P.H.; LeMasters, G.K.; Grinshpun, S.A. (2008) Proximal exposure of public schools and students to major roadways: a nationwide U.S. survey. J Environ Plan Mgmt Docket EPA–HQ–OAR–2010–0799.

[476] Green, R.S.; Smorodinsky, S.; Kim, J.J.; McLaughlin, R.; Ostro, B. (2004) Proximity of California public schools to busy roads. Environ Health Perspect 112: 61–66. Docket EPA–HQ–OAR–2010–0799.

[477] Houston, D.; Ong, P.; Wu, J.; Winer, A. (2006) Proximity of licensed child care facilities to near-roadway vehicle pollution. Am J Public Health 96: 1611–1617. Docket EPA–HQ–OAR–2010–0799.

[478] Wu, Y.; Batterman, S. (2006) Proximity of schools in Detroit, Michigan to automobile and truck traffic. J Exposure Sci Environ Epidemiol 16: 457–470. Docket EPA–HQ–OAR–2010–0799.

[479] National Research Council, 1993. Protecting Visibility in National Parks and Wilderness Areas. National Academy of Sciences Committee on Haze in National Parks and Wilderness Areas. National Academy Press, Washington, DC. Docket EPA–HQ–OAR–2010–0799. This book can be viewed on the National Academy Press Web site at *http://www.nap.edu/books/0309048443/html/.*

[480] *See* U.S. EPA 2009 Final PM ISA, Note 396.

[481] U.S. EPA (2000) Deposition of Air Pollutants to the Great Waters: Third Report to Congress. Office of Air Quality Planning and Standards. EPA–453/R–00–0005. Docket EPA–HQ–OAR–2010–0799.

contributes to toxic algae blooms and zones of depleted oxygen, which can lead to fish kills, frequently in coastal waters. Deposition of heavy metals or other toxics may lead to the human ingestion of contaminated fish, impairment of drinking water, damage to freshwater and marine ecosystem components, and limits to recreational uses. Several studies have been conducted in U.S. coastal waters and in the Great Lakes Region in which the role of ambient PM deposition and runoff is investigated.[482, 483, 484, 485, 486]

Atmospheric deposition of nitrogen and sulfur contributes to acidification, altering biogeochemistry and affecting animal and plant life in terrestrial and aquatic ecosystems across the United States. The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geology. Prolonged exposure to excess nitrogen and sulfur deposition in sensitive areas acidifies lakes, rivers and soils. Increased acidity in surface waters creates inhospitable conditions for biota and affects the abundance and nutritional value of preferred prey species, threatening biodiversity and ecosystem function. Over time, acidifying deposition also removes essential nutrients from forest soils, depleting the capacity of soils to neutralize future acid loadings and negatively affecting forest sustainability. Major effects include a decline in sensitive forest tree species, such as red spruce (Picea rubens) and sugar maple (Acer saccharum), and a loss of biodiversity of fishes, zooplankton, and macro invertebrates.

In addition to the role nitrogen deposition plays in acidification, nitrogen deposition also leads to nutrient enrichment and altered biogeochemical cycling. In aquatic systems increased nitrogen can alter species assemblages and cause eutrophication. In terrestrial systems nitrogen loading can lead to loss of nitrogen sensitive lichen species, decreased biodiversity of grasslands, meadows and other sensitive habitats, and increased potential for invasive species. For a broader explanation of the topics treated here, refer to the description in Section 6.1.2.2 of the RIA.

Adverse impacts on soil chemistry and plant life have been observed for areas heavily influenced by atmospheric deposition of nutrients, metals and acid species, resulting in species shifts, loss of biodiversity, forest decline, damage to forest productivity and reductions in ecosystem services. Potential impacts also include adverse effects to human health through ingestion of contaminated vegetation or livestock (as in the case for dioxin deposition), reduction in crop yield, and limited use of land due to contamination.

Atmospheric deposition of pollutants can reduce the aesthetic appeal of buildings and culturally important articles through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion. Atmospheric deposition may affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to adsorb corrosive gases (principally sulfur dioxide).

d. Environmental Effects of Air Toxics

Emissions from producing, transporting and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds, some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[487] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[488] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (*e.g.,* acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[489]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[490] [491] [492] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

4. Air Quality Impacts of Non-GHG Pollutants

a. Current Levels of Non-GHG Pollutants

This proposal may have impacts on ambient concentrations of criteria and air toxic pollutants. Nationally, levels of $PM_{2.5}$, ozone, NO_X, SO_X, CO and air toxics are declining.[493] However, approximately 127 million people lived in counties that exceeded any NAAQS in 2008.[494] These numbers do not include the people living in areas where there is a future risk of failing to maintain or attain the NAAQS. It is important to note that these numbers do not account for potential ozone, $PM_{2.5}$, CO, SO_2, NO_2 or lead nonattainment

[482] U.S. EPA (2004) National Coastal Condition Report II. Office of Research and Development/ Office of Water. EPA–620/R–03/002. Docket EPA–HQ–OAR–2010–0799.

[483] Gao, Y., E.D. Nelson, M.P. Field, et al. 2002. Characterization of atmospheric trace elements on PM2.5 particulate matter over the New York-New Jersey harbor estuary. *Atmos. Environ.* 36: 1077–1086. Docket EPA–HQ–OAR–2010–0799.

[484] Kim, G., N. Hussain, J.R. Scudlark, and T.M. Church. 2000. Factors influencing the atmospheric depositional fluxes of stable Pb, 210Pb, and 7Be into Chesapeake Bay. *J. Atmos. Chem.* 36: 65–79. Docket EPA–HQ–OAR–2010–0799.

[485] Lu, R., R.P. Turco, K. Stolzenbach, et al. 2003. Dry deposition of airborne trace metals on the Los Angeles Basin and adjacent coastal waters. *J. Geophys. Res.* 108(D2, 4074): AAC 11–1 to 11–24. Docket EPA–HQ–OAR–2010–0799.

[486] Marvin, C.H., M.N. Charlton, E.J. Reiner, et al. 2002. Surficial sediment contamination in Lakes Erie and Ontario: A comparative analysis. *J. Great Lakes Res.* 28(3): 437–450. Docket EPA–HQ–OAR–2010–0799.

[487] U.S. EPA. 1991. Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3–91/001. Docket EPA–HQ–OAR–2010–0799.

[488] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343. Docket EPA–HQ–OAR–2010–0799.

[489] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343. Docket EPA–HQ–OAR–2010–0799.

[490] Viskari E–L. 2000. Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327–337. Docket EPA–HQ–OAR–2010–0799.

[491] Ugrekhelidze D, F Korte, G Kvesitadze. 1997. Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24–29. Docket EPA–HQ–OAR–2010–0799.

[492] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. 1987. Toxic components of motor vehicle emissions for the spruce Picea abies. Environ. Pollut. 48:235–243. Docket EPA–HQ–OAR–2010–0799.

[493] U.S. EPA (2010) Our Nation's Air: Status and Trends through 2008. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Publication No. EPA 454/R–09–002. *http://www.epa.gov/airtrends/2010/*. Docket EPA–HQ–OAR–2010–0799.

[494] *See* U.S. EPA Trends, Note 493.

areas which have not yet been designated. Further, the majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[495] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in U.S. EPA's recent mobile source air toxics rule.[496]

b. Impacts of Proposed Standards on Future Ambient Concentrations of $PM_{2.5}$, Ozone and Air Toxics

Full-scale photochemical air quality modeling is necessary to accurately project levels of criteria pollutants and air toxics. For the final rulemaking, a national-scale air quality modeling analysis will be performed to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics (*i.e.,* benzene, formaldehyde, acetaldehyde, acrolein and 1,3-butadiene). The length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this proposal.

Sections III.G.1 and III.G.2 of the preamble present projections of the changes in criteria pollutant and air toxics emissions due to the proposed vehicle standards; the basis for those estimates is set out in Chapter 4 of the draft RIA. The atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex, and making predictions based solely on emissions changes is extremely difficult. However, based on the magnitude of the emissions changes predicted to result from the proposed standards, EPA expects that there will be an improvement in ambient air quality, pending a more comprehensive analysis for the final rulemaking.

For the final rulemaking, EPA intends to use a Community Multi-scale Air Quality (CMAQ) modeling platform as the tool for the air quality modeling. The CMAQ modeling system is a comprehensive three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations and deposition, and air toxics, over regional and urban spatial scales (*e.g.,* over the contiguous United States).[497] [498] [499] [500] The CMAQ model is a well-known and well-established tool and is commonly used by EPA for regulatory analyses and by States in developing attainment demonstrations for their State Implementation Plans. The CMAQ model version 4.7 was most recently peer-reviewed in February of 2009 for the U.S. EPA.[501]

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. EPA intends to use the most recent version of CMAQ, which reflects updates to version 4.7 to improve the underlying science. These include aqueous chemistry mass conservation improvements, improved vertical convective mixing and lowered CB05 mechanism unit yields for acrolein from 1,3-butadiene tracer reactions which were updated to be consistent with laboratory measurements.

5. Other Unquantified Health and Environmental Effects

In addition, EPA seeks comment on whether there are any other health and environmental impacts associated with advancements in vehicle GHG reduction technologies that should be considered. For example, the use of technologies and other strategies to reduce GHG emissions could have effects on a vehicle's life-cycle impacts (*e.g.,* materials usage, manufacturing, end of life disposal), beyond the issues regarding fuel production and distribution (upstream) GHG emissions discussed in Section III.C.2. EPA seeks comment on any studies or research in this area that should be considered in the future to assess a fuller range of health and environmental impacts from the light-duty vehicle fleet moving to advanced GHG-reducing technologies.

EPA is aware of some studies examining the lifecycle GHG emissions, including vehicle production-related emissions, for advanced technology vehicles.[502] The American Iron and Steel Institute (AISI) has recommended that EPA consider basing future standards on lifecycle assessments that include vehicle production, use, and end-of-life impacts; AISI is working on related research with the University of California, Davis.[503] At this point, EPA believes there is insufficient information about the lifecycle impacts of future advanced technologies to conduct the type of detailed assessments that would be needed in a regulatory context, but EPA seeks comment on any current or future studies and research underway on this topic.

H. What are the estimated cost, economic, and other impacts of the proposal?

In this section, EPA presents the costs and impacts of the proposed GHG standards. It is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to average fuel economy increases and CO_2 emissions reductions. The two agencies' standards comprise the National Program, and this discussion of costs and benefits of EPA's GHG standard does not change the fact that both the CAFE and GHG standards, jointly, will be the source of the benefits and costs of the National Program. These costs and benefits are appropriately analyzed separately by each agency and should not be added together.

This section outlines the basis for assessing the benefits and costs of the GHG standards and provides estimates of these costs and benefits. Some of these effects are private, meaning that they affect consumers and producers directly in their sales, purchases, and use of vehicles. These private effects include the increase in vehicle prices due to costs of the technology, fuel savings, and the benefits of additional driving and reduced refueling. Other

[495] U.S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007.

[496] *See* U.S. EPA 2007, Note 495.

[497] U.S. Environmental Protection Agency, Byun, D.W., and Ching, J.K.S., Eds, 1999. Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ modeling system, EPA/600/R–99/030, Office of Research and Development). Docket EPA–HQ–OAR–2010–0799.

[498] Byun, D.W., and Schere, K.L., 2006. Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, J. Applied Mechanics Reviews, 59 (2), 51–77. Docket EPA–HQ–OAR–2010–0799.

[499] Dennis, R.L., Byun, D.W., Novak, J.H., Galluppi, K.J., Coats, C.J., and Vouk, M.A., 1996. The next generation of integrated air quality modeling: EPA's Models-3, Atmospheric Environment, 30, 1925–1938. Docket EPA–HQ–OAR–2010–0799.

[500] Carlton, A., Bhave, P., Napelnok, S., Edney, E., Sarwar, G., Pinder, R., Pouliot, G., and Houyoux, M. *Model Representation of Secondary Organic Aerosol in CMAQv4.7.* Ahead of Print in Environmental Science and Technology. Accessed at: *http://pubs.acs.org/doi/abs/10.1021/es100636q?prevSearch=CMAQ&searchHistoryKey* Docket EPA–HQ–OAR–2010–0799.

[501] Allen, D. et al (2009). Report on the Peer Review of the Atmospheric Modeling and Analysis Division, National Exposure Research Laboratory, Office of Research and Development, U.S. EPA. *http://www.epa.gov/asmdnerl/peer/reviewdocs.html* Docket EPA–HQ–OAR–2010–0799.

[502] For examples, see Chapter 6 of NHTSA's Draft Environmental Impact Statement for this proposed rulemaking, ''Literature Synthesis of Life-cycle Environmental Impacts of Certain Vehicle Materials and Technologies,'' Docket NHTSA–2011–0056.

[503] See AISI comments on the 2012–2016 rulemaking and NOI/Interim Joint TAR: Document ID # EPA–HQ–OAR–2009–0472–7088 and EPA–HQ–OAR–2010–0799–0313, respectively.

costs and benefits affect people outside the markets for vehicles and their use; these effects are termed external, because they affect people in ways other than the effect on the market for and use of new vehicles and are generally not taken into account by the purchaser of the vehicle. The external effects include the climate impacts, the effects on non-GHG pollutants, energy security impacts, and the effects on traffic, accidents, and noise due to additional driving. The sum of the private and external benefits and costs is the net social benefits of the standards.

There is some debate about the behavior of private markets in the context of these standards: If consumers optimize their purchases of fuel economy, with full information and perfect foresight, in perfectly efficient markets, they should have already considered these benefits in their vehicle purchase decisions. If so, then no net private benefits would result from the program, because consumers would already buy vehicles with the amount of fuel economy that is optimal for them; requiring additional fuel economy would alter both the purchase prices of new cars and their lifetime streams of operating costs in ways that will inevitably reduce consumers' well-being. Section III.H.1 discusses this issue more fully.

The net benefits of EPA's proposal consist of the effects of the proposed standards on:

The vehicle costs;

Fuel savings associated with reduced fuel usage resulting from the proposed program

Greenhouse gas emissions;

Other air pollutants;

Other impacts, including noise, congestion, accidents;

Energy security impacts;

Changes in refueling events;

Increased driving due to the ''rebound'' effect.

EPA also presents the cost per ton of GHG reductions associated with the proposed GHG standards on a CO_2eq basis, in Section III.H.3 below.

The total present value of monetized benefits (excluding fuel savings) under the proposed standards are projected to be between $275 to $764 billion, using a 3 percent discount rate and depending on the value used for the social cost of carbon. With a 7 percent discount rate, the total present value of monetized benefits (excluding fuel savings) under the proposed standards are projected to be between $124 to $614 billion, depending on the value used for the social cost of carbon. These benefits are summarized below in Table III–80. The present value of costs of the proposed standards are estimated to be between $243 to $551 billion for new vehicle technology (assuming a 7 and 3 percent discount rate, respectively), less $579 to $1,510 billion in savings realized by consumers through fewer fuel expenditures (calculated using pre-tax fuel prices and using a 7 and 3 percent discount rate, respectively). These costs are summarized below in Table III–78 and the fuel savings are summarized in Table III–79. The total net present value of net benefits under the proposed standards are projected to be between $1.2 and $1.7 trillion, using a 3 percent discount rate and depending on the value used for the social cost of carbon. With a 7 percent discount rate, the total net present value of net benefits under the proposed standards are projected to be between $460 billion to $950 billion, depending on the value used for the social cost of carbon. The estimates developed here use as a baseline for comparison the greenhouse gas performance and fuel economy associated with MY 2016 standards. To the extent that greater fuel economy improvements than those assumed to occur under the baseline may have occurred due to market forces alone (absent these proposed standards), the analysis overestimates private and social net benefits.

While NHTSA and EPA each modeled their respective regulatory programs, the analyses were generally consistent and featured similar parameters. For this proposal, EPA has not conducted an overall uncertainty analysis of the impacts associated with its regulatory program, though it did conduct sensitivity analyses of individual components of the analysis (*e.g.,* alternative SCC estimates, rebound effect, battery costs, mass reduction costs, the indirect cost markup factor, and cost learning curves); these analyses are found in Chapters 3, 4, and 7 of the EPA DRIA. NHTSA, however, conducted a Monte Carlo simulation of the uncertainty associated with its regulatory program. The focus of the simulation model was variation around the chosen uncertainty parameters and their resulting impact on the key output parameters, fuel savings, and net benefits. Because of the similarities between the two analyses, EPA references NHTSA RIA Chapters X and XII as indicative of the relative magnitude, uncertainty and sensitivities of parameters of the cost/benefit analysis. For the final rule, EPA plans to perform sensitivity analyses for a wider variety of parameters. EPA has also analyzed the potential impact of this proposed rule on vehicle sales and employment. These impacts are not included in the analysis of overall costs and benefits of the proposed standards. Further information on these and other aspects of the economic impacts of EPA's proposed rule are summarized in the following sections and are presented in more detail in the DRIA for this rulemaking.

EPA requests comment on all aspects of the cost, savings, and benefits analysis presented here and in the DRIA. EPA also requests comment on the inputs used in these analyses as described in the Draft Joint TSD.

1. Conceptual Framework for Evaluating Consumer Impacts

For this proposed rule, EPA projects significant private gains to consumers in three major areas: (1) Reductions in spending on fuel, (2) for gasoline-fueled vehicles, time saved due to less refueling, and (3) additional driving that results from the rebound effect. In combination, these private benefits, mostly from fuel savings, appear to outweigh the costs of the standards, even without accounting for externalities.

Admittedly, these findings pose an economic conundrum. On the one hand, consumers are expected to gain significantly from the rules, as the increased cost of fuel efficient cars is smaller than the fuel savings. Yet many of these technologies are readily available; financially savvy consumers could have sought vehicles with improved fuel efficiency, and auto makers seeking those customers could have offered them. Assuming full information, perfect foresight, perfect competition, and financially rational consumers and producers, standard economic theory suggests that normal market operations would have provided the private net gains to consumers, and the only benefits of the rule would be due to external benefits. If our analysis projects net private benefits that consumers have not realized in this perfectly functioning market, then, with the above assumptions, there must be additional costs of these private net benefits that are not accounted for. This calculation assumes that consumers accurately predict and act on all the fuel-saving benefits they will get from a new vehicle, and that producers market products providing those benefits. The estimate of large private net benefits from this rule, then, suggests either that the assumptions noted above do not hold, or that EPA's analysis has missed some factor(s) tied to improved fuel economy that reduce(s) consumer welfare.

This subsection discusses the economic principles underlying the assessment of impacts on consumer well-being due to the proposed changes in the vehicles. Because conventional gasoline- and diesel-fueled vehicles have quite different characteristics from advanced technology vehicles (especially electric vehicles), the principles for these different kinds vehicles are discussed separately below.

a. Conventional Vehicles

For conventional vehicles, the estimates of technology costs developed for this proposed rule take into account the cost needed to ensure that vehicle utility (including performance, reliability, and size) stay constant, except for fuel economy and vehicle price, with some minor exceptions (*e.g.,* see the discussion of the ''Atkinson-cycle'' engine and towing capacity in III.D.3). For example, using a 4-cylinder engine instead of a 6-cylinder engine reduces fuel economy, but also reduces performance; turbocharging the 4-cylinder engine, though, produces fuel savings while maintaining performance. The cost estimates assume turbocharging accompanies engine downsizing. As a result, if the market for fuel economy is efficient and these cost estimates are correct, then the existence of large private net benefits implies that there would need to be some other changed qualities, missed in the cost estimates, that would reduce the benefits consumers receive from their vehicles.[504] We seek comments that identify any such changed qualities omitted from the analysis. Such comments should describe how changed qualities affect consumer benefits from vehicles, and provide cost estimates for eliminating the effects of the changes.

The central conundrum observed in this market, that consumers appear not to purchase products featuring levels of energy efficiency that are in their economic self-interest, has been referred to as the Energy Paradox in this setting (and in several others).[505] There are many possible reasons discussed in academic research why this might occur: [506]

Consumers might be ''myopic'' and hence undervalue future fuel savings in their purchasing decisions.

Consumers might lack the information necessary to estimate the value of future fuel savings, or not have a full understanding of this information even when it is presented.

Consumer may be accounting for uncertainty in future fuel savings when comparing upfront cost to future returns.

Consumers may consider fuel economy after other vehicle attributes and, as such, not optimize the level of this attribute (instead ''satisficing'' or selecting vehicles that have some sufficient amount of fuel economy).

Consumers might be especially averse to the short-term losses associated with the higher prices of energy efficient products relative to the future fuel savings (the behavioral phenomenon of ''loss aversion'').

Consumers might associate higher fuel economy with inexpensive, less well designed vehicles.

Even if consumers have relevant knowledge, selecting a vehicle is a highly complex undertaking, involving many vehicle characteristics. In the face of such a complicated choice, consumers may use simplified decision rules.

In the case of vehicle fuel efficiency, and perhaps as a result of one or more of the foregoing factors, consumers may have relatively few choices to purchase vehicles with greater fuel economy once other characteristics, such as vehicle class, are chosen.[507]

A great deal of work in behavioral economics identifies and elaborates factors of this sort, which help account for the Energy Paradox.[508] This point holds in the context of fuel savings (the main focus here), but it applies equally to the other private benefits, including reductions in refueling frequency and additional driving. For example, it might well be questioned whether significant reductions in refueling frequency, and corresponding private savings, are fully internalized when consumers are making purchasing decisions.

EPA discussed this issue at length in the 2012–2016 light duty rulemaking and in the medium- and heavy-duty greenhouse gas rulemaking. See 75 FR at 25510–13; 76 FR 57315–19. Considerable research indicates that the Energy Paradox may be a real and significant phenomenon, although the literature has not reached a consensus about the reasons for its existence. Several researchers have found evidence suggesting that consumers do not give full or appropriate weight to fuel economy in purchasing decisions. For example, Sanstad and Howarth [509] argue that consumers make decisions without the benefit of full information by resorting to imprecise but convenient rules of thumb. Some studies find that a substantial portion of this undervaluation can be explained by inaccurate assessments of energy savings, or by uncertainty and irreversibility of energy investments due to fluctuations in energy prices.[510] For a number of reasons, consumers may undervalue future energy savings due to routine mistakes in how they evaluate these trade-offs. For instance, the calculation of fuel savings is complex, and consumers may not make it correctly.[511] The attribute of fuel economy may be insufficiently salient, leading to a situation in which

[504] It should be noted that adding fuel-saving technology does not preclude future improvements in performance, safety, or other attributes, though it is possible that the costs of these additions may be affected by the presence of fuel-saving technology.

[505] Jaffe, A. B., and Stavins, R. N. (1994). ''The Energy Paradox and the Diffusion of Conservation Technology.'' *Resource and Energy Economics* 16(2), 91–122. Docket EPA–HQ–OAR–2010–0799.

[506] For an overview, see Helfand, Gloria and Ann Wolverton, ''Evaluating the Consumer Response to Fuel Economy: A Review of the Literature.'' *International Review of Environmental and Resource Economics* 5 (2011): 103–146. Docket EPA–HQ–OAR–2010–0799.

[507] For instance, in MY 2010, the range of fuel economy (combined city and highway) available among all listed 6-cylinder minivans was 18 to 20 miles per gallon. With a manual-transmission 4-cylinder minivan, it is possible to get 24 mpg. See *http://www.fueleconomy.gov*, which is jointly maintained by the U.S. Department of Energy and the EPA.

[508] Jaffe, A. B., and Stavins, R. N. (1994). ''The Energy Paradox and the Diffusion of Conservation Technology.'' *Resource and Energy Economics* 16(2), 91–122. Docket EPA–HQ–OAR–2010–0799. See also Allcott and Wozny, supra note.

[509] Sanstad, A., and R. Howarth (1994). '' 'Normal' Markets, Market Imperfections, and Energy Efficiency.'' *Energy Policy* 22(10): 811–818 (Docket EPA–HQ–OAR–2010–0799).

[510] Greene, D., J. German, and M. Delucchi (2009). ''Fuel Economy: The Case for Market Failure'' in *Reducing Climate Impacts in the Transportation Sector*, Sperling, D., and J. Cannon, eds. Springer Science (Docket EPA–HQ–OAR–2010–0799); Dasgupta, S., S. Siddarth, and J. Silva-Risso (2007). ''To Lease or to Buy? A Structural Model of a Consumer's Vehicle and Contract Choice Decisions.'' *Journal of Marketing Research* 44: 490–502 (Docket EPA–HQ–OAR–2010–0799); Metcalf, G., and D. Rosenthal (1995). ''The 'New' View of Investment Decisions and Public Policy Analysis: An Application to Green Lights and Cold Refrigerators,'' *Journal of Policy Analysis and Management* 14: 517–531 (Docket EPA–HQ–OAR–2010–0799); Hassett, K., and G. Metcalf (1995), ''Energy Tax Credits and Residential Conservation Investment: Evidence from Panel Data,'' *Journal of Public Economics* 57: 201–217 (Docket EPA–HQ–OAR–2010–0799); Metcalf, G., and K. Hassett (1999), ''Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data,'' *The Review of Economics and Statistics* 81(3): 516–528 (Docket EPA–HQ–OAR–2010–0799); van Soest D., and E. Bulte (2001), ''Does the Energy-Efficiency Paradox Exist? Technological Progress and Uncertainty.'' *Environmental and Resource Economics* 18: 101–12 (Docket EPA–HQ–OAR–2010–0799).

[511] Turrentine, T. and K. Kurani (2007). ''Car Buyers and Fuel Economy?'' *Energy Policy* 35: 1213–1223 (Docket EPA–HQ–OAR–2009–0472); Larrick, R. P., and J.B. Soll (2008). ''The MPG illusion.'' *Science* 320: 1593–1594 (Docket EPA–HQ–OAR–2010–0799).

consumers are not willing to pay $1 for an expected $1 present value of reduced gasoline costs.[512] Larrick and Soll (2008) find that consumers do not understand how to translate changes in miles-per-gallon into fuel savings.[513] In addition, future fuel price (a major component of fuel savings) is highly uncertain. Consumer fuel savings also vary across individuals, who travel different amounts and have different driving styles. Cost calculations based on the average do not distinguish between those that may gain or lose as a result of the policy.[514] In addition, it is possible that factors that might help explain why consumers don't purchase more fuel efficiency, such as transaction costs and differences in quality, may not be adequately measured.[515] Studies regularly show that fuel economy plays a role in consumers' vehicle purchases, but modeling that role is still in development, and there is no consensus that most consumers make fully informed tradeoffs.[516] A review commissioned by EPA finds great variability in estimates of the role of fuel economy in consumers' vehicle purchase decisions.[517] Of 27 studies, significant numbers of them find that consumers undervalue, overvalue, or value approximately correctly the fuel savings that they will receive from improved fuel economy. The variation in the value of fuel economy in these studies is so high that it appears to be inappropriate to identify one central estimate of value from the literature. Thus, estimating consumer response to higher vehicle fuel economy is still unsettled science.

EPA and NHTSA recently revised the fuel economy label on new vehicles in ways intended to improve information for consumers.[518] For instance, it presents fuel consumption data in addition to miles per gallon, in response to the concern over the difficulties of translating mpg into fuel savings; it also reports expected fuel savings or additional costs relative to an average vehicle. Whether the new label will help consumers to overcome the ''energy paradox'' is not known at this point. A literature review that contributed to the fuel economy labeling rule points out that consumers increasingly do a great deal of research on the internet before going to an auto dealer.[519] To the extent that the label improves consumers' understanding of the value of fuel economy, purchase decisions could change. Until the newly revised labels enter the marketplace with MY 2013 vehicles (or optionally sooner), the agencies may not be able to determine how vehicle purchase decisions are likely to change as a result of the new labels.

If there is a difference between expected fuel savings and consumers' willingness to pay for those fuel savings, the next question is, which is the appropriate measure of consumer benefit? Fuel savings measure the actual monetary value that consumers will receive after purchasing a vehicle; the willingness to pay for fuel economy measures the value that, before a purchase, consumers place on additional fuel economy. As noted, there are a number of reasons that consumers may incorrectly estimate the benefits that they get from improved fuel economy, including risk or loss aversion, and poor ability to calculate savings. Also as noted, fuel economy may not be as salient as other vehicle characteristics when a consumer is considering vehicles. If these arguments are valid, then there will be significant gains to consumers of the government mandating additional fuel economy.

While acknowledging the conundrum, EPA continues to value fuel savings from the proposed standards using the projected market value over the vehicles' entire lifetimes, and to report that value among private benefits of the proposed rule. Improved fuel economy will significantly reduce consumer expenditures on fuel, thus benefiting consumers. Real money is being saved and accrued by the initial buyer and subsequent owners. In addition, using a measure based on consumer consideration at the time of vehicle purchase would involve a very wide range of uncertainty, due to the lack of consensus on the value of additional fuel economy in vehicle choice models. Due partly to this factor, it is true that limitations in modeling affect our ability to estimate how much of these savings would have occurred in the absence of the rule. For example, some of the technologies predicted to be adopted in response to the rule may already be in the deployment process due to shifts in consumer demand for fuel economy, or due to expectations by auto makers of future GHG/fuel economy standards. It is not impossible that some of these savings would have occurred in the absence of the proposed standards.[520] To the extent that greater fuel economy improvements than those assumed to occur under the baseline may have occurred due to market forces alone (absent the proposed standards), the analysis overestimates private and social benefits and costs. As discussed below, limitations in modeling also affect our ability to estimate the effects of the rule on net benefits in the market for vehicles.

Consumer vehicle choice models estimate what vehicles consumers buy based on vehicle and consumer characteristics. In principle, such models could provide a means of understanding both the role of fuel economy in consumers' purchase decisions and the effects of this rule on the benefits that consumers will get from vehicles. Helfand and Wolverton discuss the wide variation in the

[512] Allcott, Hunt, and Nathan Wozny, ''Gasoline Prices, Fuel Economy, and the Energy Paradox'' (2010), available at *http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%* (Docket EPA–HQ–OAR–2010–0799). U.S. Department of Energy, 2011. ''Transportation and the Economy,'' Chapter 10 in ''Transportation Energy Data Book,'' http://cta.ornl.gov/data/tedb30/Edition30_Chapter10.pdf, Table 10.13, estimates that gas and oil costs were 15.4% of vehicle costs per mile in 2010.

[513] Sanstad, A., and R. Howarth (1994). '' 'Normal' Markets, Market Imperfections, and Energy Efficiency.''*Energy Policy* 22(10): 811–818 (Docket EPA–HQ–OAR–2010–0799); Larrick, R. P., and J.B. Soll (2008). ''The MPG illusion.'' *Science* 320: 1593–1594 (Docket EPA–HQ–OAR–2010–0799).

[514] Hausman J., Joskow P. (1982). ''Evaluating the Costs and Benefits of Appliance Efficiency Standards.'' American Economic Review 72: 220–25 (Docket EPA–HQ–OAR–2010–0799).

[515] Jaccard, Mark. ''Paradigms of Energy Efficiency's Cost and their Policy Implications: Déjà Vu All Over Again.'' Modeling the Economics of Greenhouse Gas Mitigation: Summary of a Workshop, K. John Holmes, Rapporteur. National Academies Press, 2010. *http://www.nap.edu/openbook.php?record_id=13023&page=42* (Docket EPA–HQ–OAR–2010–0799).

[516] *E.g.*, Goldberg, Pinelopi Koujianou, ''Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry,'' *Econometrica* 63(4) (July 1995): 891–951 (Docket EPA–HQ–OAR–2010–0799); Goldberg, Pinelopi Koujianou, ''The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.,'' *Journal of Industrial Economics* 46(1) (March 1998): 1–33 (Docket EPA–HQ–OAR–2010–0799); Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer (2009). ''Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets,'' Working paper (accessed 11/1/11), available at *http://web.mit.edu/knittel/www/papers/gaspaper_latest.pdf* (Docket EPA–HQ–OAR–2010–0799).

[517] Greene, David L. ''How Consumers Value Fuel Economy: A Literature Review.'' EPA Report EPA–420–R–10–008, March 2010 (Docket EPA–HQ–OAR–2010–0799).

[518] Environmental Protection Agency and Department of Transportation, ''Revisions and Additions to Motor Vehicle Fuel Economy Label,'' **Federal Register** 76(129) (July 6, 2011): 39478–39587.

[519] PRR, Inc., ''Environmental Protection Agency Fuel Economy Label: Literature Review.'' EPA–420–R–10–906, August 2010, available at *http://www.epa.gov/fueleconomy/label/420r10906.pdf* 2010 (Docket EPA–HQ–OAR–2010–0799).

[520] However, as discussed at section III.D above, the assumption of a flat baseline absent this rule rests on strong historic evidence of lack of increase in fuel economy absent either regulatory control or sharply rising fuel prices.

structure and results of these models.[521] Models or model results have not frequently been systematically compared to each other. When they have, the results show large variation over, for instance, the value that consumers place on additional fuel economy.

In order to develop greater understanding of these models, EPA is in the process of developing a vehicle choice model. It uses a ''nested logit'' structure common in the vehicle choice modeling literature. ''Nesting'' refers to the decision-tree structure of buyers' choices among vehicles the model employs, and ''logit'' refers to the specific pattern by which buyers' choices respond to differences in the overall utility that individual vehicle models and their attributes provide.[522] The nesting structure in EPA's model involves a hierarchy of choices. In its current form, at the initial decision node, consumers choose between buying a new vehicle or not. Conditional on choosing a new vehicle, consumers then choose among passenger vehicles, cargo vehicles, and ultra-luxury vehicles. The next set of choices subdivides each of these categories into vehicle type (*e.g.,* standard car, minivan, SUV, etc.). Next, the vehicle types are divided into classes (small, medium, and large SUVs, for instance), and then, at the bottom, are the individual models. At this bottom level, vehicles that are similar to each other (such as standard subcompacts, or prestige large vehicles) end up in the same ''nest.'' Substitution within a nest is considered much more likely than substitution across nests, because the vehicles within a nest are more similar to each other than vehicles in different nests. For instance, a person is more likely to substitute between a Chevrolet Aveo and a Toyota Yaris (both subcompacts) than between an Aveo and a pickup truck. In addition, substitution is greater at low decision nodes (such as individual vehicles) than at higher decision nodes (such as the buy/no buy decision), because there are more choices at lower levels than at higher levels. Parameters for the model (including demand elasticities and the value of fuel economy in purchase decisions) are being selected based on a review of values found in the literature on vehicle choice modeling. Additional discussion of this model can be found in Chapter 8.1.2.8 of the DRIA. The model is still undergoing development; the agency will seek peer review on it before it is utilized. In addition, concerns remain over the ability of any vehicle choice model to make reasonable predictions of the response of the total number and composition of new vehicle sales to changes in the prices and characteristics of specific vehicle models. EPA seeks comments on the use of vehicle choice modeling for predicting changes in sales mix due to policies, and on methods to test the ability of a vehicle choice model to produce reasonable estimates of changes in fleet mix.

The next issue is the potential for loss in consumer welfare due to the rule. As mentioned above (and discussed more thoroughly in Section III.D.3 of this preamble), the technology cost estimates developed here for conventional vehicles take into account the costs to hold other vehicle attributes, such as size and performance, constant.[523] In addition, the analysis assumes that the full technology costs are passed along to consumers. With these assumptions, because welfare losses are monetary estimates of how much consumers would have to be compensated to be made as well off as in the absence of the change,[524] the price increase measures the loss to the buyer.[525] Assuming that the full technology cost gets passed along to the buyer as an increase in price, the technology cost thus measures the welfare loss to the consumer. Increasing fuel economy would have to lead to other changes in the vehicles that consumers find undesirable for there to be additional losses not bounded by the technology costs.

b. Electric Vehicles and Other Advanced Technology Vehicles

This proposal finds that electric vehicles (EVs) may form a part (albeit limited) of some manufacturers' compliance strategy. The following discussion will focus on EVs, because they are expected to play more of a role in compliance than vehicles with other alternative fuels, but related issues may arise for other alternatively fueled vehicles. It should be noted that EPA's projection of the penetration of EVs in the MY 2025 fleet is very small (under 3%).

Electric vehicles (EVs), at the time of this rulemaking, have very different refueling infrastructures than conventional gasoline- or diesel-fueled vehicles: Refueling EVs requires either access to electric charging facilities or battery replacement. In addition, because of the expense of increased battery capacity, EVs commonly have a smaller driving range than conventional vehicles. Because of these differences, the vehicles cannot be considered conventional vehicles unmodified except for cost and fuel economy. As a result, the consumer welfare arguments presented above need to be modified to account for these differences.

A first important point to observe is that, although auto makers are required to comply with the proposed standards, producing EVs as a compliance strategy is not specifically required. Auto makers will choose to provide EVs either if they have few alternative ways to comply, or if EVs are, for some range of production, likely to be more profitable (or less unprofitable) than other ways of complying.

From the consumer perspective, it is important to observe that there is no mandate for any consumer to choose any particular kind of vehicle. An individual consumer will buy an EV only if the price and characteristics of the vehicle make it more attractive to her than other vehicles. If the range of vehicles in the conventional fleet does not shrink, the availability of EVs should not reduce consumer welfare compared to a fleet with no EVs: Increasing options should not reduce consumer well-being, because other existing options still are available. On the other hand, if the variety of vehicles in the conventional market does change, there may be consumers who are forced

[521] Helfand, Gloria and Ann Wolverton, ''Evaluating the Consumer Response to Fuel Economy: A Review of the Literature.'' *International Review of Environmental and Resource Economics* 5 (2011): 103–146 (Docket EPA–HQ–OAR–2010–0799).

[522] Logit refers to a statistical analysis method used for analyzing the factors that affect discrete choices (*i.e.*, yes/no decisions or the choice among a countable number of options).

[523] If the reference-case vehicles include different vehicle characteristics, such as improved acceleration or towing capacity, then the costs for the proposed standards would be, as here, the costs of adding compliance technologies to those reference-case vehicles. These costs may differ from those estimated here, due to our lack of information on how those vehicle characteristics might change between now and 2025.

[524] This approach describes the economic concept of compensating variation, a payment of money after a change that would make a consumer as well off after the change as before it. A related concept, equivalent variation, estimates the income change that would be an alternative to the change taking place. The difference between them is whether the consumer's point of reference is her welfare before the change (compensating variation) or after the change (equivalent variation). In practice, these two measures are typically very close together for marketed goods.

[525] Indeed, it is likely to be an overestimate of the loss to the consumer, because the consumer has choices other than buying the same vehicle with a higher price; she could choose a different vehicle, or decide not to buy a new vehicle. The consumer would choose one of those options only if the alternative involves less loss than paying the higher price. Thus, the increase in price that the consumer faces would be the upper bound of loss of consumer welfare, unless there are other changes to the vehicle due to the fuel economy improvements, unaccounted for in the costs, that make the vehicle less desirable to consumers.

to substitute to alternative vehicles. The use of the footprint-based standard is intended in part to help maintain the diversity of vehicle sizes. Because the agencies do not expect any vehicle classes to become unavailable, consumers who buy EVs therefore are expected to choose them voluntarily, in preference to the other vehicles available to them.

From a practical perspective, the key issue is whether the consumer demand for EVs is large enough to absorb all the EVs that automakers will produce in order to comply with these standards, or whether automakers will need to increase consumer purchases by providing subsidies to consumers. If enough consumers find EVs more attractive than other vehicles, and automakers therefore do not need to subsidize their purchase, then both consumers and producers will benefit from the introduction of EVs. On the other hand, it is possible that automakers will find EVs to be part of a cost-effective compliance technology but nevertheless need to price them below cost them to sell sufficient numbers. If so, then there is a welfare loss associated with the sale of EVs beyond those that would be sold in the free market. The deadweight loss can be approximated as one-half of the size of the subsidy needed for the marginal purchaser, times the number of sales that would need the subsidy. Estimating this value would require knowing the number of sales necessary beyond the expected sales level in an unregulated market, and the amount of the subsidy that would be necessary to induce the desired number of sales. Given the fledgling state of the market for EVs, neither of these values is easily knowable for the 2017 to 2025 time frame.

A number of factors will affect the likelihood of consumer acceptance of EVs. People with short commutes may find little obstacle in the relatively short driving range, but others who regularly drive long distances may find EVs' ranges limiting. The reduced tailpipe emissions and reduced noise may be attractive features to some consumers.[526] Recharging at home could be a convenient, desirable feature for people who have garages with electric charging capability, but not for people who park on the street. If an infrastructure develops for recharging vehicles with the convenience approaching that of buying gasoline, range or home recharging may become less of a barrier to purchase. Of course, other attributes of the marketed EVs, such as their performance and their passenger and storage capacity, will also affect the share of consumers who will consider them. As infrastructure, EV technology, and costs evolve over time, consumer interest in EVs will adjust as well. Thus, modeling consumer response to advanced technology vehicles in the 2017–2025 time frame poses even more challenges than those associated with modeling consumer response for conventional vehicles.

Because range is a major factor in EV acceptability, it is starting to draw attention in the research community. For instance, several studies have examined consumers' willingness to pay for increased vehicle range. Results vary, depending on when the survey was conducted (studies from the early 1990s have much higher values than more recent studies) and on household income and other demographic factors; some find range to be statistically indistinguishable from zero, while others find the value of increasing range from 150 to 300 miles to be as much as $59,000 (2009$) (see RIA Chapter 8 for more discussion).

Other research has examined how the range limitation may affect driving patterns. Pearre et al. observed daily driving patterns for 484 vehicles in the Atlanta area over a year.[527] In their sample, 9 percent of vehicles never exceeded 100 miles in one day, and 21 percent never exceeded 150 miles in one day. Lin and Greene compared the cost of reduced range to the cost of additional battery capacity for EVs.[528] They find that an ''optimized'' range of about 75 miles would be sufficient for 98% of days for ''modest'' drivers (those who average about 25 miles per day); the optimized EV range for ''average'' drivers (who average about 43 miles per day), close to 120 miles, would meet their needs on 97 percent of days. Turrentine et al. studied drivers who leased MINI E EVs (a conversion of the MINI Cooper) for a year.[529] They found that drivers adapted their driving patterns in response to EV ownership: For instance, they modified where they shopped and increased their use of regenerative braking in order to reduce range as a constraint. These finding suggest that, for some consumers, range may be a limiting factor only occasionally. If those consumers are willing to consider alternative ways of driving long distances, such as renting a gasoline vehicle or exchanging vehicles within the household, then limited range may not be a barrier to adoption for them. These studies also raise the question whether analysis of EV use should be based on the driving patterns from conventional vehicles, because consumers may use EVs differently than conventional vehicles.

EVs themselves are expected to change over time, as battery technologies and costs develop. In addition, consumer interest in EVs is likely to change over time, as early adopters share their experiences. The initial research in the area suggests that consumers put a high value on increased range, though this value appears to be changing over time. The research also suggests that some segments of the driving public may experience little, if any, restriction on their driving due to range limitations if they were to purchase EVs. At this time it is not possible to estimate whether the number of people who will choose to purchase EVs at private-market prices will be more or less than the number that auto makers are expected to produce to comply with the standards. We note that our projections of technology penetrations indicate that a very small portion (fewer than 3 percent) of new vehicles produced in 2025 will need to be EVs. For the purposes of the analysis presented here for this proposal, we assume that the consumer market will be sufficient to absorb the number of EVs expected to be used for compliance under this rule. We seek comment and further research that might provide evidence on the consumer market for EVs in the 2017–2025 period.

c. Summary

The Energy Paradox, also known as the efficiency gap, raises the question, why do private markets not provide energy savings that engineering, technology cost analyses find are cost-

[526] For instance, Hidrue et al. (Hidrue, Michael K., George R. Parsons, Willett Kempton, and Meryl P. Gardner. ''Willingness to Pay for Electric Vehicles and their Attributes.'' *Resource and Energy Economics* 33(3) (2011): 686–705 (Docket EPA–HQ–OAR–2010–0799)) find that some consumers are willing to pay $5100 for vehicles with 95% lower emissions than the vehicles they otherwise aim to purchase.

[527] Pearre, Nathaniel S., Willett Kempton, Randall L. Guensler, and Vetri V. Elango. ''Electric vehicles: How much range is required for a day's driving?'' *Transportation Research Part C* 19(6) (2011): 1171–1184 (Docket EPA–HQ–OAR–2010–0799).

[528] Lin, Zhenhong, and David Greene. ''Rethinking FCV/BEV Vehicle Range: A Consumer Value Trade-off Perspective.'' The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition, Shenzhen, China, Nov. 5–9, 2010 (Docket EPA–HQ–OAR–2010–0799).

[529] Turrentine, Tom, Dahlia Garas, Andy Lentz, and Justin Woodjack. ''The UC Davis MINI E Consumer Study.'' UC Davis Institute of Transportation Research Report UCD–ITS–RR–11–05, May 4, 2011 (Docket EPA–HQ–OAR–2010–0799).

effective? Though a number of hypotheses have been raised to explain the paradox, studies have not been able at this time to identify the relative importance of different explanations. As a result, it is not possible at this point to state with any degree of certainty whether the market for fuel efficiency is operating efficiently, or whether the market has failings.

For conventional vehicles, the key implication is that the there may be two different estimates of the value of fuel savings. One value comes from the engineering estimates, based on consumers' expected driving patterns over the vehicle's lifetime; the other value is what the consumer factors into the purchase decision when buying a vehicle. Although economic theory suggests that these two values should be the same in a well functioning market, if engineering estimates accurately measure fuel savings that consumers will experience, the available evidence does not provide support for that theory. The fuel savings estimates presented here are based on expected consumers' in-use fuel consumption rather than the value they estimate at the time that they consider purchasing a vehicle. Though the cost estimates may not have taken into account some changes that consumers may not find desirable, those omitted costs would have to be of very considerable magnitude to have a significant effect on the net benefits of this rule. The costs imposed on the consumer are measured by the costs of the technologies needed to comply with the standards. Because the cost estimates have built into them the costs required to hold other vehicle attributes constant, then, in principle, compensating consumers for the increased costs would hold them harmless, even if they paid no attention to the fuel efficiency of vehicles when making their purchase decisions.

For electric vehicles, and perhaps for other advanced-technology vehicles, other vehicle attributes are not expected to be held constant. In particular, their ranges and modes of refueling will be different from those of conventional vehicles. From a social welfare perspective, the key question is whether the number of consumers who will want to buy EVs at their private-market prices will exceed the number that auto makers are expected to produce to comply with the standards. If too few consumers are willing to buy them at their private-market prices, then auto makers will have to subsidize their prices. Though current research finds that consumers typically have a high value for increasing the range of EVs (and thus would consider a shorter range a cost of an EV), current research also suggests that consumers may find ways to adapt to the shorter range so that it is less constraining. The technologies, prices, infrastructure, and consumer experiences associated with EVs are all expected to evolve between the present and the period when this rule becomes effective. The analysis in this proposal assumes that the consumer market is sufficient to absorb the expected number of EVs without subsidies.

We seek comment and further research on the efficiency of the market for fuel economy for conventional vehicles and on the likely size of the consumer market for EVs in 2017–2025.

2. Costs Associated With the Vehicle Standards

In this section, EPA presents our estimate of the costs associated with the proposed vehicle program. The presentation here summarizes the vehicle level costs associated with the new technologies expected to be added to meet the proposed GHG standards, including hardware costs to comply with the proposed A/C credit program. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis and on an annual total basis.

The presentation here summarizes the outputs of the OMEGA model that was discussed in some detail in Section III.D of this preamble. For details behind the analysis such as the OMEGA model inputs and the estimates of costs associated with individual technologies, the reader is directed to Chapter 1 of the EPA's draft RIA and Chapter 3 of the draft Joint TSD. For more detail on the outputs of the OMEGA model and the overall vehicle program costs summarized here, the reader is directed to Chapters 3 and 5 of EPA's draft RIA.

With respect to the aggregate cost estimations presented here, EPA notes that there are a number of areas where the results of our analysis may be conservative and, in general, EPA believes we have directionally overestimated the costs of compliance with these new standards, especially in not accounting for the full range of credit opportunities available to manufacturers. For example, some cost saving programs are considered in our analysis, such as full car/truck trading, while others are not, such as advanced vehicle technology credits.

a. Costs per Vehicle

To develop costs per vehicle, EPA has used the same methodology as that used in the recent 2012–2016 final rule and the 2010 TAR. Individual technology direct manufacturing costs have been estimated in a variety of ways—vehicle and technology tear down, models developed by outside organizations, and literature review—and indirect costs have been estimated using the updated and revised indirect cost multiplier (ICM) approach that was first developed for the 2012–2016 final rule. All of these individual technology costs are described in detail in Chapter 3 of the draft joint TSD. Also described there are the ICMs used in this proposal and the ways the ICMs have been updated and revised since the 2012–2016 final rule which results in considerably higher indirect costs in this proposal than estimated in the 2012–2016 final rule. Further, we describe in detail the adjustments to technology costs to account for manufacturing learning and the cost reductions that result from that learning. We note here that learning impacts are applied only to direct manufacturing costs which differs from the 2012–2016 final rule which applied learning to both direct and indirect costs. Lastly, we have included costs associated with stranded capital (*i.e.,* capital investments that are not fully recaptured by auto makers because they would be forced to update vehicles on a more rapid schedule than they may have intended absent this proposal). Again, this is detailed in Chapter 3 of the draft joint TSD.

EPA then used the technology costs to build GHG and fuel consumption reducing packages of technologies for each of 19 different vehicle types meant to fully represent the range of baseline vehicle technologies in the marketplace (*i.e.,* number of cylinders, valve train configuration, vehicle class). This package building process as well as the process we use to determine the most cost effective packages for each of the 19 vehicle types is detailed in Chapter 1 of EPA's draft RIA. These packages are then used as inputs to the OMEGA model to estimate the most cost effective means of compliance with the proposed standards giving due consideration to the timing required for manufacturers to implement the needed technologies. That is, we assume that manufacturers cannot add the full suite of needed technologies in the first year of implementation. Instead, we expect them to add technologies to vehicles during the typical 4 to 5 year redesign cycle. As such, we expect that every vehicle can be redesigned to add significant levels of new technology every 4 to 5 years. Further, we do not expect manufacturers to redesign or refresh vehicles at a pace more rapid than the industry standard four to five year cycle.

The results, including costs associated with the air conditioning program and estimates of stranded capital as described in Chapter 3 of the draft joint TSD, are shown in Table III–65.

Table III-65 Industry Average Vehicle Costs Associated with the Proposed Standards

(2009 dollars)

Model Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	2040	2050
$/car	$194	$353	$479	$595	$718	$1,165	$1,492	$1,806	$1,942	$1,926	$1,926	$1,926
$/truck	$55	$198	$305	$417	$764	$1,200	$1,525	$1,834	$1,954	$1,938	$1,938	$1,938
Combined	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946	$1,930	$1,929	$1,929

b. Annual Costs of the Proposed National Program

The costs presented here represent the incremental costs for newly added technology to comply with the proposed program. Together with the projected increases in car and truck sales, the increases in per-car and per-truck average costs shown in Table III–65, above result in the total annual costs presented in Table III–66 below. Note that the costs presented in Table III–66 do not include the fuel savings that consumers would experience as a result of driving a vehicle with improved fuel economy. Those impacts are presented in Section III.H.4. Note also that the costs presented here represent costs estimated to occur presuming that the proposed MY 2025 standards would continue in perpetuity. Any changes to the proposed standards would be considered as part of a future rulemaking. In other words, the proposed standards would not apply only to 2017–2025 model year vehicles—they would, in fact, apply to all 2025 and later model year vehicles.

Table III-66 Undiscounted Annual Costs, & Proposed Program Costs Discounted back to 2012

(millions of 2009 dollars)

Calendar Year	Cars	Truck	Total Annual Costs
2017	$1,940	$322	$2,300
2018	$3,500	$1,130	$4,660
2019	$4,780	$1,700	$6,510
2020	$6,120	$2,340	$8,470
2021	$7,540	$4,340	$11,900
2022	$12,500	$6,840	$19,300
2023	$16,400	$8,680	$25,000
2024	$20,300	$10,400	$30,700
2025	$22,400	$11,200	$33,600
2030	$24,100	$11,600	$35,700
2040	$27,100	$12,600	$39,800
2050	$30,500	$14,100	$44,600
NPV, 3%	$373,000	$177,000	$551,000
NPV, 7%	$165,000	$78,300	$243,000

Annual costs represent undiscounted values; net present values represent annual costs discounted to 2012.

3. Cost per Ton of Emissions Reduced

EPA has calculated the cost per ton of GHG reductions associated with the proposed GHG standards on a CO_2eq basis using the costs and the emissions reductions described in Section III.F. These values are presented in Table III–67 for cars, trucks and the combined fleet. The cost per metric ton of GHG emissions reductions has been calculated in the years 2020, 2030, 2040, and 2050 using the annual vehicle compliance costs and emission reductions for each of those years. The value in 2050 represents the long-term cost per ton of the emissions reduced. EPA has also calculated the cost per metric ton of GHG emission reductions including the savings associated with reduced fuel consumption (presented below in Section III.H.4). This latter calculation does not include the other benefits associated with this program such as those associated with energy security benefits as discussed later in Section III. By including the fuel savings, the cost per ton is generally less than $0 since the estimated value of fuel savings outweighs the program costs.

Table III-67 Annual Cost per Metric Ton of CO_2eq Reduced (2009 dollars)

	Calendar Year	Undiscounted Annual Costs ($millions)	Undiscounted Annual Pre-tax Fuel Savings ($millions)	Annual CO_2eq Reduction (mmt)	$/ton (w/o fuel savings)	$/ton (w/ fuel savings
Cars	2020	$6,120	$4,840	19	$318	$67
	2030	$24,100	$54,300	183	$132	-$165
	2040	$27,100	$91,200	284	$95	-$226
	2050	$30,500	$117,000	332	$92	-$260
Trucks	2020	$2,340	$2,340	10	$245	$0
	2030	$11,600	$34,000	114	$102	-$196
	2040	$12,600	$57,500	178	$71	-$252
	2050	$14,100	$76,000	215	$66	-$288
Combined	2020	$8,470	$7,180	29	$294	$45
	2030	$35,700	$88,300	297	$120	-$177
	2040	$39,800	$149,000	462	$86	-$236
	2050	$44,600	$193,000	547	$81	-$271

4. Reduction in Fuel Consumption and Its Impacts

a. What are the projected changes in fuel consumption?

The proposed CO_2 standards will result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles will see corresponding savings associated with reduced fuel expenditures. EPA has estimated the impacts on fuel consumption for both the tailpipe CO_2 standards and the A/C credit program. While gasoline consumption would decrease under the proposed GHG standards, electricity consumption would increase slightly due to the small penetration of EVs and PHEVs (1–3% for the 2021 and 2025 MYs). The fuel savings includes both the gasoline consumption reductions and the electricity consumption increases. Note that the total number of miles that vehicles are driven each year is different under the control case than in the reference case due to the ''rebound effect,'' which is discussed in Section III.H.4.c and in Chapter 4 of the draft joint TSD. EPA also notes that consumers who drive more than our average estimates for vehicle miles traveled (VMT) will experience more fuel savings; consumers who drive less than our average VMT estimates will experience less fuel savings.

The expected impacts on fuel consumption are shown in Table III–68. The gallons reduced and kilowatt hours increased (kWh) as shown in the tables reflect impacts from the proposed CO_2 standards, including the A/C credit program, and include increased consumption resulting from the rebound effect.

Table III-68 Fuel Consumption Impacts of the Proposed Standards and A/C Credit Programs

Calendar Year	Petroleum-based Gasoline Reference (million gallons)	Petroleum-based Gasoline Reduced (million gallons)	Electricity Increased (million kWh)[a]
2017	130,544	194	115
2018	129,503	641	345
2019	128,680	1,326	695
2020	128,229	2,277	1,177
2021	128,387	3,673	1,796
2022	128,599	5,424	2,952
2023	129,312	7,520	4,673
2024	130,087	9,919	6,980
2025	131,289	12,658	9,911
2030	140,602	25,581	24,298
2040	159,582	40,391	42,369
2050	184,136	47,883	51,123
Total	5,079,096	941,839	951,392

[a] Electricity increase by vehicles not by power plants.

b. What are the fuel savings to the consumer?

Using the fuel consumption estimates presented in Section III.H.4.a, EPA can calculate the monetized fuel savings associated with the proposed standards. To do this, we multiply reduced fuel consumption in each year by the corresponding estimated average fuel price in that year, using the reference case taken from the AEO 2011 Final Release.[530] These estimates do not

[530] In the Preface to AEO 2011, the Energy Information Administration describes the reference case. They state that, "Projections by EIA are not Continued

account for the significant uncertainty in future fuel prices; the monetized fuel savings would be understated if actual future fuel prices are higher (or overstated if fuel prices are lower) than estimated. AEO is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. This has been done using both the pre-tax and post-tax gasoline prices. Since the post-tax gasoline prices are the prices paid at fuel pumps, the fuel savings calculated using these prices represent the savings consumers would see. The pre-tax fuel savings are those savings that society would see. Assuming no change in gasoline tax rates, the difference between these two columns represents the reduction in fuel tax revenues that will be received by state and federal governments—about $82 million in 2017 and $17 billion by 2050. These results are shown in Table III–69. Note that in Section III.H.9, the overall benefits and costs of the proposal are presented and, for that reason, only the pre-tax fuel savings are presented there.

statements of what will happen but of what might happen, given the assumptions and methodologies used for any particular scenario. The Reference case projection is a business-as-usual trend estimate, given known technology and technological and demographic trends.

Table III-69 Undiscounted Annual Fuel Savings, & Proposed Program Fuel Savings Discounted back to 2012 (millions of 2009 dollars)

Calendar Year	Gasoline Savings (pre-tax)	Gasoline Savings (taxed)	Electricity Costs	Total Fuel Savings (pre-tax)	Total Fuel Savings (taxed)
2017	$581	$663	$11.1	$570	$652
2018	$1,950	$2,230	$32.8	$1,920	$2,200
2019	$4,120	$4,670	$66.0	$4,060	$4,600
2020	$7,180	$8,110	$113	$7,060	$7,990
2021	$11,600	$13,100	$172	$11,400	$12,900
2022	$17,400	$19,700	$286	$17,100	$19,400
2023	$24,400	$27,500	$458	$24,000	$27,000
2024	$32,700	$36,800	$691	$32,000	$36,100
2025	$42,400	$47,200	$1,000	$41,400	$46,200
2030	$88,300	$98,100	$2,550	$85,800	$95,600
2040	$149,000	$164,000	$4,850	$144,000	$159,000
2050	$193,000	$210,000	$6,350	$187,000	$204,000
NPV, 3%	$1,550,000	$1,720,000	$47,800	$1,510,000	$1,670,000
NPV, 7%	$596,000	$660,000	$17,800	$579,000	$642,000

Annual values represent undiscounted values; net present values represent annual costs discounted to 2012.

As shown in Table III–69, the agencies are projecting that consumers would realize very large fuel savings as a result of the proposed standards. As discussed further in the introductory paragraphs of Section III.H.1, it is a conundrum from an economic perspective that these large fuel savings have not been provided by automakers and purchased by consumers. A number of behavioral and market phenomena may lead to this disparity between the fuel economy that makes financial sense to consumers and the fuel economy they purchase. Regardless how consumers make their decisions on how much fuel economy to purchase, EPA expects that, in the aggregate, they will gain these fuel savings, which will provide actual money in consumers' pockets.

c. VMT Rebound Effect

The rebound effect refers to the increase in vehicle use that results if an increase in fuel efficiency lowers the cost per mile of driving. For this proposal, EPA is using an estimate of 10 percent for the rebound effect (*i.e.,* we assume a 10 percent decrease in fuel cost per mile from our proposed standards would result in a 1 percent increase in VMT).

As we discussed in the 2012–2016 rulemaking and in Chapter 4 of the Joint TSD, this value was not derived from a single point estimate from a particular study, but instead represents a reasonable compromise between the historical estimates and the projected future estimates. This value is consistent with the rebound estimate for the most recent time period analyzed in the Small and Van Dender 2007 paper,[531] and falls within the range of the larger body of historical work on the rebound effect.[532] Recent work by David Greene on the rebound effect for light-duty vehicles in the U.S. supports the hypothesis that the rebound effect is decreasing over time,[533] which could mean that rebound estimates based on recent time period data may be more reliable than historical estimates that are based on older time period data. New work by Hymel, Small, and Van Dender also supports the theory that the rebound effect is declining over time, although the Hymel et al. estimates are higher than the 2007 Small and Van Dender estimates.[534] Furthermore, by using an estimate of the future rebound effect, analysis by Small and Greene show that the rebound effect could be in the range of 5% or lower.[535]

Most studies that estimate the rebound effect use the fuel cost per mile of driving or gasoline prices as a surrogate for fuel efficiency. Recent work conducted by Kenneth Gillingham, however, provides suggestive evidence that consumers may be less responsive to changes in fuel efficiency than to changes in fuel prices.[536] While this research pertains specifically to California, this finding suggests that the common assumption that consumers respond similarly to changes in gasoline prices and changes in fuel efficiency may overstate the potential rebound effect. Additional research is needed in this area, and EPA requests comments and data on this topic.

Another factor discussed by Gillingham is whether consumers actually respond the same way to an increase in the cost of driving compared to a decrease in the cost of driving. There is some evidence in the literature that consumers are more responsive to an increase in prices than to a decrease in prices.[537] [538] [539] Furthermore, it is also possible that consumers respond more to a large shock than a small, gradual change in prices. Since these proposed standards would decrease the cost of driving gradually over time, it is possible that the rebound effect would be much smaller than some of the estimates included in the historical literature. More research in this area is also important, and EPA invites comment and data on this aspect of the rebound effect.

Finally, for purposes of analyzing the proposed standards, EPA assumes the rebound effect will be the same whether a consumer is driving a conventional gasoline vehicle or a vehicle powered by grid electricity. We are not aware of any research that has examined consumer responses to changes in the cost per mile of driving that result from driving an electric-powered vehicle instead of a conventional gasoline vehicle. EPA requests comment and data on this topic.

Chapter 4.2.5 of the Joint TSD reviews the relevant literature and discusses in more depth the reasoning for the rebound value used here. The rebound effect is also discussed in Section II.E of the preamble. While EPA has used a weight of evidence approach for determining that 10 percent is a reasonable value to use for the rebound effect, EPA requests comments on this and alternative methodologies for estimating the rebound effect over the period that our proposed standards would go into effect. EPA also invites the submission of new data regarding estimates of the rebound effect. We also discuss two approaches for modeling the rebound effect in Chapter 4 of the DRIA; we request comment on these modeling approaches.

5. CO_2 Emission Reduction Benefits

EPA has assigned a dollar value to reductions in CO_2 emissions using global estimates of the social cost of carbon (SCC). The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. The SCC estimates used in this analysis were developed through an interagency process that included EPA, DOT/NHTSA, and other executive branch entities, and concluded in February 2010. We first used these SCC estimates in the benefits analysis for the 2012–2016 light-duty GHG rulemaking; see 75 FR at 25520. We have continued to use these estimates in other rulemaking analyses, including the heavy-duty GHG rulemaking; see 76 FR at 57332. The SCC Technical Support Document (SCC TSD) provides a complete discussion of the methods used to develop these SCC estimates.[540]

[531] Small, K. and K. Van Dender, 2007. ''Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect'', The Energy Journal, vol. 28, no. 1, pp. 25–51 (Docket EPA–HQ–OAR–2010–0799).

[532] Sorrell, S. and J. Dimitropoulos, 2007. ''UKERC Review of Evidence for the Rebound Effect, Technical Report 2: Econometric Studies'', UKERC/WP/TPA/2007/010, UK Energy Research Centre, London, October (Docket EPA–HQ–OAR–2010–0799).

[533] Greene, David, ''Rebound 2007: Analysis of National Light-Duty Vehicle Travel Statistics,'' February 9, 2010 (Docket EPA–HQ–OAR–2010–0799). This paper has been accepted for an upcoming special issue of Energy Policy, although the publication date has not yet been determined.

[534] Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender, ''Induced demand and rebound effects in road transport,'' Transportation Research Part B: Methodological, Volume 44, Issue 10, December 2010, Pages 1220–1241, ISSN 0191–2615, DOI: 10.1016/j.trb.2010.02.007. (Docket EPA–HQ–OAR–2010–0799).

[535] Report by Kenneth A. Small of University of California at Irvine to EPA, ''The Rebound Effect from Fuel Efficiency Standards: Measurement and Projection to 2030'', June 12, 2009 (Docket EPA–HQ–OAR–2010–0799). See also Greene, 2010.

[536] Gillingham, Kenneth. ''The Consumer Response to Gasoline Price Changes: Empirical Evidence and Policy Implications.'' Ph.D. diss., Stanford University, 2011. (Docket EPA–HQ–OAR–2010–0799).

[537] Dargay, J.M., Gately, D., 1997. ''The demand for transportation fuels: imperfect price-reversibility?'' Transportation Research Part B 31(1). (Docket EPA–HQ–OAR–2010–0799).

[538] Dermot Gately, 1993. ''The Imperfect Price-Reversibility of World Oil Demand,'' The Energy Journal, International Association for Energy Economics, vol. 14(4), pages 163–182. (Docket EPA–HQ–OAR–2010–0799).

[539] Sentenac-Chemin, E. (2010) Is the price effect on fuel consumption symmetric? Some evidence from an empirical study, Energy Policy (2010), doi:10.1016/j.enpol.2010.07.016 (Docket EPA–HQ–OAR–2010–0799).

[540] Docket ID EPA–HQ–OAR–2010–0799, *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon,* with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy,

The interagency group selected four SCC values for use in regulatory analyses, which we have applied in this analysis: $5, $22, $36, and $67 per metric ton of CO_2 emissions in 2010, in 2009 dollars.[541] [542] The first three values are based on the average SCC from three integrated assessment models, at discount rates of 5, 3, and 2.5 percent, respectively. SCCs at several discount rates are included because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context. The fourth value is the 95th percentile of the SCC from all three models at a 3 percent discount rate. It is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. Low probability, high impact events are incorporated into all of the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages.

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that the interagency group estimated the growth rate of the SCC directly using the three integrated assessment models rather than assuming a constant annual growth rate. This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table III–70 presents the SCC estimates used in this analysis.

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) Future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages.[543] As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

The interagency group noted a number of limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes the interagency modeling exercise even more difficult. The interagency group hopes that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

Another limitation of the GHG benefits analysis in this proposed rule is that it does not monetize the impacts associated with the non-CO_2 GHG reductions expected under the proposed standards (in this case, nitrous oxides, methane, and hydorfluorocarbons). The interagency group did not estimate the social costs of non-CO_2 GHG emissions when it developed the current social cost of CO_2 values. EPA recently requested comment on a methodology to estimate the benefits associated with non-CO_2 GHG reductions under the proposed New Source Performance Standards (NSPS) for oil and gas exploration (76 FR at 52792). Referred to as the ''global warming potential (GWP) approach,'' the calculation uses the GWP of the non-CO_2 gas to estimate CO_2 equivalents and then multiplies these CO_2 equivalent emission reductions by the social cost of CO_2.

EPA presented and requested comment on the GWP approach in the NSPS proposal as an interim method to produce estimates of the social cost of methane until the Administration develops such values. Similarly, we request comments in this proposed rulemaking on using the GWPs as an interim approach and more broadly about appropriate methods to monetize the climate benefits of non-CO_2 GHG reductions.

In addition, the U.S. government intends to revise the SCC estimates, taking into account new research findings that were not included in the first round, and has set a preliminary goal of revisiting the SCC values in the next few years or at such time as substantially updated models become available, and to continue to support research in this area. In particular, DOE and EPA hosted a series of workshops to help motivate and inform this process.[544] The first workshop focused on conceptual and methodological issues related to integrated assessment modeling and valuing climate change impacts, along with methods of incorporating these estimates into policy analysis.

Applying the global SCC estimates, shown in Table III–70, to the estimated reductions in CO_2 emissions under the proposed standards, we estimate the dollar value of the GHG related benefits for each analysis year. For internal consistency, the annual benefits are discounted back to net present value terms using the same discount rate as each SCC estimate (*i.e.,* 5%, 3%, and 2.5%) rather than 3% and 7%.[545] These estimates are provided in Table III–71.

Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury (February 2010). Also available at *http://epa.gov/otaq/climate/regulations.htm*.

[541] The interagency group decided that these estimates apply only to CO_2 emissions. Given that warming profiles and impacts other than temperature change (e.g., ocean acidification) vary across GHGs, the group concluded ''transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases'' (SCC TSD, pg 13).

[542] The SCC estimates were converted from 2007 dollars to 2008 dollars using a GDP price deflator (1.021) and again to 2009 dollars using a GDP price deflator (1.009) obtained from the Bureau of Economic Analysis, National Income and Product Accounts Table 1.1.4, *Prices Indexes for Gross Domestic Product.*

[543] National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use.* National Academies Press. See docket ID EPA–HQ–OAR–2010–0799.

[544] *Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis,* held November 18–19, 2010 and January 27–28, 2011. Materials available at: *http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE–0564?OpenDocument* and *http://yosemite.epa.gov/ee/epa/eerm.nsf/vwRepNumLookup/EE–0566?OpenDocument.* See also Docket ID EPA–HQ–OAR–2010–0799.

[545] It is possible that other benefits or costs of final regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

Table III-70: Social Cost of CO_2, 2017 – 2050[a] (in 2009 dollars per Metric Ton)

YEAR	DISCOUNT RATE AND STATISTIC			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2017	$6.36	$25.59	$40.94	$78.28
2020	$7.01	$27.10	$42.98	$83.17
2025	$8.53	$30.43	$47.28	$93.11
2030	$10.05	$33.75	$51.58	$103.06
2035	$11.57	$37.08	$55.88	$113.00
2040	$13.09	$40.40	$60.19	$122.95
2045	$14.63	$43.34	$63.59	$131.66
2050	$16.18	$46.27	$66.99	$140.37

[a] The SCC values are dollar-year and emissions-year specific.

Table III-71: Undiscounted Annual Monetized CO_2 Benefits of Proposed Vehicle Program, Annual CO_2 Emission Reductions[a] & CO_2 Benefits Discounted back to 2012 (dollar values in Millions of 2009$)

YEAR	CO_2 EMISSIONS REDUCTION (MMT)	BENEFITS			
		Avg SCC at 5% ($6-$16)[a]	Avg SCC at 3% ($26-$46)[a]	Avg SCC at 2.5% ($41-$67)[a]	95th percentile SCC at 3% ($78-$140)[a]
2017	2.1	$13	$53	$85	$162
2018	6.9	$45	$179	$286	$549
2019	14.2	$97	$378	$602	$1,160
2020	24.4	$171	$662	$1,050	$2,030
2021	39.5	$289	$1,100	$1,730	$3,360
2022	58.1	$443	$1,650	$2,600	$5,060
2023	80.2	$635	$2,330	$3,650	$7,150
2024	105.3	$866	$3,130	$4,890	$9,600
2025	133.8	$1,140	$4,070	$6,320	$12,500
2030	267.8	$2,690	$9,040	$13,800	$27,600
2040	419.8	$5,490	$17,000	$25,300	$51,600
2050	497.3	$8,050	$23,000	$33,300	$69,800
Net Present Value[b]		$32,800	$172,000	$292,000	$522,000

Notes:

[a] Except for the last row (net present value), the SCC values are dollar-year and emissions-year specific.

[b] Net present value of reduced CO_2 emissions is calculated differently from other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

6. Non-Greenhouse Gas Health and Environmental Impacts

This section presents EPA's analysis of the non-GHG health and environmental impacts that can be expected to occur as a result of the proposed 2017–2025 light-duty vehicle GHG standards. CO_2 emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutants. The vehicles that are subject to the proposed standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The proposed standards would affect exhaust emissions of these pollutants from vehicles. They would also affect emissions from upstream sources related to changes in fuel consumption. Changes in ambient ozone, $PM_{2.5}$, and air toxics that would result from the proposed standards are expected to affect human health in the form of premature deaths and other serious human health effects, as well as other important public health and welfare effects.

It is important to quantify the health and environmental impacts associated with the proposed standard because a failure to adequately consider these ancillary co-pollutant impacts could lead to an incorrect assessment of their net costs and benefits. Moreover, co-pollutant impacts tend to accrue in the near term, while any effects from reduced climate change mostly accrue over a time frame of several decades or longer.

EPA typically quantifies and monetizes the health and environmental impacts related to both PM and ozone in its regulatory impact analyses (RIAs) when possible. However, EPA was unable to do so in time for this proposal. EPA attempts to make emissions and air quality modeling decisions early in the analytical process so that we can complete the photochemical air quality modeling and use that data to inform the health and environmental impacts analysis. Resource and time constraints precluded the Agency from completing this work in time for the proposal. Instead, EPA is using PM-related benefits-per-ton values as an interim approach to estimating the PM-related benefits of the proposal. EPA also provides a characterization of the health and environmental impacts that will be quantified and monetized for the final rulemaking.

This section is split into two sub-sections: The first presents the PM-related benefits-per-ton values used to monetize the PM-related co-benefits associated with the proposal; the second explains what PM- and ozone-related health and environmental impacts EPA will quantify and monetize in the analysis for the final rule. EPA bases its analyses on peer-reviewed studies of air quality and health and welfare effects and peer-reviewed studies of the monetary values of public health and welfare improvements, and is generally consistent with benefits analyses performed for the analysis of the final Cross-State Air Pollution Rule,[546] the final 2014–2018 MY Heavy-Duty Vehicle Greenhouse Gas Rule,[547] and the final Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA.[548]

Though EPA is characterizing the changes in emissions associated with toxic pollutants, we will not be able to quantify or monetize the human health effects associated with air toxic pollutants for either the proposal or the final rule analyses. Please refer to Section III.G for more information about the air toxics emissions impacts associated with the proposed standards.

a. Economic Value of Reductions in Criteria Pollutants

As described in Section III.G, the proposed standards would reduce emissions of several criteria and toxic pollutants and precursors. In this analysis, EPA estimates the economic value of the human health benefits associated with reducing $PM_{2.5}$ exposure. Due to analytical limitations, this analysis does not estimate benefits related to other criteria pollutants (such as ozone, NO_2 or SO_2) or toxic pollutants, nor does it monetize all of the potential health and welfare effects associated with $PM_{2.5}$.

This analysis uses a ''benefit-per-ton'' method to estimate a selected suite of $PM_{2.5}$-related health benefits described below. These $PM_{2.5}$ benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of directly emitted $PM_{2.5}$, or its precursors (such as NO_X, SO_X, and VOCs), from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ as determined by full-scale air quality modeling. However, this modeling was not possible in the timeframe for this proposal.

The dollar-per-ton estimates used in this analysis are provided in Table III–72. In the summary of costs and benefits, Section III.H.9 of this preamble, EPA presents the monetized value of PM-related improvements associated with the proposal.

[546] Final Cross-State Air Pollution Rule. (76 FR 48208, August 8, 2011).

[547] U.S. Environmental Protection Agency. (2011). *Final Rulemaking to Establish Heavy-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Regulatory Impact Analysis,* Assessment and Standards Division, Office of Transportation and Air Quality, EPA–420–R–10–009, July 2011. Available on the internet: *http://www.epa.gov/otaq/climate/regulations/420r10009.pdf.*

[548] U.S. Environmental Protection Agency (U.S. EPA). 2010. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Augues. Available on the Internet at < *http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf* >. EPA–HQ–OAR–2009–0472–0241.

Table III-72 Benefits-per-ton Values (2009$) Derived Using the American Cancer Society Cohort Study for PM-related Premature Mortality (Pope et al., 2002)[a]

Year[c]	All Sources[d]		Stationary (Non-EGU) Sources[e]		Mobile Sources	
	SO_X	VOC	NO_X	Direct PM2.5	NO_X	Direct PM2.5
Estimated Using a 3 Percent Discount Rate[b]						
2015	$29,000	$1,200	$4,800	$230,000	$5,000	$280,000
2020	$32,000	$1,300	$5,300	$250,000	$5,500	$300,000
2030	$38,000	$1,600	$6,300	$290,000	$6,600	$360,000
2040	$44,000	$1,900	$7,500	$340,000	$7,900	$430,000
Estimated Using a 7 Percent Discount Rate[b]						
2015	$27,000	$1,100	$4,400	$210,000	$4,600	$250,000
2020	$29,000	$1,200	$4,800	$220,000	$5,000	$280,000
2030	$34,000	$1,400	$5,700	$260,000	$6,000	$330,000
2040	$40,000	$1,700	$6,800	$310,000	$7,200	$390,000

[a] The benefit-per-ton estimates presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six-Cities study (Laden et al., 2006), the values would be approximately two-and-a-half times larger. See below for a description of these studies.

[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.

[c] Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For intermediate years, such as 2017 (the year the standards begin), we interpolated exponentially. For years beyond 2030 (including 2040), EPA and NHTSA extrapolated exponentially based on the growth between 2020 and 2030.

[d] Note that the benefit-per-ton value for SOx is based on the value for Stationary (Non-EGU) sources; no SOx value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.

[e] Non-EGU denotes stationary sources of emissions other than electric generating units.

[a] The benefit-per-ton estimates presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six-Cities study (Laden et al., 2006), the values would be approximately two-and-a-half times larger. See below for a description of these studies.

[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.

[c] Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For intermediate years, such as 2017 (the year the standards begin), we

Continued

The benefit per-ton technique has been used in previous analyses, including EPA's 2012–2016 Light-Duty Vehicle Greenhouse Gas Rule,[549 550] and the Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA.[551] Table III–73 shows the quantified and unquantified $PM_{2.5}$-related co-benefits captured in those benefit-per-ton estimates.

Table III-73 Human Health and Welfare Effects of $PM_{2.5}$

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Unquantified Effects Changes in:
$PM_{2.5}$	Adult premature mortality Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

Consistent with the cost-benefit analysis that accompanied the NO_2 NAAQS,[552 553] the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as chronic bronchitis and a number of respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates.

A more detailed description of the benefit-per-ton estimates is provided in Chapter 4 of the Draft Joint TSD that accompanies this rulemaking. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support

interpolated exponentially. For years beyond 2030 (including 2040), EPA and NHTSA extrapolated exponentially based on the growth between 2020 and 2030.

[d] Note that the benefit-per-ton value for SOx is based on the value for Stationary (Non-EGU) sources; no SOx value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.

[e] Non-EGU denotes stationary sources of emissions other than electric generating units.

[549] U.S. Environmental Protection Agency (U.S. EPA), 2010. Regulatory Impact Analysis, Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Office of Transportation and Air Quality. April. Available at *http://www.epa.gov/otaq/climate/regulations/420r10009.pdf*. EPA-420-R-10-009.

[550] U.S. Environmental Protection Agency (U.S. EPA). 2008. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at *http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf*.

[551] U.S. Environmental Protection Agency (U.S. EPA). 2010. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Augues. Available on the Internet at < *http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf*. EPA-HQ-OAR-2009-0472-0241

[552] Although we summarize the main issues in this chapter, we encourage interested readers to see benefits chapter of the RIA that accompanied the NO_2 NAAQS for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model. Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the NO_2 NAAQS.

[553] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final NO_2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at *http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf*. Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0237 U.S. Environmental Protection Agency (U.S. EPA). 2009.

Document (TSD)[554] accompanying the recent final ozone NAAQS RIA (U.S. EPA, 2008).[555] Readers can also refer to Fann et al. (2009)[556] for a detailed description of the benefit-per-ton methodology.[557]

As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (*e.g.,* NO_2 emitted from mobile sources; direct PM emitted from stationary sources). Our estimate of $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and PM-related precursor emissions controlled by sector and multiplied by each per-ton value.

As Table III–72 indicates, EPA projects that the per-ton values for reducing emissions of non-GHG pollutants from both vehicle use and stationary sources such as fuel refineries and storage facilities will increase over time.[558] These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution.[559] They also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially in older age groups with the highest mortality risk.[560]

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties:

They do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates. EPA will conduct full-scale air quality modeling for the final rulemaking in an effort to capture this variability.

This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.

This analysis assumes that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.

There are several health benefits categories that EPA was unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because the NO_X and VOC emission reductions associated with this proposal are also precursors to ozone, reductions in NO_X and VOC would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, ozone-related benefits-per-ton estimates do not exist due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits. Please refer to Chapter 6.3 of the DRIA that accompanies this proposal for a description of the agecy's plan to quantify and monetize the PM- and ozone-related health impacts for the FRM and a description of the unquantified co-pollutant benefits associated with this rulemaking.

There are many uncertainties associated with the health impact functions used in this modeling effort. These include: Within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the concentration-response function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.

EPA has investigated methods to characterize uncertainty in the relationship between $PM_{2.5}$ exposure and premature mortality. EPA's final $PM_{2.5}$ NAAQS analysis provides a more complete picture about the overall uncertainty in $PM_{2.5}$ benefits estimates. For more information, please consult the $PM_{2.5}$ NAAQS RIA (Table 5.5).[561]

The benefit-per-ton estimates used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines and incomes, technology. These projections introduce some uncertainties to the benefit per ton estimates.

As described above, using the benefit-per-ton value derived from the ACS study (Pope et al., 2002) alone provides an incomplete characterization of $PM_{2.5}$ benefits. When placed in the

[554] U.S. Environmental Protection Agency (U.S. EPA). 2008. Technical Support Document: Calculating Benefit Per-Ton Estimates, Ozone NAAQS Docket #EPA–HQ–OAR–2007–0225–0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at <*http://www.regulations.gov*>.

[555] U.S. Environmental Protection Agency (U.S. EPA). 2008. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at <*http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf*>. Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the Ozone NAAQS.

[556] Fann, N. et al. (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health. Published online: 09 June, 2009.

[557] The values included in this report are different from those presented in the article cited above. Benefits methods change to reflect new information and evaluation of the science. Since publication of the June 2009 article, EPA has made two significant changes to its benefits methods: (1) We no longer assume that a threshold exists in PM-related models of health impacts; and (2) We have revised the Value of a Statistical Life to equal $6.3 million (year 2000$), up from an estimate of $5.5 million (year 2000$) used in the June 2009 report. Please refer to the following Web site for updates to the dollar-per-ton estimates: *http://www.epa.gov/air/benmap/bpt.html*.

[558] As we discuss in the emissions chapter of EPA's DRIA (Chapter 4), the rule would yield emission reductions from upstream refining and fuel distribution due to decreased petroleum consumption.

[559] The issue is discussed in more detail in the PM NAAQS RIA from 2006. See U.S. Environmental Protection Agency. 2006. Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation. October 2006. Available at *http://www.epa.gov/ttn/ecas/ria.html*.

[560] For more information about EPA's population projections, please refer to the following: *http://www.epa.gov/air/benmap/models/BenMAPManualAppendicesAugust2010.pdf* (See Appendix K).

[561] U.S. Environmental Protection Agency. October 2006. Final Regulatory Impact Analysis (RIA) for the Final National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation.

context of the Expert Elicitation results, this estimate falls toward the lower end of the distribution. By contrast, the estimated $PM_{2.5}$ benefits using the coefficient reported by Laden in that author's reanalysis of the Harvard Six Cities cohort fall toward the upper end of the Expert Elicitation distribution results.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as there may be localized impacts associated with the proposed rulemaking. Additionally, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. As discussed above, timing and resource constraints precluded EPA from conducting a full-scale photochemical air quality modeling analysis in time for the NPRM. For the final rule, however, a national-scale air quality modeling analysis will be performed to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics. The benefits analysis plan for the final rulemaking is discussed in the next section.

b. Human Health and Environmental Benefits for the Final Rule

i. Human Health and Environmental Impacts

To model the ozone and PM air quality benefits of the final rule, EPA will use the Community Multiscale Air Quality (CMAQ) model (see Section III.G.5. for a description of the CMAQ model). The modeled ambient air quality data will serve as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[562] BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIAs (*e.g.,* interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

Chapter 6.3 in the DRIA that accompanies this proposal lists the co-pollutant health effect concentration-response functions EPA will use to quantify the non-GHG incidence impacts associated with the final light-duty vehicles standard. These include PM- and ozone-related premature mortality, chronic bronchitis, nonfatal heart attacks, hospital admissions (respiratory and cardiovascular), emergency room visits, acute bronchitis, minor restricted activity days, and days of work and school lost.

ii. Monetized Impacts

To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as chronic bronchitis and a number of respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates. Chapter 6.3 in the DRIA that accompanies this proposal presents the monetary values EPA will apply to changes in the incidence of health and welfare effects associated with reductions in non-GHG pollutants that will occur when these GHG control strategies are finalized.

iii. Other Unquantified Health and Environmental Impacts

In addition to the co-pollutant health and environmental impacts EPA will quantify for the analysis of the final standard, there are a number of other health and human welfare endpoints that EPA will not be able to quantify or monetize because of current limitations in the methods or available data. These impacts are associated with emissions of air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and ethanol), ambient ozone, and ambient $PM_{2.5}$ exposures. Chapter 6.3 of the DRIA lists these unquantified health and environmental impacts.

While there will be impacts associated with air toxic pollutant emission changes that result from the final standard, EPA will not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[563] While EPA has since improved the tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics. EPA continues to work to address these limitations; however, EPA does not anticipate having methods and tools available for national-scale application in time for the analysis of the final rules.[564]

7. Energy Security Impacts

The proposed GHG standards require improvements in light-duty vehicle fuel efficiency which, in turn, will reduce overall fuel consumption and help to reduce U.S. petroleum imports. Reducing U.S. petroleum imports lowers both the financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. The economic value of reductions in these risks provides a measure of improved U.S. energy security. This section summarizes EPA's estimates of U.S. oil import reductions and energy security benefits from this proposal. Additional discussion of this issue can be found in Chapter 4.2.8 of the Joint TSD.

a. Implications of Reduced Petroleum Use on U.S. Imports

In 2010, U.S. petroleum import expenditures represented 14 percent of total U.S. imports of all goods and services.[565] These expenditures rose to 18 percent by April of 2011.[566] In 2010, the United States imported 49 percent of the petroleum it consumed,[567] and the

[562] Information on BenMAP, including downloads of the software, can be found at *http://www.epa.gov/ttn/ecas/benmodels.html*.

[563] Science Advisory Board. 2001. NATA—Evaluating the National-Scale Air Toxics Assessment for 1996—an SAB Advisory. *http://www.epa.gov/ttn/atw/sab/sabrev.html*.

[564] In April, 2009, EPA hosted a workshop on estimating the benefits of reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit *http://epa.gov/air/toxicair/2009workshop.html* for more information about the workshop and its associated materials.

[565] *http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WTTIMUS2&f=W.*

[566] *http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbblpd_a.htm.*

[567] *http://www.eia.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm.*

transportation sector accounted for 71 percent of total U.S. petroleum consumption. This compares to approximately 37 percent of total U.S. petroleum supplied by imports and 55 percent of U.S. petroleum consumption in the transportation sector in 1975.[568]

Requiring vehicle technology that reduces GHGs and fuel consumption in light-duty vehicles is expected to lower U.S. oil imports. EPA's estimates of reductions in fuel consumption resulting from the proposed standards are discussed in Section III.H.3 above, and in EPA's draft RIA.[569]

The agencies conducted a detailed analysis of future changes in U.S. transportation fuel consumption, petroleum imports, and domestic fuel refining projected to occur under alternative economic growth and oil price scenarios reported by the EIA in its Annual Energy Outlook 2011.[570] On the basis of this analysis, we estimate that approximately 50 percent of the reduction in fuel consumption resulting from adopting improved GHG emission and fuel efficiency standards is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent is expected to be reflected in reduced domestic fuel refining. Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum. Thus, on balance, each gallon of fuel saved as a consequence of the GHG and fuel efficiency standards is anticipated to reduce total U.S. imports of petroleum by 0.95 gallon.[571] Table III–74 below compares EPA's estimates of the reduction in imports of U.S. crude oil and petroleum-based products from this program to projected total U.S. imports for selected years.

Table III-74 Projected Import Reductions from this Proposal and Total U.S. Petroleum-Based Imports for Selected Years

(Millions of Barrels per Day, mmbd)

Year	U.S. Petroleum-Based Import Reductions from the Proposal (mmbd)	U.S. Total Petroleum-Based Imports without the Proposal (mmbb)
2020	0.141	9.26
2030	1.59	8.94
2040	2.50	NA
2050	2.97	NA

Note: NA –Not available, (forecasts reported in EIA's Annual Energy Outlook 2011 extend only to 2035)

b. Energy Security Implications

In order to understand the energy security implications of reducing U.S. petroleum imports, EPA worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the economic costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled, *The Energy Security Benefits of Reduced Oil Use, 2006–2015,* completed in March 2008. This study is included as part of the docket for this proposal.[572] [573]

[568] Source: U.S. Department of Energy, Annual Energy Review 2008, Report No. DOE/EIA–0384(2008), Tables 5.1 and 5.13c, June 26, 2009.

[569] Due to timing constraints, the energy security premiums ($/gallon) were derived using preliminary estimates of the gasoline consumption reductions projected from this proposal. The energy security benefits totals shown here were calculated with those $/gallon values along with the final quantities of gasoline consumption avoided. Relative to the preliminary gasoline consumption reductions, the reductions presented in this proposal are roughly 3% lower in total from 2017 through 2050.

[570] Energy Information Administration, Annual Energy Outlook 2011, Reference Case and other scenarios, available at *http://www.eia.gov/oiaf/aeo/tablebrowser/* (last accessed October 12, 2011).

[571] This figure is calculated as 0.50 + 0.50*0.9 = 0.50 + 0.45 = 0.95.

[572] Leiby, Paul N., *Estimating the Energy Security Benefits of Reduced U.S. Oil Imports,* Oak Ridge National Laboratory, ORNL/TM–2007/028, Final Report, 2008. (Docket EPA–HQ–OAR–2010–0162)

[573] The ORNL study *The Energy Security Benefits of Reduced Oil Use, 2006–2015,* completed in March 2008, is an updated version of the approach

Continued

When conducting its analysis, ORNL considered the full economic cost of importing petroleum into the United States. The economic cost of importing petroleum into the U.S. is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs for oil imports resulting from the effect of increasing U.S. import demand on the world oil price and on the market power of the Organization of the Petroleum Exporting Countries (*i.e.,* the ''demand'' or ''monopsony'' costs); and (2) the risk of reductions in U.S. economic output and disruption of the U.S. economy caused by sudden disruptions in the supply of imported petroleum to the U.S. (*i.e.,* ''macroeconomic disruption/adjustment costs''). In its analysis of energy security benefits from reducing U.S. petroleum imports, however, the agencies included only the latter component (discussed below).

ORNL's analysis of energy security benefits from reducing U.S. oil imports did not include an estimate of potential reductions in costs for maintaining a U.S. military presence to help secure stable oil supply from potentially vulnerable regions of the world because attributing military spending to particular missions or activities is difficult. Attempts to attribute some share of U.S. military costs to oil imports are further complicated by the need to estimate how those costs vary with incremental variations in U.S. oil imports. Several commenters for the 2012–2016 light-duty vehicle proposal recommended that the agencies attempt to estimate the avoided U.S. military costs associated with reductions in U.S. oil imports. The agencies request comment on this issue, including whether there are new studies that credibly estimate the military cost of securing stable oil supplies and, if so, how should these new estimates be factored into this proposal's energy security analysis. See Section 4.2.8 of the TSD for a more detailed discussion of the national security implications of this proposed rule.

For this action, ORNL estimated energy security premiums by incorporating the most recently available AEO 2011 Reference Case oil price forecasts and market trends. Energy security premiums for the years 2020, 2030, 2035, 2040 and 2050 are presented in Table III–75 as well as a breakdown of the components of the energy security premiums for each of these years.[574] The components of the energy security premium and their values are discussed in detail in the Joint TSD Chapter 4.2.8. The oil security premium rises over the future as a result of changing factors such as the world oil price, global supply/demand balances, U.S. oil imports and consumption, and U.S. GDP (the size of economy at risk to oil shocks). The principal factor is steadily rising oil prices.

used for estimating the energy security benefits of U.S. oil import reductions developed in an ORNL 1997 Report by Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, entitled *Oil Imports: An Assessment of Benefits and Costs.* (Docket EPA–HQ–OAR–2010–0162).

[574] AEO 2011 forecasts energy market trends and values only to 2035. The energy security premium estimates post-2035 were assumed to be the 2035 estimate.

Table III-75 Energy Security Premiums in Selected Years (2009$/Barrel)

Year (range)	Monopsony	Macroeconomic Disruption/Adjustment Costs	Total Mid-Point
2020	$11.12 ($3.78 - $21.21)	$7.10 ($3.40 - $10.96)	$18.22 ($9.53 - $29.06)
2030	$10.91 ($3.74 - $20.47)	$8.32 ($4.09 – $13.34)	$19.23 ($10.51 - $29.02)
2035	$10.11 ($3.51 - $18.85)	$8.60 ($4.41 - $13.62)	$18.71 ($10.30 – $28.20)
2040	$10.11 ($3.51 - $18.85)	$8.60 ($4.41 - $13.62)	$18.71 ($10.30 – $28.20)
2050	$10.11 ($3.51 - $18.85)	$8.60 ($4.41 - $13.62)	$18.71 ($10.30 – $28.20)

Note: Values in parentheses represent a 90% confidence interval around the central value.

The literature on energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global social cost of carbon (SCC) value, the question arises: How should the energy security premium be determined when a global perspective is taken? Monopsony benefits represent avoided payments by the United States to oil producers in foreign countries that result from a decrease in the world oil price as the U.S. decreases its consumption of imported oil.

Although there is clearly a benefit to the U.S. when considered from a domestic perspective, the decrease in price due to decreased demand in the U.S. also represents a loss to other countries. Given the redistributive nature of this monopsony effect from a global perspective, it is excluded in the energy security benefits calculations for this proposal. In contrast, the other portion of the energy security premium, the U.S. macroeconomic disruption and adjustment cost that arises from U.S. petroleum imports, does not have offsetting impacts outside of the U.S., and, thus, is included in the energy security benefits estimated for this proposal. To summarize, EPA has included only the macroeconomic disruption portion of the energy security benefits to estimate the monetary value of the total energy security benefits of this program.

For this proposal, using EPA's fuel consumption analysis in conjunction with ORNL's energy security premium estimates,[575] [576] the agencies developed estimates of the total energy security benefits for the years 2017 through 2050 as shown in Table III–76.[577]

[575] AEO 2011 forecasts energy market trends and values only to 2035. The energy security premium estimates post-2035 were assumed to be the 2035 estimate.

[576] Due to timing constraints, the energy security premiums ($/gallon) were derived using preliminary estimates of the gasoline consumption reductions projected from this proposal. The energy security benefits totals shown here were calculated with those $/gallon values along with the final quantities of gasoline consumption avoided. Relative to the preliminary gasoline consumption reductions, the reductions presented in this proposal are roughly 3% lower in total from 2017 through 2050.

[577] Estimated reductions in U.S. imports of finished petroleum products and crude oil are 95% of 54.2 million barrels (MMB) in 2020, 609 MMB

Continued

Table III-76. Undiscounted Annual Energy Security Benefits, & Proposed Program Benefits Discounted back to 2012 (2009$)

Year	Oil Imports Reduced (mmb)	Benefits ($Millions)
2017	4.4	$30
2018	14.5	$99
2019	30.0	$209
2020	51.5	$366
2021	83.1	$601
2022	123	$903
2023	170	$1,270
2024	224	$1,710
2025	286	$2,220
2030	579	$4,810
2040	914	$7,860
2050	1,083	$9,310
NPV, 3%		$81,500
NPV, 7%		$31,500

Note: Annual values represent undiscounted benefits; net present values represent annual costs discounted to 2012.

The energy security analysis conducted for this proposal estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products, particularly outside the U.S. In addition, other fuels could be displaced from the increasing use of oil worldwide. For example, if a decline in the world oil price causes an increase in oil use in China, India, or another country's industrial sector, this increase in oil consumption may displace natural gas usage. Alternatively, the increased oil use could result in a decrease in coal used to produce electricity. An increase in the consumption of petroleum products, particularly outside the U.S., could lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. However, lower usage of, for example, displaced coal would result in a decrease in greenhouse gas emissions. Therefore, any assessment of the impacts on GHG emissions from a potential increase in world oil demand would need to take into account the impacts on all portions of the global energy sector. The agencies' analyses have not attempted to estimate these effects.

in 2030, 962 MMB in 2040, and 1,140 MMB in 2050.

Since EPA anticipates that more electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) will penetrate the U.S. automobile market over time as a result of this proposal, the Agency is considering analyzing the energy security implications of these vehicles and the fuels that they consume. These vehicles run on electricity either in whole (EVs), or in part (PHEVs), which displaces conventional transportation fuel such as gasoline and diesel. EPA does not have sufficient information for this proposal to conduct an analysis of the energy security implications of increased use of EVs/PHEVs, but is considering how to conduct this type of analysis in the future. The Agency recognizes that the fleet penetration of EV/PHEV's will be relatively small in the time period of these standards (fewer than 3% of new vehicles in 2025), but views establishing a framework for examining the energy security implications of these vehicles as important for longer-term analysis.

Key questions that arise with increased use of electricity in vehicles in the U.S. include whether there is the potential for disruptions in electricity supply in general, or more specifically, from increased electrification of the U.S. vehicle fleet. Also, if there is the potential for supply disruptions in electricity markets, how likely would the disruptions be associated with disruptions in the supply of oil? In addition, what is the overall expected impact, if any, of additional EV/PHEV use on the stability and flexibility of fuel and electricity markets? Finally, such analysis may also need to consider the source of electricity used to power EVs/PHEVs. EPA solicits comments on how to best conduct this type of analysis, including any studies or research that have been published on these issues.

8. Additional Impacts

There are other impacts associated with the CO_2 emissions standards and associated reduced fuel consumption that vary with miles driven. Lower fuel consumption would, presumably, result in fewer trips to the filling station to refuel and, thus, time saved. The rebound effect, discussed in detail in Section III.H.4.c, produces additional benefits to vehicle owners in the form of consumer surplus from the increase in vehicle-miles driven, but may also increase the societal costs associated with traffic congestion, motor vehicle crashes, and noise. These effects are likely to be relatively small in comparison to the value of fuel saved as a result of the standards, but they are nevertheless important to include. Table III–77 summarizes the other economic impacts. Please refer to Preamble Section II.E and the Joint TSD that accompanies this rule for more information about these impacts and how EPA and NHTSA use them in their analyses.

Table III-77 Additional Impacts Associated with the Light-Duty Vehicle GHG Program

($Millions of 2007 dollars)

	2017	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Accidents, Noise, Congestion Costs[a]	$66	$844	$9,960	$16,900	$22,000	$176,000	$67,700
Benefits of Increased Driving[b]	$89	$1,090	$12,900	$23,600	$33,600	$244,000	$92,100
Benefits of Less Frequent Refueling	$25	$301	$3,780	$6,650	$8,800	$68,700	$26,200

[a] Note that accidents, congestion and noise are costs, so the positive values shown represent increased costs which we treat as negative benefits.

[b] Calculated using post-tax fuel prices.

9. Summary of Costs and Benefits

In this section, the agencies present a summary of costs, benefits, and net benefits of the proposed program. Table III–78 shows the estimated annual monetized costs of the proposed program for the indicated calendar years. The table also shows the net present values of those costs for the calendar years 2012–2050 using both 3 percent and 7 percent discount rates.[578] Table III–79 shows the undiscounted annual monetized fuel savings of the proposed program. The table also shows the net present values of those fuel savings for the same calendar years using both 3 percent and 7 percent discount rates. In this table, the aggregate value of fuel savings is calculated using pre-tax fuel prices since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel. Note that the fuel savings shown here result from reductions in fleet-wide fuel use. Thus, fuel savings grow over time as an increasing fraction of the fleet meets the proposed standards.

[578] For the estimation of the stream of costs and benefits, we assume that after implementation of the proposed MY 2017–2025 standards, the 2025 standards apply to each year thereafter.

Table III-78 Undiscounted Annual Costs & Costs of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)[a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Technology Costs	$2,300	$8,470	$35,700	$39,800	$44,600	$551,000	$243,000

Note:

[a] Technology costs for separate light-duty vehicle segments can be found in Section III.H.2. Annual costs shown are undiscounted values.

Table III-79 Undiscounted Annual Fuel Savings & Proposed Program Fuel Savings Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)[a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Fuel Savings (pre-tax)	$570	$7,060	$85,800	$144,000	$187,000	$1,510,000	$579,000

Note:

[a] Fuel savings for separate light-duty vehicle segments can be found in Section III.H.3. Annual costs shown are undiscounted values.

Table III–80 presents estimated annual monetized benefits for the indicated calendar years. The table also shows the net present values of those benefits for the calendar years 2012–2050 using both 3 percent and 7 percent discount rates. The table shows the benefits of reduced CO_2 emissions—and consequently the annual quantified benefits (*i.e.*, total benefits)—for each of the four social cost of carbon (SCC) values estimated by the interagency working group. As discussed in the RIA Chapter 7.2, there are some limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

In addition, these monetized GHG benefits exclude the value of net reductions in non-CO_2 GHG emissions (CH_4, N_2O, HFC) expected under this action. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero. Rather, the net reductions in non-CO_2 GHGs will contribute to this program's climate benefits, as explained in Section III.H.5.

Table III-80 Monetized Undiscounted Annual Benefits & Benefits of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate[a]	NPV, Years 2012-2050, 7% Discount Rate[a]
Reduced CO_2 Emissions at each assumed SCC value[b]							
5% (avg SCC)	$13	$171	$2,690	$5,490	$8,050	$32,800	$32,800
3% (avg SCC)	$53	$662	$9,040	$17,000	$23,000	$172,000	$172,000
2.5% (avg SCC)	$85	$1,050	$13,800	$25,300	$33,300	$292,000	$292,000
3% (95th %ile)	$162	$2,030	$27,600	$51,600	$69,800	$522,000	$522,000
Energy Security Benefits (macro-disruption costs)	$30	$366	$4,810	$7,860	$9,310	$81,500	$31,500
Accidents, Congestion, Noise Costs[g]	$66	$844	$9,960	$16,900	$22,000	$176,000	$67,700
Increased Travel Benefits	$89	$1,090	$12,900	$23,600	$33,600	$244,000	$92,100
Refueling Time Savings	$25	$301	$3,780	$6,650	$8,800	$68,700	$26,200
$PM_{2.5}$ Related Impacts[c,d,e]	$11	$150	$1,360	$2,190	$2,970	$23,800	$9,280
Non-CO_2 GHG Impacts[f]		n/a	n/a	n/a	n/a	n/a	n/a
Total Annual Benefits at each assumed SCC value[b]							
5% (avg SCC)	$101	$1,240	$15,600	$29,000	$40,700	$275,000	$124,000
3% (avg SCC)	$141	$1,730	$22,000	$40,400	$55,600	$413,000	$263,000

2.5% (avg SCC)	$173	$2,120	$26,700	$48,700	$65,900	$534,000	$384,000
3% (95th %ile)	$250	$3,100	$40,500	$75,100	$102,00 0	$764,000	$614,000

Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail. Annual costs shown are undiscounted values.

[b] Section III.H.5 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140.

[c] Note that the co-pollutant impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.

[d] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger.

[e] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.

[f] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this program (*See* DRIA Chapter 7.1). Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO_2 GHG benefits in Section III.H.5.

[g] Positive values for Accidents, Congestion, and Noise costs represent an increase in costs. Therefore, they are treated as negative values when calculating the total benefits.

Table III–81 presents estimated annual net benefits for the indicated calendar years. The table also shows the net present values of those net benefits for the calendar years 2012–2050 using both 3 percent and 7 percent discount rates. The table includes the benefits of reduced CO_2 emissions (and consequently the annual net benefits) for each of the four SCC values considered by EPA.

Table III-81 Undiscounted Annual Monetized Net Benefits & Net Benefits of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)

	2017	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Technology Costs	$2,300	$8,470	$35,700	$39,800	$44,600	$551,000	$243,000
Fuel Savings	$570	$7,060	$85,800	$144,000	$187,000	$1,510,000	$579,000
Total Annual Benefits at each assumed SCC value[b]							
5% (avg SCC)	$101	$1,240	$15,600	$29,000	$40,700	$275,000	$124,000
3% (avg SCC)	$141	$1,730	$22,000	$40,400	$55,600	$413,000	$263,000
2.5% (avg SCC)	$173	$2,120	$26,700	$48,700	$65,900	$534,000	$384,000
3% (95th %ile)	$250	$3,100	$40,500	$75,100	$102,000	$764,000	$614,000
Monetized Net Benefits at each assumed SCC value[c]							
5% (avg SCC)	-$1,630	-$166	$65,600	$133,000	$183,000	$1,230,000	$460,000
3% (avg SCC)	-$1,590	$325	$72,000	$144,000	$198,000	$1,370,000	$599,000
2.5% (avg SCC)	-$1,560	$712	$76,800	$153,000	$208,000	$1,490,000	$719,000
3% (95th %ile)	-$1,480	$1,690	$90,500	$179,000	$244,000	$1,720,000	$950,000

Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail. Annual costs shown are undiscounted values.

[b] Section VIII.H.5 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140 Section VIII.H.5 also presents these SCC estimates.

[c] Net Benefits equal Fuel Savings minus Technology Costs plus Benefits.

EPA also conducted a separate analysis of the total benefits over the model year lifetimes of the 2017 through 2025 model year vehicles. In contrast to the calendar year analysis presented above in Table III–78 through Table III–81, the model year lifetime analysis below shows the impacts of the proposed program on vehicles produced during each of the model years 2017 through 2025 over the course of their expected lifetimes. The net societal benefits over the full lifetimes of vehicles produced during each of the nine model years from 2017 through 2025 are shown in Table III–82 and Table III–83 at both 3 percent and 7 percent discount rates, respectively.

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Table III-82 Monetized Technology Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2009$; 3% Discount Rate)[h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Technology Costs	$2,270	$4,590	$6,410	$8,340	$11,700	$19,100	$24,700	$30,300	$33,100	$140,000
Fuel Savings (pre-tax)	$6,060	$14,300	$22,400	$31,800	$47,300	$61,000	$73,700	$87,000	$100,000	$444,000
Energy Security Benefits (macro-disruption costs)	$322	$763	$1,200	$1,710	$2,550	$3,310	$4,030	$4,790	$5,560	$24,200
Accidents, Congestion, Noise Costs [f]	$721	$1,740	$2,740	$3,880	$5,600	$7,150	$8,560	$10,000	$11,500	$52,000
Increased Travel Benefits	$1,040	$2,480	$3,850	$5,380	$7,720	$9,770	$11,600	$13,600	$15,500	$70,900
Refueling Time Savings	$262	$618	$967	$1,370	$2,040	$2,650	$3,230	$3,840	$4,470	$19,500
$PM_{2.5}$ Related Impacts[c,d,e]	$117	$302	$481	$692	$1,090	$1,210	$1,300	$1,380	$1,450	$8,020
Non-CO_2 GHG Impacts[g]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Reduced CO_2 Emissions at each assumed SCC value [a, b]										
5% (avg	$142	$344	$552	$802	$1,230	$1,610	$1,980	$2,390	$2,810	$11,900

SCC)										
3% (avg SCC)	$598	$1,430	$2,260	$3,240	$4,900	$6,350	$7,730	$9,200	$10,700	$46,400
2.5% (avg SCC)	$968	$2,310	$3,640	$5,190	$7,820	$10,100	$12,300	$14,600	$16,900	$73,800
3% (95th %ile)	$1,830	$4,380	$6,920	$9,910	$15,000	$19,400	$23,600	$28,100	$32,700	$142,000
Monetized Net Benefits at each assumed SCC value [a, b]										
5% (avg SCC)	$4,960	$12,500	$20,300	$29,500	$44,600	$53,300	$62,600	$72,600	$85,700	$386,000
3% (avg SCC)	$5,420	$13,600	$22,100	$32,000	$48,300	$58,100	$68,400	$79,400	$93,600	$421,000
2.5% (avg SCC)	$5,790	$14,500	$23,400	$33,900	$51,200	$61,800	$72,900	$84,800	$99,800	$448,000
3% (95th %ile)	$6,650	$16,600	$26,700	$38,600	$58,400	$71,100	$84,300	$98,300	$116,000	$516,000

Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[b] Section III.H.5 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140. Section III.H.5 also presents these SCC estimates.

[c] Note that the co-pollutant impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.

[d] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger.

[e] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.[f] Positive values for Accidents, Congestion, and Noise costs represent an increase in costs. Therefore, they are treated as negative values when calculating the total benefits.[g] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this action (*See* DRIA Chapter 7.1). Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO_2 GHG benefits in Section III.H.5.

[h] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.

Table III-83 Monetized Technology Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2009$; 7% Discount Rate) [h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Technology Costs	$2,220	$4,500	$6,290	$8,190	$11,500	$18,700	$24,200	$29,700	$32,500	$138,000
Fuel Savings (pre-tax)	$4,720	$11,200	$17,500	$24,900	$37,000	$47,700	$57,700	$68,100	$78,700	$347,000
Energy Security Benefits (macro-disruption costs)	$250	$593	$934	$1,330	$1,980	$2,580	$3,150	$3,750	$4,360	$18,900
Accidents, Congestion, Noise Costs [f]	$562	$1,360	$2,140	$3,040	$4,390	$5,600	$6,720	$7,880	$9,060	$40,800

Increased Travel Benefits	$808	$1,930	$3,000	$4,190	$6,010	$7,620	$9,080	$10,600	$12,100	$55,300
Refueling Time Savings	$203	$481	$754	$1,070	$1,590	$2,070	$2,520	$2,990	$3,480	$15,200
$PM_{2.5}$ Related Impacts[c,d,e]	$93	$240	$382	$551	$864	$964	$1,030	$1,100	$1,160	$6,390
Non-CO_2 GHG Impacts[g]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Reduced CO_2 Emissions at each assumed SCC value[a, b]										
5% (avg SCC)	$142	$344	$552	$802	$1,230	$1,610	$1,980	$2,390	$2,810	$11,900
3% (avg SCC)	$598	$1,430	$2,260	$3,240	$4,900	$6,350	$7,730	$9,200	$10,700	$46,400
2.5% (avg SCC)	$968	$2,310	$3,640	$5,190	$7,820	$10,100	$12,300	$14,600	$16,900	$73,800
3% (95th %ile)	$1,830	$4,380	$6,920	$9,910	$15,000	$19,400	$23,600	$28,100	$32,700	$142,000
Monetized Net Benefits at each assumed SCC value[a, b]										
5% (avg SCC)	$3,420	$8,920	$14,700	$21,600	$32,800	$38,200	$44,500	$51,300	$61,100	$277,000
3% (avg SCC)	$3,880	$10,000	$16,400	$24,000	$36,400	$43,000	$50,200	$58,100	$69,000	$311,000
2.5% (avg SCC)	$4,250	$10,900	$17,800	$26,000	$39,400	$46,700	$54,800	$63,500	$75,200	$338,000
3% (95th %ile)	$5,110	$13,000	$21,100	$30,700	$46,500	$56,000	$66,100	$77,000	$91,000	$406,000

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Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[b] Section III.H.5 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140. Section III.H.5 also presents these SCC estimates.

[c] Note that the co-pollutant impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.

[d] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger.

[e] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower

.[f] Positive values for Accidents, Congestion, and Noise costs represent an increase in costs. Therefore, they are treated as negative values when calculating the total benefits.

[g] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this action (*See* DRIA Chapter 7.1). Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO_2 GHG benefits in Section III.H.5.

[h] Model year values are discounted to the first year of each model year; the “Sum” represents those discounted values summed across model years.

10. U.S. Vehicle Sales Impacts and Payback Period

a. Vehicle Sales Impacts and Payback Period

Predicting the effects of this rule on vehicles entails comparing two effects. On the one hand, the vehicles designed to meet the proposed standards will become more expensive, which would, by itself, be expected to discourage sales. On the other hand, the vehicles will have improved fuel economy and thus lower operating costs, producing lower total costs over the life of vehicles, which makes them more attractive to consumers. Which of these effects dominates for potential vehicle buyers when they are considering a purchase will determine the effect on sales. However, assessing the net effect of these two competing effects is complex and uncertain, as it rests on how consumers value fuel savings at the time of purchase and the extent to which manufacturers and dealers reflect them in the purchase price. The empirical literature does not provide clear evidence on whether consumers fully consider the value of fuel savings at the time of purchase. It also generally does not speak to the efficiency of manufacturing and dealer pricing decisions. Thus, for the proposal we do not provide quantified estimates of potential sales impacts. Rather, we solicit comment on the issues raised here and on methods for estimating the effect of this rule on vehicle sales.

For years, consumers have been gaining experience with the benefits that accrue to them from owning and operating vehicles with greater fuel efficiency. Many households already own vehicles with a fairly wide range of fuel economy, and thus already have an opportunity to learn about the value of fuel economy on their own. Among two-vehicle households, for example, the least fuel-efficient vehicle averages just over 22 mpg (EPA test rating), and the range between this and the fuel economy of their other vehicle averages nearly 7 mpg. Among households that own 3 or more vehicles, the typical range of the fuel economy they offer is much wider. Consumer demand may have shifted towards such vehicles, not only because of higher fuel prices but also if many consumers are learning about the value of purchases based not only on initial costs but also on the total cost of owning and operating a vehicle over its lifetime. This type of learning should continue before and during the model years affected by this rule, particularly given the new fuel economy labels that clarify potential economic effects and should therefore reinforce that learning.

Today's proposed rule, combined with the new and easier-to-understand fuel economy label required to be on all new vehicles beginning in 2012, may increase sales above baseline levels by hastening this very type of consumer learning. As more consumers experience, as a result of the rule, the savings in time and expense from owning more fuel efficient vehicles, demand may shift yet further in the direction of the vehicles mandated under the rule. This social learning can take place both within and across households, as consumers learn from one another.

First and most directly, the time and fuel savings associated with operating more fuel efficient vehicles may be more salient to individuals who own them, which might cause their subsequent purchase decisions to shift closer to minimizing the total cost of ownership over the lifetime of the vehicle.

Second, this appreciation may spread across households through word of mouth and other forms of communications.

Third, as more motorists experience the time and fuel savings associated with greater fuel efficiency, the price of used cars will better reflect such efficiency, further reducing the cost of owning more efficient vehicles for the buyers of new vehicles (since the resale price will increase).

If these induced learning effects are strong, the rule could potentially increase total vehicle sales over time. It is not possible to quantify these learning effects years in advance and that effect may be speeded or slowed by other factors that enter into a consumer's valuation of fuel efficiency in selecting vehicles.

The possibility that the rule will (after a lag for consumer learning) increase sales need not rest on the assumption that automobile manufacturers are failing to pursue profitable opportunities to supply the vehicles that consumers demand. In the absence of the rule, no individual automobile manufacturer would find it profitable to move toward the more efficient vehicles mandated under the rule. In particular, no individual company can fully internalize the future boost to demand resulting from the rule. If one company were to make more efficient vehicles, counting on consumer learning to enhance demand in the future, that company would capture only a fraction of the extra sales so generated, because the learning at issue is not specific to any one company's fleet. Many of the extra sales would accrue to that company's competitors.

In other words, consumer learning about the benefits of fuel efficient vehicles involves positive externalities (spillovers) from one company to the others.[579] These positive externalities may lead to benefits for manufacturers as a whole. We emphasize that this discussion has been tentative and qualified. To be sure, social learning of related kinds has been identified in a number of contexts.[580] Comments are invited on the discussion offered here, with particular reference to any relevant empirical findings.

In previous rulemakings, EPA and NHTSA conducted vehicle sales analyses by comparing the up-front costs of the vehicles with the present value of five years' worth of fuel savings. We assumed that the costs for the fuel-saving technologies would be passed along fully to vehicle buyers in the vehicle prices. The up-front vehicle costs were adjusted to take into account several factors that would affect consumer costs: The increased sales tax that consumers would pay, the increase in insurance premiums, the increase in loan payments that buyers would face, and a higher resale value, with all of these factors due to the higher up-front cost of the vehicle. Those calculations resulted in an adjusted increase in costs to consumers. We then assumed that consumers considered the present value of five years of fuel savings in their vehicle purchase, which is consistent with the length of a typical new light-duty vehicle loan, and is similar to the average time that a new vehicle purchaser holds onto the vehicle.[581] The present value of fuel savings was subtracted from technology costs to get a net effect on vehicle cost of ownership. We then used a short-run demand elasticity of −1 to convert a change in price into a change in

[579] Industrywide positive spillovers of this type are hardly unique to this situation. In many industries, companies form trade associations to promote industry-wide public goods. For example, merchants in a given locale may band together to promote tourism in that locale. Antitrust law recognizes that this type of coordination can increase output.

[580] See Hunt Allcott, Social Norms and Energy Conservation, Journal of Public Economics (forthcoming 2011), available at *http://web.mit.edu/allcott/www/Allcott%202011%20JPubEc%20-%20Social%20Norms%20and%20Energy%20Conservation.pdf*; Christophe Chamley, Rational Herds: Economic Models of Social Learning (Cambridge, 2003).

[581] In this proposal, the 5-year payback assumption corresponds to an assumption that vehicle buyers take into account between 30 and 50 percent of the present value of lifetime vehicle fuel savings (with the variation depending on discount rate, model year, and car vs. truck).

quantity demanded of vehicles.[582] An elasticity of −1 means that a 1% increase in price leads to a 1% reduction in quantity sold. In the vehicle sales analyses, if five years of fuel savings outweighed the adjusted technology costs, then vehicle sales were predicted to increase; if the fuel savings were smaller than the adjusted technology costs, sales would decrease, compared to a world without the standards.

We do not here present a vehicle sales analysis using this approach. This rule takes effect for MY 2017–2025. In the intervening years, it is possible that the assumptions underlying this analysis, as well as market conditions, might change. Instead, we present a payback period analysis to estimate the number of years of fuel savings needed to recover the up-front costs of the new technologies. In other words, the payback period identifies the break-even point for new vehicle buyers.

A payback period analysis examines how long it would take for the expected fuel savings to outweigh the increased cost of a new vehicle. For example, a new 2025 MY vehicle is estimated to cost $1,946 more (on average, and relative to the reference case vehicle) due to the addition of new GHG reducing/fuel economy improving technology (see Section III.D.6 for details on this cost estimate). This new technology will result in lower fuel consumption and, therefore, savings in fuel expenditures (see Section III.H.10 for details on fuel savings). But how many months or years would pass before the fuel savings exceed the upfront costs?

The payback analysis uses annual miles driven (vehicle miles traveled, or VMT) and survival rates consistent with the emission and benefits analyses presented in Chapter 4 of the Joint TSD. The control case includes fuel savings associated with A/C controls. Not included here are the likely A/C-related maintenance savings as discussed in Chapter 2 of EPA's RIA. Further, this analysis does not include other private impacts, such as reduced refueling events, or other societal impacts, such as the potential rebound miles driven or the value of driving those rebound miles, or noise, congestion and accidents, since the focus is meant to be on those factors consumers think about most while in the showroom considering a new car purchase. Car/truck fleet weighting is handled as described in Chapter 1 of the Joint TSD. The costs take into account the effects of the increased costs on sales tax, insurance, resale value, and finance costs. More detail on this analysis can be found in Chapter 5 of EPA's draft RIA.

Table III–84 presents results for MY 2021 because it is the last year before the mid-term review impacts, if any, will take place, and MY 2025 because it is the last year of the program. The payback period in 2021 is shorter than that in 2025, because the technologies required to meet the proposed MY 2021 standards are more cost-effective than those for MY 2025. In all cases, the payback periods are less than 4 years.

Table III-84 Estimated Payback Period for Model Years 2021 and 2025 (Years)[a]

Model Year	Estimated Payback Period for Cash Purchase, 3% Discount Rate	Estimated Payback Period for Cash Purchase, 7% Discount Rate	Estimated Payback Period for Purchase on Credit, 3% Discount Rate	Estimated Payback Period for Purchase on Credit, 7% Discount Rate
2021	2.7	2.9	2.9	2.8
2025	3.7	3.9	3.9	3.9

[a] The value here includes nationwide average sales tax of 5.32% and increased insurance premiums of 1.85% in year one decreasing to 0% by year 9. Financing costs assume a 5 year loan at 5.52 percent. These percentages are discussed in Section 8.1.1 of EPA's DRIA.

Most people purchase a new vehicle using credit rather than paying cash up front. A common car loan today is a five year, 60 month loan. As of July, 2011, the national average interest rate for a 5 year new car loan was 5.52 percent.[583] If the increased vehicle cost is spread out over 5 years at 5.52 percent, the analysis for a MY 2025 vehicle would

[582] For a durable good such as an auto, the elasticity may be smaller in the long run: Though people may be able to change the timing of their purchase when price changes in the short run, they must eventually make the investment. We request comment on whether or when a long-run elasticity should be used for a rule that phases in over time, as well as how to find good estimates for the long-run elasticity.

[583] "National Auto Loan Rates for July 21, 2011," *http://www.bankrate.com/finance/auto/national-auto-loan-rates-for-july-21–2011.aspx*, accessed 7/26/11 (Docket EPA–HQ–OAR–2010–0799).

look like that shown in Table III–85. As can be seen in this table, the fuel savings immediately outweigh the increased payments on the car loan, amounting to $145 in discounted net savings (3% discount rate) in the first year and similar savings for the next four years although savings decline somewhat due to reduced VMT as the average vehicle ages. Results are similar using a 7% discount rate. This means that for every month that the average owner is making a payment for the financing of the average new vehicle their monthly fuel savings would be greater than the increase in the loan payments. This amounts to a savings on the order of $12 per month throughout the duration of the 5 year loan. Note that in year six when the car loan is paid off, the net savings equal the fuel savings less the increased insurance premiums (as would be the case for the remaining years of ownership).

Table III-85 Payback Period on a 2025 MY New Vehicle Purchase via Credit (2009 dollars)

Year of Ownership	Increased Vehicle Cost[a] (undiscounted)	Annual Fuel Savings[b] (undiscounted)	Annual Discounted Net Savings at 3%[c]	Annual Discounted Net Savings at 7%[c]
1	-$489	$643	$145	$133
2	-$488	$634	$133	$117
3	-$487	$630	$127	$107
4	-$485	$614	$109	$88
5	-$484	$601	$96	$74
6	-$11	$572	$477	$387
7	-$6	$543	$443	$346
8	-$1	$512	$409	$308

[a] This uses the same increased cost as Table III-12 but spreads it out over 5 years assuming a 5 year car loan at 5.52 percent.

[b] Calculated using AEO 2011 reference case fuel prices including taxes.

[c] Note that the cumulative discounted fuel savings are identical to those shown in Table III-12. Here we show discounted net savings.

The lifetime fuel savings and net savings can also be calculated for those who purchase the vehicle using cash and for those who purchase the vehicle with credit. This calculation applies to the vehicle owner who retains the vehicle for its entire life and drives the vehicle each year at the rate equal to the national projected average. The results are shown in Table III–86. In either case, the present value of the lifetime net savings is greater than $4,200 at a 3% discount rate, or $2,900 at a 7% discount rate.

Table III-86 Lifetime Discounted Net Savings on a 2025 MY New Vehicle Purchase (2009 dollars)

Purchase Option	Increased Discounted Vehicle Cost	Lifetime Discounted Fuel Savings [b]	Lifetime Discounted Net Savings
3% discount rate			
Cash	$2,189	$6,568	$4,378
Credit [a]	$2,310	$6,568	$4,258
7% discount rate			
Cash	$2,180	$5,154	$2,972
Credit [a]	$2,147	$5,154	$3,004

[a] Assumes a 5 year loan at 5.52 percent.

[b] Fuel savings here were calculated using AEO 2011 reference case fuel prices including taxes.

Note that throughout this consumer payback discussion, the analysis reflects the average number of vehicle miles traveled per year. Drivers who drive more miles than the average would incur fuel-related savings more quickly and, therefore, the payback would come sooner. Drivers who drive fewer miles than the average would incur fuel related savings more slowly and, therefore, the payback would come later.

Another method to estimate effects on vehicle sales is to model the market for vehicles. Consumer vehicle choice models estimate what vehicles consumers buy based on vehicle and consumer characteristics. In principle, such models could provide a means of understanding both the role of fuel economy in consumers' purchase decisions and the effects of this rule on the benefits that consumers will get from vehicles. Helfand and Wolverton discuss the wide variation in the structure and results of these models.[584] Models or model results have not frequently been systematically compared to each other. When they have, the results show large variation over, for instance, the value that consumers place on additional fuel economy. As discussed in Section III.H.1 and in Chapter 8.1.2.8 of the DRIA, EPA is exploring development of a consumer vehicle choice model, but the model is not sufficiently developed for use in this NPRM.

The effect of this rule on the use and scrappage of older vehicles will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, the fuel efficiency of used vehicles, and the total sales of new vehicles. If the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' prices, sales of new vehicles could rise, while scrappage rates of used vehicles will increase slightly. This will cause the turnover of the vehicle fleet (*i.e.,* the retirement of used vehicles and their replacement by new models) to accelerate slightly, thus accentuating the anticipated effect of the rule on fleet-wide fuel consumption and CO_2 emissions. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles will decline, as will the rate at which used vehicles are retired from service. This effect will slow the replacement of used vehicles by new models, and thus partly reduce the anticipated effects of this rule on fuel use and emissions.

Because of the uncertainty regarding how the value of projected fuel savings from this rule to potential buyers will compare to their estimates of increases in new vehicle prices, we have not attempted to estimate explicitly the effects of the rule on scrappage of older vehicles and the turnover of the vehicle fleet.

Chapter 5 of EPA's DRIA provides more information on the payback period analysis, and Chapter 8 of EPA's DRIA has further discussion of methods for examining the effects of this rule on vehicle sales. We welcome comments on all aspects of this discussion, including the full range of considerations and assumptions which influence market behavior and outcomes and associated uncertainties. We also welcome comments on all the parameters described here, as well as other quantitative estimates of the effects of this proposal on sales, accompanied by detailed descriptions of the methodologies used.

11. Employment Impacts

a. Introduction

Although analysis of employment impacts is not part of a cost-benefit analysis (except to the extent that labor costs contribute to costs), employment impacts of federal rules are of particular concern in the current economic climate

[584] Helfand, Gloria, and Ann Wolverton. "Evaluating the Consumer Response to Fuel Economy: A Review of the Literature." *International Review of Environmental and Resource Economics* 5 (2011): 103–146 (Docket EPA–HQ–OAR–2010–0799).

of sizeable unemployment. When President Obama requested that the agencies develop this program, he sought a program that would ''strengthen the [auto] industry and enhance job creation in the United States.'' [585] The recently issued Executive Order 13563, ''Improving Regulation and Regulatory Review'' (January 18, 2011), states, ''Our regulatory system must protect public health, welfare, safety, and our *environment* while promoting economic growth, innovation, competitiveness, and *job creation''* (emphasis added). EPA is accordingly providing partial estimates of the effects of this proposal on domestic employment in the auto manufacturing and parts sectors, while qualitatively discussing how it may affect employment in other sectors more generally.

This proposal is expected to affect employment in the United States through the regulated sector—the auto manufacturing industry—and through several related sectors, specifically, industries that supply the auto manufacturing industry (*e.g.,* vehicle parts), auto dealers, the fuel refining and supply sectors, and the general retail sector. According to the U.S. Bureau of Labor Statistics, in 2010, about 677,000 people in the U.S. were employed in the Motor Vehicle and Parts Manufacturing Sector (NAICS 3361, 3362, and 3363). About 129,000 people in the U.S. were employed specifically in the Automobile and Light Truck Manufacturing Sector (NAICS 33611), the directly regulated sector, since it encompasses the auto manufacturers that are responsible for complying with the proposed standards.[586] The employment effects of this rule are expected to expand beyond the regulated sector. Though some of the parts used to achieve the proposed standards are likely to be built by auto manufacturers themselves, the auto parts manufacturing sector also plays a significant role in providing those parts, and will also be affected by changes in vehicle sales. Changes in light duty vehicle sales, discussed in Section III.H.10, could affect employment for auto dealers. As discussed in Chapter 5.4 of the DRIA, this proposal is expected to reduce the amount of fuel these vehicles use, and thus affect the petroleum refinery and supply industries. Finally, since the net reduction in cost associated with this proposal is expected to lead to lower household expenditures on fuel net of vehicle costs, consumers then will have additional discretionary income that can be spent on other goods and services.

When the economy is at full employment, an environmental regulation is unlikely to have much impact on net overall U.S. employment; instead, labor would primarily be shifted from one sector to another. These shifts in employment impose an opportunity cost on society, approximated by the wages of the employees, as regulation diverts workers from other activities in the economy. In this situation, any effects on net employment are likely to be transitory as workers change jobs (*e.g.,* some workers may need to be retrained or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers).

On the other hand, if a regulation comes into effect during a period of high unemployment, a change in labor demand due to regulation may affect net overall U.S. employment because the labor market is not in equilibrium. In such a period, both positive and negative employment effects are possible.[587] Schmalansee and Stavins point out that net positive employment effects are possible in the near term when the economy is at less than full employment due to the potential hiring of idle labor resources by the regulated sector to meet new requirements (*e.g.,* to install new equipment) and new economic activity in sectors related to the regulated sector.[588] In the longer run, the net effect on employment is more difficult to predict and will depend on the way in which the related industries respond to the regulatory requirements. As Schmalansee and Stavins note, it is possible that the magnitude of the effect on employment could vary over time, region, and sector, and positive effects on employment in some regions or sectors could be offset by negative effects in other regions or sectors. For this reason, they urge caution in reporting partial employment effects since it can ''paint an inaccurate picture of net employment impacts if not placed in the broader economic context.''

It is assumed that the official unemployment rate will have declined to 5.3 percent by the time this rule takes effect and so the effect of the regulation on labor will be to shift workers from one sector to another.[589] Those shifts in employment impose an opportunity cost on society, approximated by the wages of the employees, as regulation diverts workers from other activities in the economy. In this situation, any effects on net employment are likely to be transitory as workers change jobs (*e.g.,* some workers may need to be retrained or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers). It is also possible that the state of the economy will be such that positive or negative employment effects will occur.

A number of different approaches have been used in published literature to conduct employment analysis. All potential methods of estimating employment impacts of a rule have advantages and limitations. We seek comment on the analytical approach presented here, other appropriate methods for analyzing employment impacts for this rulemaking, and the inputs used here for employment analysis.

b. Approaches to Quantitative Employment Analysis

Measuring the employment impacts of a policy depend on a number of inputs and assumptions. For instance, as discussed, assumptions about the overall state of unemployment in the economy play a major role in measured job impacts. The inputs to the models commonly are the changes in quantities or expenditures in the affected sectors; model results may vary in different studies depending on the assumptions about the levels of those inputs, and which sectors receive those changes. Which sectors are included in the study can also affect the results. For instance, a study of this program that looks only at employment impacts in the refinery sector may find negative effects, because consumers will purchase less gasoline; a study that looks only at the auto parts sector, on the other hand, may find positive impacts, because the program will require redesigned or additional parts for vehicles. In both instances, these would only be partial perspectives

[585] President Barack Obama. ''Presidential Memorandum Regarding Fuel Efficiency Standards. The White House, Office of the Press Secretary, May 21, 2010. *http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.*

[586] U.S. Bureau of Labor Statistics, Quarterly Census of Employment and Wages, as accessed on August 9, 2011.

[587] Masur and Posner, *http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1920441.*

[588] Schmalensee, Richard, and Robert N. Stavins. ''A Guide to Economic and Policy Analysis of EPA's Transport Rule.'' White paper commissioned by Excelon Corporation, March 2011 (Docket EPA–HQ–OAR–2010–0799).

[589] Office of Management and Budget, ''Fiscal Year 2012 Mid-Session Review: Budget of the U.S. Government.'' *http://www.whitehouse.gov/sites/default/files/omb/budget/fy2012/assets/12msr.pdf*, p. 10.

on the overall change in national employment due to Federal regulation.

i. Conceptual Framework for Employment Impacts in the Regulated Sector

One study by Morgenstern, Pizer, and Shih[590] provides a retrospective look at the impacts of regulation in employment in the regulated sectors by estimating the effects on employment of spending on pollution abatement for four highly polluting/regulated U.S. industries (pulp and paper, plastics, steel, and petroleum refining) using data for six years between 1979 and 1991. The paper provides a theoretical framework that can be useful for examining the impacts of a regulatory change on the regulated sector in the medium to longer term. In particular, it identifies three separate ways that employment levels may change in the regulated industry in response to a new (or more stringent) regulation.

Demand effect: higher production costs due to the regulation will lead to higher market prices; higher prices in turn reduce demand for the good, reducing the demand for labor to make that good. In the authors' words, the ''extent of this effect depends on the cost increase passed on to consumers as well as the demand elasticity of industry output.''

Cost effect: as costs go up, plants add more capital and labor (holding other factors constant), with potentially positive effects on employment. In the authors' words, as ''production costs rise, more inputs, including labor, are used to produce the same amount of output.''

Factor-shift effect: post-regulation production technologies may be more or less labor-intensive (*i.e.,* more/less labor is required per dollar of output). In the authors' words, ''environmental activities may be more labor intensive than conventional production,'' meaning that ''the amount of labor per dollar of output will rise,'' though it is also possible that ''cleaner operations could involve automation and less employment, for example.''

According to the authors, the ''demand effect'' is expected to have a negative effect on employment,[591] the ''cost effect'' to have a positive effect on employment, and the ''factor-shift effect'' to have an ambiguous effect on employment. Without more information with respect to the magnitude of these competing effects, it is not possible to predict the total effect environmental regulation will have on employment levels in a regulated sector.

The authors conclude that increased abatement expenditures generally have not caused a significant change in employment in those sectors. More specifically, their results show that, on average across the industries studied, each additional $1 million spent on pollution abatement results in a (statistically insignificant) net increase of 1.5 jobs.

This approach to employment analysis has the advantage of carefully controlling for many possibly confounding effects in order to separate the effect of changes in regulatory costs on employment. It was, however, conducted for only four sectors. It could also be very difficult to update the study for other sectors, because one of the databases on which it relies, the Pollution Abatement Cost and Expenditure survey, has been conducted infrequently since 1994, with the last survey conducted in 2005. The empirical estimates provided by Morgenstern et al. are not relevant to the case of fuel economy standards, which are very different from the pollution control standards on industrial facilities that were considered in that study. In addition, it does not examine the effects of regulation on employment in sectors related to but outside of the regulated sector. Nevertheless, the theory that Morgenstern et al. developed continues to be useful in this context.

The following discussion of additional methodologies draws from Berck and Hoffmann's review of employment models.[592]

ii. Computable General Equilibrium (CGE) Models

Computable general equilibrium (CGE) models are often used to assess the impacts of policy. These models include a stylized representation of supply and demand curves for all major markets in the economy. The labor market is commonly included. CGE models are very useful for looking at interaction effects of markets: ''They allow for substitution among inputs in production and goods in consumption.'' Thus, if one market experiences a change, such as a new regulation, then the effects can be observed in all other markets. As a result, they can measure the employment changes in the economy due to a regulation. Because they usually assume equilibrium in all markets, though, they typically lack involuntary unemployment. If the total amount of labor changes, it is due to people voluntarily entering or leaving the workforce. As a result, these models may not be appropriate for measuring effects of a policy on unemployment, because of the assumption that there is no involuntary unemployment. In addition, because of the assumptions of equilibrium in all markets and forward-looking consumers and firms, they are designed for examining the long-run effects of a policy but may offer little insight into its short-run effects.

iii. Input-Output (IO) Models

Input-output models represent the economy through a matrix of coefficients that describe the connections between supplying and consuming sectors. In that sense, like CGE models, they describe the interconnections of the economy. These interconnections look at how changes in one sector ripple through the rest of the economy. For instance, a requirement for additional technology for vehicles requires additional steel, which requires more workers in both the auto and steel sectors; the additional workers in those sectors then have more money to spend, which leads to more employment in retail sectors. These are known as ''multiplier'' effects, because an initial impact in one sector gets multiplied through the economy. Unlike CGE models, input-output models have fixed, linear relationships among the sectors (*e.g.,* substitution among inputs or goods is not allowed), and quantity supplied need not equal quantity demanded. In particular, these models do not allow for price changes—an increase in the demand for labor or capital does not result in a change in its price to help reallocate it to its best use. As a result, these models cannot capture opportunity costs from using resources in one area of the economy over another. The multipliers take an initial impact and can increase it substantially.

IO models are commonly used for regional analysis of projects. In a regional analysis, the markets are commonly considered small enough that wages and prices are determined outside the region, and any excess

[590] Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. ''Jobs Versus the Environment: An Industry-Level Perspective.'' *Journal of Environmental Economics and Management* 43 (2002): 412–436 (Docket EPA–HQ–OAR–2010–0799).

[591] As will be discussed below, the demand effect in this proposal is potentially an exception to this rule. While the vehicles become more expensive, they also produce reduced fuel expenditures; the reduced fuel costs provide a countervailing impact on vehicle sales. As discussed in Preamble Section III.H.1, this possibility that vehicles may become more attractive to consumers after the program poses a conundrum: Why have interactions between vehicle buyers and producers not provided these benefits without government intervention?

[592] Berck, Peter, and Sandra Hoffmann. ''Assessing the Employment Impacts of Environmental and Natural Resource Policy.'' Environmental and Resource Economics 22 (2002): 133–156 (Docket EPA–HQ–OAR–2010–0799) (Docket EPA–HQ–OAR–2010–0799).

supply or demand is due to exports and imports (or, in the case of labor, emigration or immigration). For national-level employment analysis, the use of input-output models requires the assumption that workers flow into or out of the labor market perfectly freely. Wages do not adjust; instead, people join into or depart from the labor pool as production requires them. For other markets as well, there is no substitution of less expensive inputs for more expensive ones. As a result, IO models provide an upper bound on employment impacts. As Berck and Hoffmann note, ''For the same reason, they can be thought of as simulating very short-run adjustment,'' in contrast to the CGE's implicit assumption of long-run adjustment. Changes in production processes, introducing new technologies, or learning over time due to new regulatory requirements are also generally not captured by IO models, as they are calibrated to already established relationships between inputs and outputs.

iv. Hybrid Models

As Berck and Hoffmann note, input-output models and CGE models ''represent a continuum of closely related models.'' Though not separately discussed by Berck and Hoffmann, some hybrid models combine some of the features of CGE models (*e.g.,* prices that can change) with input-output relationships. For instance, a hybrid model may include the ability to examine disequilibrium phenomena, such as labor being at less than full employment. Hybrid models depend on assumptions about how adjustments in the economy occur. CGE models characterize equilibria but say little about the pathway between them, while IO models assume that adjustments are largely constrained by previously defined relationships; the effectiveness of hybrid models depends on their success in overcoming the limitations of each of these approaches. Hybrid models could potentially be used to model labor market impacts of various vehicle policy options, although a number of judgments need to be made about the appropriate assumptions underlying the model as well as the empirical basis for the modeling results.

v. Single Sectors

It is possible to conduct a bottom-up analysis of the partial effect of regulation on employment in a single sector by estimating the change in output or expenditures in a sector and multiplying it by an estimate of the number of workers per unit of output or expenditures, under the assumption that labor demand is proportional to output or expenditures. As Berck and Hoffmann note, though, ''Compliance with regulations may create additional jobs that are not accounted for.'' While such an analysis can approximate the effects in that one sector in a simple way, it also may miss important connections to related sectors.

vi. Ex-Post Econometric Studies

A number of ex-post econometric analyses examine the net effect of regulation on employment in regulated sectors. Morgenstern, Pizer, and Shih (2002), discussed above, and Berman and Bui (2001) are two notable examples that rely on highly disaggregated establishment-level time series data to estimate longer-run employment effects.[593] While often a sophisticated treatment of the issues analyzed, these studies commonly analyze specific scenarios or sectors in the past; care needs to be taken in extrapolating their results to other scenarios and to the future. For instance, neither of these two studies examines the auto industry and are therefore of limited applicability in this context.

vii. Summary

All methods of estimating employment impacts of a regulation have advantages and limitations. CGE models may be most appropriate for long-term impacts, but the usual assumption of equilibrium in the employment market means that it is not useful for looking at changes in overall employment: overall levels are likely to be premised on full employment. IO models, on the other hand, may be most appropriate for small-scale, short-term effects, because they assume fixed relationships across sectors and do not require market equilibria. Hybrid models, which combine some features of CGEs with IO models, depend upon key assumptions and economic relationships that are built into them. Single-sector models are simple and straightforward, but they are often based on the assumptions that labor demand is proportional to output, and that other sectors are not affected. Finally, econometric models have been developed to evaluate the longer-run net effects of regulation on sector employment, though these are ex-post analyses commonly of specific sectors or situations, and the results may not have direct bearing for the regulation being reviewed. We seek comment on the analytical approaches presented here, the inputs used below for employment analysis, and other appropriate methods for analyzing employment impacts for this rulemaking.

[593] Berman, Eli, and Linda T. Bui, (2001) ''Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin,'' *Journal of Public Economics,* 79, 265—295 (Docket EPA–HQ–OAR–2010–0799).

c. Employment analysis of this proposal

As mentioned above, this program is expected to affect employment in the regulated sector (auto manufacturing) and other sectors directly affected by the proposal: auto parts suppliers, auto dealers, the fuel supply market (which will face reduced petroleum production due to reduced fuel demand but which may see additional demand for electricity or other fuels), and consumers (who will face higher vehicle costs and lower fuel expenditures). In addition, as the discussion above suggests, each of these sectors could potentially have ripple effects in the rest of the economy. These ripple effects depend much more heavily on the state of the macroeconomy than do the direct effects. At the national level, employment may increase in one industry or region and decrease in another, with the net effect being smaller than either individual-sector effect. EPA does not attempt to quantify the net effects of the regulation on overall national employment.

The discussion that follows provides a partial, bottom-up quantitative estimate of the effects of this proposal on the regulated sector (the auto industry; for reasons discussed below, we include some quantitative assessment of effects on suppliers to the industry, although they are not regulated directly). It also includes qualitative discussion of the effects of the proposal on other sectors. Focusing quantification of employment impacts on the regulated sector has some advantages over quantifying all impacts. First, the analysis relies on data generated as part of the rulemaking process, which focuses on the regulated sector; as a result, what is presented here is based on internally consistent assumptions and estimates made in this proposal. Secondly, as discussed above, net effects on employment in the economy as a whole depend heavily on the overall state of the economy when this rule has its effects. Focusing on the regulated sector provides insight into employment effects in that sector without having to make assumptions about the state of the economy when this rule has its impacts. We include a qualitative discussion of employment effects other sectors to provide a broader perspective on the impacts of this rule.

As noted above, in a full-employment economy, any changes in employment will result from people changing jobs or voluntarily entering or exiting the workforce. In a full-employment economy, employment impacts of this proposal will change employment in specific sectors, but it will have small, if any, effect on aggregate employment. This rule would take effect in 2017 through 2025; by then, the current high unemployment may be moderated or ended. For that reason, this analysis does not include multiplier effects, but instead focuses on employment impacts in the most directly affected industries. Those sectors are likely to face the most concentrated employment impacts. The agencies seek comment on other sectors that are likely to be significantly affected and thus warrant further analysis in the final rulemaking analysis.

i. Employment Impacts in the Auto Industry

Following the Morgenstern et al. conceptual framework for the impacts of regulation on employment in the regulated sector, we consider three effects for the auto sector: the demand effect, the cost effect, and the factor shift effect. However, we are only able to offer quantitative estimates for the cost effect. We note that these estimates, based on extrapolations from current data, become more uncertain as time goes on.

(1) The Demand Effect

The demand effect depends on the effects of this proposal on vehicle sales. If vehicle sales increase, then more people will be required to assemble vehicles and their components. If vehicle sales decrease, employment associated with these activities will unambiguously decrease. Unlike in Morgenstern et al.'s study, where the demand effect unambiguously decreased employment, there are countervailing effects in the vehicle market due to the fuel savings resulting from this program. On one hand, this proposal will increase vehicle costs; by itself, this effect would reduce vehicle sales. On the other hand, this proposal will reduce the fuel costs of operating the vehicle; by itself, this effect would increase vehicle sales, especially if potential buyers have an expectation of higher fuel prices. The sign of demand effect will depend on which of these effects dominates. Because, as described in Chapter 8.1, we have not quantified the impact on sales for this proposal, we do not quantify the demand effect.

(2) The Cost Effect

The demand effect, discussed above, measures employment changes due to new vehicle sales only. The cost effect measures employment impacts due to the new or additional technologies needed for vehicles to comply with the proposed standards. As DRIA Chapter 8.2.3.1.3 explains, we estimate the cost effect by multiplying the costs of rule compliance by ratios of workers to each $1 million of expenditures in that sector. The magnitude and relative size of these ratios depends on the sectors' labor intensity of the production process.

The use of these ratios has both advantages and limitations. It is often possible to estimate these ratios for quite specific sectors of the economy; as a result, it is not necessary to extrapolate employment ratios from possibly unrelated sectors. On the other hand, these estimates are averages for the sectors, covering all the activities in those sectors; they may not be representative of the labor required when expenditures are required on specific activities, as the factor shift effect (discussed below) indicates. In addition, these estimates do not include changes in sectors that supply these sectors, such as steel or electronics producers. They thus may best be viewed as the effects on employment in the auto sector due to the changes in expenditures in that sector, rather than as an assessment of all employment changes due to these changes in expenditures.

Some of the costs of this proposal will be spent directly in the auto manufacturing sector, but some of the costs will be spent in the auto parts manufacturing sector. Because we do not have information on the proportion of expenditures in each sector, we separately present the ratios for both the auto manufacturing sector and the auto parts manufacturing sector. These are not additive, but should instead be considered as a range of estimates for the cost effect, depending on which sector adds technologies to the vehicles to comply with the regulation.

We use several public sources for estimates of employment per $1 million expenditures: The U.S. Bureau of Labor Statistics' (BLS) Employment Requirements Matrix (ERM);[594] the Census Bureau's Annual Survey of Manufactures[595] (ASM); and the Census Bureau's Economic Census. DRIA Chapter 8.2.3.1.2 provides details on all these sources. The ASM and the Economic Census have more sectoral detail than the ERM; we provide estimates for both Motor Vehicle Manufacturing and Light Duty Vehicle Manufacturing sectors for comparison purposes. For all of these, we adjust for the ratio of domestic production to domestic sales. The maximum value for employment impacts per $1 million expenditures (after accounting for the share of domestic production) in 2009 was estimated to be 2.049 if all the additional costs are in the parts sector; the minimum value is 0.407, if all the additional costs are in the light-duty vehicle manufacturing sector: That is, the range of employment impacts is between 0.4 and 2 additional jobs per $1 million expenditures in the sector. The different data sources provide similar magnitudes for the estimates for the sectors. Parts manufacturing appears to be more labor-intensive than vehicle manufacturing; light-duty vehicle manufacturing appears to be slightly less labor-intensive than motor vehicle manufacturing as a whole. As discussed in the DRIA, trends in the BLS ERM are used to estimate productivity improvements over time that are used to adjust these ratios over time. Table III–87 shows the cost estimates developed for this rule, discussed in Section III.H.2. Multiplying those cost estimates by the maximum and minimum values for the cost effect (maximum using the ASM ratio if all additional costs are in the parts sector, and minimum using the Economic Census ratio for the light-duty sector if all additional costs are borne by auto manufacturers) provides the cost effect employment estimates. This is a simple way to examine the relationship between labor required and expenditure, and we seek comment on refining this method.

While we estimate employment impacts beginning with the first year of the standard (2017), some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff in anticipation of compliance with the standard.

[594] *http://www.bls.gov/emp/ep_data_emp_requirements.htm.*

[595] *http://www.census.gov/manufacturing/asm/index.html.*

Table III-87 Employment Effects due to Increased Expenditures on Vehicles and Parts

Year	*Costs (before adjustment for domestic proportion of production) ($Millions)*	*Minimum employment effect if all expenditures are in light duty vehicle mfg sector*	*Maximum employment effect if all expenditures are in the parts sector*
2017	$ 2,300	600	3,600
2018	$ 4,656	1,200	7,000
2019	$ 6,507	1,600	9,400
2020	$ 8,467	1,900	11,800
2021	$ 11,878	2,600	15,900
2022	$ 19,340	4,100	25,000
2023	$ 25,036	5,000	31,200
2024	$ 30,738	5,900	37,000
2025	$ 33,561	6,200	39,000

(3) The Factor Shift Effect

The factor shift effect looks at the effects on employment due to changes in labor intensity associated with a regulation. As noted above, the estimates of the cost effect assume constant labor per $1 million in expenditures, though the new technologies may be either more or less labor-intensive than the existing ones. An estimate of the factor shift effect would either increase or decrease the estimate used for the cost effect.

We are not quantifying the factor shift effect here, for lack of data on the labor intensity of all the possible technologies that manufacturers could use to comply with the proposed standards. As discussed in DRIA Chapter 8.2.3.1.3, though, for a subset of the technologies, EPA-sponsored research (discussed in Chapter 3.2.1.1 of the Joint TSD), which compared new technologies to existing ones at the level of individual components, found that labor use for the new technologies increased: The new fuel-saving technologies use more labor than the baseline technologies. For instance, switching from a conventional mid-size vehicle to a hybrid version of that vehicle involves an additional $395.85 in labor costs, which we estimate to require an additional 8.6 hours per vehicle.[596] For a subset of the technologies likely to be used to meet the standards in this proposal, then, the factor shift effect increases labor demand, at least in the short run; in the long run, as with all technologies, the cost structure is likely to change due to learning, economies of scale, etc. The technologies examined in this research are, however, only a subset of the technologies that auto makers may use to comply with the standards proposed here. As a result, these results cannot be considered definitive evidence that the factor-shift effect increases employment for this rule. We therefore do not quantify the factor shift effect.

[596] FEV, Inc. ''Light Duty Technology Cost Analysis, Power-Split and P2 HEV Case Studies.'' EPA Report EPA–420–R–11_015, November 2011 (Docket EPA–HQ–OAR–2010–0799).

(4) Summary of Employment Effects in the Auto Sector

While we are not able to quantify the demand or factor shift effects, the cost effect results show that the employment effects of the increased spending in the regulated sector (and, possibly, the parts sector) are expected to be positive and on the order of a few thousand in the initial years of the program. As noted above, the motor vehicle and parts manufacturing sectors employed about 677,000 people in 2010, with automobile and light truck manufacturing accounting for about 129,000 of that total.

ii. Effects on Employment for Auto Dealers

The effects of the proposed standards on employment for auto dealers depend principally on the effects of the standards on light duty vehicle sales. In addition, auto dealers may be affected by changes in maintenance and service costs. Increases in those costs are likely to increase labor demand in dealerships.

Although this proposal predicts very small penetration of advanced technology vehicles, the uncertainty on consumer acceptance of such technology vehicles is even greater. As discussed in Section III.H.1.b, consumers may find some characteristics of electric vehicles and plug-in hybrid electric vehicles, such as the ability to fuel with electricity rather than gasoline, attractive; they may find other characteristics, such as the limited range for electric vehicles, undesirable. As a result, some consumers will find that EVs will meet their needs, but other buyers will choose more conventional vehicles. Auto dealers may play a major role in explaining the merits and disadvantages of these new technologies to vehicle buyers. There may be a temporary need for increased employment to train sales staff in the new technologies as the new technologies become available.

iii. Effects on Employment in the Auto Parts Sector

As discussed in the context of employment in the auto industry, some vehicle parts are made in-house by auto manufacturers; others are made by independent suppliers who are not directly regulated, but who will be affected by the proposed standards as well. The additional expenditures on technologies are expected to have a positive effect on employment in the parts sector as well as the manufacturing sector; the breakdown in employment between the two sectors is difficult to predict. The effects on the parts sector also depend on the effects of the proposed standards on vehicle sales and on the labor intensity of the new technologies, qualitatively in the same ways as for the auto manufacturing sector.

iv. Effects on Employment for Fuel Suppliers

In addition to the effects on the auto manufacturing and parts sectors, these rules will result in changes in fuel use that lower GHG emissions. Fuel saving, principally reductions in liquid fuels such as gasoline and diesel, will affect employment in the fuel suppliers industry sectors throughout the supply chain, from refineries to gasoline stations. To the extent that the proposed standards result in increased use of electricity, natural gas, or other fuels, employment effects will result from providing these fuels and developing the infrastructure to supply them to consumers.

Expected petroleum fuel consumption reductions can be found in Section III.H.3. While those figures represent fuel savings for purchasers of fuel, it represents a loss in value of output for the petroleum refinery industry, fuel distribution, and gasoline stations. The loss of expenditures to petroleum fuel suppliers throughout the petroleum fuel supply chain, from the petroleum refiners to the gasoline stations, is likely to result in reduced employment in these sectors.

This rule is also expected to lead to increases in electricity consumption by vehicles, as discussed in Section III.H.4. This new fuel may require additional infrastructure, such as electricity charging locations. Providing this infrastructure will require some increased employment. In addition, the generation of electricity will also require some additional labor. We have insufficient information at this time to predict whether the increases in labor associated with increased infrastructure provision and fuel generation for these newer fuels will be greater or less than the employment reductions associated with reduced demand for petroleum fuels.

v. Effects on Employment Due to Impacts on Consumer Expenditures

As a result of these proposed standards, consumers will pay a higher up-front cost for the vehicles, but they will recover those costs in a fairly short payback period (see Section III.H.10.b); indeed, people who finance their vehicles are expected to find that their fuel savings per month exceed the increase in the loan cost (though this depends on the particular loan rate a consumer receives). As a result, consumers will have additional money to spend on other goods and services, though, for those who do not finance their vehicles, it will occur after the initial payback period. These increased expenditures will support employment in those sectors where consumers spend their savings.

These increased expenditures will occur in 2017 and beyond. If the economy returns to full employment by that time, any change in consumer expenditures would primarily represent a shift in employment among sectors. If, on the other hand, the economy still has substantial unemployment, these expenditures would contribute to employment through increased consumer demand.

d. Summary

The primary employment effects of this proposal are expected to be found throughout several key sectors: auto manufacturers, auto dealers, auto parts manufacturing, fuel production and supply, and consumers. This rule initially takes effect in model year 2017, a time period sufficiently far in the future that the current sustained high unemployment at the national level may be moderated or ended. In an economy with full employment, the primary employment effect of a rulemaking is likely to be to move employment from one sector to another, rather than to increase or decrease employment. For that reason, we focus our partial quantitative analysis on employment in the regulated sector, to examine the impacts on that sector directly. We discuss the likely direction of other impacts in the regulated sector as well as in other directly related sectors, but we do not quantify those impacts, because they are more difficult to quantify with reasonable accuracy, particularly so far into the future.

For the regulated sector, we have not quantified the demand effect. The cost effect is expected to increase employment by 600–3,600 workers in 2017 depending on the share of that employment that is in the auto manufacturing sector compared to the auto parts manufacturing sector. As mentioned above, some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff to prepare to comply with the standard. The demand effect is ambiguous and depends on changes in vehicle sales, which are not quantified for this proposal. Though we do not have estimates of the factor shift effect for all potential compliance technologies, the evidence which we do have for some technologies suggests that many of the technologies will have increased labor needs.

Effects in other sectors that are predicated on vehicle sales are also ambiguous. Changes in vehicle sales are expected to affect labor needs in auto dealerships and in parts manufacturing. Increased expenditures for auto parts are expected to require increased labor to build parts, though this effect also depends on any changes in the labor intensity of production; as noted, the subset of potential compliance technologies for which data are available show increased labor requirements. Reduced fuel production implies less employment in the petroleum sectors. Finally, consumer spending is expected to affect employment through changes in expenditures in general retail sectors; net fuel savings by consumers are expected to increase demand (and therefore employment) in other sectors.

I. Statutory and Executive Order Reviews

a. Executive Order 12866: ''Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review''

Under section 3(f)(1) of Executive Order 12866 (58 FR 51735, October 4, 1993), this action is an ''economically significant regulatory action'' because it is likely to have an annual effect on the economy of $100 million or more. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for review under Executive Orders 12866 and 13563 (76 FR 3821, January 21, 2011) and any changes made in response to OMB recommendations have been documented in the docket for this action as required by CAA section 307(d)(4)(B)(ii).

In addition, EPA prepared an analysis of the potential costs and benefits associated with this action. This analysis is contained in the Draft Regulatory Impact Analysis, which is available in the docket for this rulemaking and at the docket internet address listed under **ADDRESSES** above.

b. Paperwork Reduction Act

The information collection requirements in this proposed rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.* The Information Collection Request (ICR) document prepared by EPA has been assigned EPA ICR number 0783.61.

The Agency proposes to collect information to ensure compliance with the provisions in this rule. This includes a variety of requirements for vehicle manufacturers. Section 208(a) of the Clean Air Act requires that vehicle manufacturers provide information the Administrator may reasonably require to determine compliance with the regulations; submission of the information is therefore mandatory. We will consider confidential all information meeting the requirements of section 208(c) of the Clean Air Act.

As shown in Table III–88, the total annual reporting burden associated with this proposal is about 5,100 hours and $1.36 million, based on a projection of 33 respondents. The estimated burden for vehicle manufacturers is a total estimate for new reporting requirements. Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

Table III-88 Estimated Burden for Reporting and Recordkeeping Requirements

Number of respondents	Annual burden hours	Annual costs
33	5,133	$1,357,578

An agency may not conduct or sponsor, and a person is not required to respond to a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

To comment on the Agency's need for this information, the accuracy of the provided burden estimates, and any suggested methods for minimizing respondent burden, including the use of automated collection techniques, EPA has established a public docket for this rule, which includes this ICR, under Docket ID number EPA–HQ–OAR–2010–0799. Submit any comments related to the ICR for this proposed rule to EPA and OMB. See 'Addresses' section at the beginning of this notice for where to submit comments to EPA. Send comments to OMB at the Office of Information and Regulatory Affairs, Office of Management and Budget, 725 17th Street NW., Washington, DC 20503, Attention: Desk Office for EPA. Since OMB is required to make a decision concerning the ICR between 30 and 60 days after December 1, 2011, a comment to OMB is best assured of having its full effect if OMB receives it by January 3, 2012. The final rule will respond to any OMB or public comments on the information collection requirements contained in this proposal.

c. Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of this rule on small entities, small entity is defined as: (1) A small business as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201 (see table below); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

Table III–89 provides an overview of the primary SBA small business categories included in the light-duty vehicle sector:

Table III-89 Primary SBA Small Business Categories in the Light-Duty Vehicle Sector

Industry [a]	Defined as Small Entity by SBA if Less Than or Equal to:	NAICS Codes [b]
Vehicle manufacturers (including small volume manufacturers)	1,000 employees	336111, 336112
Independent commercial importers	$7 million annual sales	811111, 811112, 811198
	$23 million annual sales	441120
	100 employees	423110
Alternative Fuel Vehicle Converters	750 employees	336312, 336322, 336399
	1,000 employees	335312
	$7 million annual sales	811198

a. Light-duty vehicle entities that qualify as small businesses would not be subject to this proposed rule. We are proposing to exempt small business entities from the proposed standards.

b. North American Industrial Classification System

After considering the economic impacts of today's proposal on small entities, EPA certifies that this action will not have a significant economic impact on a substantial number of small entities. As with the MY 2012–2016 GHG standards, EPA is proposing to exempt manufacturers meeting SBA's definition of small business as described in 13 CFR 121.201 due to unique issues involved with establishing appropriate GHG standards for these small businesses and the potential need to develop a program that would be structured differently for them (which would require more time), and the extremely small emissions contribution of these entities. EPA would instead consider appropriate GHG standards for these entities as part of a future regulatory action.

Potentially affected small entities fall into three distinct categories of businesses for light-duty vehicles: Small volume manufacturers (SVMs), independent commercial importers (ICIs), and alternative fuel vehicle converters. Based on our preliminary assessment, EPA has identified a total of about 21 entities that fit the Small Business Administration (SBA) criterion of a small business. There are about 4 small manufacturers, including three electric vehicle manufacturers, 8 ICIs, and 9 alternative fuel vehicle converters in the light-duty vehicle market which are small businesses (no major vehicle manufacturers meet the small-entity criteria as defined by SBA). EPA estimates that these small entities comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., and therefore the proposed exemption will have a negligible impact on the GHG emissions reductions from the proposed standards.

As discussed in Section III.B.7, EPA is proposing to allow small businesses to waive their small entity exemption and optionally certify to the GHG standards. This would allow small entity manufacturers to earn CO_2 credits under the GHG program, if their actual fleetwide CO_2 performance was better than their fleetwide CO_2 target standard. EPA proposes to make the GHG program opt-in available starting in MY 2014, as the MY 2012, and potentially the MY 2013, certification process will have already occurred by the time this rulemaking is finalized. EPA is also proposing that manufacturers certifying to the GHG standards for MY 2014 would be eligible to generate early credits for vehicles sold in MY 2012 and MY 2013. Manufacturers waiving their small entity exemption would be required to meet all aspects of the GHG standards and program requirements across their entire product line. However, the exemption waiver would be optional for small entities and presumably manufacturers would only opt into the GHG program if it is economically advantageous for them to do so, for example through the generation and sale of CO_2 credits. Therefore, EPA believes adding this voluntary option does not affect EPA's determination that the proposed standards would impose no significant adverse impact on small entities.

Some commenters to the 2012–2016 light duty vehicle GHG rulemaking argued that EPA is obligated under the RFA to consider indirect impacts of the rules in assessing impacts on small businesses, in particular potential impacts on stationary sources that would not be directly regulated by the rule. EPA disagrees. When considering whether a rule should be certified, the RFA requires an agency to look only at the small entities to which the proposed rule will apply and which will be subject to the requirement of the specific rule in question. 5 U.S.C. 603, 605 (b); *Mid-Tex Elec. Coop.* v. *FERC,* 773 F.3d 327, 342 (DC Cir. 1985). Reading section 605 in light of section 603, we conclude that an agency may properly certify that no regulatory flexibility analysis is necessary when it determines that the rule will not have a significant economic impact on a substantial number of small entities that are subject to the requirements of the rule; see also *Cement Kiln Recycling Coalition,* v. *EPA,* 255 F.3d 855, 869 (DC Cir. 2001). DC Circuit has consistently rejected the contention that the RFA applies to small businesses indirectly affected by the regulation of other entities.[597]

Since the proposal would regulate exclusively large motor vehicle manufacturers and small vehicle manufacturers are exempted from the standards, EPA is properly certifying that the 2017–2025 standards would not have a significant economic impact on a substantial number of small entities directly subject to the rule or otherwise would have a positive economic effect on all of the small entities opting in to the rule.

We continue to be interested in the potential impacts of the proposed rule on small entities and welcome comments on issues related to such impacts.

d. Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), Public Law 104–4, establishes requirements for Federal agencies to assess the effects of their regulatory actions on State, local, and tribal governments and the private sector.

This proposal contains no Federal mandates (under the regulatory provisions of Title II of the UMRA) for State, local, or tribal governments. The rule imposes no enforceable duty on any State, local or tribal governments. This action is also not subject to the requirements of section 203 of UMRA because EPA has determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments. EPA has determined that this proposal contains a Federal mandate that may result in expenditures of $100 million or more for the private sector in any one year. EPA believes that the proposal represents the least costly, most cost-effective approach to revise the light duty vehicle standards as authorized by section 202(a)(1). See Section III.A.2.a above. The costs and benefits associated with the proposal are discussed above and in the Draft Regulatory Impact Analysis, as required by the UMRA.

e. Executive Order 13132: ''Federalism''

This proposed action would not have federalism implications. It will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. This rulemaking would apply to manufacturers of motor vehicles and not to state or local governments; state and local governments that purchase new model year 2017 and later vehicles will enjoy substantial fuel savings from these more fuel efficient vehicles. Thus, Executive Order 13132 does not apply to this action. Although section 6 of Executive Order 13132 does not apply to this action, EPA did consult with representatives of state and local governments in developing this action.

In the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and State and local governments, EPA specifically solicits comment on this proposed action from State and local officials.

f. Executive Order 13175: ''Consultation and Coordination with Indian Tribal Governments''

This proposed rule does not have tribal implications, as specified in Executive Order 13175 (65 FR 67249, November 9, 2000). This rule will be implemented at the Federal level and impose compliance costs only on vehicle manufacturers. Tribal governments would be affected only to the extent they purchase and use regulated vehicles; tribal governments that purchase new model year 2017 and later vehicles will enjoy substantial fuel savings from these more fuel efficient vehicles. Thus, Executive Order 13175 does not apply to this rule. EPA specifically solicits additional comment on this proposed rule from tribal officials.

g. Executive Order 13045: ''Protection of Children from Environmental Health Risks and Safety Risks''

This action is subject to EO 13045 (62 FR 19885, April 23, 1997) because it is an economically significant regulatory action as defined by EO 12866, and EPA believes that the environmental health or safety risk addressed by this action may have a disproportionate effect on children. Climate change impacts, and in particular the determinations of the Administrator in the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act (74 FR 66496, December 15, 2009), are summarized in Section III.F.2. In making those Findings, the Administrator placed weight on the fact that certain groups, including children, are particularly vulnerable to climate-related health effects. In those Findings, the Administrator determined that the health effects of climate change linked to observed and projected elevated concentrations of GHGs include the increased likelihood of more frequent and intense heat waves, increases in ozone concentrations over broad areas of the country, an increase of the severity of extreme weather events such as hurricanes and floods, and increasing severity of coastal storms due to rising sea levels. These effects can all increase mortality and morbidity, especially in

[597] In any case, any impacts on stationary sources arise because of express statutory requirements in the CAA, not as a result of vehicle GHG regulation. Moreover, GHGs have become subject to regulation under the CAA by virtue of other regulatory actions taken by EPA before this proposal.

vulnerable populations such as children, the elderly, and the poor. In addition, the occurrence of wildfires in North America have increased and are likely to intensify in a warmer future. PM emissions from these wildfires can contribute to acute and chronic illnesses of the respiratory system, including pneumonia, upper respiratory diseases, asthma, and chronic obstructive pulmonary disease, especially in children.

EPA has estimated reductions in projected global mean surface temperature and sea level rise as a result of reductions in GHG emissions associated with the standards proposed in this action (Section III.F.3). Due to their vulnerability, children may receive disproportionate benefits from these reductions in temperature and the subsequent reduction of increased ozone and severity of weather events.

The public is invited to submit comments or identify peer-reviewed studies and data that assess effects of early life exposure to the pollutants addressed by this proposed rule.

h. Executive Order 13211: ''Energy Effects''

Executive Order 13211;[598] applies to any rule that: (1) Is determined to be economically significant as defined under E.O. 12866, and is likely to have a significant adverse effect on the supply, distribution, or use of energy; or (2) that is designated by the Administrator of the Office of Information and Regulatory Affairs as a significant energy action. If the regulatory action meets either criterion, we must evaluate the adverse energy effects of the proposed rule and explain why the proposed regulation is preferable to other potentially effective and reasonably feasible alternatives considered by us.

The proposed rule seeks to establish passenger car and light truck fuel economy standards that would significantly reduce the consumption of petroleum, would achieve energy security benefits, and would not have any adverse energy effects (Section III.H.7). In fact, this rule has a positive effect on energy supply and use. Because the GHG emission standards finalized today result in significant fuel savings, this rule encourages more efficient use of fuels. Accordingly, this proposed rulemaking action is not designated as a significant energy action as defined by E.O. 13211.

[598] 66 FR 28355 (May 18, 2001).

i. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (''NTTAA''), Public Law 104–113, 12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.,* materials, specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

For CO_2 emissions, EPA is proposing to collect data over the same tests that are used for the MY 2012–2016 CO_2 standards and for the CAFE program. This will minimize the amount of testing done by manufacturers, since manufacturers are already required to run these tests. For A/C credits, EPA is proposing to use a consensus methodology developed by the Society of Automotive Engineers (SAE) and also a new A/C test. EPA knows of no consensus standard available for the A/C test.

j. Executive Order 12898: ''Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations''

Executive Order (E.O.) 12898 (59 FR 7629 (Feb. 16, 1994)) establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States.

With respect to GHG emissions, EPA has determined that this proposed rule will not have disproportionately high and adverse human health or environmental effects on minority or low-income populations because it increases the level of environmental protection for all affected populations without having any disproportionately high and adverse human health or environmental effects on any population, including any minority or low-income population. The reductions in CO_2 and other GHGs associated with the proposed standards will affect climate change projections, and EPA has estimated reductions in projected global mean surface temperatures and sea-level rise (Section III.F.3). Within settlements experiencing climate change, certain parts of the population may be especially vulnerable; these include the poor, the elderly, those already in poor health, the disabled, those living alone, and/or indigenous populations dependent on one or a few resources.[599] Therefore, these populations may receive disproportionate benefits from reductions in GHGs.

For non-GHG co-pollutants such as ozone, $PM_{2.5}$, and toxics, EPA has concluded that it is not practicable to determine whether there would be disproportionately high and adverse human health or environmental effects on minority and/or low income populations from this proposed rule.

J. Statutory Provisions and Legal Authority

Statutory authority for the vehicle controls proposed today is found in section 202(a) (which authorizes standards for emissions of pollutants from new motor vehicles which emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare), 202(d), 203–209, 216, and 301 of the Clean Air Act, 42 U.S.C. 7521(a), 7521(d), 7522, 7523, 7524, 7525, 7541, 7542, 7543, 7550, and 7601. Statutory authority for EPA to establish CAFE test procedures is found in section 32904(c) of the Energy Policy and Conservation Act, 49 U.S.C. section 32904(c).

IV. NHTSA Proposed Rule for Passenger Car and Light Truck CAFE Standards for Model Years 2017–2025

A. Executive Overview of NHTSA Proposed Rule

1. Introduction

The National Highway Traffic Safety Administration (NHTSA) is proposing Corporate Average Fuel Economy (CAFE) standards for passenger automobiles (passenger cars) and nonpassenger automobiles (light trucks) for model years (MY) 2017–2025. NHTSA's proposed CAFE standards would require passenger cars and light trucks to meet an estimated combined average of 49.6 mpg in MY 2025. This represents an average annual increase of

[599] U.S. EPA. (2009). Technical Support Document for Endangerment or Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC: U.S. EPA. Retrieved on April 21, 2009 from *http://epa.gov/climatechange/endangerment/downloads/TSD_Endangerment.pdf.*

4 percent from the estimated 34.4 mpg combined fuel economy level expected in MY 2016. Due to these proposed standards, we project total fuel savings of approximately 173 billion gallons over the lifetimes of the vehicles sold in model years 2017–2025, with corresponding net societal benefits of over $358 billion using a 3 percent discount rate,[600] or $262 billion using a 7 percent discount rate.

While NHTSA has been setting fuel economy standards since the 1970s, as discussed in Section I, NHTSA's proposed MYs 2017–2025 CAFE standards are part of a National Program made up of complementary regulations by NHTSA and the Environmental Protection Agency. Today's proposed standards build upon the success of the first phase of the National Program, finalized on May 7, 2010, in which NHTSA and EPA set coordinated CAFE and greenhouse gas (GHG) standards for MYs 2012–2016 passenger cars and light trucks. Because of the very close relationship between improving fuel economy and reducing carbon dioxide (CO_2) tailpipe emissions, a large majority of the projected benefits are achieved jointly with EPA's GHG rule, described in detail above in Section III of this preamble. These proposed CAFE standards are consistent with the President's National Fuel Efficiency Policy announcement of May 19, 2009, which called for harmonized rules for all automakers, instead of three overlapping and potentially inconsistent requirements from DOT, EPA, and the California Air Resources Board. And finally, the proposed CAFE standards and the analysis supporting them also respond to President's Obama's May 2010 memorandum requesting the agencies to develop, through notice and comment rulemaking, a coordinated National Program for passenger cars and light trucks for MYs 2017 to 2025.

2. Why does NHTSA set CAFE standards for passenger cars and light trucks?

Improving vehicle fuel economy has been long and widely recognized as one of the key ways of achieving energy independence, energy security, and a low carbon economy.[601] The significance accorded to improving fuel economy reflects several factors. Conserving energy, especially reducing the nation's dependence on petroleum, benefits the U.S. in several ways. Improving energy efficiency has benefits for economic growth and the environment, as well as other benefits, such as reducing pollution and improving security of energy supply. More specifically, reducing total petroleum use decreases our economy's vulnerability to oil price shocks. Reducing dependence on oil imports from regions with uncertain conditions enhances our energy security. Additionally, the emission of CO_2 from the tailpipes of cars and light trucks due to the combustion of petroleum is one of the largest sources of U.S. CO_2 emissions.[602] Using vehicle technology to improve fuel economy, and thereby reducing tailpipe emissions of CO_2, is one of the three main measures for reducing those tailpipe emissions of CO_2.[603] The two other measures for reducing the tailpipe emissions of CO_2 are switching to vehicle fuels with lower carbon content and changing driver behavior, *i.e.,* inducing people to drive less.

Reducing Petroleum Consumption To Improve Energy Security and Save the U.S. Money

In 1975, Congress enacted the Energy Policy and Conservation Act (EPCA), mandating that NHTSA establish and implement a regulatory program for motor vehicle fuel economy to meet the various facets of the need to conserve energy, including ones having energy independence and security, environmental, and foreign policy implications. The need to reduce energy consumption is even more crucial today than it was when EPCA was enacted. U.S. energy consumption has been outstripping U.S. energy production at an increasing rate. Improving our energy and national security by reducing our dependence on foreign oil has been a national objective since the first oil price shocks in the 1970s. Net petroleum imports accounted for approximately 51 percent of U.S. petroleum consumption in 2009.[604] World crude oil production is highly concentrated, exacerbating the risks of supply disruptions and price shocks as the recent unrest in North Africa and the Persian Gulf highlights. The export of U.S. assets for oil imports continues to be an important component of U.S. trade deficits. Transportation accounted for about 71 percent of U.S. petroleum consumption in 2009.[605] Light-duty vehicles account for about 60 percent of transportation oil use, which means that they alone account for about 40 percent of all U.S. oil consumption.

Gasoline consumption in the U.S. has historically been relatively insensitive to fluctuations in both price and consumer income, and people in most parts of the country tend to view gasoline consumption as a non-discretionary expense. Thus, when gasoline's share in consumer expenditures rises, the public experiences fiscal distress. Recent tight

[600] This value is based on what NHTSA refers to as "Reference Case" inputs, which are based on the assumptions that NHTSA has employed for its main analysis (as opposed to sensitivity analyses to examine the effect of variations in the assumptions on costs and benefits). The Reference Case inputs include fuel prices based on the AEO 2011 Reference Case, a 3 percent and a 7 percent discount rate, a 10 percent rebound effect, a value for the social cost of carbon (SCC) of $22/metric ton CO_2 (in 2010, rising to $45/metric ton in 2050, at a 3 percent discount rate), etc. For a full listing of the Reference Case input assumptions, see Section IV.C.3 below.

[601] Among the reports and studies noting this point are the following:

John Podesta, Todd Stern and Kim Batten, "Capturing the Energy Opportunity; Creating a Low-Carbon Economy," Center for American Progress (November 2007), pp. 2, 6, 8, and 24–29, available at: *http://www.americanprogress.org/issues/2007/11/pdf/energy_chapter.pdf* (last accessed Sept. 24, 2011).

Sarah Ladislaw, Kathryn Zyla, Jonathan Pershing, Frank Verrastro, Jenna Goodward, David Pumphrey, and Britt Staley, "A Roadmap for a Secure, Low-Carbon Energy Economy; Balancing Energy Security and Climate Change," World Resources Institute and Center for Strategic and International Studies (January 2009), pp. 21–22; available at: *http://pdf.wri.org/secure_low_carbon_energy_economy_roadmap.pdf* (last accessed Sept. 24, 2011).

Alliance to Save Energy *et al.,* "Reducing the Cost of Addressing Climate Change Through Energy Efficiency" (2009), available at: *http://www.aceee.org/files/pdf/white-paper/ReducingtheCostofAddressingClimateChange_synopsis.pdf* (last accessed Sept. 24, 2011).

John DeCicco and Freda Fung, "Global Warming on the Road; The Climate Impact of America's Automobiles," Environmental Defense (2006) pp. iv–vii; available at: *http://www.edf.org/sites/default/files/5301_Globalwarmingontheroad_0.pdf* (last accessed Sept. 24, 2011).

"Why is Fuel Economy Important?," a Web page maintained by the Department of Energy and Environmental Protection Agency, available at *http://www.fueleconomy.gov/feg/why.shtml* (last accessed Sept. 24, 2011);

Robert Socolow, Roberta Hotinski, Jeffery B. Greenblatt, and Stephen Pacala, "Solving The Climate Problem: Technologies Available to Curb CO_2 Emissions," Environment, volume 46, no. 10, 2004, pages 8–19, available at: *http://www.princeton.edu/mae/people/faculty/socolow/ENVIRONMENTDec2004issue.pdf* (last accessed Sept. 24, 2011).

[602] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (April 2010), pp. ES–5, ES–8, and 2–17. Available at *http://www.epa.gov/climatechange/emissions/usgginv_archive.html* (last accessed Sept. 25, 2011).

[603] Podesta *et al.,* p. 25; Ladislaw *et al.* p. 21; DeCicco *et al.* p. vii; "Reduce Climate Change, a Web page maintained by the Department of Energy and Environmental Protection Agency at *http://www.fueleconomy.gov/feg/climate.shtml* (last accessed Sept. 24, 2011).

[604] Energy Information Administration, "How dependent are we on foreign oil?" *Available at http://www.eia.gov/energy_in_brief/foreign_oil_dependence.cfm* (last accessed August 28, 2011).

[605] Energy Information Administration, Annual Energy Outlook 2011, "Oil/Liquids." *Available at http://www.eia.gov/forecasts/aeo/MT_liquidfuels.cfm* (last accessed August 28, 2011).

global oil markets led to prices over $100 per barrel, with gasoline reaching as high as $4 per gallon in many parts of the U.S., causing financial hardship for many families and businesses. This fiscal distress can, in some cases, have macroeconomic consequences for the economy at large.

Additionally, since U.S. oil production is only affected by fluctuations in prices over a period of years, any changes in petroleum consumption (as through increased fuel economy levels for the on-road fleet) largely flow into changes in the quantity of imports. Since petroleum imports account for about 2 percent of GDP, increases in oil imports can create a discernible fiscal drag. As a consequence, measures that reduce petroleum consumption, like fuel economy standards, will directly benefit the balance-of-payments account, and strengthen the U.S. economy to some degree. And finally, U.S. foreign policy has been affected by decades by rising U.S. and world dependency on crude oil as the basis for modern transportation systems, although fuel economy standards have at best an indirect impact on U.S. foreign policy.

Reducing Petroleum Consumption To Reduce Climate Change Impacts

CO_2 is the natural by-product of the combustion of fuel to power motor vehicles. The more fuel-efficient a vehicle is, the less fuel it needs to burn to travel a given distance. The less fuel it burns, the less CO_2 it emits in traveling that distance.[606] Since the amount of CO_2 emissions is essentially constant per gallon combusted of a given type of fuel, the amount of fuel consumption per mile is closely related to the amount of CO_2 emissions per mile. Motor vehicles are the second largest GHG-emitting sector in the U.S. after electricity generation, and accounted for 27 percent of total U.S. GHG emissions in 2008.[607] Concentrations of greenhouse gases are at unprecedented levels compared to the recent and distant past, which means that fuel economy improvements to reduce those emissions are a crucial step toward addressing the risks of global climate change. These risks are well documented in Section III of this notice, and in NHTSA's draft Environmental Impact Statement (DEIS) accompanying these proposed standards.

Fuel economy gains since 1975, due both to the standards and to market factors, have resulted in saving billions of barrels of oil and avoiding billions of metric tons of CO_2 emissions. In December 2007, Congress enacted the Energy Independence and Security Act (EISA), amending EPCA to require substantial, continuing increases in fuel economy. NHTSA thus sets CAFE standards today under EPCA, as amended by EISA, in order to help the U.S. passenger car and light truck fleet save fuel to promote energy independence, energy security, and a low carbon economy.

3. Why is NHTSA proposing CAFE standards for MYs 2017–2025 now?

a. President's Memorandum

During the public comment period for the MY 2012–2016 proposed rulemaking, many stakeholders encouraged NHTSA and EPA to begin working toward standards for MY 2017 and beyond in order to maintain a single nationwide program. After the publication of the final rule establishing MYs 2012–2016 CAFE and GHG standards, President Obama issued a Memorandum on May 21, 2010 requesting that NHTSA, on behalf of the Department of Transportation, and EPA work together to develop a national program for model years 2017–2025.[608] Specifically, he requested that the agencies develop *''* * * a coordinated national program under the CAA [Clean Air Act] and the EISA [Energy Independence and Security Act of 2007] to improve fuel efficiency and to reduce greenhouse gas emissions of passenger cars and light-duty trucks of model years 2017–2025.''* The President recognized that our country could take a leadership role in addressing the global challenges of improving energy security and reducing greenhouse gas pollution, stating that *''America has the opportunity to lead the world in the development of a new generation of clean cars and trucks through innovative technologies and manufacturing that will spur economic growth and create high-quality domestic jobs, enhance our energy security, and improve our environment.''*

The Presidential Memorandum stated *''The program should also seek to achieve substantial annual progress in reducing transportation sector greenhouse gas emissions and fossil fuel consumption, consistent with my Administration's overall energy and climate security goals, through the increased domestic production and use of existing, advanced, and emerging technologies, and should strengthen the industry and enhance job creation in the United States.''* Among other things, the agencies were tasked with researching and then developing standards for MYs 2017 through 2025 that would be appropriate and consistent with EPA's and NHTSA's respective statutory authorities, in order to continue to guide the automotive sector along the road to reducing its fuel consumption and GHG emissions, thereby ensuring corresponding energy security and environmental benefits. Several major automobile manufacturers and CARB sent letters to EPA and NHTSA in support of a MYs 2017 to 2025 rulemaking initiative as outlined in the President's May 21, 2010 announcement.[609] The agencies began working immediately on the next phase of the National Program, work which has culminated in the standards proposed in this notice for MYs 2017–2025.

b. Benefits of Continuing the National Program

The National Program is both needed and possible because the relationship between improving fuel economy and reducing CO_2 tailpipe emissions is a very close one. In the real world, there is a single pool of technologies for reducing fuel consumption and CO_2 emissions. Using these technologies in the way that minimizes fuel consumption also minimizes CO_2 emissions. While there are emission control technologies that can capture or destroy the pollutants that are produced by imperfect combustion of fuel (*e.g.,* carbon monoxide), there are at present no such technologies for CO_2. In fact, the only way at present to reduce tailpipe emissions of CO_2 is by reducing

[606] Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, ''Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base,'' National Academies Press, 1992, at 287. *Available at http://www.nap.edu/catalog.php?record_id=1605* (last accessed Sept. 25, 2011).

[607] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008 (April 2010), p. 2–17. Available at *http://www.epa.gov/climatechange/emissions/usgginv_archive.html* (last accessed Sept. 25, 2011).

[608] The Presidential Memorandum is found at: *http://www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards.* For the reader's reference, the President also requested the Administrators of EPA and NHTSA to issue joint rules under the CAA and EISA to establish fuel efficiency and greenhouse gas emissions standards for commercial medium-and heavy-duty on-highway vehicles and work trucks beginning with the 2014 model year. The agencies recently promulgated final GHG and fuel efficiency standards for heavy duty vehicles and engines for MYs 2014–2018. 76 FR 57106 (September 15, 2011).

[609] These commitment letters in response to the May 21, 2010 Presidential Memorandum are available at *http://www.epa.gov/otaq/climate/proposedregs.htm#cl*; and *http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Stakeholder+Commitment+Letters* (last accessed August 28, 2011).

fuel consumption. The National Program thus has dual benefits: it conserves energy by improving fuel economy, as required of NHTSA by EPCA and EISA; in the process, it necessarily reduces tailpipe CO_2 emissions consonant with EPA's purposes and responsibilities under the Clean Air Act.

Additionally, by setting harmonized Federal standards to regulate both fuel economy and greenhouse gas emissions, the agencies are able to provide a predictable regulatory framework for the automotive industry while preserving the legal authorities of NHTSA, EPA, and the State of California. Consistent, harmonized, and streamlined requirements under the National Program, both for MYs 2012–2016 and for MYs 2017–2025, hold out the promise of continuing to deliver energy and environmental benefits, cost savings, and administrative efficiencies on a nationwide basis that might not be available under a less coordinated approach. The National Program makes it possible for the standards of two different Federal agencies and the standards of California and other ''Section 177'' states to act in a unified fashion in providing these benefits. A harmonized approach to regulating passenger car and light truck fuel economy and GHG emissions is critically important given the interdependent goals of addressing climate change and ensuring energy independence and security. Additionally, a harmonized approach would help to mitigate the cost to manufacturers of having to comply with multiple sets of Federal and State standards.

One aspect of this phase of the National Program that is unique for NHTSA, however, is that the passenger car and light truck CAFE standards for MYs 2022–2025 must be conditional, while EPA's standards for those model years will be legally binding when adopted in this round. EISA requires NHTSA to issue CAFE standards for ''at least 1, but not more than 5, model years.'' [610] To maintain the harmonization benefits of the National Program, NHTSA will therefore propose and adopt standards for all 9 model years from 2017–2025, but the last 4 years of standards will not be legally binding as part of this rulemaking. The passenger car and light truck CAFE standards for MYs 2022–2025 will be determined with finality in a subsequent, *de novo* notice and comment rulemaking conducted in full compliance with EPCA/EISA and other applicable law—beyond simply reviewing the analysis and findings in the present rulemaking to see whether they are still accurate and applicable, and taking a fresh look at all relevant factors based on the best and most current information available at that future time.

To facilitate that future effort, NHTSA and EPA will conduct a comprehensive mid-term evaluation. Up to date information will be developed and compiled for the evaluation, through a collaborative, robust, and transparent process, including notice and comment. The agencies fully expect to conduct the mid-term evaluation in close coordination with the California Air Resources Board (CARB), consistent with the agencies' commitment to maintaining a single national framework for regulation of fuel economy and GHG emissions.[611] Prior to beginning NHTSA's rulemaking process and EPA's mid-term evaluation, the agencies will jointly prepare a draft Technical Assessment Report (TAR) to examine afresh the issues and, in doing so, conduct similar analyses and projections as those considered in the current rulemaking, including technical and other analyses and projections relevant to each agency's authority to set standards as well as any relevant new issues that may present themselves. The agencies will provide an opportunity for public comment on the draft TAR, and appropriate peer review will be performed of underlying analyses in the TAR. The assumptions and modeling underlying the TAR will be available to the public, to the extent consistent with law. The draft TAR is expected to be issued no later than November 15, 2017. After the draft TAR and public comment, the agencies will consult and coordinate as NHTSA develops its NPRM. NHTSA will ensure that the subsequent final rule will be timed to provide sufficient lead time for industry to make whatever changes to their products that the rulemaking analysis deems maximum feasible based on the new information available. At the very latest, NHTSA will complete its subsequent rulemaking on the standards with at least 18 months lead time as required by EPCA,[612] but additional lead time may be provided.

B. Background

1. Chronology of Events Since the MY 2012–2016 Final Rule Was Issued

Section I above covers the chronology of events in considerable detail, and we refer the reader there.

2. How has NHTSA developed the proposed CAFE standards since the President's announcement?

The CAFE standards proposed in this NPRM are based on much more analysis conducted by the agencies since July 29, including in-depth modeling analysis by DOT/NHTSA to support the proposed CAFE standards, and further refinement of a number of our baseline, technology, and economic assumptions used to evaluate the proposed standards and their impacts. This NPRM, the draft joint TSD, and NHTSA's PRIA and EPA's DRIA contain much more information about the analysis underlying these proposed standards. The following sections provide the basis for NHTSA's proposed passenger car and light truck CAFE standards for MYs 2017–2025, the standards themselves, the estimated impacts of the proposed standards, and much more information about the CAFE program relevant to the 2017–2025 timeframe.

C. Development and Feasibility of the Proposed Standards

1. How was the baseline vehicle fleet developed?

a. Why do the agencies establish a baseline and reference vehicle fleet?

As also discussed in Section II.B above, in order to determine what levels of stringency are feasible in future model years, the agencies must project what vehicles will exist in those model years, and then evaluate what technologies can feasibly be applied to those vehicles in order to raise their fuel economy and lower their CO_2 emissions. The agencies therefore established a ''baseline'' vehicle fleet representing those vehicles, based on the best available transparent information. The agencies then developed a ''reference'' fleet, projecting the baseline fleet sales into MYs 2017–2025 and accounting for the effect that the MY 2012–2016 CAFE standards have on the baseline fleet.[613] This

[610] 49 U.S.C. 32902(b)(3)(B).

[611] The agencies also fully expect that any adjustments to the standards as a result of the mid-term evaluation process from the levels enumerated in the current rulemaking will be made with the participation of CARB and in a manner that continues the harmonization of state and Federal vehicle standards.

[612] 49 U.S.C. 32902(a).

[613] In order to calculate the impacts of the proposed future GHG and CAFE standards, it is necessary to estimate the composition of the future vehicle fleet absent those proposed standards in order to conduct comparisons. The first step in this process was to develop a fleet based on model year 2008 data. This 2008-based fleet includes vehicle sales volumes, GHG/fuel economy performance, and contains a listing of the base technologies on every 2008 vehicle sold. The second step was to

reference fleet is then used for comparisons of technologies' incremental cost and effectiveness, as well as for other relevant comparisons in the rule.

b. What data did the agencies use to construct the baseline, and how did they do so?

As explained in the draft joint TSD, both agencies used a baseline vehicle fleet constructed beginning with EPA fuel economy certification data for the 2008 model year, the most recent model year for which final data is currently available from manufacturers. These data were used as the source for MY 2008 production volumes and some vehicle engineering characteristics, such as fuel economy compliance ratings, engine sizes, numbers of cylinders, and transmission types.

For this NPRM, NHTSA and EPA chose again to use MY 2008 vehicle data as the basis of the baseline fleet. MY 2008 is now the most recent model year for which the industry had what the agencies would consider to be ''normal'' sales. Complete MY 2009 data is now available for the industry, but the agencies believe that the model year was disrupted by the economic downturn and the bankruptcies of both General Motors and Chrysler. CAFE compliance data shows that there was a significant reduction in the number of vehicles sold by both companies and by the industry as a whole. These abnormalities led the agencies to conclude that MY 2009 data was likely not representative for projecting the future fleet for purposes of this analysis. While MY 2010 data is likely more representative for projecting the future fleet, it was not complete and available in time for it to be used for the NPRM analysis. Therefore, for purposes of the NPRM analysis, NHTSA and EPA chose to use MY 2008 CAFE compliance data for the baseline since it was the latest, most representative transparent data set that we had available. However, the agencies plan to use the MY 2010 data, if available, to develop an updated market forecast for use in the final rule. If and when the MY 2010 data becomes available, NHTSA will place a copy of this data into its rulemaking docket.

Some information important for analyzing new CAFE standards is not contained in the EPA fuel economy certification data. EPA staff estimated vehicle wheelbase and track widths using data from Motortrend.com and Edmunds.com. This information is necessary for estimating vehicle footprint, which is required for the analysis of footprint-based standards.

Considerable additional information regarding vehicle engineering characteristics is also important for estimating the potential to add new technologies in response to new CAFE standards. In general, such information helps to avoid ''adding'' technologies to vehicles that already have the same or a more advanced technology. Examples include valvetrain configuration (*e.g.,* OHV, SOHC, DOHC), presence of cylinder deactivation, and fuel delivery (*e.g.,* MPFI, SIDI). To the extent that such engineering characteristics were not available in certification data, EPA staff relied on data published by Ward's Automotive, supplementing this with information from Internet sites such as Motortrend.com and Edmunds.com. NHTSA staff also added some more detailed engineering characteristics (*e.g.,* type of variable valve timing) using data available from ALLDATA® Online. Combined with the certification data, all of this information yielded the MY 2008 baseline vehicle fleet. NHTSA also reviewed information from manufacturers' confidential product plans submitted to the agency, but did not rely on that information for developing the baseline or reference fleets.

After the baseline was created the next step was to project the sales volumes for 2017–2025 model years. EPA used projected car and truck volumes for this period from Energy Information Administration's (EIA's) 2011 Interim Annual Energy Outlook (AEO).[614] However, AEO projects sales only at the car and truck level, not at the manufacturer and model-specific level, which are needed in order to estimate the effects new standards will have on individual manufacturers. Therefore, EPA purchased data from CSM–Worldwide and used their projections of the number of vehicles of each type predicted to be sold by manufacturers in 2017–2025.[615] This provided the year-by-year percentages of cars and trucks sold by each manufacturer as well as the percentages of each vehicle segment. Using these percentages normalized to the AEO projected volumes then provided the manufacturer-specific market share and model-specific sales for model years 2011–2016.

The processes for constructing the MY 2008 baseline vehicle fleet and subsequently adjusting sales volumes to construct the MY 2017–2025 baseline vehicle fleet are presented in detail in Chapter 1 of the Joint Technical Support Document accompanying today's proposed rule.

The agencies assume that without adoption of the proposed rule, that during the 2017–2025 period, manufacturers will not improve fuel economy levels beyond the levels required in the MY 2016 standards. However, it is possible that manufacturers may be driven by market forces to raise the fuel economy of their fleets. The recently-adopted fuel economy and environment labels (''window stickers''), for example, may make consumers more aware of the benefits of higher fuel economy, and may cause them to demand more fuel-efficient vehicles during that timeframe. Moreover, the agencies' analysis indicates that some fuel-saving technologies may save money for manufacturers. In Chapter X of the PRIA, NHTSA examines the impact of an alternative ''market-driven'' baseline, which allows for some increases in fuel economy due to ''voluntary overcompliance'' beyond the MY 2016 levels. NHTSA seeks comment on what assumptions about fuel economy increases are most likely to accurately predict what would happen in the absence of the proposed rule.

NHTSA invites comment on the process used to develop the market forecast, and on whether the agencies should consider alternative approaches to producing a forecast at the level of detail we need for modeling. If commenters wish to offer alternatives, we ask that they address how manufacturers' future fleets would be

project that 2008-based fleet volume into MYs 2017–2025. This is called the reference fleet, and it represents the fleet volumes (but, until later steps, not levels of technology) that the NHTSA and EPA expect would exist in MYs 2017–2025 absent any change due to regulation in 2017–2025.

After determining the reference fleet, a third step is needed to account for technologies (and corresponding increases in cost and reductions in fuel consumption and CO_2 emissions) that could be added to MY 2008-technology vehicles in the future, taking into previously-promulgated standards, and assuming MY 2016 standards are extended through MY2025. NHTSA accomplished this by using the CAFE model to add technologies to that MY 2008-based market forecast such that each manufacturer's car and truck CAFE and average CO_2 levels reflect baseline standards. The model's output, the reference case (or adjusted baseline, or no-action alternative), is the light-duty fleet estimated to exist in MYs 2017–2025 without new GHG/CAFE standards covering MYs 2017–2025.

[614] Department of Energy, Energy Information Administration, Annual Energy Outlook (AEO) 2011, Early Release. *Available at http://www.eia.gov/forecasts/aeo/.* Both agencies regard AEO a credible source not only of such forecasts, but also of many underlying forecasts, including forecasts of the size of the future light vehicle market. The agencies used the early release version of AEO 2011 and confirmed later that changes reflected in the final version were insignificant with respect to the relative volumes of passenger cars and light trucks.

[615] The agencies explain in Chapter I of the draft Joint TSD why data from CSM was chosen for creating the baseline for this rulemaking.

defined in terms of specific products, and the sales volumes and technical characteristics (*e.g.,* fuel economy, technology content, vehicle weight, and other engineering characteristics) of those products. The agency also invites comment regarding what sensitivity analyses—if any—we should do related to the market forecast. For example, should the agency evaluate the extent to which its analysis is sensitive to projections of the size of the market, manufacturers' respective market shares, the relative growth of different market segments, and or the relative growth of the passenger car and light truck markets? If so, how would commenters suggest that we do that?

c. How is the development of the baseline fleet for this rule different from the baseline fleet that NHTSA used for the MY 2012–2016 (May 2010) final rule?

The development of the baseline fleet for this rulemaking utilizes the same procedures used in the development of the baseline fleet for the MY 2012–2016 rulemaking. Compared to that rulemaking, the change in the baseline is much less dramatic—the MY 2012–2016 rulemaking was the first rulemaking in which NHTSA did not use manufacturer product plan data to develop the baseline fleet,[616] so evaluating the difference between the baseline fleet used in the MY 2011 final rule and in the MY 2012–2016 rulemaking was informative at that time regarding some of the major impacts of that switch. In this proposal, we are using basically the same MY 2008 based file as the starting point in the MY 2012–2016 analysis, and simply using an updated AEO forecast and an updated CSM forecast. Of those, most differences are in input assumptions rather than the basic approach and methodology. These include changes in various macroeconomic assumptions underlying the AEO and CSM forecasts and the use of results obtained by using DOE's National Energy Modeling System (NEMS) to repeat the AEO 2011 analysis without forcing increased passenger car volumes, and without assuming post-MY 2016 increases in the stringency of CAFE standards.[617]

Another change in the baseline fleet from the last rulemaking involved our redefinition of the list of manufacturers to account for realignment and ownership changes taking place within the industry. The reported results supporting this rulemaking recognize that Volvo vehicles are no longer a part of Ford, but are reported as a separate company, Geely; that Saab vehicles are no longer part of GM, but are reported as part of Spyker which purchased Saab from GM in 2010; and that Chrysler, along with Ferrari and Maserati, are reported as Fiat.

In addition, low volume specialty manufacturers omitted from the analysis supporting the MY 2012–2016 rulemaking have been included in the analysis supporting this rulemaking. These include Aston Martin, Lotus, and Tesla.

d. How is this baseline different quantitatively from the baseline that NHTSA used for the MY 2012–2016 (May 2010) final rule?

As discussed above, the current baseline was developed from adjusted MY 2008 compliance data and covers MY 2017–2025. This section describes, for the reader's comparison, some of the differences between the current baseline and the MY 2012–2016 CAFE rule baseline. This comparison provides a basis for understanding general characteristics and measures of the difference between the two baselines. The current baseline, while developed using the same methods as the baseline used for MY 2012–2016 rulemaking, reflects updates to the underlying commercially-available forecast of manufacturer and market segment shares of the future passenger car and light truck market. Again, the differences are in input assumptions rather than the basic approach and methodology. It also includes changes in various macroeconomic assumptions underlying the AEO forecasts and the use of the AEO Unforced Reference Case. Another change in the market input data from the last rulemaking involved our redefinition of the list of manufacturers to account for realignment taking place within the industry.

Estimated vehicle sales:

The sales forecasts, based on the Energy Information Administration's (EIA's) Early Annual Energy Outlook for 2011 (Interim AEO 2011), used in the current baseline indicate that the total number of light vehicles expected to be sold during MYs 2012–2016 is 79 million, or about 15.8 million vehicles annually. NHTSA's MY 2012–2016 final rule forecast, based on AEO 2010, of the total number of light vehicles likely to be sold during MY 2012 through MY 2016 was 80 million, or about 16 million vehicles annually. Light trucks are expected to make up 37 percent of the MY 2016 baseline market forecast in the current baseline, compared to 34 percent of the baseline market forecast in the MY 2012–2016 final rule. These changes in both the overall size of the light vehicle market and the relative market shares of passenger cars and light trucks reflect changes in the economic forecast underlying AEO, changes in AEO's forecast of future fuel prices, and use of the Unforced Reference Case.

Estimated manufacturer market shares:

These changes are reflected below in Table IV–1, which shows the agency's sales forecasts for passenger cars and light trucks under the current baseline and the MY 2012–2016 final rule. There has been a general decrease in MY 2016 forecast overall sales (from AEO) and for all manufacturers (reflecting CSM's forecast of manufacturers' market shares), with the exception of Chrysler, when the current baseline is compared to that used in the MY 2012–2016 rulemaking. There were no significant shifts in manufacturers' market shares between the two baselines. The effect of including the low volume specialty manufacturers and accounting for known corporate realignments in the current baseline appear to be negligible. For individual manufacturers, there have been shifts in the shares of passenger car and light trucks, as would

[616] The agencies' reasons for not relying on product plan data for the development of the baseline fleet were discussed in the Regulatory Impact Analysis for the MYs 2012–2016 rulemaking and at 74 FR 49487–89. While a baseline developed using publicly and commercially available sources has both advantages and disadvantages relative to a baseline developed using manufacturers' product plans, NHTSA currently concludes, as it did in the course of that prior rulemaking, that the advantages outweigh the disadvantages. Commenters generally supported the more transparent approach employed in the MYs 2012–2016 rulemaking.

[617] Similar to the analyses supporting the MYs 2012–2016 rulemaking, the agencies have used the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate the future relative market shares of passenger cars and light trucks. However, NEMS methodology includes shifting vehicle sales volume, starting after 2007, away from fleets with lower fuel economy (the light-truck fleet) towards vehicles with higher fuel economies (the passenger car fleet) in order to facilitate compliance with CAFE and GHG MYs 2012–2016 standards. Because we use our market projection as a baseline relative to which we measure the effects of new standards, and we attempt to estimate the industry's ability to comply with new standards without changing product mix, the Interim AEO 2011-projected shift in passenger car market share as a result of required fuel economy improvements creates a circularity. Therefore, for the current analysis, the agencies developed a new projection of passenger car and light truck sales shares by running scenarios from the Interim AEO 2011 reference case that first deactivate the above-mentioned sales-volume shifting methodology and then hold post-2017 CAFE standards constant at MY 2016 levels. Incorporating these changes reduced the projected passenger car share of the light vehicle market by an average of about 5 percent during 2017–2025. NHTSA and EPA refer to this as the ''Unforced Reference Case.''

be expected given that the agency is relying on different underlying assumptions as discussed above and in Chapter 1 of the joint TSD.

[618] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012–2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

Table IV-1. Sales Forecasts [Production for U.S. sale in MY 2016, thousand units]

Manufacturer	MY 2012-2016 Final Rule[618]		Current Baseline	
	Passenger	Nonpassenger	Passenger	Nonpassenger
Aston Martin			1	
BMW	423	171	383	184
Daimler	271	126	245	136
Fiat/Chrysler	400	462	392	498
Ford	1,559	911	1,393	930
Geely/Volvo			94	50
General Motors	1,514	1,342	1,391	1,444
Honda	930	545	862	588
Hyundai	518	92	489	99
Kia	548	115	512	124
Lotus			0.3	
Mazda	420	72	393	78
Mitsubishi	83	55	80	60
Nissan	946	381	869	410
Porsche	33	17	30	18
Spyker/Saab			18	2
Subaru	207	117	236	74
Suzuki	103	20	94	21
Tata	65	42	59	46
Tesla			27	
Toyota	2,226	1,077	2,043	1,159
Volkswagen	583	124	528	134
Total	10,832	5,669	10,139	6,055

Estimated achieved fuel economy levels:

The current baseline market forecast shows industry-wide average fuel economy levels somewhat lower in MY 2016 than shown in the baseline market forecast for the MY 2012–2016 rulemaking. Under the current baseline, average fuel economy for MY 2016 is 27.0 mpg, versus 27.3 mpg under the baseline in the MY 2012–2016 rulemaking. The 0.3 mpg change relative to the MY 2012–2016 rulemaking's baseline is the result of changes in the shares of passenger car and light trucks in the MY 2016 market as noted above—more light trucks generally equals lower average fuel economy—and not the result of changes in the capabilities of the car and truck fleets.

These differences are shown in greater detail below in Table IV–2, which shows manufacturer-specific CAFE levels (not counting FFV credits that some manufacturers expect to earn) from the current baseline versus the MY 2012–2016 rulemaking baseline for passenger cars and light trucks. Table IV–3 shows the combined averages of these planned CAFE levels in the respective baseline fleets. These tables demonstrate that there are no significant differences in CAFE for either passenger cars or light trucks at the manufacturer level between the current baseline and the MY 2012–2016 rulemaking baseline. The differences become more significant at the manufacturer level when combined CAFE levels are considered. Here we see a general decline in CAFE at the manufacturer level due to the increased share of light trucks. Because the agencies have, as for the MY 2012–2016 rulemaking, based this market forecast on vehicles in the MY 2008 fleet, these changes in CAFE levels reflect changes in vehicle mix, not changes in the fuel economy achieved by individual vehicle models.

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Table IV-2. Current Baseline CAFE Levels in MY 2016 versus MY 2012-2016 Rulemaking CAFE Levels

Manufacturer	MY 2012-2016 Final Rule[619]		Current Baseline	
	Passenger	Non passenger	Passenger	Non passenger
Aston Martin			18.83	
BMW	27.19	23.04	27.19	23.03
Daimler	25.25	21.12	25.50	21.13
Fiat/Chrysler	28.69	22.19	27.74	22.19
Ford	28.14	21.31	28.24	21.32
Geely/Volvo			25.89	21.08
General Motors	28.42	21.45	28.38	21.45
Honda	33.98	25.05	33.83	25.02
Hyundai	32.02	24.30	31.74	24.29
Kia	32.98	23.74	32.70	23.74
Lotus			29.66	
Mazda	30.94	26.41	30.77	26.40
Mitsubishi	28.94	23.59	28.86	23.57
Nissan	32.04	22.11	31.98	22.10
Porsche	26.22	19.98	26.22	19.98
Spyker/Saab			26.54	19.79
Subaru	29.44	26.91	29.59	27.37
Suzuki	30.84	23.29	30.77	23.29
Tata	24.58	19.74	24.58	19.71
Tesla			244.00	
Toyota	35.33	24.25	35.22	24.26
Volkswagen	28.99	20.23	28.90	20.24
Total/Average	30.73	22.59	30.65	22.56

[619] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012–2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

Table IV-3. Current Baseline CAFE Levels in MY 2016 versus MY 2012-2016 Rulemaking

CAFE Levels (Combined)

Manufacturer	MY 2012-2016 Final Rule[620]	Current Baseline
Aston Martin		18.83
BMW	25.85	25.68
Daimler	23.77	23.75
Fiat/Chrysler	24.79	24.33
Ford	25.17	24.99
Geely/Volvo		23.99
General Motors	24.66	24.37
Honda	30.03	29.61
Hyundai	30.56	30.18
Kia	30.89	30.46
Lotus		29.66
Mazda	30.18	29.95
Mitsubishi	26.53	26.33
Nissan	28.38	27.97
Porsche	23.74	23.48
Spyker/Saab		25.70
Subaru	28.47	29.03
Suzuki	29.30	29.04
Tata	22.42	22.19
Tesla		244.00
Toyota	30.75	30.27
Volkswagen	26.94	26.60
Total/Average	27.34	27.03

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e. How does manufacturer product plan data factor into the baseline used in this rule?

In December 2010, NHTSA requested that manufacturers provide information regarding future product plans, as well as information regarding the context for those plans (*e.g.,* estimates of future fuel prices), and estimates of the future availability, cost, and efficacy of fuel-saving technologies.[621] The purpose of this request was to acquire updated information regarding vehicle manufacturers' future product plans to assist the agency in assessing what corporate CAFE standards should be established for passenger cars and light trucks manufactured in model years 2017 and beyond. The request was being issued in preparation for today's joint NPRM.

NHTSA indicated that it requested information for MYs 2010–2025 primarily as a basis for subsequent discussions with individual manufacturers regarding their capabilities for the MYs 2017–2025 time frame as it worked to develop today's NPRM. NHTSA indicated that the information received would supplement other information to be used by NHTSA to develop a realistic forecast of the vehicle market in MY 2017 and beyond, and to evaluate what technologies may feasibly be applied by manufacturers to

[620] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012–2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

[621] 75 FR 80430.

achieve compliance with potential future standards. NHTSA further indicated that information regarding later model years could help the agency gain a better understanding of how manufacturers' plans through MY 2025 relate to their longer-term expectations regarding foreseeable regulatory requirements, market trends, and prospects for more advanced technologies.

NHTSA also indicated that it would consider information regarding the model years requested when considering manufacturers' planned schedules for redesigning and freshening their products, in order to examine how manufacturers anticipate tying technology introduction to product design schedules. In addition, the agency requested information regarding manufacturers' estimates of the future vehicle population, and fuel economy improvements and incremental costs attributed to technologies reflected in those plans.

Given the importance that responses to this request for comment may have in informing NHTSA's proposed CAFE rulemaking, whether as part of the basis for the standards or as an independent check on them, NHTSA requested that commenters fully respond to each question, particularly by providing information regarding the basis for technology costs and effectiveness estimates.

We have already noted that in past CAFE rulemakings, NHTSA used manufacturers' product plans—and other information—to build market forecasts providing the foundation for the agency's rulemaking analysis. This issue has been the subject of much debate over the past several rulemakings since NHTSA began actively working on CAFE again following the lifting of the appropriations riders in 2001. The agency continues to believe that these market forecasts reflected the most technically sound forecasts the agency could have then developed for this purpose. Because the agency could not disclose confidential business information in manufacturers' product plans, NHTSA provided summarized information, such as planned CAFE levels and technology application rates, rather than the fuel economy levels and technology content of specific vehicle model types.

In preparing the MY 2012–2016 rule jointly with EPA, however, NHTSA revisited this practice, and concluded that for that rulemaking, it was important that all reviewers have equal access to all details of NHTSA's analysis. NHTSA provided this level of transparency by releasing not only the agency's CAFE modeling system, but also by releasing all model inputs and outputs for the agency's analysis, all of which are available on NHTSA's Web site at *http://www.nhtsa.gov/fuel-economy*. Therefore, NHTSA worked with EPA, as it did in preparing for analysis supporting today's proposal, to build a market forecast based on publicly- and commercially-available sources. NHTSA continues to believe that the potential technical benefits of relying on manufacturers' plans for future products are outweighed by the transparency gained in building a market forecast that does not rely on confidential business information, but also continues to find product plan information to be an important point of reference for meetings with individual manufacturers. We seek comment on what value manufacturer product plan might have in the future, and whether it continues to be useful to request manufacturer product plans to inform rulemaking analyses, specifically the baseline forecast used in rulemaking analyses.

f. What sensitivity analyses is NHTSA conducting on the baseline?

As discussed below in Section IV.G, when evaluating the potential impacts of new CAFE standards, NHTSA considered the potential that, depending on how the cost and effectiveness of available technologies compare to the price of fuel, manufacturers would add more fuel-saving technology than might be required solely for purposes of complying with CAFE standards. This reflects that agency's consideration that there could, in the future, be at least *some* market for fuel economy improvements beyond the required MY 2016 CAFE levels. In this sensitivity analysis, this causes some additional technology to be applied, more so under baseline standards than under the more stringent standards proposed today by the agency. Results of this sensitivity analysis are summarized in Section IV.G and in NHTSA's PRIA accompanying today's notice.

g. How else is NHTSA considering looking at the baseline for the final rule?

Beyond the sensitivity analysis discussed above, NHTSA is also considering developing and using a vehicle choice model to estimate the extent to which sales volumes would shift in response to changes in vehicle prices and fuel economy levels. As discussed IV.C.4, the agency is currently sponsoring research directed toward developing such a model. If that effort is successful, the agency will consider integrating the model into the CAFE modeling system and using the integrated system for future analysis of potential CAFE standards. If the agency does so, we expect that the vehicle choice model would impact estimated fleet composition not just under new CAFE standards, but also under baseline CAFE standards.

2. How were the technology inputs developed?

As discussed above in Section II.E, for developing the technology inputs for these proposed MYs 2017–2025 CAFE and GHG standards, the agencies primarily began with the technology inputs used in the MYs 2012–2016 CAFE final rule and in the 2010 TAR. The agencies have also updated information based on newly completed FEV tear down studies and new vehicle simulation work conducted by Ricardo Engineering, both of which were contracted by EPA. Additionally, the agencies relied on a model developed by Argonne National Laboratory to estimate hybrid, plug-in hybrid and electric vehicle battery costs. More detail is available regarding how the agencies developed the technology inputs for this proposal above in Section II.E, in Chapter 3 of the Joint TSD, and in Section V of NHTSA's PRIA.

a. What technologies does NHTSA consider?

Section *II.E.*1 above describes the fuel-saving technologies considered by the agencies that manufacturers could use to improve the fuel economy of their vehicles during MYs 2017–2025. Many of the technologies described in this section are readily available, well known, and could be incorporated into vehicles once production decisions are made. Other technologies, added for this rulemaking analysis, are considered that are not currently in production, but are beyond the initial research phase, under development and are expected to be in production in the next 5–10 years. As discussed, the technologies considered fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, and hybrid technologies. Table IV–4 below lists all the technologies considered and provides the abbreviations used for them in the CAFE model,[622] as well as their year of availability, which for purposes of NHTSA's analysis means the first model year in the rulemaking

[622] The abbreviations are used in this section both for brevity and for the reader's reference if they wish to refer to the expanded decision trees and the model input and output sheets, which are available in Docket No. NHTSA–2010–0131 and on NHTSA's Web site.

period that the CAFE model is allowed to apply a technology to a manufacturer's fleet.[623] ''Year of availability'' recognizes that technologies must achieve a level of technical viability before they can be implemented in the CAFE model, and are thus a means of constraining technology use until such time as it is considered to be technologically feasible. For a more detailed description of each technology and their costs and effectiveness, we refer the reader to Chapter 3 of the Joint TSD and Section V of NHTSA's PRIA.

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[622] The abbreviations are used in this section both for brevity and for the reader's reference if they wish to refer to the expanded decision trees and the model input and output sheets, which are available in Docket No. NHTSA–2010–0131 and on NHTSA's Web site.

Table IV-4. List of Technologies in NHTSA's Analysis

Technology	Model abbreviation	Year available
Low Friction Lubricants - Level 1	LUB1	2007
Engine Friction Reduction - Level 1	EFR1	2007
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	2017
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	2007
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	2007
Cylinder Deactivation on SOHC	DEACS	2007
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2007
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	2007
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	2007
Continuously Variable Valve Lift (CVVL)	CVVL	2007
Cylinder Deactivation on DOHC	DEACD	2007
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2007
Cylinder Deactivation on OHV	DEACO	2007
Variable Valve Actuation - CCP and DVVL on OHV	VVA	2007
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	2007

Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	TRBDS1_SD	2007
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	TRBDS1_MD	2007
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	TRBDS1_LD	2007
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	TRBDS2_SD	2012
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	TRBDS2_MD	2012
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	TRBDS2_LD	2012
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2012
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	2012
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	2012
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	2017
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	2017

Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	2017
Advanced Diesel - Small Displacement	ADSL_SD	2017
Advanced Diesel - Medium Displacement	ADSL_MD	2017
Advanced Diesel - Large Displacement	ADSL_LD	2017
6-Speed Manual/Improved Internals	6MAN	2007
High Efficiency Gearbox (Manual)	HETRANSM	2017
Improved Auto. Trans. Controls/Externals	IATC	2007
6-Speed Trans with Improved Internals (Auto)	NAUTO	2007
6-speed DCT	DCT	2007
8-Speed Trans (Auto or DCT)	8SPD	2014
High Efficiency Gearbox (Auto or DCT)	HETRANS	2017
Shift Optimizer	SHFTOPT	2017
Electric Power Steering	EPS	2007
Improved Accessories - Level 1	IACC1	2007
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	IACC2	2014
12V Micro-Hybrid (Stop-Start)	MHEV	2007
Strong Hybrid - Level 1	SHEV1	2012
Strong Hybrid - Level 2	SHEV2	2017
Plug-in Hybrid - 30 mi range	PHEV1	2020
Electric Vehicle (Early Adopter) - 75 mile range	EV1	2017
Electric Vehicle (Broad Market) - 150 mile range	EV4	2017

Mass Reduction - Level 1	MR1	2007
Mass Reduction - Level 2	MR2	2007
Mass Reduction - Level 3	MR3	2007
Mass Reduction - Level 4	MR4	2011
Mass Reduction - Level 5	MR5	2016
Low Rolling Resistance Tires - Level 1	ROLL1	2007
Low Rolling Resistance Tires - Level 2	ROLL2	2017
Low Drag Brakes	LDB	2007
Secondary Axle Disconnect	SAX	2007
Aero Drag Reduction, Level 1	AERO1	2007
Aero Drag Reduction, Level 2	AERO2	2011

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For purposes of this proposal and as discussed in greater detail in the Joint TSD, NHTSA and EPA built upon the list of technologies used by agencies for the MYs 2017–2025 CAFE and GHG standards. NHTSA and EPA had additional technologies to the list that that the agencies expect to be in production during the MYs 2017–2025 timeframe. These new technologies included higher BMEP turbocharged and downsized engines, advanced diesel engines, higher efficiency transmissions, additional mass reduction levels, PHEVs, EVs, etc.

b. How did NHTSA determine the costs and effectiveness of each of these technologies for use in its modeling analysis?

Building on cost estimates developed for the MYs 2012–2016 CAFE and GHG final rule and the 2010 TAR, the agencies incorporated new cost and effectiveness estimates for the new technologies being considered and some of the technologies carried over from the MYs 2012–2016 final rule and 2010 TAR. This joint work is reflected in Chapter 3 of the Joint TSD and in Section II of this preamble, as summarized below. For more detailed information on the effectiveness and cost of fuel-saving technologies, please refer to Chapter 3 of the Joint TSD and Section V of NHTSA's PRIA.

For this proposal the FEV tear down work was expanded to include an 8-speed DCT, a power-split hybrid, which was used to determine a P2 hybrid cost, and a mild hybrid with stop-start technology. Additionally, battery costs have been revised using Argonne National Laboratory's battery cost model. The model developed by ANL allows users to estimate unique battery pack cost using user customized input sets for different hybridization applications, such as strong hybrid, PHEV and EV. Based on staff input and public feedback EPA and NHTSA have modified how the indirect costs, using ICMs, were derived and applied. The updates are discussed at length in Chapter 3 of the Joint TSD and in Chapter 5 of NHTSA's PRIA.

Some of the effectiveness estimates for technologies applied in MYs 2012–2016 and 2010 TAR have remained the same. However, nearly all of the effectiveness estimates for carryover technologies have been updated based on a newer version of EPA's lumped parameter model, which was calibrated by the vehicle simulation work performed by Ricardo Engineering. The Ricardo simulation study was also used to estimate the effectiveness for the technologies newly considered for this proposal like higher BMEP turbocharged and downsized engine, advanced transmission technologies and P2 Hybrids. While NHTSA and EPA apply technologies differently, the agencies have sought to ensure that the resultant effectiveness of applying technologies is consistent between the two agencies.

NHTSA notes that, in developing technology cost and effectiveness estimates, the agencies have made every effort to hold constant aspects of vehicle performance and utility typically valued by consumers, such as horsepower, carrying capacity, drivability, durability, noise, vibration and harshness (NVH) and towing and hauling capacity. For example, NHTSA includes in its analysis technology cost and effectiveness estimates that are specific to performance passenger cars (*i.e.,* sports cars), as compared to nonperformance passenger cars. NHTSA seeks comment on the extent to which commenters believe that the agencies have been successful in holding constant these elements of vehicle performance and utility in developing the technology cost and effectiveness estimates.

The agency notes that the technology costs included in this proposal take into account only those associated with the initial build of the vehicle. Although comments were received to the MYs

2012–2016 rulemaking that suggested there could be additional maintenance required with some new technologies (*e.g.,* turbocharging, hybrids, etc.), and that additional maintenance costs could occur as a result, the agencies have not explicitly incorporated maintenance costs (or potential savings) as a separate element in this analysis. The agency requests comments on this topic and will undertake a more detailed review of these potential costs for the final rule.

For some of the technologies, NHTSA's inputs, which are designed to be as consistent as practicable with EPA's, indicate negative incremental costs. In other words, the agency is estimating that some technologies, if applied in a manner that holds performance and utility constant, will, following initial investment (for, *e.g.,* R&D and tooling) by the manufacturer and its suppliers, incrementally improve fuel savings and reduce vehicle costs. Nonetheless, in the agency's central analysis, these and other technologies are applied only insofar as is necessary to achieve compliance with standards defining any given regulatory alternative (where the baseline no action alternative assumes CAFE standards are held constant after MY 2016). The agency has also performed a sensitivity analysis involving market-based application of technology—that is, the application of technology beyond the point needed to achieve compliance, if the cost of the technology is estimated to be sufficiently attractive relative to the accompanying fuel savings. NHTSA has invited comment on all of its technology estimates, and specifically requests comment on the likelihood that each technology will, if applied in a manner that holds vehicle performance and utility constant, be able to both deliver the estimated fuel savings *and* reduce vehicle cost. The agency also invites comment on whether, for the final rule, its central analysis should be revised to include estimated market-driven application of technology.

The tables below provide examples of the incremental cost and effectiveness estimates employed by the agency in developing this proposal, according to the decision trees used in the CAFE modeling analysis. Thus, the effectiveness and cost estimates are not absolute to a single reference vehicle, but are incremental to the technology or technologies that precede it.

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Table IV-5. Technology Effectiveness Estimates Employed in the CAFE Model for Certain Technologies

	Subcomp. Car	Compact Car	Midsize Car	Large Car	Perform. Subcomp. Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car	Minivan LT	Small LT	Midsize LT	Large LT
VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%)												
Low friction lubricants (level 1)	0.5	0.5	0.7	0.8	0.5	0.5	0.7	0.8	0.7	0.6	0.7	0.7
Engine friction reduction (level 1)	2.0	2.0	2.6	2.7	2.0	2.0	2.6	2.7	2.6	2.0	2.6	2.4
VVT—Dual cam phasing (DCP)	2.0	2.0	2.5	2.7	2.0	2.0	2.5	2.7	2.6	2.0	2.6	2.4
Discrete variable valve lift (DVVL) on DOHC	2.8	2.8	3.6	3.9	2.8	2.8	3.6	3.9	3.5	2.8	3.5	3.4

Cylinder deactivation on OHV	4.7	4.7	5.9	6.3	4.7	4.7	5.9	6.3	5.9	4.7	5.9	5.5
Stoichiometric gasoline direct injection	1.6	1.6	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.6	1.5	1.5
Turbocharging and downsizing (level 1)	7.2	7.2	8.3	7.8	7.2	6.7	7.5	7.8	7.9	7.1	7.9	7.3
Turbocharging and downsizing (level 2)	2.9	2.9	3.5	3.7	2.9	2.9	3.5	3.7	3.4	2.9	3.4	3.4
Cooled exhaust gas recirculation (EGR) – (level 1)	3.6	3.6	3.5	3.5	3.6	3.6	3.5	3.5	3.6	3.6	3.6	3.6

Cooled exhaust gas recirculation (EGR) – (level 2)	1.0	1.0	1.4	1.4	1.0	1.0	1.4	1.4	1.1	1.0	1.1	1.2
Advanced Diesel	5.5	5.5	2.8	2.9	5.5	5.5	2.8	2.9	3.4	5.3	3.4	3.5
6-speed auto. trans. with improved internals	1.9	1.9	2.0	2.0	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.1
6-speed DCT	4.0	4.0	4.1	3.8	4.0	3.4	4.1	3.8	n/a	3.8	n/a	n/a
High Efficiency Gearbox	2.2	2.2	2.7	2.6	2.2	2.2	2.7	2.6	3.1	2.5	3.1	3.7
Shift Optimizer	3.3	3.3	4.1	4.3	3.3	3.3	4.1	4.3	4.1	3.3	4.1	3.9
Electric power steering	1.5	1.5	1.3	1.1	1.5	1.5	1.3	1.1	1.0	1.2	1.0	0.8

12V micro-hybrid	1.7	1.7	2.1	2.2	1.7	1.7	2.1	2.2	2.09	1.8	2.1	2.1
Strong Hybrid (level 2)	10.1	10.1	6.5	6.9	10.1	9.7	6.5	6.8	5.2	10.0	8.2	7.3
Plug-in Hybrid	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7	40.7
Electric Vehicle (Early Adopter)	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5
Low Rolling Resistance Tires (level 1)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Low Rolling Resistance Tires (level 2)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Aero Drag Reduction (level 1)	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Aero Drag Reduction (level 2)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Table IV-6. Technology Cost Estimates Employed in the CAFE Model for Certain Technologies

	Subcomp. Car	Compact Car	Midsize Car	Large Car	Perform. Subcomp. Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car	Minivan LT	Small LT	Midsize LT	Large LT
VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE ($)												
Nominal baseline engine (for cost purposes)	Inline 4	Inline 4	Inline 4	V6	Inline 4	V6	V6	V8	V6	Inline 4	V6	V8
Low friction lubricants (level 1)	16	16	16	24	16	24	24	32	24	16	24	32
Engine friction reduction (level 1)	60	60	60	90	60	90	90	120	90	60	90	120
VVT—Dual cam phasing (DCP)	44	44	44	88	44	88	88	88	88	44	88	88

Discrete variable valve lift (DVVL) on DOHC	160	160	160	240	160	240	240	320	240	160	240	320
Cylinder deactivation on OHV	204	204	204	204	204	204	204	204	204	204	204	204
Stoichiometric gasoline direct injection	268	268	268	402	268	402	5402	536	402	268	402	536
Turbocharging and downsizing (level 1)	490	490	490	20	490	20	20	639	20	490	20	639
Turbocharging and downsizing (level 2)	26	26	26	260	26	260	260	439	260	26	260	439

Cooled exhaust gas recirculation (EGR) – (level 1)	303	303	303	303	303	303	303	303	303	303	303	303
Cooled exhaust gas recirculation (EGR) – (level 2)	520	520	520	(296)	520	(296)	(296)	(296)	(296)	520	(296)	(296)
Advanced Diesel	873	873	873	844	873	844	844	1693	844	873	844	1693
6-speed auto. trans. with improved internals	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)	(39)

6-speed DCT	(107)	(107)	(107)	(73)	(107)	(73)	(73)	(73)	n/a	(107)	n/a	n/a
High Efficiency Gearbox	248	248	248	248	248	248	248	248	248	248	248	248
Shift Optimizer	2	2	2	2	2	2	2	2	2	2	2	2
Electric power steering	108	108	108	108	108	108	108	108	108	108	108	108
12V micro-hybrid	322	322	382	411	322	322	382	411	410	363	421	476
Strong Hybrid (level 2)	3526	3526	3705	4261	3526	3526	3705	4261	4677	4057	4332	4464
Plug-in Hybrid	10,686	10,686	11,864	15,514	10,686	10,686	11,864	15,514	n/a	14,055	n/a	n/a
Electric Vehicle (Early Adopter)	3,001	3,001	3.719	3,998	3,001	3,001	3.719	3,998	n/a	4,580	n/a	n/a
Low Rolling Resistance Tires (level 1)	7	7	7	7	7	7	7	7	7	7	7	7

Low Rolling Resistance Tires (level 2)	72	72	72	72	72	72	72	72	72	72	72	72
Aero Drag Reduction (level 1)	48	48	48	48	48	48	48	48	48	48	48	48
Aero Drag Reduction (level 2)	162	162	162	162	162	162	162	162	162	162	162	162

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c. How does NHTSA use these assumptions in its modeling analysis?

NHTSA relies on several inputs and data files to conduct the compliance analysis using the CAFE model, as discussed further below and in Chapter 5 of the PRIA. For the purposes of applying technologies, the CAFE model primarily uses three data files, one that contains data on the vehicles expected to be manufactured in the model years covered by the rulemaking and identifies the appropriate stage within the vehicle's life-cycle for the technology to be applied, one that contains data/parameters regarding the available technologies the model can apply, and one that contains economic assumption inputs for calculating the costs and benefits of the standards. The inputs for the first two data files are discussed below.

As discussed above, the CAFE model begins with an initial state of the domestic vehicle market, which in this case is the market for passenger cars and light trucks to be sold during the period covered by the proposed standards. The vehicle market is defined on a year-by-year, model-by-model, engine-by-engine, and transmission-by-transmission basis, such that each defined vehicle model refers to a separately defined engine and a separately defined transmission. Comparatively, EPA's OMEGA model defines the vehicle market using representative vehicles at the vehicle platform level, which are binned into 5 year timeframes instead of year-by-year.

For the current standards, which cover MYs 2017–2025, the light-duty vehicle (passenger car and light truck) market forecast was developed jointly by NHTSA and EPA staff using MY 2008 CAFE compliance data. The MY 2008 compliance data includes about 1,100 vehicle models, about 400 specific engines, and about 200 specific transmissions, which is a somewhat lower level of detail in the representation of the vehicle market than that used by NHTSA in prior CAFE analyses—previous analyses would count a vehicle as ''new'' in any year when significant technology differences are made, such as at a redesign.[624] However, within the limitations of information that can be made available to the public, it provides the foundation for a reasonable analysis of manufacturer-specific costs and the analysis of attribute-based CAFE standards, and is much greater than the level of detail used by many other models and analyses relevant to light-duty vehicle fuel economy.[625]

In addition to containing data about each vehicle, engine, and transmission, this file contains information for each technology under consideration as it pertains to the specific vehicle (whether the vehicle is equipped with it or not), the estimated model year the vehicle is undergoing a refresh or redesign, and information about the vehicle's subclass for purposes of technology application. In essence, the model considers whether it is appropriate to apply a technology to a vehicle.

Is a vehicle already equipped, or can it not be equipped, with a particular technology?

The market forecast file provides NHTSA the ability to identify, on a technology-by-technology basis, which technologies may already be present (manufactured) on a particular vehicle, engine, or transmission, or which technologies are not applicable (due to technical considerations or engineering constraints) to a particular vehicle, engine, or transmission. These identifications are made on a model-by-model, engine-by-engine, and transmission-by-transmission basis. For example, if the market forecast file indicates that Manufacturer X's Vehicle Y is manufactured with Technology Z, then for this vehicle Technology Z will be shown as used. Additionally, NHTSA has determined that some technologies are only suitable or unsuitable when certain vehicle, engine, or transmission conditions exist. For example, secondary axle disconnect is only suitable for 4WD vehicles and cylinder deactivation is unsuitable for any engine with fewer than 6 cylinders. Similarly, comments received to the 2008 NPRM indicated that cylinder deactivation could not likely be applied to vehicles equipped with manual transmissions during the rulemaking timeframe, due primarily to the cylinder deactivation system not being able to anticipate gear shifts. The CAFE model employs ''engineering constraints'' to address issues like these, which are a programmatic method of controlling technology application that is independent of other constraints. Thus, the market forecast file would indicate that the technology in question should not be applied to the particular vehicle/engine/transmission (*i.e.,* is unavailable). Since multiple vehicle models may be equipped with an engine or transmission, this may affect multiple models. In using this aspect of the market forecast file, NHTSA ensures the CAFE model only applies technologies in an appropriate manner, since before any application of a technology can occur, the model checks the market forecast to see if it is either already present or unavailable. NHTSA seeks comment on the continued appropriateness of the engineering constraints used by the model, and specifically whether many of the technical constraints will be resolved (and therefore the engineering constraints should be changed) given the increased focus of engineering resources that will be working to solve these technical challenges.

Whether a vehicle can be equipped with a particular technology could also theoretically depend on certain technical considerations related to incorporating the technology into particular vehicles. For example, GM commented on the MY 2012–2016 NPRM that there are certain issues in implementing turbocharging and downsizing technologies on full-size trucks, like concerns related to engine knock, drivability, control of boost pressure, packaging complexity, enhanced cooling for vehicles that are designed for towing or hauling, and noise, vibration and harshness. NHTSA stated in response that we believed that such technical considerations are well recognized within the industry and it is standard industry practice to address each during the design and development phases of applying turbocharging and downsizing technologies. The cost and effectiveness estimates used in the final rule for MYs 2012–2016, as well as the cost and effectiveness estimates employed in this NPRM, are based on analysis that assumes each of these factors is addressed prior to production implementation of the technologies. NHTSA continues to believe that these issues are accounted for by industry, but we seek comment on whether the engineering constraints should be used to address concerns like these (and if so, how), or alternatively, whether some of the things that the agency currently treats as engineering constraints should be (or actually are) accounted for in the cost and effectiveness estimates through assumptions like those described above, and whether the agency might be double-constraining the application of technology.

Is a vehicle being redesigned or refreshed?

Manufacturers typically plan vehicle changes to coincide with certain stages

[639] *See, e.g.,* Kleit A.N., 1990. ''The Effect of Annual Changes in Automobile Fuel Economy Standards.'' Journal of Regulatory Economics 2: 151–172 (Docket EPA–HQ–OAR–2009–0472–0015); Berry, Steven, James Levinsohn, and Ariel Pakes, 1995. ''Automobile Prices in Market Equilibrium,'' Econometrica 63(4): 841–940 (Docket NHTSA–2009–0059–0031); McCarthy, Patrick S., 1996.

of a vehicle's life cycle that are appropriate for the change, or in this case the technology being applied. In the automobile industry there are two terms that describe when technology changes to vehicles occur: Redesign and refresh (*i.e.,* freshening). Vehicle redesign usually refers to significant changes to a vehicle's appearance, shape, dimensions, and powertrain. Redesign is traditionally associated with the introduction of ''new'' vehicles into the market, often characterized as the ''next generation'' of a vehicle, or a new platform. Vehicle refresh usually refers to less extensive vehicle modifications, such as minor changes to a vehicle's appearance, a moderate upgrade to a powertrain system, or small changes to the vehicle's feature or safety equipment content. Refresh is traditionally associated with mid-cycle cosmetic changes to a vehicle, within its current generation, to make it appear ''fresh.'' Vehicle refresh generally occurs no earlier than two years after a vehicle redesign, or at least two years before a scheduled redesign. To be clear, this is a general description of how manufacturers manage their product lines and refresh and redesign cycles but in some cases the timeframes could be shorter and others longer depending on market factors, regulations, etc. For the majority of technologies discussed today, manufacturers will only be able to apply them at a refresh or redesign, because their application would be significant enough to involve some level of engineering, testing, and calibration work.[626]

Some technologies (*e.g.,* those that require significant revision) are nearly always applied only when the vehicle is expected to be redesigned, like turbocharging and engine downsizing, or conversion to diesel or hybridization. Other technologies, like cylinder deactivation, electric power steering, and low rolling resistance tires can be applied either when the vehicle is expected to be refreshed or when it is expected to be redesigned, while low friction lubricants, can be applied at any time, regardless of whether a refresh or redesign event is conducted. Accordingly, the model will only apply a technology at the particular point deemed suitable. These constraints are intended to produce results consistent with how we assume manufacturers will apply technologies in the future based on how they have historically implemented new technologies. For each technology under consideration, NHTSA specifies whether it can be applied any time, at refresh/redesign, or only at redesign. The data forms another input to the CAFE model. NHTSA develops redesign and refresh schedules for each of a manufacturer's vehicles included in the analysis, essentially based on the last known redesign year for each vehicle and projected forward using a 5 to 8-year redesign and a 2–3 year refresh cycle, and this data is also stored in the market forecast file. While most vehicles are projected to follow a 5-year redesign a few of the niche market or small-volume manufacturer vehicles (*i.e.* luxury and performance vehicles) and large trucks are assumed to have 6- to 8-year redesigns based on historic redesign schedules and the agency's understanding of manufacturers' intentions moving forward. This approach is used because of the nature of the current baseline, which as a single year of data does not contain its own refresh and redesign cycle cues for future model years, and to ensure the complete transparency of the agency's analysis. We note that this approach is different from what NHTSA has employed previously for determining redesign and refresh schedules, where NHTSA included the redesign and refresh dates in the market forecast file as provided by manufacturers in confidential product plans. Vehicle redesign/refresh assumptions are discussed in more detail in Chapter 5 of the PRIA and in Chapter 3 of the TSD.

NHTSA has previously received comments stating that manufacturers do not necessarily adhere to strict five-year redesign cycles, and may add significant technologies by redesigning vehicles at more frequent intervals, albeit at higher costs. Conversely, other comments received stated that as compared to full-line manufacturers, small-volume manufacturers in fact may have 7 to 8-year redesign cycles.[627] The agency believes that manufacturers can and will accomplish much improvement in fuel economy and GHG reductions while applying technology consistent with their redesign schedules.

Once the model indicates that a technology should be applied to a vehicle, the model must evaluate which technology should be applied. This will depend on the vehicle subclass to which the vehicle is assigned; what technologies have already been applied to the vehicle (*i.e.,* where in the ''decision tree'' the vehicle is); when the technology is first available (*i.e.,* year of availability); whether the technology is still available (*i.e.,* ''phase-in caps''); and the costs and effectiveness of the technologies being considered. Technology costs may be reduced, in turn, by learning effects and short- vs. long-term ICMs, while technology effectiveness may be increased or reduced by synergistic effects between technologies. In the technology input file, NHTSA has developed a separate set of technology data variables for each of the twelve vehicle subclasses. Each set of variables is referred to as an ''input sheet,'' so for example, the subcompact passenger car input sheet holds the technology data that is appropriate for the subcompact subclass. Each input sheet contains a list of technologies available for members of the particular vehicle subclass. The following items are provided for each technology: The name of the technology, its abbreviation, the decision tree with which it is associated, the (first) year in which it is available, the year-by-year cost estimates and effectiveness (fuel consumption reduction) estimates, its applicability and the consumer value

[626] For example, applying material substitution through weight reduction, or even something as simple as low rolling-resistance tires, to a vehicle will likely require some level of validation and testing to ensure that the vehicle may continue to be certified as compliant with NHTSA's Federal Motor Vehicle Safety Standards (FMVSS). Weight reduction might affect a vehicle's crashworthiness; low rolling-resistance tires might change a vehicle's braking characteristics or how it performs in crash avoidance tests.

[627] In the MY 2011 final rule, NHTSA noted that the CAR report submitted by the Alliance, prepared by the Center for Automotive Research and EDF, stated that ''For a given vehicle line, the time from conception to first production may span two and one-half to five years,'' but that ''The time from first production (''Job#1'') to the last vehicle off the line (''Balance Out'') may span from four to five years to eight to ten years or more, depending on the dynamics of the market segment.'' The CAR report then stated that ''At the point of final production of the current vehicle line, a new model with the same badge and similar characteristics may be ready to take its place, continuing the cycle, or the old model may be dropped in favor of a different product.'' See NHTSA–2008–0089–0170.1, Attachment 16, at 8 (393 of pdf). NHTSA explained that this description, which states that a vehicle model will be redesigned or dropped after 4–10 years, was consistent with other characterizations of the redesign and freshening process, and supported the 5-year redesign and 2–3 year refresh cycle assumptions used in the MY 2011 final rule. See id., at 9 (394 of pdf). Given that the situation faced by the auto industry today is not so wholly different from that in March 2009, when the MY 2011 final rule was published, and given that the commenters did not present information to suggest that these assumptions are unreasonable (but rather simply that different manufacturers may redesign their vehicles more or less frequently, as the range of cycles above indicates), NHTSA believes that the assumptions remain reasonable for purposes of this NPRM analysis. See also ''Car Wars 2009–2012, The U.S. automotive product pipeline,'' John Murphy, Research Analyst, Merrill Lynch research paper, May 14, 2008 and ''Car Wars 2010–2013, The U.S. automotive product pipeline,'' John Murphy, Research Analyst, Bank of America/Merrill Lynch research paper, July 15, 2009. *Available at http://www.autonews.com/assets/PDF/CA66116716.PDF* (last accessed October 11, 2011).

loss. The phase-in values and the potential stranded capital costs are common for all vehicle subclasses and are thus listed in a separate input sheet that is referenced for all vehicle subclasses.

To which vehicle subclass is the vehicle assigned?

As part of its consideration of technological feasibility, the agency evaluates whether each technology could be implemented on all types and sizes of vehicles, and whether some differentiation is necessary in applying certain technologies to certain types and sizes of vehicles, and with respect to the cost incurred and fuel consumption and CO_2 emissions reduction achieved when doing so. The 2010 NAS Report differentiated technology application using eight vehicle ''classes'' (4 car classes and 4 truck classes).[628] NAS's purpose in separating vehicles into these classes was to create groups of ''like'' vehicles, *i.e.,* vehicles similar in size, powertrain configuration, weight, and consumer use, and for which similar technologies are applicable. NAS also used these vehicle classes along with powertrain configurations (*e.g.*.4 cylinder, 6 cylinder or 8 cylinder engines) to determine unique cost and effectiveness estimates for each class of vehicles.

NHTSA similarly differentiates vehicles by ''subclass'' for the purpose of applying technologies to ''like'' vehicles and assessing their incremental costs and effectiveness. NHTSA assigns each vehicle manufactured in the rulemaking period to one of 12 subclasses: For passenger cars, Subcompact, Subcompact Performance, Compact, Compact Performance, Midsize, Midsize Performance, Large, and Large Performance; and for light trucks, Small SUV/Pickup/Van, Midsize SUV/Pickup/Van, Large SUV/Pickup/Van, and Minivan. The agency seeks comment on the appropriateness of these 12 subclasses for the MYs 2017–2025 timeframe. The agency is also seeking comment on the continued appropriateness of maintaining separate ''performance'' vehicle classes or if as fuel economy stringency increases the market for performance vehicles will decrease.

For this NPRM, NHTSA divides the vehicle fleet into subclasses based on model inputs, and applies subclass-specific estimates, also from model inputs, of the applicability, cost, and effectiveness of each fuel-saving technology. The model's estimates of the cost to improve the fuel economy of each vehicle model thus depend upon the subclass to which the vehicle model is assigned. Each vehicle's subclass is stored in the market forecast file. When conducting a compliance analysis, if the CAFE model seeks to apply technology to a particular vehicle, it checks the market forecast to see if the technology is available and if the refresh/redesign criteria are met. If these conditions are satisfied, the model determines the vehicle's subclass from the market data file, which it then uses to reference another input called the technology input file. NHTSA reviewed its methodology for dividing vehicles into subclasses for purposes of technology application that it used in the MY 2011 final rule and for the MYs 2012–2016 rulemaking, and concluded that the same methodology would be appropriate for this NPRM for MYs 2017–2025. Vehicle subclasses are discussed in more detail in Chapter 5 of the PRIA and in Chapter 3 of the TSD.

For the reader's reference, the subclasses and example vehicles from the market forecast file are provided in the tables below.

[628] The NAS classes included two-seater convertibles and coupes; small cars; intermediate and large cars; high-performance sedans; unit-body standard trucks; unit-body high-performance trucks; body-on-frame small and midsize trucks; and body.

Passenger Car Subclasses Example (MY 2008) Vehicles

Class	Example vehicles
Subcompact	Chevy Aveo, Hyundai Accent
Subcompact performance	Mazda MX-5, BMW Z4
Compact	Chevy Cobalt, Nissan Sentra and Altima
Compact performance	Audi S4, Mazda RX-8
Mid-size	Chevy Impala, Toyota Camry, Honda Accord, Hyundai Azera
Mid-size performance	Chevy Corvette, Ford Mustang (V8), Nissan G37 Coupe
Large	Audi A8, Cadillac CTS and DTS
Large performance	Bentley Arnage, Daimler CL600

Light Truck Subclasses Example (MY 2008) Vehicles

Class	Example vehicles
Minivans	Dodge Caravan, Toyota Sienna
Small SUV/Pickup/Van	Ford Escape and Ranger, Nissan Rogue
Mid-size SUV/Pickup/Van	Chevy Colorado, Jeep Wrangler, Toyota Tacoma
Large SUV/Pickup/Van	Chevy Silverado, Ford E-Series, Toyota Sequoia

What technologies have already been applied to the vehicle (i.e., where in the ''decision trees'' is it)?

NHTSA's methodology for technology analysis evaluates the application of individual technologies and their incremental costs and effectiveness. Individual technologies are assessed relative to the prior technology state, which means that it is crucial to understand what technologies are already present on a vehicle in order to determine correct incremental cost and effectiveness values. The benefit of the incremental approach is transparency in accounting, insofar as when individual technologies are added incrementally to individual vehicles, it is clear and easy to determine how costs and effectiveness add up as technology levels increase and explicitly accounting for any synergies that exist between technologies which are already present on the vehicle and new technologies being applied.

To keep track of incremental costs and effectiveness and to know which technology to apply and in which order, the CAFE model's architecture uses a logical sequence, which NHTSA refers to as ''decision trees,'' for applying fuel economy-improving technologies to individual vehicles. For purposes of this proposal, NHTSA reviewed the MYs 2012–2016 final rule's technology sequencing architecture, which was based on the MY 2011 final rule's decision trees that were jointly developed by NHTSA and Ricardo, and, as appropriate, updated the decision trees to include new technologies that have been defined for the MYs 2017–2025 timeframe.

In general, and as described in great detail in Chapter 5 of the current PRIA,[629] each technology is assigned to one of the five following categories based on the system it affects or impacts: Engine, transmission, electrification/accessory, hybrid or

[629] Additional details about technologies are categorized can be found in the MY 2011 final rule.

vehicle. Each of these categories has its own decision tree that the CAFE model uses to apply technologies sequentially during the compliance analysis. The decision trees were designed and configured to allow the CAFE model to apply technologies in a cost-effective, logical order that also considers ease of implementation. For example, software or control logic changes are implemented before replacing a component or system with a completely redesigned one, which is typically a much more expensive and integration intensive option. In some cases, and as appropriate, the model may combine the sequential technologies shown on a decision tree and apply them simultaneously, effectively developing dynamic technology packages on an as-needed basis. For example, if compliance demands indicate, the model may elect to apply LUB, EFR, and ICP on a dual overhead cam engine, if they are not already present, in one single step. An example simplified decision tree for engine technologies is provided below; the other simplified decision trees may be found in Chapter 5 of the PRIA. Expanded decision trees are available in the docket for this NPRM.

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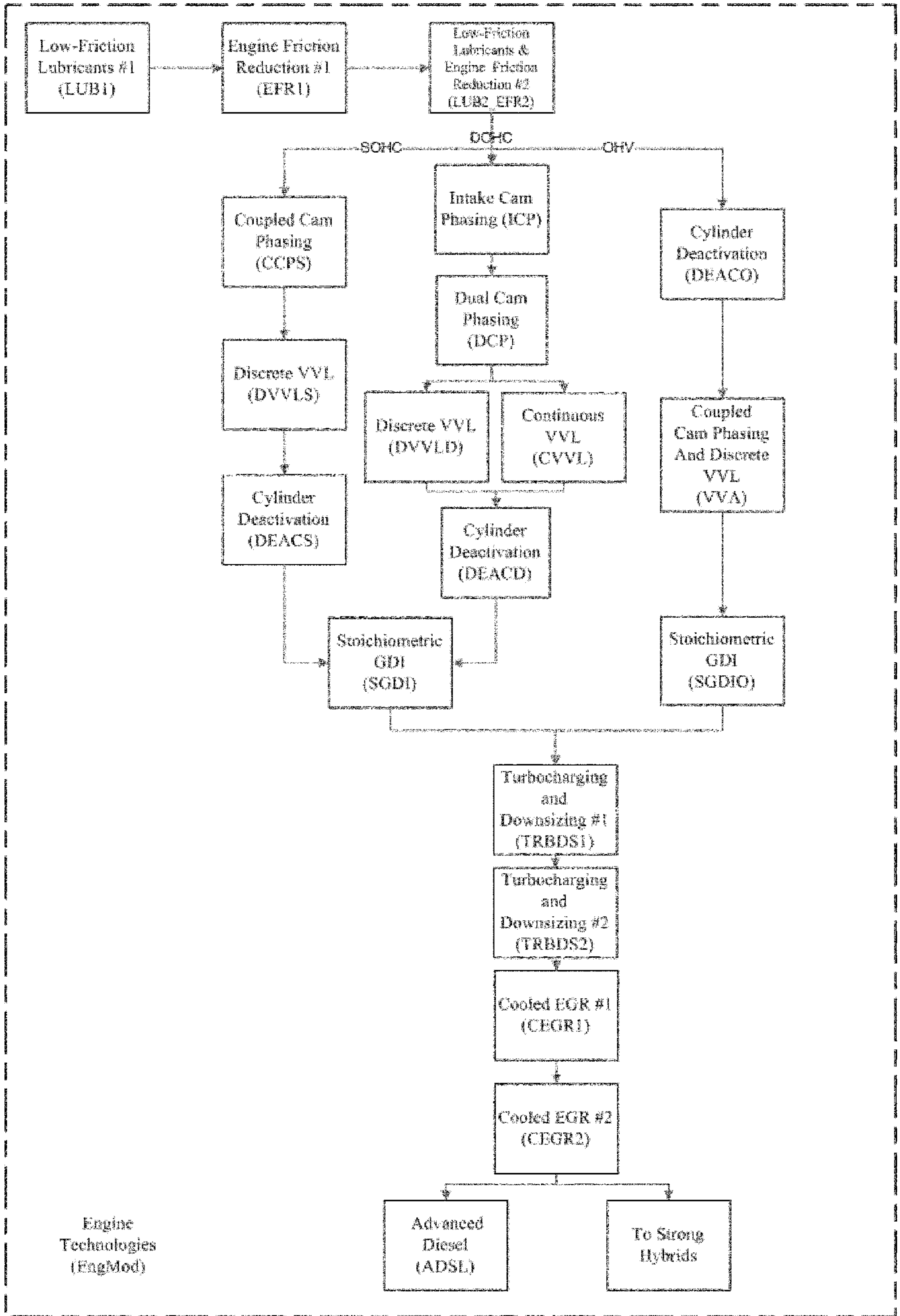

Simplified Engine Decision Tree Used in the CAFE Model

Each technology within the decision trees has an incremental cost and an incremental effectiveness estimate associated with it, and estimates are specific to a particular vehicle subclass (see the tables in Chapter 5 of the PRIA).

Each technology's incremental estimate takes into account its position in the decision tree path. If a technology is located further down the decision tree, the estimates for the costs and effectiveness values attributed to that technology are influenced by the incremental estimates of costs and effectiveness values for prior technology applications. In essence, this approach accounts for ''in-path'' effectiveness synergies, as well as cost effects that occur between the technologies in the same path. When comparing cost and effectiveness estimates from various sources and those provided by commenters in this and the previous CAFE rulemakings, it is important that the estimates evaluated are analyzed in the proper context, especially as concerns their likely position in the decision trees and other technologies that may be present or missing. Not all estimates available in the public domain or that have been (or will be) offered for the agencies' consideration can be evaluated in an ''apples-to-apples'' comparison with those used by the CAFE model, since in some cases the order of application, or included technology content, is inconsistent with that assumed in the decision tree.

The MY 2011 final rule discussed in detail the revisions and improvements made to the CAFE model and decision trees during that rulemaking process, including the improved handling and accuracy of valve train technology application and the development and implementation of a method for accounting path-dependent correction factors in order to ensure that technologies are evaluated within the proper context. The reader should consult the MY 2011 final rule documents for further information on these modeling techniques, all of which continued to be utilized in developing this proposal.[630] To the extent that the decision trees have changed for purposes of the MYs 2012–2016 final rule and this NPRM, it was due not to revisions in the order of technology application, but rather to redefinitions of technologies or addition or subtraction of technologies.

Is the next technology available in this model year?

Some of technologies considered are available on vehicles today, and thus will be available for application (albeit in varying degrees) in the model starting in MY 2017. Other technologies, however, will not become available for purposes of NHTSA's analysis until later in the rulemaking time frame. When the model is considering whether to add a technology to a vehicle, it checks its year of availability—if the technology is available, it may be added; if it is not available, the model will consider whether to switch to a different decision tree to look for another technology, or will skip to the next vehicle in a manufacturer's fleet. The year of availability for each technology is provided above in Table IV–4.

The agency has received comments previously stating that if a technology is currently available or available prior to the rulemaking timeframe that it should be immediately made available in the model. In response, as discussed above, technology ''availability'' is not determined based simply on whether the technology exists, but depends also on whether the technology has achieved a level of technical viability that makes it appropriate for widespread application. This depends in turn on component supplier constraints, capital investment and engineering constraints, and manufacturer product cycles, among other things. Moreover, even if a technology is available for application, it may not be available for every vehicle. Some technologies may have considerable fuel economy benefits, but cannot be applied to some vehicles due to technological constraints—for example, cylinder deactivation cannot be applied to vehicles with current 4-cylinder engines (because not enough cylinders are present to deactivate some and continue moving the vehicle) or on vehicles with manual transmissions within the rulemaking timeframe. The agencies have provided for increases over time to reach the mpg level of the MY 2025 standards precisely because of these types of constraints, because they have a real effect on how quickly manufacturers can apply technology to vehicles in their fleets. NHTSA seeks comment on the appropriateness of the assumed years of availability.

Has the technology reached the phase-in cap for this model year?

Besides the refresh/redesign cycles used in the CAFE model, which constrain the rate of technology application at the vehicle level so as to ensure a period of stability following any modeled technology applications, the other constraint on technology application employed in NHTSA's analysis is ''phase-in caps.'' Unlike vehicle-level cycle settings, phase-in caps constrain technology application at the vehicle manufacturer level.[631] They are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process. At a high level, phase-in caps and refresh/redesign cycles work in conjunction with one another to avoid the modeling process out-pacing an OEM's limited pool of available resources during the rulemaking time frame and the years leading up to the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. Even though this rulemaking is being proposed 5 years before it takes effect, OEM's will still be utilizing their limited resources to meet the MYs 2012–2016 CAFE standards. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards.

NHTSA has been developing the concept of phase-in caps for purposes of the agency's modeling analysis over the course of the last several CAFE rulemakings, as discussed in greater detail in the MY 2011 final rule,[632] in the MY 2012–2016 final rule and in Chapter 5 of the PRIA and Chapter 3 of the Joint TSD. The MYs 2012–2016 final rule like the MY 2011 final rule employed non-linear phase-in caps (that is, caps that varied from year to year) that were designed to respond to previously received comments on technology deployment.

For purposes of this NPRM for MYs 2017–2025, as in the MY 2011 and MYs 2012–2016 final rules, NHTSA combines phase-in caps for some groups of similar technologies, such as valve phasing technologies that are applicable to different forms of engine design (SOHC, DOHC, OHV), since they are very similar from an engineering and implementation standpoint. When the phase-in caps for two technologies are combined, the maximum total

[630] *See, e.g.,* 74 FR 14238–46 (Mar. 30, 2009) for a full discussion of the decision trees in NHTSA's MY 2011 final rule, and Docket No. NHTSA–2009–0062–0003.1 for an expanded decision tree used in that rulemaking.

[631] While phase-in caps are expressed as specific percentages of a manufacturer's fleet to which a technology may be applied in a given model year, phase-in caps cannot always be applied as precise limits, and the CAFE model in fact allows ''override'' of a cap in certain circumstances. When only a small portion of a phase-in cap limit remains, or when the cap is set to a very low value, or when a manufacturer has a very limited product line, the cap might prevent the technology from being applied at all since any application would cause the cap to be exceeded. Therefore, the CAFE model evaluates and enforces each phase-in cap constraint after it has been exceeded by the application of the technology (as opposed to evaluating it before application), which can result in the described overriding of the cap.

[632] NEED A FOOTNOTE HERE

application of either or both to any manufacturer's fleet is limited to the value of the cap.[633]

In developing phase-in cap values for purposes of this NPRM, NHTSA reviewed the MYs 2012–2016 final rule's phase-in caps, which for the majority of technologies were set to reach 85 or 100 percent by MY 2016, although more advanced technologies like diesels and strong hybrids reach only 15 percent by MY 2016. The phase-in caps used in the MYs 2012–2016 final were developed to harmonize with EPA's proposal and consider the fact that manufacturers, as part of the information shared during the discussions that occurred during summer 2011, appeared to be anticipating higher technology application rates than assumed in prior rules. NHTSA determined that these phase-in caps for MY 2016 were still reasonable and thus used those caps as the starting point for the MYs 2017–2025 phase-in caps. For many of the carryover technologies this means that for MYs 2017–2025 the phase-in caps are assumed to be 100 percent. NHTSA along with EPA used confidential OEM submissions, trade press articles, company publications and press releases to estimate the phase-in caps for the newly defined technologies that will be entering the market just before or during the MYs 2017–2025 time frame. For example, advanced cooled EGR engines have a phase-in cap of 3 percent per year through MY 2021 and then 10 percent per year through 2025. The agency seeks comment on the appropriateness of both the carryover phase-in caps and the newly defined ones proposed in this NPRM.

Is the technology less expensive due to learning effects?

In the past two rulemakings NHTSA has explicitly accounted for the cost reductions a manufacturer might realize through learning achieved from experience in actually applying a technology. These cost reductions, due to learning effects, were taken into account through two kinds of mutually exclusive learning, ''volume-based'' and ''time-based.'' NHTSA and EPA included a detailed description of the learning effect in the MYs 2012–2016 final rule and the more recent heavy-duty rule.[634]

Most studies of the effect of experience or learning on production costs appear to assume that cost reductions begin only after some initial volume threshold has been reached, but not all of these studies specify this threshold volume. The rate at which costs decline beyond the initial threshold is usually expressed as the percent reduction in average unit cost that results from each successive doubling of cumulative production volume, sometimes referred to as the learning rate. Many estimates of experience curves do not specify a cumulative production volume beyond which cost reductions would no longer occur, instead depending on the asymptotic behavior of the effect for learning rates below 100 percent to establish a floor on costs.

In past rulemaking analyses, as noted above, both agencies have used a learning curve algorithm that applied a learning factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analyses, EPA has simplified the approach by using an ''every two years'' based learning progression rather than a pure production volume progression (*i.e.,* after two years of production it was assumed that production volumes would have doubled and, therefore, costs would be reduced by 20 percent).[635]

In the MYs 2012–2016 light-duty rule, the agencies employed an additional learning algorithm to reflect the volume-based learning cost reductions that occur further along on the learning curve. This additional learning algorithm was termed ''time-based'' learning simply as a means of distinguishing this algorithm from the volume-based algorithm mentioned above, although both of the algorithms reflect the volume-based learning curve supported in the literature. To avoid confusion, we are now referring to this learning algorithm as the ''flat portion'' of the learning curve. This way, we maintain the clarity that all learning is, in fact, volume-based learning, and that the level of cost reductions depend only on where on the learning curve a technology's learning progression is. We distinguish the flat portion of the curve from the ''steep portion'' of the curve to indicate the level of learning taking place in the years following implementation of the technology. The agencies have applied the steep portion learning algorithm for those technologies considered to be newer technologies likely to experience rapid cost reductions through manufacturer learning, and the flat portion learning algorithm for those technologies considered to be mature technologies likely to experience only minor cost reductions through manufacturer learning. As noted above, the steep portion learning algorithm results in 20 percent lower costs after two full years of implementation (*i.e.,* the MY 2016 costs are 20 percent lower than the MYs 2014 and 2015 costs). Once two steep portion learning steps have occurred (for technologies having the steep portion learning algorithm applied while flat portion learning would begin in year 2 for technologies having the flat portion learning algorithm applied), flat portion learning at 3 percent per year becomes effective for 5 years. Beyond 5 years of learning at 3 percent per year, 5 years of learning at 2 percent per year, then 5 at 1 percent per year become effective.

Technologies assumed to be on the steep portion of the learning curve are hybrids and electric vehicles, while no learning is applied to technologies likely to be affected by commodity costs (LUB, ROLL) or that have loosely-defined BOMs (EFR, LDB), as was the case in the MY 2012–2016 final rule. Chapter 3 of the Joint TSD and the PRIA shows the specific learning factors that NHTSA has applied in this analysis for each technology, and discusses learning factors and each agency's use of them further. EPA and NHTSA included discussion of learning cost assumptions in the RIAs and TSD Chapter 3. Since the agencies had to project how learning will occur with new technologies over a long period of time, we request comments on the assumptions of learning costs and methodology. In particular, we are interested in input on the assumptions for advanced 27-bar BMEP cooled EGR engines, which are currently still in the experimental stage and not expected to be available in

[633] *See* 74 FR at 14270 (Mar. 30, 2009) for further discussion and examples.

[634] 76 FR 57106, 57320 (Sept. 15, 2011).

[635] To clarify, EPA has simplified the steep portion of the volume learning curve by assuming that production volumes of a given technology will have doubled within two years time. This has been done largely to allow for a presentation of estimated costs during the years of implementation, without the need to conduct a feedback loop that ensures that production volumes have indeed doubled. If EPA was to attempt such a feedback loop, it would need to estimate first year costs, feed those into OMEGA, review the resultant technology penetration rate and volume increase, calculate the learned costs, feed those into OMEGA (since lower costs would result in higher penetration rates, review the resultant technology penetration rate and volume increase, etc., until an equilibrium was reached. To do this for the dozens of technologies considered in the analysis for this rulemaking was deemed not feasible. Instead, EPA estimated the effects of learning on costs, fed those costs into OMEGA, and reviewed the resultant penetration rates. The assumption that volumes have doubled after two years is based solely on the assumption that year two sales are of equal or greater number than year one sales and, therefore, have resulted in a doubling of production. This could be done on a daily basis, a monthly basis, or a yearly basis as was done for this analysis.

volume production until 2017. For our analysis, we have based estimates of the costs of high-BMEP engines on current (or soon to be current) production engines, and assumed that learning (and the associated cost reductions) begins as early as 2012. We seek comment on the appropriateness of these pre-production applications of learning.

Is the technology more or less effective due to synergistic effects?

When two or more technologies are added to a particular vehicle model to improve its fuel efficiency and reduce CO_2 emissions, the resultant fuel consumption reduction may sometimes be higher or lower than the product of the individual effectiveness values for those items.[636] This may occur because one or more technologies applied to the same vehicle partially address the same source (or sources) of engine, drivetrain or vehicle losses. Alternately, this effect may be seen when one technology shifts the engine operating points, and therefore increases or reduces the fuel consumption reduction achieved by another technology or set of technologies. The difference between the observed fuel consumption reduction associated with a set of technologies and the product of the individual effectiveness values in that set is referred to for purposes of this rulemaking as a ''synergy.'' Synergies may be positive (increased fuel consumption reduction compared to the product of the individual effects) or negative (decreased fuel consumption reduction). An example of a positive synergy might be a vehicle technology that reduces road loads at highway speeds (*e.g.,* lower aerodynamic drag or low rolling resistance tires), that could extend the vehicle operating range over which cylinder deactivation may be employed. An example of a negative synergy might be a variable valvetrain system technology, which reduces pumping losses by altering the profile of the engine speed/load map, and a six-speed automatic transmission, which shifts the engine operating points to a portion of the engine speed/load map where pumping losses are less significant.

As the complexity of the technology combinations is increased, and the number of interacting technologies grows accordingly, it becomes increasingly important to account for these synergies. NHTSA and EPA determined synergistic impacts for this proposed rule using EPA's ''lumped parameter'' analysis tool, which EPA describes at length in Chapter 3 of the TSD. The lumped parameter tool is a spreadsheet model that represents energy consumption in terms of average performance over the fuel economy test procedure, rather than explicitly analyzing specific drive cycles. The tool begins with an apportionment of fuel consumption across several loss mechanisms and accounts for the average extent to which different technologies affect these loss mechanisms using estimates of engine, drivetrain and vehicle characteristics that are averaged over the 2-cycle CAFE drive cycle. Results of this analysis were generally consistent with those of full-scale vehicle simulation modeling performed in 2010–2011 for EPA by Ricardo, Inc.

For the current rulemaking, NHTSA is using an updated version of lumped parameter tool that incorporates results from simulation modeling performed in 2010–2011 by Ricardo, Inc. NHTSA and EPA incorporate synergistic impacts in their analyses in slightly different manners. Because NHTSA applies technologies individually in its modeling analysis, NHTSA incorporates synergistic effects between pairings of individual technologies. The use of discrete technology pair incremental synergies is similar to that in DOE's National Energy Modeling System (NEMS).[637] Inputs to the CAFE model incorporate NEMS-identified pairs, as well as additional pairs from the set of technologies considered in the CAFE model.

NHTSA notes that synergies that occur within a decision tree are already addressed within the incremental values assigned and therefore do not require a synergy pair to address. For example, all engine technologies take into account incremental synergy factors of preceding engine technologies, and all transmission technologies take into account incremental synergy factors of preceding transmission technologies. These factors are expressed in the fuel consumption improvement factors in the input files used by the CAFE model.

For applying incremental synergy factors in separate path technologies, the CAFE model uses an input table (see the tables in Chapter 3 of the TSD and in the PRIA) that lists technology pairings and incremental synergy factors associated with those pairings, most of which are between engine technologies and transmission/electrification/hybrid technologies. When a technology is applied to a vehicle by the CAFE model, all instances of that technology in the incremental synergy table which match technologies already applied to the vehicle (either pre-existing or previously applied by the CAFE model) are summed and applied to the fuel consumption improvement factor of the technology being applied. Many of the synergies for the strong hybrid technology fuel consumption reductions are included in the incremental value for the specific hybrid technology block since the model applies all available electrification, engine and transmission technologies before applying strong hybrid technologies.

The U.S. DOT Volpe Center has entered into a contract with Argonne National Laboratory (ANL) to provide full vehicle simulation modeling support for this MYs 2017–2025 rulemaking. While this modeling was not completed in time for use in this NPRM, NHTSA intends to use this modeling to validate/update technology effectiveness estimates and synergy factors for the final rulemaking analysis. This simulation modeling will be accomplished using ANL's full vehicle simulation tool called ''Autonomie,'' which is the successor to ANL's Powertrain System Analysis Toolkit (PSAT) simulation tool, and ANL's expertise with advanced vehicle technologies.

d. Where can readers find more detailed information about NHTSA's technology analysis?

Much more detailed information is provided in Chapter 5 of the PRIA, and a discussion of how NHTSA and EPA jointly reviewed and updated technology assumptions for purposes of this NPRM is available in Chapter 3 of the TSD. Additionally, all of NHTSA's model input and output files are now public and available for the reader's review and consideration. The technology input files can be found in the docket for this NPRM, Docket No. NHTSA–2010–0131, and on NHTSA's Web site. And finally, because much of NHTSA's technology analysis for

[636] More specifically, the products of the differences between one and the technology-specific levels of effectiveness in reducing fuel consumption. For example, not accounting for interactions, if technologies A and B are estimated to reduce fuel consumption by 10 percent (i.e., 0.1) and 20 percent (i.e., 0.2) respectively, the ''product of the individual effectiveness values'' would be 1–0.1 times 1–0.2, or 0.9 times 0.8, which equals 0.72, corresponding to a combined effectiveness of 28 percent rather than the 30 percent obtained by adding 10 percent to 20 percent. The ''synergy factors'' discussed in this section further adjust these multiplicatively combined effectiveness values.

[637] U.S. Department of Energy, Energy Information Administration, *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2007,* May 2007, Washington, DC, DOE/EIAM070(2007), at 29–30. *Available at http://tonto.eia.doe.gov/ftproot/modeldoc/m070(2007).pdf* (last accessed Sept. 25, 2011).

purposes of this proposal builds on the work that was done for the MY 2011 and MYs 2012–2016 final rules, we refer readers to those documents as well for background information concerning how NHTSA's methodology for technology application analysis has evolved over the past several rulemakings, both in response to comments and as a result of the agency's growing experience with this type of analysis.[638]

3. How did NHTSA develop its economic assumptions?

NHTSA's analysis of alternative CAFE standards for the model years covered by this rulemaking relies on a range of forecast variables, economic assumptions, and parameter values. This section describes the sources of these forecasts, the rationale underlying each assumption, and the agency's choices of specific parameter values. These economic values play a significant role in determining the benefits of alternative CAFE standards, as they have for the last several CAFE rulemakings. Under those alternatives where standards would be established by reference to their costs and benefits, these economic values also affect the levels of the CAFE standards themselves. Some of these variables have more important effects on the level of CAFE standards and the benefits from requiring alternative increases in fuel economy than do others, and the following discussion places more emphasis on these inputs.

In reviewing these variables and the agency's estimates of their values for purposes of this proposed rule, NHTSA reconsidered comments it had previously received on the NPRM for MYs 2012–16 CAFE standards and to the NOI/Interim Joint TAR, and also reviewed newly available literature. The agency elected to revise some of its economic assumptions and parameter estimates for this rulemaking, while retaining others. For the reader's reference, Table IV–7 below summarizes the values used to calculate the economic benefits from each alternative.

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[638] 74 FR 14233–308 (Mar. 30, 2009).

Table IV-7. Economic Values for Estimating Benefits (2009$)

Fuel Economy Rebound Effect	10%
"Gap" between test and on-road MPG for liquid-fueled vehicles	20%
"Gap" between test and on-road wall electricity consumption for electric and plug-in hybrid electric vehicles	30%
Value of refueling time per ($ per vehicle-hour)	$21.43
Average tank volume refilled during refueling stop	65%
Annual annual growth in average vehicle use	2001-30: 1.1% 2031-50: 0.5%
Fuel Prices (2017-50 average, $/gallon)	
Retail gasoline price	$3.71
Pre-tax gasoline price	$3.35
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$ 0.00
Price Shock Component	$ 0.185 in 2025
Military Security Component	$ 0.00
Total Economic Costs ($/gallon)	$ 0.185 in 2025
Emission Damage Costs (2020, $/short ton)	
Carbon monoxide	$ 0
Volatile organic compounds (VOC)	$ 1,300
Nitrogen oxides (NO_X) – vehicle use	$ 5,500
Nitrogen oxides (NO_X) – fuel production and distribution	$ 5,300
Particulate matter ($PM_{2.5}$) – vehicle use	$ 300,000

Particulate matter ($PM_{2.5}$) – fuel production and distribution	$ 250,000
Sulfur dioxide (SO_2)	$ 32,000
Annual CO_2 Damage Cost (per metric ton)	variable depending on discount rate and year (see Table II-9 above for 2017 estimates)
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.056
Accidents	$ 0.024
Noise	$ 0.001
Total External Costs	$ 0.080
External Costs from Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.049
Accidents	$0.027
Noise	$0.001
Total External Costs	$0.077
Discount Rates Applied to Future Benefits	3%, 7%

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a. Costs of Fuel Economy-Improving Technologies

Building on cost estimates developed for the MYs 2012–2016 CAFE and GHG final rule and the 2010 TAR, the agencies incorporated new cost estimates for the new technologies being considered and some of the technologies carried over from the MYs 2012–2016 final rule and 2010 TAR. This joint work is reflected in Chapter 3 of the Joint TSD and in Section II of this preamble, as summarized below. For more detailed information on cost of fuel-saving technologies, please refer to Chapter 3 of the Joint TSD and Chapter V of NHTSA's PRIA.

The technology cost estimates used in this analysis are intended to represent manufacturers' direct costs for high-volume production of vehicles with these technologies. NHTSA explicitly accounts for the cost reductions a manufacturer might realize through learning achieved from experience in actually applying a technology, which means that technologies become cheaper over the rulemaking time frame; learning effects are described above and in Chapter 3 of the draft joint TSD and Chapters V and VII of NHTSA's PRIA. NHTSA notes that, in developing technology cost estimates, the agencies have made every effort to hold constant aspects of vehicle performance and utility typically valued by consumers, such as horsepower, carrying capacity, drivability, durability, noise, vibration and harshness (NVH) and towing and hauling capacity. For example, NHTSA includes in its analysis technology cost estimates that are specific to performance passenger cars (*i.e.,* sports cars), as compared to nonperformance passenger cars. NHTSA seeks comment on the extent to which commenters believe that the agencies have been successful in holding constant these elements of vehicle performance and utility in developing the technology cost estimates. Additionally, the agency notes that the technology costs included in this proposal take into account only those associated with the initial build of the vehicle. Although comments were received to the MYs 2012–2016 rulemaking that suggested there could be additional maintenance required with some new technologies (*e.g.,* turbocharging, hybrids, etc.), and that additional maintenance costs could occur as a result. The agency requests comments on this topic and will undertake a more detailed review of these potential costs for the final rule.

Additionally, NHTSA recognizes that manufacturers' actual costs for employing these technologies include additional outlays for accompanying design or engineering changes to models that use them, development and testing of prototype versions, recalibrating engine operating parameters, and integrating the technology with other attributes of the vehicle. Manufacturers' indirect costs for employing these technologies also include expenses for product development and integration, modifying assembly processes and training assembly workers to install them, increased expenses for operation and maintaining assembly lines, higher initial warranty costs for new technologies, any added expenses for selling and distributing vehicles that use these technologies, and manufacturer and dealer profit. These indirect costs have been accounted for in this rulemaking through use of ICMs, which have been revised for this rulemaking as discussed above, in Chapter 3 of the draft joint TSD, and in Chapters V and VII of NHTSA's PRIA.

b. Potential Opportunity Costs of Improved Fuel Economy

An important concern is whether achieving the fuel economy improvements required by the proposed CAFE standards will require manufacturers to modify the performance, carrying capacity, safety, or comfort of some vehicle models. To the extent that it does so, the resulting sacrifice in the value of those models represents an additional cost of achieving the required improvements in fuel economy. (This possibility is addressed in detail in Section IV.G.6.) Although exact dollar values that potential buyers attach to specific vehicle attributes are difficult to infer, differences in vehicle purchase prices and buyers' choices among competing models that feature varying combinations of these characteristics clearly demonstrate that changes in these attributes affect the utility and economic value they offer to potential buyers.[639]

NHTSA and EPA have approached this potential problem by developing cost estimates for fuel economy-improving technologies that include any additional manufacturing costs that would be necessary to maintain the originally planned levels of performance, comfort, carrying capacity, and safety of any light-duty vehicle model to which those technologies are applied. In doing so, the agencies followed the precedent established by the 2002 NAS Report, which estimated ''constant performance and utility'' costs for fuel economy technologies. NHTSA has followed this precedent in its efforts to refine the technology costs it uses to analyze alternative passenger car and light truck CAFE standards for MYs 2017–2025. Although the agency has reduced its estimates of manufacturers' costs for most technologies for use in this rulemaking, these revised estimates are still intended to represent costs that would allow manufacturers to maintain the performance, carrying capacity, and utility of vehicle models while improving their fuel economy.

While we believe that our cost estimates for fuel economy-improving technologies include adequate provisions for accompanying costs that are necessary to prevent any degradation in other vehicle attributes, it is possible that they do not include adequate allowance to prevent sacrifices in these attributes on all vehicle models. If this is the case, the true economic costs of achieving higher fuel economy should include the opportunity costs to vehicle owners of any accompanying reductions vehicles' performance, carrying capacity, and utility, and omitting these will cause the agency's estimated technology costs to underestimate the true economic costs of improving fuel economy.

It would be desirable to estimate explicitly the changes in vehicle buyers' welfare from the combination of higher prices for new vehicle models, increases in their fuel economy, and any accompanying changes in other vehicle attributes. The net change in buyer's welfare that results from the combination of these changes would provide a more accurate estimate of the true economic costs for improving fuel economy. The agency is in the process of developing a model of potential vehicle buyers' decisions about whether to purchase a new car or light truck and their choices from among the available models, which will allow it to conduct such an analysis. This process is expected to be completed for use in analyzing final CAFE standards for MY 2017–25; in the meantime, Section IV.G.6 below includes a detailed analysis and discussion of how omitting possible changes in vehicle attributes other than their prices and fuel economy might affect its estimates of benefits and costs resulting from the standards proposed in this NPRM.

c. The On-Road Fuel Economy ''Gap''

Actual fuel economy levels achieved by light-duty vehicles in on-road driving fall somewhat short of their levels measured under the laboratory-like test conditions used by EPA to establish its published fuel economy ratings for different models. In analyzing the fuel savings from alternative CAFE standards, NHTSA has previously adjusted the actual fuel economy performance of each light truck model downward from its rated value to reflect the expected size of this on-road fuel economy ''gap.'' On December 27, 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' rated fuel economy levels closer to their actual on-road fuel economy levels.[640]

In its Final Rule, however, EPA estimated that actual on-road fuel

[639] *See, e.g.,* Kleit A.N., 1990. ''The Effect of Annual Changes in Automobile Fuel Economy Standards.'' Journal of Regulatory Economics 2: 151–172 (Docket EPA–HQ–OAR–2009–0472–0015); Berry, Steven, James Levinsohn, and Ariel Pakes, 1995. ''Automobile Prices in Market Equilibrium,'' Econometrica 63(4): 841–940 (Docket NHTSA–2009–0059–0031); McCarthy, Patrick S., 1996.

[640] 71 FR 77871 (Dec. 27, 2006).

economy for light-duty vehicles averages approximately 20 percent lower than published fuel economy levels, somewhat larger than the 15 percent shortfall it had previously assumed. For example, if the overall EPA fuel economy rating of a light truck is 20 mpg, EPA estimated that the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be only 80 percent of that figure, or 16 mpg (20*.80). NHTSA employed EPA's revised estimate of this on-road fuel economy gap in its analysis of the fuel savings resulting from alternative CAFE standards evaluated in the MY 2011 final rule.

In the course of developing its CAFE standards for MY 2012–16, NHTSA conducted additional analysis of this issue. The agency used data on the number of passenger cars and light trucks of each model year that were registered for use during calendar years 2000 through 2006, average rated fuel economy for passenger cars and light trucks produced during each model year, and estimates of average miles driven per year by cars and light trucks of different ages. These data were combined to develop estimates of the average fuel economy that the U.S. passenger vehicle fleet would have achieved from 2000 through 2006 if cars and light trucks of each model year achieved the same fuel economy levels in actual on-road driving as they did under test conditions when new.

Table IV–8 compares NHTSA's estimates of fleet-wide average fuel economy under test conditions for 2000 through 2006 to the Federal Highway Administration's (FHWA) published estimates of actual on-road fuel economy achieved by passenger cars and light trucks during each of those years.[641] As it shows, FHWA's estimates of actual fuel economy for passenger cars ranged from 21–23 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions over this period, and FHWA's estimates of actual fuel economy for light trucks ranged from 16–18 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions. Thus, these results appear to confirm that the 20 percent on-road fuel economy gap represents a reasonable estimate for use in evaluating the fuel savings likely to result from more stringent fuel economy and CO_2 standards in MYs 2017–2025.

[641] Federal Highway Administration, Highway Statistics, 2000 through 2006 editions, Table VM–1; *See http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm* (last accessed March 1, 2010).

Table IV-8. Estimated Fleet-Wide Fuel Economy of Passenger Cars and Light Trucks Compared to Reported Fuel Economy

YEAR	PASSENGER CARS			LIGHT-DUTY TRUCKS		
	NHTSA Estimated Test MPG	FHWA Reported Actual MPG	Percent Difference	NHTSA Estimated Test MPG	FHWA Reported Actual MPG	Percent Difference
2000	28.2	21.9	-22.2%	20.8	17.4	-16.3%
2001	28.2	22.1	-21.7%	20.8	17.6	-15.5%
2002	28.3	22.0	-22.3%	20.9	17.5	-16.2%
2003	28.4	22.2	-21.9%	21.0	17.2	-18.0%
2004	28.5	22.5	-21.1%	21.0	17.2	-18.3%
2005	28.6	22.1	-22.8%	21.1	17.7	-16.3%
2006	28.8	22.5	-21.8%	21.2	17.8	-16.2%
Avg., 2000-2006	28.4	22.2	-22.0%	21.0	17.5	-16.7%

The comparisons reported in this table must be interpreted with some caution, however, because the estimates of annual car and truck use used to develop these estimates are submitted to FHWA by individual states, which use differing definitions of passenger cars and light trucks. (For example, some states classify minivans as cars, while others define them as light trucks.) At the same time, while total gasoline consumption can be reasonably estimated from excise tax receipts, separate estimates of gasoline consumption by cars and trucks are not available. For these reasons, NHTSA has chosen not to rely on its separate estimates of the on-road fuel economy gap for cars and light trucks. However, the agency does believe that these results confirm that the 20 percent on-road fuel economy discount represents a reasonable estimate for use in evaluating the fuel savings likely to result from CAFE standards for both cars and light trucks. NHTSA employs this value for vehicles operating on liquid fuels (gasoline, diesel, and gasoline/alcohol blends), and uses it to analyze the impacts of proposed CAFE standards for model years 2017–25 on the use of these fuels.

In the recent TAR, EPA and NHTSA assumed that the overall energy shortfall for the vehicles employing electric drivetrains, including plug-in hybrid and battery-powered electric vehicles, is 30 percent. This value was derived from the agencies' engineering judgment based on the limited available information. During the stakeholder meetings conducted prior to the technical assessment, confidential business information (CBI) was supplied by several manufacturers which indicated that electrically powered vehicles had greater variability in their on-road energy consumption than vehicles powered by internal combustion engines, although other manufacturers suggested that the on-road/laboratory differential attributable to electric operation should approach that of liquid fuel operation in the future. Second, data from EPA's 2006 analysis of the ''five cycle'' fuel economy label as part of the rulemaking discussed above supported a larger on-road shortfall for vehicles with hybrid-electric drivetrains, partly because real-world driving tends to have higher acceleration/deceleration rates than are employed on the 2-cycle test. This diminishes the fuel economy benefits of regenerative braking, which can result in a higher test fuel economy for hybrids than is achieved under normal on-road conditions.[642] Finally, heavy accessory load, extremely high or low temperatures, and aggressive driving have deleterious impacts of unknown magnitudes on battery performance. Consequently, the agencies judged that 30 percent was a reasonable estimate for use in the TAR, and NHTSA believes that it continues to represent the most reliable estimate for use in the current analysis.

One of the most significant factors responsible for the difference between test and on-road fuel economy is the use of air conditioning. While the air conditioner is turned off during the FTP and HFET tests, drivers often use air conditioning under warm, humid conditions. The air conditioning compressor can also be engaged during ''defrost'' operation of the heating system.[643] In the MYs 2012–2016 rulemaking, EPA estimated the impact of an air conditioning system at approximately 14.3 grams CO_2/mile for an average vehicle without any of the improved air conditioning technologies discussed in that rulemaking. For a 27 mpg (330 g CO_2/mile) vehicle, this would account for is approximately 20 percent of the total estimated on-road gap (or about 4 percent of total fuel consumption).

In the MY 2012–2016 rule, EPA estimated that 85 percent of MY 2016 vehicles would reduce their tailpipe CO_2 emissions attributable to air conditioner efficiency by 40 percent through the use of advanced air conditioning technologies, and that incorporating this change would reduce the average on-road gap by about 2 percent.[644] However, air conditioning-related fuel consumption does not decrease proportionally as engine efficiency improves, because the engine load due attributable to air conditioner operation is approximately constant across engine efficiency and technology. As a consequence, air conditioning operation represents an increasing percentage of vehicular fuel consumption as engine efficiency increases.[645] Because these two effects are expected approximately to counterbalance each other, NHTSA has elected not to adjust its estimate of the on-road gap for use in this proposal.

d. Fuel Prices and the Value of Saving Fuel

Future fuel prices are the single most important input into the economic analysis of the benefits of alternative CAFE standards because they determine the value of future fuel savings, which account for approximately 90% of total economic benefits from requiring higher fuel economy. NHTSA relies on the most recent fuel price projections from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2011 Reference Case to estimate the economic value of fuel savings projected to result from alternative CAFE standards for MY 2017–25. The AEO 2011 Reference Case forecasts of gasoline and diesel fuel prices represents EIA's most up-to-date estimate of the most likely course of future prices for petroleum products. EIA is widely recognized as an impartial and authoritative source of analysis and forecasts of U.S. energy production, consumption, and prices, and its forecasts are widely relied upon by federal agencies for use in regulatory analysis and for other purposes. Its forecasts are derived using EIA's National Energy Modeling System (NEMS), which includes detailed representations of supply pathways, sources of demand, and their interaction to determine prices for different forms of energy.

As compared to the gasoline prices used in NHTSA's Final Rule establishing CAFE standards for MY 2012–2016 (which relied on forecasts from AEO 2010), the AEO 2011 Reference Case fuel prices are slightly higher through the year 2020, but slightly lower for most years thereafter. Expressed in constant 2009 dollars, the AEO 2011 Reference Case forecast of retail gasoline prices (which include federal, state, and local taxes) during 2017 is $3.25 per gallon, rising gradually to $3.71 by the year 2035. However, valuing fuel savings over the full lifetimes of passenger cars and light trucks affected by the standards proposed for MYs 2017–25 requires fuel price forecasts that extend through 2060, approximately the last year during which a significant number of MY 2025 vehicles will remain in service.[646] To obtain fuel price forecasts for the years 2036 through 2060, the agency assumes that retail fuel prices will continue to increase after 2035 at the average annual rate (0.7%) projected for 2017–2035 in the AEO 2011 Reference Case. This assumption results in a projected retail price of gasoline that reaches $4.16 in 2050. Over the entire period from 2017–2050, retail gasoline prices are projected to average $3.67, as Table IV–7 reported previously.

The value of fuel savings resulting from improved fuel economy to buyers of light-duty vehicles is determined by the retail price of fuel, which includes Federal, State, and any local taxes imposed on fuel sales. Because fuel taxes represent transfers of resources from fuel buyers to government agencies, however, rather than real resources that are consumed in the process of supplying or using fuel, NHTSA deducts their value from retail fuel prices to determine the value of fuel savings resulting from more stringent CAFE standards to the U.S. economy.

NHTSA follows the assumptions used by EIA in AEO 2011 that State and local gasoline taxes will keep pace with inflation in nominal terms, and thus remain constant when expressed in constant dollars. In contrast, EIA assumes that Federal gasoline taxes will remain unchanged in nominal terms, and thus decline throughout the forecast period when expressed in constant dollars. These differing assumptions about the likely future behavior of Federal and State/local fuel taxes are consistent with recent historical experience, which reflects the fact that Federal as well as most State motor fuel taxes are specified on a cents-per-gallon rather than an ad valorem basis, and typically require legislation to change. Subtracting fuel taxes from the retail prices forecast in AEO 2011 results in projected values for saving gasoline of $3.29 per gallon during 2017, rising to $3.48 per gallon by the year 2035, and to $3.65 by the year 2050. Over this entire period, pre-tax gasoline prices are projected to average $3.32 per gallon.

EIA also includes forecasts reflecting high and low global oil prices in each year's complete AEO, which reflect uncertainties regarding OPEC behavior as well as future levels of oil production and demand. These alternative scenarios project retail gasoline prices that range from a low of $2.30 to a high

[642] EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR parts 86 and 600, 71 FR 77872, 77879 (Dec. 27, 2006). *Available at http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf.*

[643] EPA, *Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates,* at 70. Office of Transportation and Air Quality EPA420–R–06–017 December 2006, Chapter II, *http://www.epa.gov/fueleconomy/420r06017.pdf.*

[644] 4% of the on-road gap x 40% reduction in air conditioning fuel consumption x 85% of the fleet = ~2%.

[645] As an example, the air conditioning load of 14.3 g/mile of CO_2 is a smaller percentage (4.3%) of 330 g/mile than 260 (5.4%).

[646] The agency defines the maximum lifetime of vehicles as the highest age at which more than 2 percent of those originally produced during a model year remain in service. In the case of light trucks, for example, this age has typically been 36 years for recent model years.

of $4.85 per gallon during 2020, and from $2.12 to $5.36 per gallon during 2035 (all figures in 2009 dollars). In conjunction with our assumption that fuel taxes will remain constant in real or inflation-adjusted terms over this period, these forecasts imply pre-tax values of saving fuel ranging from $1.91 to $4.46 per gallon during 2020, and from $1.77 to $5.01 per gallon in 2035 (again, all figures are in constant 2009 dollars). In conducting the analysis of uncertainty in benefits and costs from alternative CAFE standards required by OMB, NHTSA evaluated the sensitivity of its benefits estimates to these alternative forecasts of future fuel prices; detailed results and discussion of this sensitivity analysis can be found in the agency's PRIA. Generally, this analysis confirms that the primary economic benefit resulting from the rule—the value of fuel savings—is extremely sensitive to alternative forecasts of future fuel prices.

e. Consumer Valuation of Fuel Economy and Payback Period

The agency uses slightly different assumptions about the length of time over which potential vehicle buyers consider fuel savings from higher fuel economy, and about how they discount those future fuel savings, in different aspects of its analysis. For most purposes, the agency assumes that buyers value fuel savings over the first five years of a new vehicle's lifetime; the five-year figure represents approximately the current average term of consumer loans to finance the purchase of new vehicles.

To simulate manufacturers' assessment of the net change in the value of an individual vehicle model to prospective buyers from improving its fuel economy, NHTSA discounts fuel savings over the first five years of its lifetime using a 7 percent rate. The resulting value is deducted from the technology costs that would be incurred by its manufacturer to improve that model's fuel economy, in order to determine the change in its value to potential buyers. Since this is also the additional amount its manufacturer could expect to receive when selling the vehicle after improving its fuel economy, this can also be viewed as the ''effective cost'' of the improvement from its manufacturers' perspective. The CAFE model uses these estimates of effective costs to identify the sequence in which manufacturers are likely to select individual models for improvements in fuel economy, as well as to identify the most cost-effective technologies for doing so.

The average of effective cost to its manufacturer for increasing the fuel economy of a model also represents the change in its value from the perspective of potential buyers. Under the assumption that manufacturers change the selling price of each model by this amount, its average value also represents the average change in its net or effective price to would-be buyers. As part of our sensitivity case analyzing the potential for manufacturers to over-comply with CAFE standards—that is, to produce a lineup of vehicle models whose sales-weighted average fuel economy exceeds that required by prevailing standards—NHTSA used the extreme assumption that potential buyers value fuel savings only during the first year they expect to own a new vehicle.

The agency notes that these varying assumptions about future time horizons and discount rates for valuing fuel savings are used only to analyze manufacturers' responses to requiring higher fuel economy and buyers' behavior in response to manufacturers' compliance strategies. When estimating the aggregate value to the U.S. economy of fuel savings resulting from alternative increases in CAFE standards—or the ''social'' value of fuel savings—the agency includes fuel savings over the entire expected lifetimes of vehicles that would be subject to higher standards, rather than over the shorter periods we assume manufacturers employ to represent the preferences of vehicle buyers, or that buyers use to assess changes in the net price or new vehicles.

Valuing fuel savings over vehicles' entire lifetimes recognizes the savings in fuel costs that subsequent owners of vehicles will experience from higher fuel economy, even if their initial purchasers do not expect to recover the remaining value of fuel savings when they re-sell those vehicles, or for other reasons do not value fuel savings beyond the assumed five-year time horizon. The agency acknowledges that it has not accounted for any effects of increased costs for financing, insuring, or maintaining vehicles with higher fuel economy, over either this limited payback period or the full lifetimes of vehicles.

The procedure the agency uses for calculating lifetime fuel savings is discussed in detail in the following section, while discussion about the time horizon over which potential buyers may consider fuel savings in their vehicle purchasing decisions is provided in more detail in Section IV.G.6 below.

f. Vehicle Survival and Use Assumptions

NHTSA's analysis of fuel savings and related benefits from adopting more stringent fuel economy standards for MYs 2017–2025 passenger cars and light trucks begins by estimating the resulting changes in fuel use over the entire lifetimes of the affected vehicles. The change in total fuel consumption by vehicles produced during each model year is calculated as the difference between their total fuel use over their lifetimes with a higher CAFE standard in effect, and their total lifetime fuel consumption under a baseline in which CAFE standards remained at their 2016 levels. The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number expected to remain in service during each year following their production and sale.[647] This is calculated by multiplying the number of vehicles originally produced during a model year by the proportion typically expected to remain in service at their age during each later year, often referred to as a ''survival rate.''

As discussed in more detail in Section II.B.3 above and in Chapter 1 of the TSD, to estimate production volumes of passenger cars and light trucks for individual manufacturers, NHTSA relied on a baseline market forecast constructed by EPA staff beginning with MY 2008 CAFE certification data. After constructing a MY 2008 baseline, EPA and NHTSA used projected car and truck volumes for this period from Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2011 in the NPRM analysis.[648] However,

[647] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 2 during calendar year 2001, and to reach their maximum age of 26 years during calendar year 2025. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 26 years, while light trucks have a maximum lifetime of 36 years. See Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, ''Vehicle Survivability and Travel Mileage Schedules,'' DOT HS 809 952, 8–11 (January 2006). *Available at http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf* (last accessed Sept. 26, 2011).

[648] *Available at http://www.eia.gov/forecasts/aeo/index.cfm* (last accessed Sept. 26, 2011). NHTSA and EPA made the simplifying assumption that projected sales of cars and light trucks during each calendar year from 2012 through 2016 represented the likely production volumes for the corresponding model year. The agency did not attempt to establish the exact correspondence between projected sales during individual calendar years and production volumes for specific model years.

Annual Energy Outlook forecasts only total car and light truck sales, rather than sales at the manufacturer and model-specific level, which the agencies require in order to estimate the effects new standards will have on individual manufacturers.[649]

To estimate sales of individual car and light truck models produced by each manufacturer, EPA purchased data from CSM Worldwide and used its projections of the number of vehicles of each type (car or truck) that will be produced and sold by manufacturers in model years 2011 through 2015.[650] This provided year-by-year estimates of the percentage of cars and trucks sold by each manufacturer, as well as the sales percentages accounted for by each vehicle market segment. (The distributions of car and truck sales by manufacturer and by market segment for the 2016 model year and beyond were assumed to be the same as CSM's forecast for the 2015 calendar year.) Normalizing these percentages to the total car and light truck sales volumes projected for 2017 through 2025 in AEO 2011 provided manufacturer-specific market share and model-specific sales estimates for those model years. The volumes were then scaled to AEO 2011 total volume for each year.

To estimate the number of passenger cars and light trucks originally produced during model years 2017 through 2025 that will remain in use during subsequent years, the agency applied age-specific survival rates for cars and light trucks to its forecasts of passenger car and light truck sales for each of those model years. In 2008, NHTSA updated its previous estimates of car and light truck survival rates using the most current registration data for vehicles produced during recent model years, in order to ensure that they reflected recent increases in the durability and expected life spans of cars and light trucks.[651] However, the agency does not attempt to forecast changes in those survival rates over the future.

The next step in estimating fuel use is to calculate the total number of miles that cars and light trucks remaining in use will be driven each year. To estimate the total number of miles driven by cars or light trucks produced in a model year during each subsequent year, the number projected to remain in use during that year is multiplied by the average number of miles those vehicles are expected to be driven at the age they will have reached in that year. The agency estimated annual usage of cars and light trucks of each age using data from the Federal Highway Administration's 2001 National Household Travel Survey (NHTS).[652] Because these estimates reflect the historically low gasoline prices that prevailed at the time the 2001 NHTS was conducted, however, NHTSA adjusted them to account for the effect on vehicle use of the higher fuel prices projected over the lifetimes of model year 2017–25 cars and light trucks. Details of this adjustment are provided in Chapter VIII of the PRIA and Chapter 4 of the draft Joint TSD.

The estimates of annual miles driven at different vehicle ages derived from the 2001 NHTS were also adjusted to reflect projected future growth in average use for vehicles at every age over their lifetimes. Increases in average annual use of cars and light trucks, which have averaged approximately 1 percent annually over the past two decades, have been an important source of historical growth in the total number of miles they are driven each year. To estimate future growth in their average annual use for purposes of this rulemaking, NHTSA calculated the rate of growth in the adjusted mileage schedules derived from the 2001 NHTS that would be necessary for total car and light truck travel to increase at the rate forecast in the AEO 2011 Reference Case.[653] This rate was calculated to be consistent with future changes in the overall size and age distributions of the U.S. passenger car and light truck fleets that result from the agency's forecasts of total car and light truck sales and updated survival rates. The resulting growth rate in average annual car and light truck use is approximately 1.1 percent from 2017 through 2030, and declines to 0.5 percent per year thereafter. [654] While the adjustment for future fuel prices reduces average annual mileage at each age from the values derived using the 2001 NHTS, the adjustment for expected future growth in average vehicle use increases it. The net effect of these two adjustments is to increase expected lifetime mileage for MY 2017–25 passenger cars and light trucks by about 22 percent from the estimates originally derived from the 2001 NHTS.

Finally, the agency estimated total fuel consumption by passenger cars and light trucks remaining in use each year by dividing the total number of miles surviving vehicles are driven by the fuel economy they are expected to achieve under each alternative CAFE standard. Each model year's total lifetime fuel consumption is the sum of fuel use by the cars or light trucks produced during that model year over its life span. In turn, the savings in lifetime fuel use by cars or light trucks produced during each model year affected by this proposed rule that will result from each alternative CAFE standard is the difference between its lifetime fuel use at the fuel economy level it attains under the Baseline alternative, and its lifetime fuel use at the higher fuel economy level it is projected to achieve under that alternative standard.[655]

g. Accounting for the Fuel Economy Rebound Effect

The fuel economy rebound effect refers to the fact that some of the fuel

[649] Because AEO 2011's ''car'' and ''truck'' classes did not reflect NHTSA's recent reclassification (in March 2009 for enforcement beginning MY 2011) of many two wheel drive SUVs from the non-passenger (*i.e.,* light truck) fleet to the passenger car fleet, EPA staff made adjustments to account for such vehicles in the baseline.

[650] EPA also considered other sources of similar information, such as J.D. Powers, and concluded that CSM was better able to provide forecasts at the requisite level of detail for most of the model years of interest.

[651] Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, ''Vehicle Survivability and Travel Mileage Schedules,'' DOT HS 809 952, 8–11 (January 2006). *Available at http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf* (last accessed Sept. 26, 2011). These updated survival rates suggest that the expected lifetimes of recent-model passenger cars and light trucks are 13.8 and 14.5 years.

[652] For a description of the Survey, see *http://nhts.ornl.gov/introduction.shtml#2001* (last accessed September 26, 2011).

[653] This approach differs from that used in the MY 2011 final rule, where it was assumed that future growth in the total number of cars and light trucks in use resulting from projected sales of new vehicles was adequate by itself to account for growth in total vehicle use, without assuming continuing growth in average vehicle use.

[654] While the adjustment for future fuel prices reduces average mileage at each age from the values derived from the 2001 NHTS, the adjustment for expected future growth in average vehicle use increases it. The net effect of these two adjustments is to increase expected lifetime mileage by about 18 percent significantly for both passenger cars and about 16 percent for light trucks.

[655] To illustrate these calculations, the agency's adjustment of the AEO 2009 Revised Reference Case forecast indicates that 9.26 million passenger cars will be produced during 2012, and the agency's updated survival rates show that 83 percent of these vehicles, or 7.64 million, are projected to remain in service during the year 2022, when they will have reached an age of 10 years. At that age, passenger achieving the fuel economy level they are projected to achieve under the Baseline alternative are driven an average of about 800 miles, so surviving model year 2012 passenger cars will be driven a total of 82.5 billion miles (= 7.64 million surviving vehicles × 10,800 miles per vehicle) during 2022. Summing the results of similar calculations for each year of their 26-year maximum lifetime, model year 2012 passenger cars will be driven a total of 1,395 billion miles under the Baseline alternative. Under that alternative, they are projected to achieve a test fuel economy level of 32.4 mpg, which corresponds to actual on-road fuel economy of 25.9 mpg (= 32.4 mpg × 80 percent). Thus their lifetime fuel use under the Baseline alternative is projected to be 53.9 billion gallons (= 1,395 billion miles divided by 25.9 miles per gallon).

savings expected to result from higher fuel economy, such as an increase in fuel economy required by the adoption of higher CAFE standards, may be offset by additional vehicle use. The increase in vehicle use occurs because higher fuel economy reduces the fuel cost of driving, which is typically the largest single component of the monetary cost of operating a vehicle, and vehicle owners respond to this reduction in operating costs by driving more. Even with their higher fuel economy, this additional driving consumes some fuel, so this effect reduces the fuel savings that result when raising CAFE standards requires manufacturers to improve fuel economy. The rebound effect refers to the fraction of fuel savings expected to result from increased fuel economy that is offset by additional driving.[656]

The magnitude of the rebound effect is an important determinant of the actual fuel savings that are likely to result from adopting stricter CAFE standards. Research on the magnitude of the rebound effect in light-duty vehicle use dates to the early 1980s, and generally concludes that a significant rebound effect occurs when vehicle fuel efficiency improves.[657] The most common approach to estimating its magnitude has been to analyze survey data on household vehicle use, fuel consumption, fuel prices, and other factors affecting household travel behavior to estimate the response of vehicle use to differences in the fuel efficiency of individual vehicles. Because this approach most closely matches the definition of the rebound effect, which is the response of vehicle use to differences in fuel economy, the agency regards these studies as likely to produce the most reliable estimates of the rebound effect. Other studies have relied on econometric analysis of annual U.S. data on vehicle use, fuel efficiency, fuel prices, and other variables to estimate the response of total or average vehicle use to changes in fleet-wide average fuel economy and its effect on fuel cost per mile driven. More recent studies have analyzed yearly variation in vehicle ownership and use, fuel prices, and fuel economy among states over an extended time period in order to measure the response of vehicle use to changing fuel costs per mile.[658]

Another important distinction among studies of the rebound effect is whether they assume that the effect is constant, or allow it to vary in response to changes in fuel costs, personal income, or vehicle ownership. Most studies using aggregate annual data for the U.S. assume a constant rebound effect, although some of these studies test whether the effect varies as changes in retail fuel prices or average fuel efficiency alter fuel cost per mile driven. Studies using household survey data estimate significantly different rebound effects for households owning varying numbers of vehicles, with most concluding that the rebound effect is larger among households that own more vehicles. Finally, recent studies using state-level data conclude that the rebound effect varies directly in response to changes in personal income, the degree of urbanization of U.S. cities, and differences in traffic congestion levels, as well as fuel costs. Some studies conclude that the long-run rebound effect is significantly larger than the immediate response of vehicle use to increased fuel efficiency. Although their estimates of the time required for the rebound effect to reach its long-run magnitude vary, this long-run effect is probably more appropriate for evaluating the fuel savings likely to result from adopting stricter CAFE standards for future model years.

In order to provide a more comprehensive overview of previous estimates of the rebound effect, NHTSA has updated its previous review of published studies of the rebound effect to include those conducted as recently as 2010. The agency performed a detailed analysis of several dozen separate estimates of the long-run rebound effect reported in these studies, which is summarized in Table IV–9 below.[659] As the table indicates, these estimates range from as low as 7 percent to as high as 75 percent, with a mean value of 23 percent. Both the type of data used and authors' assumption about whether the rebound effect varies over time have important effects on its estimated magnitude. The 34 estimates derived from analysis of U.S. annual time-series data produce a mean estimate of 18 percent for the long-run rebound effect, while the mean of 23 estimates based on household survey data is considerably larger (31 percent), and the mean of 15 estimates based on pooled state data (23 percent) is close to that for the entire sample. The 37 estimates assuming a constant rebound effect produce a mean of 23 percent, identical to the mean of the 29 estimates reported in studies that allowed the rebound effect to vary in response to fuel prices and fuel economy levels, vehicle ownership, or household income. Updated to reflect the most recent available information on these variables, the mean of these estimates is 19 percent, as Table IV–9 reports.

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[656] Formally, the rebound effect is often expressed as the elasticity of vehicle use with respect to the cost per mile driven. Additionally, it is consistently expressed as a positive percentage (rather than as a negative decimal fraction, as this elasticity is normally expressed).

[657] Some studies estimate that the long-run rebound effect is significantly larger than the immediate response to increased fuel efficiency. Although their estimates of the adjustment period required for the rebound effect to reach its long-run magnitude vary, this long-run effect is probably more appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply to future model years.

[658] In effect, these studies treat U.S. states as a data ''panel'' by applying appropriate estimation procedures to data consisting of each year's average values of these variables for the separate states.

[659] In some cases, NHTSA derived estimates of the overall rebound effect from more detailed results reported in the studies. For example, where studies estimated different rebound effects for households owning different numbers of vehicles but did not report an overall value, the agency computed a weighted average of the reported values using the distribution of households among vehicle ownership categories.

Table IV-9. Summary of Published Estimates of the Rebound Effect

Category of Estimates	Number of Studies	Number of Estimates	Range		Distribution		
			Low	High	Median	Mean	Std. Dev.
All Estimates	23	72	7%	75%	21%	23%	13%
Published Estimates	17	50	7%	75%	22%	24%	14%
Authors' Preferred Estimates	17	17	9%	75%	22%	22%	15%
U.S. Time-Series Estimates	7	34	7%	45%	14%	18%	9%
Household Survey Estimates	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Estimates	3	15	8%	58%	22%	23%	12%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect (1) Reported Estimates	10	29	10%	45%	23%	23%	10%
Updated to 2010 (2)	11	33	6%	56%	15%	19%	13%

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Table IV-10. Social Cost of CO_2 Emissions for Selected Future Years (2009$ per metric ton)

Discount Rate	5%	3%	2.5%	3%
Source	Average of estimates			95th percentile estimate
2012	$5.28	$23.06	$37.53	$70.14
2015	$5.93	$24. 58	$39.57	$74.03
2020	$7.01	$27.10	$42.98	$83.17
2025	$8. 53	$30.43	$47.28	$93.11
2030	$10.05	$33.75	$51.58	$103.06
2035	$11.57	$37.08	$55.88	$113.00
2040	$13.09	$40.40	$60.19	$122.95
2045	$14.63	$43. 34	$63.59	$131.66
2050	$16.18	$46.27	$66.99	$140.37

Some recent studies provide evidence that the rebound effect has been declining over time. This result appears plausible for two reasons: First, the responsiveness of vehicle use to variation in fuel costs would be expected to decline as they account for a smaller proportion of the total monetary cost of driving, which has been the case until recently. Second, rising personal incomes would be expected to reduce the sensitivity of vehicle use to fuel costs as the time component of driving costs—which is likely to be related to income levels—accounts for a larger fraction the total cost of automobile travel. At the same time, however, rising incomes are strongly associated with higher auto ownership levels, which increase households' opportunities to substitute among vehicles in response to varying fuel prices and differences in their fuel economy levels. This is likely to increase the sensitivity of households' overall vehicle use to differences in the fuel economy levels of individual vehicles.

Small and Van Dender combined time series data for states to estimate the rebound effect, allowing its magnitude to vary in response to fuel prices, fleet-wide average fuel economy, the degree of urbanization of U.S. cities, and personal income levels.[660] The authors employ a model that allows the effect of fuel cost per mile on vehicle use to vary in response to changes in personal income levels and increasing urbanization of U.S. cities. For the time period 1966–2001, their analysis implied a long-run rebound effect of 22 percent, which is consistent with previously published studies. Continued growth in personal incomes over this period reduces their estimate of the long-run rebound effect during its last five years (1997–2001) to 11 percent, and an unpublished update through 2004 prepared by the authors reduced their estimate of the long-run rebound effect for the period 2000–2004 to 6 percent.[661]

More recently, Hymel, Small and Van Dender extended the previous analysis to include traffic congestion levels in urbanized areas.[662] Although controlling for the effect of congestion on vehicle use increased their estimates of the rebound effect, these authors also found that the rebound effect appeared to be declining over time. For the time period 1966–2004, their estimate of the long-run rebound effect was 24 percent, while for the last year of that period their estimate was 13 percent, significantly above the previous Small and Van Dender estimate of a 6 percent

[660] Small, K. and K. Van Dender, 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect", The Energy Journal, vol. 28, no. 1, pp. 25–51.

[661] Small, K. and K. Van Dender, 2007b. "Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy," OECD/ITF Joint Transport Research Centre Discussion Papers 2007/16, OECD, International Transport Forum.

[662] Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender, "Induced demand and rebound effects in road transport," Transportation Research Part B: Methodological, Volume 44, Issue 10, December 2010, Pages 1220–1241, ISSN 0191–2615, DOI: 10.1016/j.trb.2010.02.007.

rebound effect for the period 2000–2004.

Recent research by Greene (under contract to EPA) using U.S. national time-series data for the period 1966–2007 lends further support to the hypothesis that the rebound effect is declining over time.[663] Greene found that fuel prices had a statistically significant impact on VMT, yet fuel efficiency did not, and statistical testing rejected the hypothesis of equal elasticities of vehicle use with respect to gasoline prices and fuel efficiency. Greene also tested model formulations that allowed the effect of fuel cost per mile on vehicle use to decline with rising per capita income; his preferred form of this model produced estimates of the rebound effect that declined to 12 percent in 2007.

In light of findings from recent research, the agency's judgment is that the apparent decline over time in the magnitude of the rebound effect justifies using a value for future analysis that is lower than many historical estimates, which average 15–25 percent. Because the lifetimes of vehicles affected by the alternative CAFE standards considered in this rulemaking will extend from 2017 until 2060, a value that is at the low end of historical estimates appears to be appropriate. Thus as it elected to do in its previous analysis of the effects of raising CAFE standards for MY 2012–16 cars and light trucks, NHTSA uses a 10 percent rebound effect in its analysis of fuel savings and other benefits from higher CAFE standards for MY 2017–25 vehicles. Recognizing the wide range of uncertainty surrounding its correct value, however, the agency also employs estimates of the rebound effect ranging from 5 to 20 percent in its sensitivity testing. The 10 percent figure is at the low end of those reported in almost all previous research, and it is also below most estimates of the historical and current magnitude of the rebound effect developed by NHTSA. However, other recent research—particularly that conducted by Small and Van Dender and by Greene—suggests that the magnitude of the rebound effect has declined over time, and is likely to continue to do so. As a consequence, NHTSA concluded that a value at the low end of the historical estimates reported here is likely to provide a more reliable estimate of its magnitude during the future period spanned by NHTSA's analysis of the impacts of this rule. The 10 percent estimate lies between the 10–30 percent range of estimates for the historical rebound effect reported in most previous research, and is at the upper end of the 5–10 percent range of estimates for the future rebound effect reported in recent studies. In summary, the 10 percent value was not derived from a single estimate or particular study, but instead represents a compromise between historical estimates and projected future estimates. Chapter 4.2.5 of the Joint TSD reviews the relevant literature and discusses in more depth the reasoning for the rebound value used here.

h. Benefits From Increased Vehicle Use

The increase in vehicle use from the rebound effect provides additional benefits to their users, who make more frequent trips or travel farther to reach more desirable destinations. This additional travel provides benefits to drivers and their passengers by improving their access to social and economic opportunities away from home. As evidenced by their decisions to make more frequent or longer trips when improved fuel economy reduces their costs for driving, the benefits from this additional travel exceed the costs drivers and passengers incur in traveling these additional distances.

The agency's analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel costs drivers incur plus the consumer surplus they receive from the additional accessibility it provides.[664] NHTSA estimates the value of the consumer surplus provided by added travel as one-half of the product of the decline in fuel cost per mile and the resulting increase in the annual number of miles driven, a standard approximation for changes in consumer surplus resulting from small changes in prices. Because the increase in travel depends on the extent of improvement in fuel economy, the value of benefits it provides differs among model years and alternative CAFE standards.

i. The Value of Increased Driving Range

Improving vehicles' fuel economy may also increase their driving range before they require refueling. By extending the upper limit of the range vehicles can travel before refueling is needed, the per-vehicle average number of refueling trips per year is expected to decline. This reduction in refueling frequency provides a time savings benefit to owners.[665]

NHTSA estimated a number of parameters regarding consumers' refueling habits using newly-available observational and interview data from a 2010–2011 NASS study conducted at fueling stations throughout the nation. A (non-exhaustive) list of key parameters derived from this study is as follows: Average number of gallons of fuel purchased, length of time to refuel and pay, length of time to drive to the fueling station, primary reason for refueling, and number of adult vehicle occupants.

Using these and other parameters (detailed explanation of parameters and methodology provided in Chapter VIII of NHTSA's PRIA), NHTSA estimated the decrease in number of refueling cycles for each model year's fleet attributable to improvements in actual on-road MPG resulting from the proposed CAFE standards. NHTSA acknowledges—and adjusts for—the fact that many refueling trips occur for reasons other than a low reading on the gas gauge (for example, many consumers refuel on a fixed schedule). NHTSA separately estimated the value of vehicle-hour refueling time and applied this to the projected decrease in number of refueling cycles to estimate the aggregate fleet-wide value of refueling time savings for each year that a given model year's vehicles are expected to remain in service.

As noted in the PRIA, NHTSA assumed a constant fuel tank size in estimating the impact of higher CAFE requirements on the frequency of refueling. NHTSA seeks comment regarding this assumption. Specifically, NHTSA seeks comment from manufacturers regarding their intention to retain fuel tank size or driving range in their redesigned vehicles. Will fuel economy improvements translate into increased driving range, or will fuel tanks be reduced in size to maintain current driving range?

j. Added Costs From Congestion, Crashes and Noise

Increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. To estimate the economic costs associated with these consequences of added driving, NHTSA applies estimates of per-mile congestion, accident, and noise costs caused by

[663] Greene, David, ''Rebound 2007: Analysis of National Light-Duty Vehicle Travel Statistics,'' February 9, 2010. This paper has been accepted for an upcoming special issue of Energy Policy, although the publication date has not yet been determined.

[664] The consumer surplus provided by added travel is estimated as one-half of the product of the decline in fuel cost per mile and the resulting increase in the annual number of miles driven.

[665] If manufacturers respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting cost saving will presumably be reflected in lower vehicle sales prices.

increased use of automobiles and light trucks developed previously by the Federal Highway Administration.[666] These values are intended to measure the increased costs resulting from added congestion and the delays it causes to other drivers and passengers, property damages and injuries in traffic accidents, and noise levels contributed by automobiles and light trucks. NHTSA previously employed these estimates in its analysis accompanying the MY 2011 final CAFE rule, as well as in its analysis of the effects of higher CAFE standards for MY 2012–16. After reviewing the procedures used by FHWA to develop them and considering other available estimates of these values, the agency continues to find them appropriate for use in this proposal. The agency multiplies FHWA's estimates of per-mile costs by the annual increases in automobile and light truck use from the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year.

k. Petroleum Consumption and Import Externalities

i. Changes in Petroleum Imports

Based on a detailed analysis of differences in fuel consumption, petroleum imports, and imports of refined petroleum products among alternative scenarios presented in AEO 2011, NHTSA estimates that approximately 50 percent of the reduction in fuel consumption resulting from adopting higher CAFE standards is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would reduce domestic fuel refining.[667] Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum.[668] Thus on balance, each 100 gallons of fuel saved as a consequence of higher CAFE standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 95 gallons.[669]

ii. Benefits From Reducing U.S. Petroleum Imports

U.S. consumption and imports of petroleum products impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) Higher prices for petroleum products resulting from the effect of U.S. petroleum demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion against resulting price increases.[670] Reducing these costs by lowering U.S. petroleum imports represents another source of benefits from stricter CAFE standards and the savings in consumption of petroleum-based fuels that would result from higher fuel economy. Higher U.S. imports of crude oil or refined petroleum products increase the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above their market prices. Conversely, lowering U.S. imports of crude petroleum or refined fuels by reducing domestic fuel consumption can reduce these external costs, and any reduction in their total value that results from improved fuel economy represents an economic benefit of more stringent CAFE standards, in addition to the value of saving fuel itself.

The first component of the external costs imposed by U.S. petroleum consumption and imports (often termed the ''monopsony cost'' of U.S. oil imports), measures the increase in payments from domestic oil consumers to foreign oil suppliers beyond the increased purchase price of petroleum itself that results when increased U.S. import demand raises the world price of petroleum.[671] However, this monopsony cost or premium represents a financial transfer from consumers of petroleum products to oil producers, and does not entail the consumption of real economic resources. Thus the decline in its value that occurs when reduced U.S. demand for petroleum products causes a decline in global petroleum prices produces no savings in economic resources globally or domestically, although it does reduce the value of the financial transfer from U.S. consumers of petroleum products to foreign suppliers of petroleum. Accordingly, NHTSA's analysis of the benefits from adopting proposed CAFE standards for MY 2017–2025 cars and light trucks excludes the reduced value of monopsony payments by U.S. oil consumers that would result from lower fuel consumption.

The second component of external costs imposed by U.S. petroleum consumption and imports reflects the potential costs to the U.S. economy from disruptions in the supply of imported petroleum. These costs arise because interruptions in the supply of petroleum products reduces U.S. economic output, as well as because firms are unable to adjust prices, output levels, and their use of energy, labor and other inputs smoothly and rapidly in response to the sudden changes in prices for petroleum products that are caused by interruptions in their supply. Reducing U.S. petroleum consumption and imports lowers these potential costs, and the amount by which it does so represents an economic benefit in addition to the savings in fuel costs that result from higher fuel economy. NHTSA estimates and includes this value in its analysis of the economic benefits from adopting higher CAFE standards for MY 2017–2025 cars and light trucks.

The third component of external costs imposed by U.S. petroleum consumption and imports includes expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion against resulting price increases. NHTSA recognizes that potential national and energy security risks exist due to the possibility of tension over oil supplies. Much of the world's oil and gas supplies are located in countries facing social, economic, and demographic challenges,

[666] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study; See http://www.fhwa.dot.gov/policy/hcas/final/index.htm* (last accessed March 1, 2010).

[667] Differences in forecast annual U.S. imports of crude petroleum and refined products among the Reference, High Oil Price, and Low Oil Price scenarios analyzed in EIA's Annual Energy Outlook 2011 range from 35–74 percent of differences in projected annual gasoline and diesel fuel consumption in the U.S. These differences average 53 percent over the forecast period spanned by AEO 2011.

[668] Differences in forecast annual U.S. imports of crude petroleum among the Reference, High Oil Price, and Low Oil Price scenarios analyzed in EIA's Annual Energy Outlook 2011 range from 67–104 percent of differences in total U.S. refining of crude petroleum, and average 90 percent over the forecast period spanned by AEO 2011.

[669] This figure is calculated as 50 gallons + 50 gallons * 90% = 50 gallons + 45 gallons = 95 gallons.

[670] See, *e.g.,* Bohi, Douglas R. and W. David Montgomery (1982). Oil Prices, Energy Security, and Import Policy, Washington, DC: Resources for the Future, Johns Hopkins University Press; Bohi, D.R. and M.A. Toman (1993). ''Energy and Security: Externalities and Policies,'' Energy Policy 21:1093–1109 (Docket NHTSA–2009–0062–24); and Toman, M.A. (1993). ''The Economics of Energy Security: Theory, Evidence, Policy,'' in A.V. Kneese and J.L. Sweeney, eds. (1993) (Docket NHTSA–2009–0062–23). Handbook of Natural Resource and Energy Economics, Vol. III. Amsterdam: North-Holland, pp. 1167–1218.

[671] The reduction in payments from U.S. oil purchasers to domestic petroleum producers is not included as a benefit, since it represents a transfer that occurs entirely within the U.S. economy.

thus making them even more vulnerable to potential local instability. Because of U.S. dependence on oil, the military could be called on to protect energy resources through such measures as securing shipping lanes from foreign oil fields. Thus, to the degree to which the proposed rules reduce reliance upon imported energy supplies or promote the development of technologies that can be deployed by either consumers or the nation's defense forces, the United States could expect benefits related to national security, reduced energy costs, and increased energy supply. Although NHTSA recognizes that there clearly is a benefit to the United States from reducing dependence on foreign oil, we have been unable to calculate the monetary benefit that the United States will receive from the improvements in national security expected to result from this program. We have therefore included *only* the macroeconomic disruption portion of the energy security benefits to estimate the monetary value of the total energy security benefits of this program. We have calculated energy security in very specific terms, as the reduction of both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. Reducing the amount of oil imported reduces those risks, and thus increases the nation's energy security.

Similarly, while the costs for building and maintaining the SPR are more clearly attributable to U.S. petroleum consumption and imports, these costs have not varied historically in response to changes in U.S. oil import levels. Thus the agency has not attempted to estimate the potential reduction in the cost for maintaining the SPR that might result from lower U.S. petroleum imports, or to include an estimate of this value among the benefits of reducing petroleum consumption through higher CAFE standards.

In analyzing benefits from its recent actions to increase light truck CAFE standards for model years 2005–07 and 2008–11, NHTSA relied on a 1997 study by Oak Ridge National Laboratory (ORNL) to estimate the value of reduced economic externalities from petroleum consumption and imports.[672] More recently, ORNL updated its estimates of the value of these externalities, using the analytic framework developed in its original 1997 study in conjunction with recent estimates of the variables and parameters that determine their value.[673] The updated ORNL study was subjected to a detailed peer review commissioned by EPA, and ORNL's estimates of the value of oil import externalities were subsequently revised to reflect their comments and recommendations of the peer reviewers.[674] Finally, at the request of EPA, ORNL has repeatedly revised its estimates of external costs from U.S. oil imports to reflect changes in the outlook for world petroleum prices, as well as continuing changes in the structure and characteristics of global petroleum supply and demand.

As the preceding discussion indicates, NHTSA's analysis of benefits from adopting higher CAFE standards includes only the reduction in economic disruption costs that is anticipated to result from reduced consumption of petroleum-based fuels and the associated decline in U.S. petroleum imports. ORNL's updated analysis reports that this benefit, which is in addition to the savings in costs for producing fuel itself, is most likely to amount to $0.185 per gallon of fuel saved by requiring MY 2017–25 cars and light trucks to achieve higher fuel economy. However, considerable uncertainty surrounds this estimate, and ORNL's updated analysis also indicates that a range of values extending from a low of $0.091 per gallon to a high of $0.293 per gallon should be used to reflect this uncertainty.

We note that the calculation of energy security benefits does not include energy security costs associated with reliance on foreign sources of lithium and rare earth metals for HEVs and EVs. The agencies intend to attempt to quantify this impact for the final rule stage, and seek public input on information that would enable agencies to develop this analysis. NHTSA also seeks public input on the projections that energy security benefits will grow rapidly through 2025.

l. Air Pollutant Emissions

i. Changes in Criteria Air Pollutant Emissions

Criteria air pollutants include carbon monoxide (CO), hydrocarbon compounds (usually referred to as "volatile organic compounds," or VOC), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and sulfur oxides (SO_X). These pollutants are emitted during vehicle storage and use, as well as throughout the fuel production and distribution system. While reductions in domestic fuel refining, storage, and distribution that result from lower fuel consumption will reduce emissions of these pollutants, additional vehicle use associated with the fuel economy rebound effect will increase their emissions. The net effect of stricter CAFE standards on total emissions of each criteria pollutant depends on the relative magnitude of reductions in its emissions during fuel refining and distribution, and increases in its emissions resulting from additional vehicle use. Because the relationship between emissions in fuel refining and vehicle use is different for each criteria pollutant, the net effect of fuel savings from the proposed standards on total emissions of each pollutant is likely to differ.

With the exception of SO_2, NHTSA calculated annual emissions of each criteria pollutant resulting from vehicle use by multiplying its estimates of car and light truck use during each year over their expected lifetimes by per-mile emission rates for each vehicle class, fuel type, model year, and age. These emission rates were developed by U.S. EPA using its Motor Vehicle Emission Simulator (MOVES 2010a).[675] Emission rates for SO_2 were calculated by NHTSA using average fuel sulfur content estimates supplied by EPA, together with the assumption that the entire sulfur content of fuel is emitted in the form of SO_2.[676] Total SO_2 emissions under each alternative CAFE standard were calculated by applying the resulting emission rates directly to estimated annual gasoline and diesel fuel use by cars and light trucks.

Changes in emissions of criteria air pollutants resulting from alternative increases in CAFE standards for MY

[672] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs,* ORNL–6851, Oak Ridge National Laboratory, November 1, 1997. *Available at http://www.esd.ornl.gov/eess/energy_analysis/files/ORNL6851.pdf* (last accessed October 11, 2011).

[673] Leiby, Paul N., "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," Oak Ridge National Laboratory, ORNL/TM–2007/028, Revised July 23, 2007. *Available at http://www.esd.ornl.gov/eess/energy_analysis/files/Leiby2007%20Estimating%20the%20Energy%20Security%20Benefits%20of%20Reduced%20U.S.%20Oil%20Imports%20ornl-tm-2007–028%20rev2007Jul25.pdf* (last accessed October 11, 2011).

[674] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports,* ICF, Inc., September 2007. *Available at* Docket No. NHTSA–2009–0059–0160.

[675] The MOVES model assumes that the per-mile rates at which these pollutants are emitted are determined by EPA regulations and the effectiveness of catalytic after-treatment of engine exhaust emissions, and are thus unaffected by changes in car and light truck fuel economy.

[676] These are 30 and 15 parts per million (ppm, measured on a mass basis) for gasoline and diesel respectively, which produces emission rates of 0.17 grams of SO_2 per gallon of gasoline and 0.10 grams per gallon of diesel.

2017–2025 cars and light trucks are calculated from the differences between emissions under each alternative increase in CAFE standards, and emissions under the baseline alternative.

Emissions of criteria air pollutants also occur during each phase of fuel production and distribution, including crude oil extraction and transportation, fuel refining, and fuel storage and transportation. NHTSA estimates the reductions in criteria pollutant emissions from producing and distributing fuel that would occur under alternative CAFE standards using emission rates obtained by EPA from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, which provides estimates of air pollutant emissions that occur in different phases of fuel production and distribution.[677] [678] EPA modified the GREET model to change certain assumptions about emissions during crude petroleum extraction and transportation, as well as to update its emission rates to reflect adopted and pending EPA emission standards.

The resulting emission rates were applied to the agency's estimates of fuel consumption under alternative CAFE standards to develop estimates of total emissions of each criteria pollutant during fuel production and distribution. The agency then employed the estimates of the effects of *changes* in fuel consumption on domestic and imported sources of fuel supply discussed previously to calculate the effects of reductions in fuel use on changes in imports of refined fuel and domestic refining. NHTSA's analysis assumes that reductions in imports of refined fuel would reduce criteria pollutant emissions during fuel storage and distribution only. Reductions in domestic fuel refining using imported crude oil as a feedstock are assumed to reduce emissions during fuel refining, storage, and distribution. Finally, reduced domestic fuel refining using domestically produced crude oil is assumed to reduce emissions during all four phases of fuel production and distribution.[679]

Finally, NHTSA calculated the net changes in domestic emissions of each criteria pollutant by summing the increases in emissions projected to result from increased vehicle use, and the reductions anticipated to result from lower domestic fuel refining and distribution.[680] As indicated previously, the effect of adopting higher CAFE standards on total emissions of each criteria pollutant depends on the relative magnitude of the resulting reduction in emissions from fuel refining and distribution, and the increase in emissions from additional vehicle use. Although these net changes vary significantly among individual criteria pollutants, the agency projects that on balance, adopting higher CAFE standards for MY 2017–25 cars and light trucks would reduce emissions of all criteria air pollutants except carbon monoxide (CO).

The net changes in direct emissions of fine particulates ($PM_{2.5}$) and other criteria pollutants that contribute to the formation of ''secondary'' fine particulates in the atmosphere (such as NO_X, SO_X, and VOCs) are converted to economic values using estimates of the reductions in health damage costs per ton of emissions of each pollutant that is avoided, which were developed by EPA. These savings represent the estimated reductions in the value of damages to human health resulting from lower atmospheric concentrations and population exposure to air pollution that occur when emissions of each pollutant that contributes to atmospheric $PM_{2.5}$ concentrations are reduced. The value of reductions in the risk of premature death due to exposure to fine particulate pollution ($PM_{2.5}$) accounts for a majority of EPA's estimated values of reducing criteria pollutant emissions, although the value of avoiding other health impacts is also included in these estimates.

These values do not include a number of unquantified benefits, such as reduction in the welfare and environmental impacts of $PM_{2.5}$ pollution, or reductions in health and welfare impacts related to other criteria air pollutants (ozone, NO_2, and SO_2) and air toxics. EPA estimates different per-ton values for reducing emissions of PM and other criteria pollutants from vehicle use than for reductions in emissions of those same pollutants during fuel production and distribution.[681] NHTSA applies these separate values to its estimates of changes in emissions from vehicle use and from fuel production and distribution to determine the net change in total economic damages from emissions of these pollutants.

EPA projects that the per-ton values for reducing emissions of criteria pollutants from both mobile sources (including motor vehicles) and stationary sources such as fuel refineries and storage facilities will increase over time. These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution, as well as future population growth, which increases population exposure to future levels of air pollution.

ii. Reductions in CO_2 Emissions

Emissions of carbon dioxide and other greenhouse gases (GHGs) occur throughout the process of producing and distributing transportation fuels, as well as from fuel combustion itself. Emissions of GHGs also occur in generating electricity, which NHTSA's analysis anticipates will account for an increasing share of energy consumption by cars and light trucks produced in the model years that would be subject to their proposed rules. By reducing the volume of fuel consumed by passenger cars and light trucks, higher CAFE standards will reduce GHG emissions generated by fuel use, as well as throughout the fuel supply system. Lowering these emissions is likely to slow the projected pace and reduce the ultimate extent of future changes in the global climate, thus reducing future economic damages that changes in the global climate are expected to cause. By reducing the probability that climate changes with potentially catastrophic economic or environmental impacts will occur, lowering GHG emissions may also result in economic benefits that exceed the resulting reduction in the expected future economic costs caused

[677] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions in Transportation (GREET) Model,* Version 1.8, June 2007, *available at http://www.transportation.anl.gov/modeling_simulation/GREET/index.html* (last accessed October 11, 2011).

[678] Emissions that occur during vehicle refueling at retail gasoline stations (primarily evaporative emissions of volatile organic compounds, or VOCs) are already accounted for in the ''tailpipe'' emission factors used to estimate the emissions generated by increased light truck use. GREET estimates emissions in each phase of gasoline production and distribution in mass per unit of gasoline energy content; these factors are then converted to mass per gallon of gasoline using the average energy content of gasoline.

[679] In effect, this assumes that the distances crude oil travels to U.S. refineries are approximately the same regardless of whether it travels from domestic oilfields or import terminals, and that the distances that gasoline travels from refineries to retail stations are approximately the same as those from import terminals to gasoline stations. We note that while assuming that all changes in upstream emissions result from a decrease in petroleum production and transport, our analysis of downstream criteria pollutant impacts assumes no change in the composition of the gasoline fuel supply.

[680] All emissions from increased vehicle use are assumed to occur within the U.S., since CAFE standards would apply only to vehicles produced for sale in the U.S.

[681] These reflect differences in the typical geographic distributions of emissions of each pollutant, their contributions to ambient $PM_{2.5}$ concentrations, pollution levels (predominantly those of $PM_{2.5}$), and resulting changes in population exposure.

by more gradual changes in the earth's climatic systems.

Quantifying and monetizing benefits from reducing GHG emissions is thus an important step in estimating the total economic benefits likely to result from establishing higher CAFE standards. Because carbon dioxide emissions account for nearly 95 percent of total GHG emissions that result from fuel combustion during vehicle use, NHTSA's analysis of the effect of higher CAFE standards on GHG emissions focuses mainly on estimating changes in emissions of CO_2. The agency estimates emissions of CO_2 from passenger car and light truck use by multiplying the number of gallons of each type of fuel (gasoline and diesel) they are projected to consume under alternative CAFE standards by the quantity or mass of CO_2 emissions released per gallon of fuel consumed. This calculation assumes that the entire carbon content of each fuel is converted to CO_2 emissions during the combustion process.

NHTSA estimates emissions of CO_2 that occur during fuel production and distribution using emission rates for each stage of this process (feedstock production and transportation, fuel refining and fuel storage and distribution) derived from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model. For liquid fuels, NHTSA converts these rates to a per-gallon basis using the energy content of each fuel, and multiplies them by the number of gallons of each type of fuel produced and consumed under alternative standards to estimate total CO_2 emissions from fuel production and distribution. GREET supplies emission rates for electricity generation that are expressed as grams of CO_2 per unit of energy, so these rates are simply multiplied by the estimates of electrical energy used to charge the on-board storage batteries of plug-in hybrid and battery electric vehicles. As with all other effects of alternative CAFE standards, the reduction in CO_2 emissions resulting from each alternative increase in standards is measured by the difference in total emissions from producing and consuming fuel energy used by MY 2017–25 cars and light trucks with those higher CAFE standards in effect, and total CO_2 emissions from supplying and using fuel energy consumed under the baseline alternative. Unlike criteria pollutants, the agency's estimates of CO_2 emissions include those occurring in domestic fuel production and consumption, as well as in overseas production of petroleum and refined fuel for export to the U.S. Overseas emissions are included because GHG emissions throughout the world contribute equally to the potential for changes in the global climate.

iii. Economic Value of Reductions in CO_2 Emissions

NHTSA takes the economic benefits from reducing CO_2 emissions into account in developing and analyzing the alternative CAFE standards it has considered for MY 2017–25. Because research on the impacts of climate change does not produce direct estimates of the economic benefits from reducing CO_2 or other GHG emissions, these benefits are assumed to be the ''mirror image'' of the estimated incremental costs resulting from increases in emissions. Thus the benefits from reducing CO_2 emissions are usually measured by the savings in estimated economic damages that an equivalent *increase* in emissions would otherwise have caused. The agency does not include estimates of the economic benefits from reducing GHGs other than CO_2 in its analysis of alternative CAFE standards.

NHTSA estimates the value of the reductions in emissions of CO_2 resulting from adopting alternative CAFE standards using a measure referred to as the ''social cost of carbon,'' abbreviated SCC. The SCC is intended to provide a monetary measure of the additional economic impacts likely to result from changes in the global climate that would result from an incremental increase in CO_2 emissions. These potential effects include changes in agricultural productivity, the economic damages caused by adverse effects on human health, property losses and damages resulting from rising sea levels, and the value of ecosystem services. The SCC is expressed in constant dollars per additional metric ton of CO_2 emissions occurring during a specific year, and is higher for more distant future years because the damages caused by an additional ton of emissions increase with larger concentrations of CO_2 in the earth's atmosphere.

Reductions in CO_2 emissions that are projected to result from lower fuel production and consumption during each year over the lifetimes of MY 2017–25 cars and light trucks are multiplied by the estimated SCC appropriate for that year to determine the economic benefit from reducing emissions during that year. The net present value of these annual benefits is calculated using a discount rate that is consistent with that used to develop the estimate of each SCC estimate. This calculation is repeated for the reductions in CO_2 emissions projected to result from each alternative increase in CAFE standards.

NHTSA evaluates the economic benefits from reducing CO_2 emissions using estimates of the SCC developed by an interagency working group convened for the specific purpose of developing new estimates for use by U.S. Federal agencies in regulatory evaluations. The group's purpose in developing new estimates of the SCC was to allow Federal agencies to incorporate the social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have relatively modest impacts on cumulative global emissions, as most Federal regulatory actions can be expected to have. NHTSA previously relied on the SCC estimates developed by this interagency group to analyze the alternative CAFE standards it considered for MY 2012–16 cars and light trucks, as well as the fuel efficiency standards it adopted for MY 014–18 heavy-duty vehicles.

The interagency group convened on a regular basis over the period from June 2009 through February 2010, to explore technical literature in relevant fields and develop key inputs and assumptions necessary to generate estimates of the SCC. Agencies participating in the interagency process included the Environmental Protection Agency and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy.

The interagency group's main objective was to develop a range of SCC values using clearly articulated input assumptions grounded in the existing scientific and economic literatures, in conjunction with a range of models that employ different representations of climate change and its economic impacts. The group clearly acknowledged the many uncertainties that its process identified, and recommended that its estimates of the SCC should be updated periodically to incorporate developing knowledge of the science and economics of climate impacts. Specifically, it set a preliminary goal to revisit the SCC values within two years, or as substantial improvements in understanding of the science and economics of climate impacts and updated models for estimating and valuing these impacts become available. The group ultimately selected four SCC values for use in federal regulatory analyses. Three values were based on the average of SCC estimates developed using three different climate economic models (referred to as integrated assessment models), using discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate from the combined distribution of values generated by the three models at a 3 percent discount rate, represents the possibility of possibility of higher-than-expected impacts from the accumulation of GHGs in the earth's atmosphere, and the consequently larger economic damages.

Table IV–10 summarizes the interagency group's estimates of the SCC during various future years, which the agency has updated to 2009 dollars to correspond to the other values it uses to estimate economic benefits from the alternative CAFE standards considered in this NPRM.[682]

Table IV-9. Summary of Published Estimates of the Rebound Effect

Category of Estimates	Number of Studies	Number of Estimates	Range		Distribution		
			Low	High	Median	Mean	Std. Dev.
All Estimates	23	72	7%	75%	21%	23%	13%
Published Estimates	17	50	7%	75%	22%	24%	14%
Authors' Preferred Estimates	17	17	9%	75%	22%	22%	15%
U.S. Time-Series Estimates	7	34	7%	45%	14%	18%	9%
Household Survey Estimates	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Estimates	3	15	8%	58%	22%	23%	12%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect (1) Reported Estimates	10	29	10%	45%	23%	23%	10%
Updated to 2010 (2)	11	33	6%	56%	15%	19%	13%

[682] The SCC estimates reported in the table assume that the damages resulting from increased emissions are constant for small departures from the baseline emissions forecast incorporated in each estimate, an approximation that is reasonable for policies with projected effects on CO_2 emissions that are small relative to cumulative global emissions.

Table IV-10. Social Cost of CO_2 Emissions for Selected Future Years (2009$ per metric ton)

Discount Rate	5%	3%	2.5%	3%
Source	Average of estimates			95th percentile estimate
2012	$5.28	$23.06	$37.53	$70.14
2015	$5.93	$24. 58	$39.57	$74.03
2020	$7.01	$27.10	$42.98	$83.17
2025	$8. 53	$30.43	$47.28	$93.11
2030	$10.05	$33.75	$51.58	$103.06
2035	$11.57	$37.08	$55.88	$113.00
2040	$13.09	$40.40	$60.19	$122.95
2045	$14.63	$43. 34	$63.59	$131.66
2050	$16.18	$46.27	$66.99	$140.37

As Table IV–10 shows, the four SCC estimates selected by the interagency group for use in regulatory analyses are $5, $23, $38, and $70 per metric ton (in 2009 dollars) for emissions occurring in the year 2012. The value that the interagency group centered its attention on is the average SCC estimate developed using different models and a 3 percent discount rate, or $23 per metric ton in 2012. To capture the uncertainties involved in regulatory impact analysis, however, the group emphasized the importance of considering the full range of estimated SCC values. As the table also shows, the SCC estimates also rise over time; for example, the average SCC at the 3 percent discount rate increases to $27 per metric ton of CO_2 by 2020 and reaches $46 per metric ton of CO_2 in 2050.

Details of the process used by the interagency group to develop its SCC estimates, complete results including year-by-year estimates of each of the four values, and a thorough discussion of their intended use and limitations is provided in the document *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.[683]

m. Discounting Future Benefits and Costs

Discounting future fuel savings and other benefits accounts for the reduction in their value when they are deferred until some future date, rather than received immediately. The value of benefits that are not expected to occur until the future is lower partly because people value current consumption more highly than equivalent consumption at some future date—stated simply, they are impatient—and partly because they expect their living standards to be higher in the future, so additional consumption will improve their well-being by more today than it will in the future. The discount rate expresses the percent decline in the value of these benefits—as viewed from today's perspective—for each year they are deferred into the future. In evaluating the benefits from alternative increases in CAFE standards for MY 2017–2025 passenger cars and light trucks, NHTSA primarily employs a discount rate of 3 percent per year, but in accordance with OMB guidance, also presents these benefit and cost estimates using a 7 percent discount rate.

While it presents results that reflect both discount rates, NHTSA believes that the 3 percent rate is more appropriate for discounting future benefits from increased CAFE standards, because the agency expects that most or all of vehicle manufacturers' costs for complying with higher CAFE standards will ultimately be reflected in higher selling prices for their new vehicle models. By increasing sales prices for new cars and light trucks, CAFE regulations will thus primarily affect vehicle purchases and other private consumption decisions. Both economic theory and OMB guidance on discounting indicate that the future benefits and costs of regulations that mainly affect private consumption

[683] This document is available in the docket for the 2012–2016 rulemaking (NHTSA–2009–0059).

should be discounted at consumers' rate of time preference.[684]

Current OMB guidance also indicates that savers appear to discount future consumption at an average real (that is, adjusted to remove the effect of inflation) rate of about 3 percent when they face little risk about the future. Since the real interest rate that savers require to persuade them to defer consumption into the future represents a reasonable estimate of consumers' rate of time preference, NHTSA believes that the 3 percent rate is appropriate for discounting projected future benefits and costs resulting from higher CAFE standards.

Because there is some uncertainty about whether vehicle manufacturers will completely recover their costs for complying with higher CAFE standards by increasing vehicle sales prices, however, NHTSA also presents benefit and cost estimates discounted using a higher rate. To the extent that manufacturers are unable to recover their costs for meeting higher CAFE standards by increasing new vehicle prices, these costs are likely to displace other investment opportunities available to them. OMB guidance indicates that the real economy-wide opportunity cost of capital is the appropriate discount rate to apply to future benefits and costs when the primary effect of a regulation is "* * * to displace or alter the use of capital in the private sector," and OMB estimates that this rate currently averages about 7 percent.[685] Thus the agency's analysis of alternative increases in CAFE standards for MY 2017–25 cars and light trucks also reports benefits and costs discounted at a 7 percent rate.

One important exception to the agency's use of 3 percent and 7 percent discount rates is arises in discounting benefits from reducing CO_2 emissions over the lifetimes of MY 2017–2025 cars and light trucks to their present values. In order to ensure consistency in the derivation and use of the interagency group's estimates of the unit values of reducing CO_2 emissions (or SCC), the benefits from reducing CO_2 emissions during each future year are discounted using the same "intergenerational" discount rates that were used to derive each of the alternative values. As indicated in Table IV–10 above, these rates are 2.5 percent, 3 percent, and 5 percent depending on which estimate of the SCC is being employed.[686]

n. Accounting for Uncertainty in Benefits and Costs

In analyzing the uncertainty surrounding its estimates of benefits and costs from alternative CAFE standards, NHTSA considers alternative estimates of those assumptions and parameters likely to have the largest effect. These include the projected costs of fuel economy-improving technologies and their anticipated effectiveness in reducing fuel consumption, forecasts of future fuel prices, the magnitude of the rebound effect, the reduction in external economic costs resulting from lower U.S. oil imports, and the discount rate applied to future benefits and costs. The range for each of these variables employed in the uncertainty analysis was previously identified in the sections of this notice discussing each variable.

The uncertainty analysis was conducted by assuming either independent normal or beta probability distributions for each of these variables, using the low and high estimates for each variable as the values between which 90 percent of observed values are expected to fall. Each trial of the uncertainty analysis employed a set of values randomly drawn from these probability distributions, under the assumption that the value of each variable is independent from those of the others. In cases where the data on the possible distribution of parameters was relatively sparse, making a choice of distributions difficult, a beta distribution is commonly employed to give more weight to both tails than would be the case had a normal distribution been employed. Benefits and costs of each alternative standard were estimated using each combination of variables, and a total of nearly 40,000 trials were used to estimate the likely range of estimated benefits and costs for each alternative standard.

o. Where can readers find more information about the economic assumptions?

Much more detailed information is provided in Chapter VIII of the PRIA, and a discussion of how NHTSA and EPA jointly reviewed and updated economic assumptions for purposes of this proposal is available in Chapter 4 of the draft Joint TSD. In addition, all of NHTSA's model input and output files are now public and available for the reader's review and consideration. The economic input files can be found in the docket for this proposed rule, NHTSA–2010–0131, and on NHTSA's Web site.[687]

Finally, because much of NHTSA's economic analysis for purposes of this proposal builds on the work that was done for the final rule establishing CAFE standards for MYs 2012–16, we refer readers to that document as well. It contains valuable background information concerning how NHTSA's assumptions regarding economic inputs for CAFE analysis have evolved over the past several rulemakings, both in response to comments and as a result of the agency's growing experience with this type of analysis.[688]

4. How does NHTSA use the assumptions in its modeling analysis?

In developing today's proposed CAFE standards, NHTSA has made significant use of results produced by the CAFE Compliance and Effects Model (commonly referred to as "the CAFE Model" or "the Volpe model"), which DOT's Volpe National Transportation Systems Center developed specifically to support NHTSA's CAFE rulemakings. The model, which has been constructed specifically for the purpose of analyzing potential CAFE standards, integrates the following core capabilities:

(1) Estimating how manufacturers could apply technologies in response to new fuel economy standards,

(2) Estimating the costs that would be incurred in applying these technologies,

(3) Estimating the physical effects resulting from the application of these technologies, such as changes in travel demand, fuel consumption, and emissions of carbon dioxide and criteria pollutants, and

(4) Estimating the monetized societal benefits of these physical effects.

An overview of the model follows below. Separate model documentation provides a detailed explanation of the functions the model performs, the calculations it performs in doing so, and how to install the model, construct inputs to the model, and interpret the model's outputs. Documentation of the model, along with model installation files, source code, and sample inputs are available at NHTSA's Web site. The model documentation is also available in the docket for today's proposed rule, as are inputs for and outputs from

[684] *Id.*

[685] Office of Management and Budget, Circular A–4, "Regulatory Analysis," September 17, 2003, 33. *Available at http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf* (last accessed Sept. 26, 2011).

[686] The fact that the 3 percent discount rate used by the interagency group to derive its central estimate of the SCC is identical to the 3 percent short-term or "intra-generational" discount rate used by NHTSA to discount future benefits other than reductions in CO_2 emissions is coincidental, and should not be interpreted as a required condition that must be satisfied in future rulemakings.

[687] *See http://www.nhtsa.gov/fuel-economy.*

[688] 74 FR 14308–14358 (Mar. 30, 2009).

analysis of today's proposed CAFE standards.

a. How does the model operate?

As discussed above, the agency uses the CAFE model to estimate how manufacturers could attempt to comply with a given CAFE standard by adding technology to fleets that the agency anticipates they will produce in future model years. This exercise constitutes a simulation of manufacturers' decisions regarding compliance with CAFE standards.

This compliance simulation begins with the following inputs: (a) The baseline and reference market forecast discussed above in Section IV.C.1 and Chapter 1 of the TSD, (b) technology-related estimates discussed above in Section IV.C.2 and Chapter 3 of the TSD, (c) economic inputs discussed above in Section IV.C.3 and Chapter 4 of the TSD, and (d) inputs defining baseline and potential new CAFE standards. For each manufacturer, the model applies technologies in a sequence that follows a defined engineering logic (''decision trees'' discussed in the MY 2011 final rule and in the model documentation) and a cost-minimizing strategy in order to identify a set of technologies the manufacturer could apply in response to new CAFE standards.[689] The model applies technologies to each of the projected individual vehicles in a manufacturer's fleet, considering the combined effect of regulatory and market incentives. Depending on how the model is exercised, it will apply technology until one of the following occurs:

(1) The manufacturer's fleet achieves compliance[690] with the applicable standard, and continuing to add technology in the current model year would be attractive neither in terms of stand-alone (*i.e.,* absent regulatory need) cost effectiveness nor in terms of facilitating compliance in future model years;[691]

(2) The manufacturer ''exhausts''[692] available technologies; or

(3) For manufacturers estimated to be willing to pay civil penalties, the manufacturer reaches the point at which doing so would be more cost-effective (from the manufacturer's perspective) than adding further technology.[693]

As discussed below, the model has also been modified in order to—as an option—apply more technology than may be necessary to achieve compliance in a given model year, or to facilitate compliance in later model years. This ability to simulate ''voluntary overcompliance'' reflects the potential that manufacturers will apply some technologies to some vehicles if doing so would be sufficiently inexpensive compared to the expected reduction in owners' outlays for fuel.

The model accounts explicitly for each model year, applying most technologies when vehicles are scheduled to be redesigned or freshened, and carrying forward technologies between model years. The CAFE model accounts explicitly for each model year because EPCA requires that NHTSA make a year-by-year determination of the appropriate level of stringency and then set the standard at that level, while ensuring ratable increases in average fuel economy.[694] The multiyear planning capability and (optional) simulation of ''voluntary overcompliance'' and EPCA credit mechanisms increase the model's ability to simulate manufacturers' real-world behavior, accounting for the fact that manufacturers will seek out compliance paths for several model years at a time, while accommodating the year-by-year requirement.

The model also calculates the costs, effects, and benefits of technologies that it estimates could be added in response to a given CAFE standard.[695] It calculates costs by applying the cost estimation techniques discussed above in Section IV.C.2, and by accounting for the number of affected vehicles. It accounts for effects such as changes in vehicle travel, changes in fuel consumption, and changes in greenhouse gas and criteria pollutant emissions. It does so by applying the fuel consumption estimation techniques also discussed in Section IV.C.2, and the vehicle survival and mileage accumulation forecasts, the rebound effect estimate and the fuel properties and emission factors discussed in Section IV.C.3. Considering changes in travel demand and fuel consumption, the model estimates the monetized value of accompanying benefits to society, as discussed in Section IV.C.3. The model calculates both the undiscounted and discounted value of benefits that accrue over time in the future.

The CAFE model has other capabilities that facilitate the development of a CAFE standard. The integration of (a) Compliance simulation and (b) the calculation of costs, effects,

[689] NHTSA does its best to remain scrupulously neutral in the application of technologies through the modeling analysis, to avoid picking technology ''winners.'' The technology application methodology has been reviewed by the agency over the course of several rulemakings, and commenters have been generally supportive of the agency's approach. *See, e.g.,* 74 FR 14238–14246 (Mar. 30, 2009).

[690] The model has been modified to provide the ability—as an option—to account for credit mechanisms (*i.e.,* carry-forward, carry-back, transfers, and trades) when determining whether compliance has been achieved. For purposes of determining maximum feasible CAFE standards, NHTSA cannot consider these mechanisms, and exercises the CAFE model without enabling these options.

[691] In preparation for the MY 2012–2016 rulemaking, the model was modified in order to apply additional technology in early model years if doing so will facilitate compliance in later model years. This is designed to simulate a manufacturer's decision to plan for CAFE obligations several years in advance, which NHTSA believes better replicates manufacturers' actual behavior as compared to the year-by-year evaluation which EPCA would otherwise require.

[692] In a given model year, the model makes additional technologies available to each vehicle model within several constraints, including (a) Whether or not the technology is applicable to the vehicle model's technology class, (b) whether the vehicle is undergoing a redesign or freshening in the given model year, (c) whether engineering aspects of the vehicle make the technology unavailable (*e.g.,* secondary axle disconnect cannot be applied to two-wheel drive vehicles), and (d) whether technology application remains within ''phase in caps'' constraining the overall share of a manufacturer's fleet to which the technology can be added in a given model year. Once enough technology is added to a given manufacturer's fleet in a given model year that these constraints make further technology application unavailable, technologies are ''exhausted'' for that manufacturer in that model year.

[693] This possibility was added to the model to account for the fact that under EPCA/EISA, manufacturers must pay fines if they do not achieve compliance with applicable CAFE standards. 49 U.S.C. 32912(b). NHTSA recognizes that some manufacturers will find it more cost-effective to pay fines than to achieve compliance, and believes that to assume these manufacturers would exhaust available technologies before paying fines would cause unrealistically high estimates of market penetration of expensive technologies such as diesel engines and strong hybrid electric vehicles, as well as correspondingly inflated estimates of both the costs and benefits of any potential CAFE standards. NHTSA thus includes the possibility of manufacturers choosing to pay fines in its modeling analysis in order to achieve what the agency believes is a more realistic simulation of manufacturer decision-making. Unlike flex-fuel and other credits, NHTSA is not barred by statute from considering fine-payment in determining maximum feasible standards under EPCA/EISA. 49 U.S.C. 32902(h).

[694] 49 U.S.C. 32902(a) states that at least 18 months before the beginning of each model year, the Secretary of Transportation shall prescribe by regulation average fuel economy standards for automobiles manufactured by a manufacturer in that model year, and that each standard shall be the maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that year. NHTSA has long interpreted this statutory language to require year-by-year assessment of manufacturer capabilities. 49 U.S.C. 32902(b)(2)(C) also requires that standards increase ratably between MY 2011 and MY 2020.

[695] As for all of its other rulemakings, NHTSA is required by Executive Order 12866 (as amended by Executive Order 13563) and DOT regulations to analyze the costs and benefits of CAFE standards. Executive Order 12866, 58 FR 51735 (Oct. 4, 1993); DOT Order 2100.5, ''Regulatory Policies and Procedures,'' 1979, *available at http://regs.dot.gov/rulemakingrequirements.htm* (last accessed February 21, 2010).

and benefits facilitates analysis of sensitivity of results to model inputs. The model can also be used to evaluate many (*e.g.,* 200 per model year) potential levels of stringency sequentially, and identify the stringency at which specific criteria are met. For example, it can identify the stringency at which net benefits to society are maximized, the stringency at which a specified total cost is reached, or the stringency at which a given average required fuel economy level is attained. This allows the agency to compare more easily the impacts in terms of fuel savings, emissions reductions, and costs and benefits of achieving different levels of stringency according to different criteria. The model can also be used to perform uncertainty analysis (*i.e.,* Monte Carlo simulation), in which input estimates are varied randomly according to specified probability distributions, such that the uncertainty of key measures (*e.g.,* fuel consumption, costs, benefits) can be evaluated.

b. Has NHTSA considered other models?

As discussed in the most recent CAFE rulemaking, while nothing in EPCA requires NHTSA to use the CAFE model, and in principle, NHTSA could perform all of these tasks through other means, the model's capabilities have greatly increased the agency's ability to rapidly, systematically, and reproducibly conduct key analyses relevant to the formulation and evaluation of new CAFE standards.[696]

NHTSA notes that the CAFE model not only has been formally peer-reviewed and tested and reviewed through three rulemakings, but also has some features especially important for the analysis of CAFE standards under EPCA/EISA. Among these are the ability to perform year-by-year analysis, and the ability to account for engineering differences between specific vehicle models.

EPCA requires that NHTSA set CAFE standards for each model year at the level that would be ''maximum feasible'' for that year. Doing so requires the ability to analyze each model year and, when developing regulations covering multiple model years, to account for the interdependency of model years in terms of the appropriate levels of stringency for each one. Also, as part of the evaluation of the economic practicability of the standards, as required by EPCA, NHTSA has traditionally assessed the annual costs and benefits of the standards. In response to comments regarding an early version of the CAFE model, DOT modified the CAFE model in order to account for dependencies between model years and to better represent manufacturers' planning cycles, in a way that still allowed NHTSA to comply with the statutory requirement to determine the appropriate level of the standards for each model year.

The CAFE model is also able to account for important engineering differences between specific vehicle models, and to thereby reduce the risk of applying technologies that may be incompatible with or already present on a given vehicle model. By combining technologies incrementally and on a model-by-model basis, the CAFE model is able to account for important engineering differences between vehicle models and avoid unlikely technology combinations

The CAFE model also produces a single vehicle-level output file that, for each vehicle model, shows which technologies were present at the outset of modeling, which technologies were superseded by other technologies, and which technologies were ultimately present at the conclusion of modeling. For each vehicle, the same file shows resultant changes in vehicle weight, fuel economy, and cost. This provides for efficient identification, analysis, and correction of errors, a task with which the public can now assist the agency, since all inputs and outputs are public.

Such considerations, as well as those related to the efficiency with which the CAFE model is able to analyze attribute-based CAFE standards and changes in vehicle classification, and to perform higher-level analysis such as stringency estimation (to meet predetermined criteria), sensitivity analysis, and uncertainty analysis, lead the agency to conclude that the model remains the best available to the agency for the purposes of analyzing potential new CAFE standards.

c. What changes has DOT made to the model?

Between promulgation of the MY 2012–2016 CAFE standards and today's proposal regarding MY 2017–2025 standards, the CAFE model has been revised to make some minor improvements, and to add some significant new capabilities: (1) Accounting for electricity used to charge electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), (2) accounting for use of ethanol blends in flexible-fuel vehicles (FFVs), (3) accounting for costs (*i.e.,* ''stranded capital'') related to early replacement of technologies, (4) accounting for previously-applied technology when determining the extent to which a manufacturer could expand use of the technology, (5) applying technology-specific estimates of changes in consumer value, (6) simulating the extent to which manufacturers might utilize EPCA's provisions regarding generation and use of CAFE credits, (7) applying estimates of fuel economy adjustments (and accompanying costs) reflecting increases in air conditioner efficiency, (8) reporting privately-valued benefits, (9) simulating the extent to which manufacturers might voluntarily apply technology beyond levels needed for compliance with CAFE standards, and (10) estimating changes in highway fatalities attributable to any applied reductions in vehicle mass. These capabilities are described below, and in greater detail in the CAFE model documentation.[697]

To support evaluation of the effects electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs) could have on energy consumption and associated costs and environmental effects, DOT has expanded the CAFE model to estimate the amount of electricity that would be required to charge these vehicles (accounting for the potential that PHEVs can also run on gasoline). The model calculates the cost of this electricity, as well as the accompanying upstream criteria pollutant and greenhouse gas emissions.

Similar to this expansion to account for the potential the PHEVs can be refueled with gasoline or recharged with electricity, DOT has expanded the CAFE model to account for the potential that other flexible-fuel vehicles can be operated on multiple fuels. In particular, the model can account for ethanol FFVs consuming E85 or gasoline, and to report consumption of both fuels, as well as corresponding costs and upstream emissions.

Among the concerns raised in the past regarding how technology costs are estimated has been one that stranded capital costs be considered. Capital becomes ''stranded'' when capital equipment is retired or its use is discontinued before the equipment has been fully depreciated and the equipment still retains some value or usefulness. DOT has modified the CAFE model to, if specified for a given technology, when that technology is replaced by a newly applied technology, apply a stream of costs representing the stranded capital cost of the replaced technology. This cost is in addition to the cost for producing the newly

[696] 75 FR 25598–25599.

[697] Model documentation is available on NHTSA's Web site.

applied technology in the first year of production.

As documented in prior CAFE rulemakings, the CAFE model applies ''phase-in caps'' to constrain technology application at the vehicle manufacturer level. They are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards. When the MY 2012–2016 rulemaking analysis was completed, the model performed the relevant test by comparing a given phase-in cap to the amount (*i.e.,* the share of the manufacturer's fleet) to which the technology had been added by the model. DOT has since modified the CAFE model to take into account the extent to which a given manufacturer has already applied the technology (*i.e.,* as reflected in the market forecast specified as a model inputs), and to apply the relevant test based on the total application of the technology.

The CAFE model requires inputs defining the technology-specific cost and efficacy (*i.e.,* percentage reduction of fuel consumption), and has, to date, effectively assumed that these input values reflect application of the technology in a manner that holds vehicle performance and utility constant. Considering that some technologies may, nonetheless, offer owners greater or lesser value (beyond that related to fuel outlays, which the model calculates internally based on vehicle fuel type and fuel economy), DOT has modified the CAFE model to accept and apply technology-specific estimates of any value gain realized or loss incurred by vehicle purchasers.[698]

For the MY 2012–2016 CAFE rulemaking analysis, DOT modified the CAFE model to accommodate specification and accounting for credits a manufacturer is assumed to earn by producing flexible fuel vehicles (FFVs). Although NHTSA cannot consider such credits when determining maximum feasible CAFE standards, the agency presented an analysis that included FFV credits, in order to communicate the extent to which use of such credits might cause actual costs, effects, and benefits to be lower than estimated in NHTSA's formal analysis. As DOT explained at the time, it was unable to account for other EPCA credit mechanisms, because attempts to do so had been limited by complex interactions between those mechanisms and the multiyear planning aspects of the CAFE model. DOT has since modified the CAFE model to provide the ability to account for any or all of the following flexibilities provided by EPCA: FFV credits, credit carry-forward and carry-back (between model years), credit transfers (between passenger car and light truck fleets), and credit trades (between manufacturers). The model accounts for EPCA-specified limitations applicable to these flexibilities (*e.g.,* limits on the amount of credit that can be transferred between passenger car and light truck fleets). These capabilities in the model provide a basis for more accurately estimating costs, effects, and benefits that may actually result from new CAFE standards. Insofar as some manufacturers actually do earn and use CAFE credits, this provides NHTSA with the ability to examine outcomes more realistically than EPCA allows for purposes of setting new CAFE standards.

NHTSA is today proposing CAFE standards reflecting EPA's proposal to change fuel economy calculation procedures such that a vehicle's fuel consumption improvement will be accounted for if the vehicle has technologies that reduce the amount of energy needed to power the air conditioner. To facilitate analysis of these standards, DOT has modified the CAFE model to account for these adjustments, based on inputs specifying the average amount of improvement anticipated, and the estimated average cost to apply the underlying technology.

Considering that past CAFE rulemakings indicate that most of the benefits of CAFE standards are realized by vehicle owners, DOT has modified the CAFE model to estimate not just social benefits, but also private benefits. The model accommodates separate discount rates for these two valuation methods (*e.g.,* a 3% rate for social benefits with a 7% rate for private benefits). When calculating private benefits, the model includes changes in outlays for fuel taxes (which, as economic transfers, are excluded from social benefits) and excludes changes in economic externalities (*e.g.,* monetized criteria pollutant and greenhouse gas emissions).

Since 2003, the CAFE model (and its predecessors) have provided the ability to estimate the extent to which a manufacturer with a history of paying civil penalties allowed under EPCA might decide to add some fuel-saving technology, but not enough to comply with CAFE standards. In simulating this decision-making, the model considers the cost to add the technology, the calculated reduction in civil penalties, and the calculated present value (at the time of vehicle purchase) of the change in fuel outlays over a specified ''payback period'' (*e.g.,* 5 years). For a manufacturer assumed to be willing to pay civil penalties, the model stops adding technology once paying fines becomes more attractive than continuing to add technology, considering these three factors. As an extension of this simulation approach, DOT has modified the CAFE model to, if specified, simulate the potential that a manufacturer would add more technology than required for purposes of compliance with CAFE standards. When set to operate in this manner, the model will continue to apply technology to a manufacturer's CAFE-compliant fleet until applying further technology will incur more in cost than it will yield in calculated fuel savings over a specified ''payback period'' that is set separately from the payback period applicable until compliance is achieved. In its analysis supporting MY 2012–2016 standards adopted in 2010, NHTSA estimated the extent to which reductions in vehicle mass might lead to changes in the number of highway fatalities occurring over the useful life of the MY 2012–2016 fleet. NHTSA performed these calculations outside the CAFE model (using vehicle-specific mass reduction calculations from the model), based on agency analysis of relevant highway safety data. DOT has since modified the CAFE model to perform these calculations, using an analytical structure indicated by an update to the underlying safety analysis. The model also applies an input value indicating the economic value of a statistical life, and includes resultant benefits (or disbenefits) in the calculation of total social benefits.

In comments on recent NHTSA rulemakings, some reviewers have suggested that the CAFE model should be modified to estimate the extent to which new CAFE standards would induce changes in the mix of vehicles in the new vehicle fleet. NHTSA agrees that a ''market shift'' model, also called a consumer vehicle choice model, could provide useful information regarding the possible effects of potential new CAFE standards. NHTSA has contracted with the Brookings Institution (which has subcontracted with researchers at U.C. Davis, U.C. Irvine) to develop a vehicle choice model estimated at the vehicle configuration level that can be

[698] For example, a value gain could be specified for a technology expected to improve ride quality, and a value loss could be specified for a technology expected to reduce vehicle range.

implemented as part of DOT's CAFE model. As discussed further in Section V of the PRIA, past efforts by DOT staff demonstrated that a vehicle could be added to the CAFE model, but did not yield credible coefficients specifying such a model. If a suitable and credibly calibrated vehicle choice model becomes available in time—whether through the Brookings-led research or from other sources, DOT may integrate a vehicle choice model into the CAFE model for the final rule.

NHTSA anticipates this integration of a vehicle choice model would be structurally and operationally similar to the integration we implemented previously. As under the version applied in support of today's announcement, the CAFE model would begin with an agency-estimated market forecast, estimate to what extent manufacturers might apply additional fuel-saving technology to each vehicle model in consideration of future fuel prices and baseline or alternative CAFE standards and fuel prices, and calculate resultant changes in the fuel economy (and possibly fuel type) and price of individual vehicle models. With an integrated market share model, the CAFE model would then estimate how the sales volumes of individual vehicle models would change in response to changes in fuel economy levels and prices throughout the light vehicle market, possibly taking into account interactions with the used vehicle market. Having done so, the model would replace the sales estimates in the original market forecast with those reflecting these model-estimated shifts, repeating the entire modeling cycle until converging on a stable solution.

Based on past experience, we anticipate that this recursive simulation will be necessary to ensure consistency between sales volumes and modeled fuel economy standards, because achieved CAFE levels depend on sales mix and, under attribute-based CAFE standards, required CAFE levels also depend on sales mix. NHTSA anticipates, therefore, that application of a market share model would impact estimates of all of the following for a given schedule of CAFE standards: overall market volume, manufacturer market shares and product mix, required and achieved CAFE levels, technology application rates and corresponding incurred costs, fuel consumption, greenhouse gas and criteria pollutant emissions, changes in highway fatalities, and economic benefits.

Past testing by DOT/NHTSA staff did not indicate major shifts in broad measures (*e.g.,* in total costs or total benefits), but that testing emphasized shorter modeling periods (*e.g.,* 1–5 model years) and less stringent standards than reflected in today's proposal. Especially without knowing the characteristics of a future vehicle choice model, it is difficult to anticipate the potential degree to which its inclusion would impact analytical outcomes.

NHTSA invites comment on the above changes to the CAFE model. The agency's consideration of any alternative approaches will be facilitated by specific recommendations regarding implementation within the model's overall structure. NHTSA also invites comment regarding above-mentioned prospects for inclusion of a vehicle choice model. The agency's consideration will be facilitated by specific information demonstrating that inclusion of such a model would lead to more realistic estimates of costs, effects, and benefits, or that inclusion of such a model would lead to less realistic estimates.

d. Does the model set the standards?

Since NHTSA began using the CAFE model in CAFE analysis, some commenters have interpreted the agency's use of the model as the way by which the agency chooses the maximum feasible fuel economy standards. As the agency explained in its most recent CAFE rulemaking, this is incorrect.[699] Although NHTSA currently uses the CAFE model as a tool to inform its consideration of potential CAFE standards, the CAFE model does not determine the CAFE standards that NHTSA proposes or promulgates as final regulations. The results it produces are completely dependent on inputs selected by NHTSA, based on the best available information and data available in the agency's estimation at the time standards are set. Ultimately, NHTSA's selection of appropriate CAFE standards is governed and guided by the statutory requirements of EPCA, as amended by EISA: NHTSA sets the standard at the maximum feasible average fuel economy level that it determines is achievable during a particular model year, considering technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy.

e. How does NHTSA make the model available and transparent?

Model documentation, which is publicly available in the rulemaking docket and on NHTSA's Web site, explains how the model is installed, how the model inputs (all of which are available to the public)[700] and outputs are structured, and how the model is used. The model can be used on any Windows-based personal computer with Microsoft Office 2003 or 2007 and the Microsoft .NET framework installed (the latter available without charge from Microsoft). The executable version of the model and the underlying source code are also available at NHTSA's Web site. The input files used to conduct the core analysis documented in this proposal are available in the public docket. With the model and these input files, anyone is capable of independently running the model to repeat, evaluate, and/or modify the agency's analysis.

Because the model is available on NHTSA's web site, the agency has no way of knowing how widely the model has been used. The agency is, however, aware that the model has been used by other federal agencies, vehicle manufacturers, private consultants, academic researchers, and foreign governments. Some of these individuals have found the model complex and challenging to use. Insofar as the model's sole purpose is to help DOT staff efficiently analyze potential CAFE standards, DOT has not expended significant resources trying to make the model as ''user friendly'' as commercial software intended for wide use. However, DOT wishes to facilitate informed comment on the proposed standards, and encourages reviewers to contact the agency promptly if any difficulties using the model are encountered.

NHTSA arranged for a formal peer review of an older version of the model, has responded to reviewers' comments, and has considered and responded to model-related comments received over the course of four CAFE rulemakings. In the agency's view, this steady and expanding outside review over the course of nearly a decade of model development has helped DOT to significantly strengthen the model's capabilities and technical quality, and has greatly increased transparency, such that all model code is publicly available, and all model inputs and outputs are publicly available in a form that should allow reviewers to reproduce the agency's analysis. NHTSA is currently preparing arrangements for a formal peer review of the current CAFE model. Depending on the schedule for that

[699] 75 FR 25600.

[700] We note, however, that files from any supplemental analysis conducted that relied in part on confidential manufacturer product plans cannot be made public, as prohibited under 49 CFR part 512.

review, DOT will consider possible model revisions and, as feasible, attempt to make any appropriate revisions before performing analysis supporting final CAFE standards for MY 2017 and beyond.

D. Statutory Requirements

1. EPCA, as Amended by EISA

a. Standard Setting

EPCA, as amended by EISA, contains a number of provisions regarding how NHTSA must set CAFE standards. NHTSA must establish separate CAFE standards for passenger cars and light trucks [701] for each model year,[702] and each standard must be the maximum feasible that NHTSA believes the manufacturers can achieve in that model year.[703] When determining the maximum feasible level achievable by the manufacturers, EPCA requires that the agency consider the four statutory factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy.[704] In addition, the agency has the authority to and traditionally does consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety. The ultimate determination of what standards can be considered maximum feasible involves a weighing and balancing of these factors, and the balance may shift depending on the information before the agency about the expected circumstances in the model years covered by the rulemaking. Always in conducting that balancing, however, the implication of the ''maximum feasible'' requirement is that it calls for setting a standard that exceeds what might be the minimum requirement if the agency determines that the manufacturers can achieve a higher level, and that the agency's decision support the overarching purpose of EPCA, energy conservation.[705]

Besides the requirement that standards be maximum feasible for the fleet in question, EPCA/EISA also contains several other requirements. The standards must be attribute-based and expressed in the form of a mathematical function—NHTSA has thus far based standards on vehicle footprint, and for this rulemaking has expressed them in the form of a constrained linear function that generally sets higher (more stringent) mpg targets for smaller-footprint vehicles and lower (less stringent) mpg targets for larger-footprint vehicles. Second, the standards are subject to a minimum requirement regarding stringency: they must be set at levels high enough to ensure that the combined U.S. passenger car and light truck fleet achieves an average fuel economy level of not less than 35 mpg not later than MY 2020.[706] Third, between MY 2011 and MY 2020, the standards must ''increase ratably'' in each model year.[707] This requirement does not have a precise mathematical meaning, particularly because it must be interpreted in conjunction with the requirement to set the standards for each model year at the level determined to be the maximum feasible level for that model year. Generally speaking, the requirement for ratable increases means that the annual increases should not be disproportionately large or small in relation to each other. The second and third requirements no longer apply after MY 2020, at which point standards must simply be maximum feasible. And fourth, EISA requires NHTSA to issue CAFE standards for ''at least 1, but not more than 5, model years.''[708] This issue is discussed in section IV.B above.

The following sections discuss the statutory factors behind ''maximum feasible'' in more detail.

i. Statutory Factors Considered in Determining the Achievable Level of Average Fuel Economy

As none of the four factors is defined in EPCA and each remains interpreted only to a limited degree by case law, NHTSA has considerable latitude in interpreting them. NHTSA interprets the four statutory factors as set forth below.

(1) Technological Feasibility

''Technological feasibility'' refers to whether a particular technology for improving fuel economy is available or can become available for commercial application in the model year for which a standard is being established. Thus, the agency is not limited in determining the level of new standards to technology that is already being commercially applied at the time of the rulemaking. It can, instead, set technology-forcing standards, *i.e.,* ones that make it necessary for manufacturers to engage in research and development in order to bring a new technology to market. There are certain technologies that the agency has considered for this rulemaking, for example, that we know to be in the research phase now but which we are fairly confident can be commercially applied by the rulemaking timeframe, and very confident by the end of the rulemaking timeframe. It is important to remember, however, that while the technological feasibility factor may encourage the agency to look toward more technology-forcing standards, and while this could certainly be appropriate given EPCA's overarching purpose of energy conservation depending on the rulemaking, that factor must also be balanced with the other of the four statutory factors. Thus, while ''technological feasibility'' can drive standards higher by assuming the use of technologies that are not yet commercial, ''maximum feasible'' is still also defined in terms of economic practicability, for example, which might caution the agency against basing standards (even fairly distant future standards) entirely on such technologies. By setting standards at levels consistent with an analysis that assumes the use of these nascent technologies at levels that seem reasonable, the agency believes a more reasonable balance is ensured. Nevertheless, as the ''maximum feasible'' balancing may vary depending on the circumstances at hand for the model years in which the standards are set, the extent to which technological feasibility is simply met or plays a more dynamic role may also shift.

(2) Economic Practicability

''Economic practicability'' refers to whether a standard is one ''within the financial capability of the industry, but not so stringent as to'' lead to ''adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice.'' [709] The agency has explained in the past that this factor can be especially important during rulemakings in which the automobile industry is facing significantly adverse economic conditions (with corresponding risks to jobs). Consumer acceptability is also an element of economic practicability, one which is particularly difficult to gauge during times of uncertain fuel prices.[710]

[701] 49 U.S.C. 32902(b)(1).

[702] 49 U.S.C. 32902(a).

[703] *Id.*

[704] 49 U.S.C. 32902(f).

[705] *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1197 (9th Cir. 2008) (''Whatever method it uses, NHTSA cannot set fuel economy standards that are contrary to Congress' purpose in enacting the EPCA—energy conservation.'').

[706] 49 U.S.C. 32902(b)(2)(A).

[707] 49 U.S.C. 32902(b)(2)(C).

[708] 49 U.S.C. 32902(b)(3)(B).

[709] 67 FR 77015, 77021 (Dec. 16, 2002).

[710] *See, e.g., Center for Auto Safety* v. *NHTSA (CAS),* 793 F.2d 1322 (DC Cir. 1986) (Administrator's consideration of market demand as component of economic practicability found to be reasonable); *Public Citizen* v. *NHTSA,* 848 F.2d 256 (Congress established broad guidelines in the fuel economy statute; agency's decision to set lower

Continued

In a rulemaking such as the present one, looking out into the more distant future, economic practicability is a way to consider the uncertainty surrounding future market conditions and consumer demand for fuel economy in addition to other vehicle attributes. In an attempt to ensure the economic practicability of attribute-based standards, NHTSA considers a variety of factors, including the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology, the specific fleet mixes of different manufacturers, and assumptions about the cost of the standards to consumers and consumers' valuation of fuel economy, among other things.

At the same time, however, the law does not preclude a CAFE standard that poses considerable challenges to any individual manufacturer. The Conference Report for EPCA, as enacted in 1975, makes clear, and the case law affirms, ''(A) determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy.'' [711] Instead, the agency is compelled ''to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers.'' [712] The law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole. Thus, while a particular CAFE standard may pose difficulties for one manufacturer, it may also present opportunities for another. NHTSA has long held that the CAFE program is not necessarily intended to maintain the competitive positioning of each particular company. Rather, it is intended to enhance the fuel economy of the vehicle fleet on American roads, while protecting motor vehicle safety and being mindful of the risk to the overall United States economy.

Consequently, ''economic practicability'' must be considered in the context of the competing concerns associated with different levels of standards. Prior to the MY 2005–2007 rulemaking, the agency generally sought to ensure the economic practicability of standards in part by setting them at or near the capability of the ''least capable manufacturer'' with a significant share of the market, *i.e.,* typically the manufacturer whose vehicles are, on average, the heaviest and largest. In the first several rulemakings establishing attribute-based standards, the agency applied marginal cost benefit analysis. This ensured that the agency's application of technologies was limited to those that would pay for themselves and thus should have significant appeal to consumers. We note that for this rulemaking, the agency can and has limited its application of technologies to those that are projected to be cost-effective within the rulemaking time frame, with or without the use of such analysis.

Whether the standards maximize net benefits has thus been a touchstone in the past for NHTSA's consideration of economic practicability. Executive Order 12866, as amended by Executive Order 13563, states that agencies should ''select, in choosing among alternative regulatory approaches, those approaches that maximize net benefits * * *'' In practice, however, agencies, including NHTSA, must consider situations in which the modeling of net benefits does not capture all of the relevant considerations of feasibility. In this case, the NHTSA balancing of the statutory factors suggests that the maximum feasible stringency for this rulemaking points to another level besides the modeled net benefits maximum, and such a situation is well within the guidance provided by EO's 12866 and 13563.[713]

The agency's consideration of economic practicability depends on a number of factors. Expected availability of capital to make investments in new technologies matters; manufacturers' expected ability to sell vehicles with new technologies matters; likely consumer choices matter; and so forth. NHTSA's analysis of the impacts of this rulemaking does incorporate assumptions to capture aspects of consumer preferences, vehicle attributes, safety, and other factors relevant to an impact estimate; however, it is difficult to capture every such constraint. Therefore, it is well within the agency's discretion to deviate from a modeled net benefits maximum in the face of evidence of economic impracticability, and if the agency concludes that the modeled net benefits maximum would not represent the maximum feasible level for future CAFE standards. Economic practicability is a complex factor, and like the other factors must also be considered in the context of the overall balancing and EPCA's overarching purpose of energy conservation. Depending on the conditions of the industry and the assumptions used in the agency's analysis of alternative stringencies, NHTSA could well find that standards that maximize net benefits, or that are higher or lower, could be economically practicable, and thus maximum feasible.

(3) The Effect of Other Motor Vehicle Standards of the Government on Fuel Economy

''The effect of other motor vehicle standards of the Government on fuel economy,'' involves an analysis of the effects of compliance with emission, safety, noise, or damageability standards on fuel economy capability and thus on average fuel economy. In previous CAFE rulemakings, the agency has said that pursuant to this provision, it considers the adverse effects of other motor vehicle standards on fuel economy. It said so because, from the CAFE program's earliest years [714] until present, the effects of such compliance on fuel economy capability over the history of the CAFE program have been negative ones. In those instances in which the effects are negative, NHTSA has said that it is called upon to ''mak[e] a straightforward adjustment to the fuel economy improvement projections to account for the impacts of other Federal standards, principally those in the areas of emission control, occupant safety, vehicle damageability, and vehicle noise. However, only the unavoidable consequences should be accounted for. The automobile manufacturers must be expected to adopt those feasible methods of achieving compliance with other Federal standards which minimize any adverse fuel economy effects of those standards.'' [715] For example, safety standards that have the effect of increasing vehicle weight lower vehicle fuel economy capability and thus decrease the level of average fuel economy that the agency can determine to be feasible.

The ''other motor vehicle standards'' consideration has thus in practice functioned in a fashion similar to the provision in EPCA, as originally enacted, for adjusting the statutorily-specified CAFE standards for MY 1978–1980 passengers cars.[716] EPCA did not permit NHTSA to amend those standards based on a finding that the maximum feasible level of average fuel economy for any of those three years was greater or less than the standard

standard was a reasonable accommodation of conflicting policies).

[711] *CEI–I,* 793 F.2d 1322, 1352 (DC Cir. 1986).

[712] *Id.*

[713] *See* 70 FR at 51435 (Aug. 30, 2005); *CBD* v. *NHTSA,* 538 F.3d at 1197 (9th Cir. 2008).

[714] 42 FR 63184, 63188 (Dec. 15, 1977). *See also* 42 FR 33534, 33537 (Jun. 30, 1977).

[715] 42 FR 33534, 33537 (Jun. 30, 1977).

[716] That provision was deleted as obsolete when EPCA was codified in 1994.

specified for that year. Instead, it provided that the agency could only reduce the standards and only on one basis: if the agency found that there had been a Federal standards fuel economy reduction, *i.e.,* a reduction in fuel economy due to changes in the Federal vehicle standards, *e.g.,* emissions and safety, relative to the year of enactment, 1975.

The ''other motor vehicle standards'' provision is broader than the Federal standards fuel economy reduction provision. Although the effects analyzed to date under the ''other motor vehicle standards'' provision have been negative, there could be circumstances in which the effects are positive. In the event that the agency encountered such circumstances, it would be required to consider those positive effects. For example, if changes in vehicle safety technology led to NHTSA's amending a safety standard in a way that permits manufacturers to reduce the weight added in complying with that standard, that weight reduction would increase vehicle fuel economy capability and thus increase the level of average fuel economy that could be determined to be feasible.

In the wake of *Massachusetts* v. *EPA* and of EPA's endangerment finding, granting of a waiver to California for its motor vehicle GHG standards, and its own establishment of GHG standards, NHTSA is confronted with the issue of how to treat those standards under EPCA/EISA, such as in the context of the ''other motor vehicle standards'' provision. To the extent the GHG standards result in increases in fuel economy, they would do so almost exclusively as a result of inducing manufacturers to install the same types of technologies used by manufacturers in complying with the CAFE standards.

Comment is requested on whether and in what way the effects of the California and EPA standards should be considered under EPCA/EISA, *e.g.,* under the ''other motor vehicle standards'' provision, consistent with NHTSA's independent obligation under EPCA/EISA to issue CAFE standards. The agency has already considered EPA's proposal and the harmonization benefits of the National Program in developing its own proposal.

(4) The Need of the United States To Conserve Energy

''The need of the United States to conserve energy'' means ''the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum.'' [717] Environmental implications principally include those associated with reductions in emissions of criteria pollutants and CO_2. A prime example of foreign policy implications are energy independence and energy security concerns.

(a) Fuel Prices and the Value of Saving Fuel

Projected future fuel prices are a critical input into the preliminary economic analysis of alternative CAFE standards, because they determine the value of fuel savings both to new vehicle buyers and to society, which is related to the consumer cost (or rather, benefit) of our need for large quantities of petroleum. In this rule, NHTSA relies on fuel price projections from the U.S. Energy Information Administration's (EIA) most recent Annual Energy Outlook (AEO) for this analysis. Federal government agencies generally use EIA's projections in their assessments of future energy-related policies.

(b) Petroleum Consumption and Import Externalities

U.S. consumption and imports of petroleum products impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) Higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to provide a response option should a disruption in commercial oil supplies threaten the U.S. economy, to allow the United States to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and to provide a national defense fuel reserve. Higher U.S. imports of crude oil or refined petroleum products increase the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above the resource costs of producing them. Conversely, reducing U.S. imports of crude petroleum or refined fuels or reducing fuel consumption can reduce these external costs.

(c) Air Pollutant Emissions

While reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of various pollutants, additional vehicle use associated with the rebound effect [718] from higher fuel economy will increase emissions of these pollutants. Thus, the net effect of stricter CAFE standards on emissions of each pollutant depends on the relative magnitudes of its reduced emissions in fuel refining and distribution, and increases in its emissions from vehicle use.[719] Fuel savings from stricter CAFE standards also result in lower emissions of CO_2, the main greenhouse gas emitted as a result of refining, distribution, and use of transportation fuels. Reducing fuel consumption reduces carbon dioxide emissions directly, because the primary source of transportation-related CO_2 emissions is fuel combustion in internal combustion engines.

NHTSA has considered environmental issues, both within the context of EPCA and the National Environmental Policy Act, in making decisions about the setting of standards from the earliest days of the CAFE program. As courts of appeal have noted in three decisions stretching over the last 20 years,[720] NHTSA defined the ''need of the Nation to conserve energy'' in the late 1970s as including ''the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum.'' [721] In 1988, NHTSA included climate change concepts in its CAFE notices and prepared its first environmental assessment addressing that subject.[722] It cited concerns about climate change as one of its reasons for limiting the extent of its reduction of the CAFE standard for MY 1989 passenger cars.[723] Since then, NHTSA has considered the benefits of reducing tailpipe carbon dioxide emissions in its fuel economy

[717] 42 FR 63184, 63188 (1977).

[718] The ''rebound effect'' refers to the tendency of drivers to drive their vehicles more as the cost of doing so goes down, as when fuel economy improves.

[719] *See* Section IV.G below for NHTSA's evaluation of this effect.

[720] *Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, 1325 n. 12 (DC Cir. 1986); *Public Citizen* v. *NHTSA,* 848 F.2d 256, 262–3 n. 27 (DC Cir. 1988) (noting that ''NHTSA itself has interpreted the factors it must consider in setting CAFE standards as including environmental effects''); and *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172 (9th Cir. 2007).

[721] 42 FR 63184, 63188 (Dec. 15, 1977) (emphasis added).

[722] 53 FR 33080, 33096 (Aug. 29, 1988).

[723] 53 FR 39275, 39302 (Oct. 6, 1988).

rulemakings pursuant to the statutory requirement to consider the nation's need to conserve energy by reducing fuel consumption.

ii. Other Factors Considered by NHTSA

The agency historically has considered the potential for adverse safety consequences in setting CAFE standards. This practice is recognized approvingly in case law. As the courts have recognized, ''NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program.'' *Competitive Enterprise Institute* v. *NHTSA,* 901 F.2d 107, 120 n. 11 (DC Cir. 1990) (''*CEI I''*) (citing 42 FR 33534, 33551 (June 30, 1977)). The courts have consistently upheld NHTSA's implementation of EPCA in this manner. *See, e.g., Competitive Enterprise Institute* v. *NHTSA,* 956 F.2d 321, 322 (DC Cir. 1992) (''*CEI II''*) (in determining the maximum feasible fuel economy standard, ''NHTSA has always taken passenger safety into account.'') (citing *CEI I,* 901 F.2d at 120 n. 11); *Competitive Enterprise Institute* v. *NHTSA,* 45 F.3d 481, 482–83 (DC Cir. 1995) (''*CEI III''*) (same); *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1203–04 (9th Cir. 2008) (upholding NHTSA's analysis of vehicle safety issues associated with weight in connection with the MY 2008–11 light truck CAFE rule). Thus, in evaluating what levels of stringency would result in maximum feasible standards, NHTSA assesses the potential safety impacts and considers them in balancing the statutory considerations and to determine the maximum feasible level of the standards.

Under the universal or ''flat'' CAFE standards that NHTSA was previously authorized to establish, manufacturers were encouraged to respond to higher standards by building smaller, less safe vehicles in order to ''balance out'' the larger, safer vehicles that the public generally preferred to buy, which resulted in a higher mass differential between the smallest and the largest vehicles, with a correspondingly greater risk to safety. Under the attribute-based standards being proposed today, that risk is reduced because building smaller vehicles would tend to raise a manufacturer's overall CAFE obligation, rather than only raising its fleet average CAFE, and because all vehicles are required to continue improving their fuel economy. In prior rulemakings, NHTSA limited the application of mass reduction in our modeling analysis to vehicles over 5,000 lbs GVWR,[724] but for purposes of today's proposed standards, NHTSA has revised its modeling analysis to allow some application of mass reduction for most types of vehicles, although it is concentrated in the largest and heaviest vehicles, because we believe that this is more consistent with how manufacturers will actually respond to the standards. However, as discussed above, NHTSA does not mandate the use of any particular technology by manufacturers in meeting the standards. More information on the approach to modeling manufacturer use of mass reduction is available in Chapter 3 of the draft Joint TSD and in Section V of the PRIA; and the estimated safety impacts that may be due to the proposed MY 2017–2025 CAFE standards are described in section IV.G below.

iii. Factors That NHTSA Is Prohibited From Considering

EPCA also provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several EPCA provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance.[725] As discussed further below, manufacturers can earn compliance credits by exceeding the CAFE standards and then use those credits to achieve compliance in years in which their measured average fuel economy falls below the standards. Manufacturers can also increase their CAFE levels through MY 2019 by producing alternative fuel vehicles. EPCA provides an incentive for producing these vehicles by specifying that their fuel economy is to be determined using a special calculation procedure that results in those vehicles being assigned a high fuel economy level.

The effect of the prohibitions against considering these statutory flexibilities in setting the CAFE standards is that the flexibilities remain voluntarily-employed measures. If the agency were instead to assume manufacturer use of those flexibilities in setting new standards, that assumption would result in higher standards and thus tend to require manufacturers to use those flexibilities. By keeping NHTSA from including them in our stringency determination, the provision ensures that the statutory credits remain described above remain true compliance flexibilities.

On the other hand, NHTSA does not believe that flexibilities other than those expressly identified in EPCA are similarly prohibited from being included in the agency's determination of what standards would be maximum feasible. In order to better meet EPCA's overarching purpose of energy conservation, the agency is therefore considering manufacturers' ability to increase the calculated fuel economy levels of their vehicles through A/C efficiency improvements, as proposed by EPA, in the proposed CAFE stringency levels for passenger cars and light trucks for MYs 2017–2025. NHTSA would similarly consider manufacturers' ability to raise their fuel economy using off-cycle technologies as potentially relevant to our determination of maximum feasible CAFE standards, but because we and EPA do not believe that we can yet reasonably predict an average amount by which manufacturers will take advantage of this opportunity, it did not seem reasonable for the proposed standards to include it in our stringency determination at this time. We expect to re-evaluate whether and how to include off-cycle credits in determining maximum feasible standards as the off-cycle technologies and how manufacturers may be expected to employ them become better defined in the future.

Additionally, because we interpret the prohibition against including the defined statutory credits in our determination of maximum feasible standards as applying only to the flexibilities expressly identified in 49 U.S.C. 32902(h), NHTSA must, for the first time in this rulemaking, determine how to consider the fuel economy of dual-fueled automobiles after the statutory credit sunsets in MY 2019. Once there is no statutory credit to protect as a compliance flexibility, it does not seem reasonable to NHTSA to continue to interpret the statute as prohibiting the agency from setting maximum feasible levels at a higher standard, if possible, by considering the fuel economy of dual-fueled automobiles as measured by EPA. The overarching purpose of EPCA is better served by interpreting 32902(h)(2) as moot once the statutory credits provided for in 49 U.S.C. 32905 and 32906 have expired.

49 U.S.C. 32905(b) and (d) states that the special fuel economy measurement prescribed by Congress for dual-fueled automobiles applies only ''in model years 1993 through 2019.'' 49 U.S.C. 32906(a) also provides that the section 32905 calculation will sunset in 2019, as evidenced by the phase-out of the

[724] *See* 74 FR 14396–14407 (Mar. 30, 2009).

[725] 49 U.S.C. 32902(h).

allowable increase due to that credit; it is clear that the phase-out of the allowable increase in a manufacturer's CAFE levels due to use of dual-fueled automobiles relates only to the special statutory calculation (and not to other ways of incorporating the fuel economy of dual-fueled automobiles into the manufacturer's fleet calculation) by virtue of language in section 32906(b), which states that ''in applying subsection (a) [*i.e.,* the phasing out maximum increase], the Administrator of the Environmental Protection Agency shall determine the increase in a manufacturer's average fuel economy attributable to dual fueled automobiles by subtracting from the manufacturer's average fuel economy calculated under section 32905(e) the number equal to what the manufacturer's average fuel economy would be if it were calculated by the formula under section 32904(a)(1). * * * '' By referring back to the special statutory calculation, Congress makes clear that the phase-out applies only to increases in fuel economy attributable to dual-fueled automobiles due to the special statutory calculation in sections 32905(b) and (d). Similarly, we interpret Congress' statement in section 32906(a)(7) that the maximum increase in fuel economy attributable to dual-fueled automobiles is ''0 miles per gallon for model years after 2019'' within the context of the introductory language of section 32906(a) and the language of section 32906(b), which, again, refers clearly to the statutory credit, and not to dual-fueled automobiles generally. It would be an absurd result if the phase-out of the credit meant that manufacturers would be effectively penalized, in CAFE compliance, for building dual-fueled automobiles like plug-in hybrid electric vehicles, which may be important ''bridge'' vehicles in helping consumers move toward full electric vehicles.

NHTSA has therefore considered the fuel economy of plug-in hybrid electric vehicles (the only dual-fueled automobiles that we predict in significant numbers in MY 2020 and beyond; E85-capable FFVs are not predicted in great numbers after the statutory credit sunsets, and we do not have sufficient information about potential dual-fueled CNG/gasoline vehicles to make reasonable estimates now of their numbers in that time frame in determining the maximum feasible level of the MY 2020–2025 CAFE standards for passenger cars and light trucks.

iv. Determining the Level of the Standards by Balancing the Factors

NHTSA has broad discretion in balancing the above factors in determining the appropriate levels of average fuel economy at which to set the CAFE standards for each model year. Congress ''specifically delegated the process of setting * * * fuel economy standards with broad guidelines concerning the factors that the agency must consider.'' [726] The breadth of those guidelines, the absence of any statutorily prescribed formula for balancing the factors and other considerations, the fact that the relative weight to be given to the various factors may change from rulemaking to rulemaking as the underlying facts change, and the fact that the factors may often be conflicting with respect to whether they militate toward higher or lower standards give NHTSA broad discretion to decide what weight to give each of the competing policies and concerns and then determine how to balance them. The exercise of that discretion is subject to the necessity of ensuring that NHTSA's balancing does not undermine the fundamental purpose of EPCA, energy conservation,[727] and as long as that balancing reasonably accommodates ''conflicting policies that were committed to the agency's care by the statute.'' [728] The balancing of the factors in any given rulemaking is highly dependent on the factual and policy context of that rulemaking and the agency's assumptions about the factual and policy context during the time frame covered by the standards at issue. Given the changes over time in facts bearing on assessment of the various factors, such as those relating to economic conditions, fuel prices, and the state of climate change science, the agency recognizes that what was a reasonable balancing of competing statutory priorities in one rulemaking may or may not be a reasonable balancing of those priorities in another rulemaking.[729] Nevertheless, the agency retains substantial discretion under EPCA to choose among reasonable alternatives.

EPCA neither requires nor precludes the use of any type of cost-benefit analysis as a tool to help inform the balancing process. As discussed above, while NHTSA used marginal cost-benefit analysis in the first two rulemakings to establish attribute-based CAFE standards, it was not required to do so and is not required to continue to do so. Regardless of what type of analysis is or is not used, considerations relating to costs and benefits remain an important part of CAFE standard setting.

Because the relevant considerations and factors can reasonably be balanced in a variety of ways under EPCA, and because of uncertainties associated with the many technological and cost inputs, NHTSA considers a wide variety of alternative sets of standards, each reflecting different balancing of those policies and concerns, to aid it in discerning reasonable outcomes. Among the alternatives providing for an increase in the standards in this rulemaking, the alternatives range in stringency from a set of standards that increase, on average, 2 percent annually to a set of standards that increase, on average, 7 percent annually.

v. Other Standards

(1) Minimum Domestic Passenger Car Standard

The minimum domestic passenger car standard was added to the CAFE program through EISA, when Congress gave NHTSA explicit authority to set universal standards for domestically-manufactured passenger cars at the level of 27.5 mpg or 92 percent of the average fuel economy of the combined domestic and import passenger car fleets in that model year, whichever was greater.[730] This minimum standard was intended to act as a ''backstop,'' ensuring that domestically-manufactured passenger cars reached a given mpg level even if the market shifted in ways likely to reduce overall fleet mpg. Congress was silent as to whether the agency could or should develop similar backstop standards for imported passenger cars and light trucks. NHTSA has struggled with this question since EISA was enacted.

NHTSA has proposed minimum standards for domestically-manufactured passenger cars in Section IV.E below, but we also seek comment on whether to consider, for the final rule, the possibility of minimum standards for imported passenger cars and light trucks. Although we are not proposing such standards, we believe it may be prudent to explore this concept again given the considerable amount of time between now and 2017–2025 (particularly the later years), and the accompanying uncertainty in our market forecast and other assumptions,

[726] *Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, 1341 (C.A.D.C. 1986).

[727] *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1195 (9th Cir. 2008).

[728] *CAS,* 1338 (quoting *Chevron U.S.A., Inc.* v. *Natural Resources Defense Council, Inc.,* 467 U.S. 837, 845).

[729] *CBD* v. *NHTSA,* 538 F.3d 1172, 1198 (9th Cir. 2008).

[730] 49 U.S.C. 32902(b)(4).

that might make such minimum standards relevant to help ensure that currently-expected fuel economy improvements occur during that time frame. To help commenters' consideration of this question, Section IV.E presents illustrative levels of minimum standards for those other fleets.

The minimum domestic passenger car standard was added to the CAFE program through EISA, when Congress gave NHTSA explicit authority to set universal standards for domestically-manufactured passenger cars at the level explained above. This minimum standard was intended to act as a "backstop," ensuring that domestically-manufactured passenger cars reached a given mpg level even if the market shifted in ways likely to reduce overall fleet mpg. Congress was silent as to whether the agency could or should develop similar backstop standards for imported passenger cars and light trucks. NHTSA has struggled with this question since EISA was enacted.

In the MY 2011 final rule, facing comments split fairly evenly between support and opposition to additional backstop standards, NHTSA noted Congress' silence with respect to minimum standards for imported passenger cars and light trucks and "accept[ed] at least the possibility that * * * [it] could be reasonably interpreted as permissive rather than restrictive," but concluded based on the record for that rulemaking as a whole that additional minimum standards were not necessary for MY 2011, given the lack of leadtime for manufacturers to change their MY 2011 vehicles, the apparently-growing public preference for smaller vehicles, and the anti-backsliding characteristics of the footprint-based curves.[731]

In the MYs 2012–2016 final rule where NHTSA declined to set minimum standards for imported passenger cars and light trucks, the agency did so not because we believed that we did not have authority to do so, but because we believed that our assumptions about the future fleet mix were reliable within the rulemaking time frame, and that backsliding was very unlikely and would not be sufficient to warrant the regulatory burden of additional minimum standards for those fleets.[732] NHTSA also expressed concern about the possibility of additional minimum standards imposing inequitable regulatory burdens of the kind that attribute-based standards sought to avoid, stating that:

> Unless the backstop was at a very weak level, above the high end of this range, then some percentage of manufacturers would be above the backstop even if the performance of the entire industry remains fully consistent with the emissions and fuel economy levels projected for the final standards. For these manufacturers and any other manufacturers who were above the backstop, the objectives of an attribute-based standard would be compromised and unnecessary costs would be imposed. This could directionally impose increased costs for some manufacturers. It would be difficult if not impossible to establish the level of a backstop standard such that costs are likely to be imposed on manufacturers only when there is a failure to achieve the projected reductions across the industry as a whole. An example of this kind of industry-wide situation could be when there is a significant shift to larger vehicles across the industry as a whole, or if there is a general market shift from cars to trucks. The problem the agencies are concerned about in those circumstances is not with respect to any single manufacturer, but rather is based on concerns over shifts across the fleet as a whole, as compared to shifts in one manufacturer's fleet that may be more than offset by shifts the other way in another manufacturer's fleet. However, in this respect, a traditional backstop acts as a manufacturer-specific standard.[733]

NHTSA continues to believe that the risk of additional minimum standards imposing inequitable regulatory burdens on certain manufacturers is real, but at the same time, we recognize that given the time frame of the current rulemaking, the agency cannot be as certain about the unlikelihood of future market changes. Depending on the price of fuel and consumer preferences, the "kind of industry-wide situation" described in the MYs 2012–2016 rule is possible in the 2017–2025 time frame, particularly in the later years.

Because the agency does not have sufficient information at this time regarding what tradeoffs might be associated with additional minimum standards, specifically, whether the risk of backsliding during MYs 2017–2025 sufficiently outweighs the possibility of imposing inequitable regulatory burdens on certain manufacturers, we are seeking comment in this NPRM on these issues but not proposing additional minimum standards at this time. We also seek comment on how to structure additional minimum standards (*e.g.,* whether they should be flat or attribute-based, and if the latter, how that would work), and at what level additional minimum standards should potentially be set. The tables in Section IV.E provide an illustration of what levels the additional minimum standards would require if the agency followed the same 92 percent guideline required by EISA for domestically-manufactured passenger cars.

(2) Alternative Standards for Certain Manufacturers

Because EPCA states that standards must be set for "* * * automobiles manufactured by manufacturers," and because Congress provided specific direction on how small-volume manufacturers could obtain exemptions from the passenger car standards, NHTSA has long interpreted its authority as pertaining to setting standards for the industry as a whole. Prior to this NPRM, some manufacturers raised with NHTSA the possibility of NHTSA and EPA setting alternate standards for part of the industry that met certain (relatively low) sales volume criteria—specifically, that separate standards be set so that "intermediate-size," limited-line manufacturers do not have to meet the same levels of stringency that larger manufacturers have to meet until several years later. These manufacturers argued that the same level of standards would not be technologically feasible or economically practicable in the same time frame for them, due to their inability to spread compliance burden across a larger product lineup, and difficulty in obtaining fuel economy-improving technologies quickly from suppliers. NHTSA seeks comment on whether or how EPCA, as amended by EISA, could be interpreted to allow such alternate standards for certain parts of the industry.

2. Administrative Procedure Act

To be upheld under the "arbitrary and capricious" standard of judicial review in the APA, an agency rule must be rational, based on consideration of the relevant factors, and within the scope of the authority delegated to the agency by the statute. The agency must examine the relevant data and articulate a satisfactory explanation for its action including a "rational connection between the facts found and the choice made." *Burlington Truck Lines, Inc.* v. *United States,* 371 U.S. 156, 168 (1962).

Statutory interpretations included in an agency's rule are subjected to the two-step analysis of *Chevron, U.S.A., Inc.* v. *Natural Resources Defense Council,* 467 U.S. 837, 104 S.Ct. 2778, 81 L.Ed.2d 694 (1984). Under step one, where a statute "has directly spoken to the precise question at issue," *id.* at 842, 104 S.Ct. 2778, the court and the agency "must give effect to the unambiguously

[731] 74 FR at 14412 (Mar. 30, 2009).

[732] 75 FR 25324, at 25368–70 (May 7, 2010).

[733] *Id.* at 25369.

expressed intent of Congress,'' *id.* at 843, 104 S.Ct. 2778. If the statute is silent or ambiguous regarding the specific question, the court proceeds to step two and asks ''whether the agency's answer is based on a permissible construction of the statute.'' *Id.*

If an agency's interpretation differs from the one that it has previously adopted, the agency need not demonstrate that the prior position was wrong or even less desirable. Rather, the agency would need only to demonstrate that its new position is consistent with the statute and supported by the record, and acknowledge that this is a departure from past positions. The Supreme Court emphasized this recently in *FCC v. Fox Television,* 129 S.Ct. 1800 (2009). When an agency changes course from earlier regulations, ''the requirement that an agency provide reasoned explanation for its action would ordinarily demand that it display awareness that it *is* changing position,'' but ''need not demonstrate to a court's satisfaction that the reasons for the new policy are *better* than the reasons for the old one; it suffices that the new policy is permissible under the statute, that there are good reasons for it, and that the agency *believes* it to be better, which the conscious change of course adequately indicates.'' [734] The APA also requires that agencies provide notice and comment to the public when proposing regulations,[735] as we are doing here today.

3. National Environmental Policy Act

As discussed above, EPCA requires the agency to determine what level at which to set the CAFE standards for each model year by considering the four factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy. NEPA directs that environmental considerations be integrated into that process. To accomplish that purpose, NEPA requires an agency to compare the potential environmental impacts of its proposed action to those of a reasonable range of alternatives.

To explore the environmental consequences in depth, NHTSA has prepared a draft environmental impact statement (''EIS''). The purpose of an EIS is to ''provide full and fair discussion of significant environmental impacts and [to] inform decisionmakers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the human environment.'' 40 CFR 1502.1.

NEPA is ''a procedural statute that mandates a process rather than a particular result.'' *Stewart Park & Reserve Coal., Inc.* v. *Slater,* 352 F.3d at 557. The agency's overall EIS-related obligation is to ''take a 'hard look' at the environmental consequences before taking a major action.'' *Baltimore Gas & Elec. Co.* v. *Natural Res. Def. Council, Inc.,* 462 U.S. 87, 97, 103 S.Ct. 2246, 76 L.Ed.2d 437 (1983). Significantly, ''[i]f the adverse environmental effects of the proposed action are adequately identified and evaluated, the agency is not constrained by NEPA from deciding that other values outweigh the environmental costs.'' *Robertson* v. *Methow Valley Citizens Council,* 490 U.S. 332, 350, 109 S.Ct. 1835, 104 L.Ed.2d 351 (1989).

The agency must identify the ''environmentally preferable'' alternative, but need not adopt it. ''Congress in enacting NEPA * * * did not require agencies to elevate environmental concerns over other appropriate considerations.'' *Baltimore Gas and Elec. Co.* v. *Natural Resources Defense Council, Inc.,* 462 U.S. 87, 97 (1983). Instead, NEPA requires an agency to develop alternatives to the proposed action in preparing an EIS. 42 U.S.C. 4332(2)(C)(iii). The statute does not command the agency to favor an environmentally preferable course of action, only that it make its decision to proceed with the action after taking a hard look at environmental consequences.

E. What are the proposed CAFE standards?

1. Form of the Standards

Each of the CAFE standards that NHTSA is proposing today for passenger cars and light trucks is expressed as a mathematical function that defines a fuel economy target applicable to each vehicle model and, for each fleet, establishes a required CAFE level determined by computing the sales-weighted harmonic average of those targets.[736]

As discussed above in Section II.C, NHTSA has determined passenger car fuel economy targets using a constrained linear function defined according to the following formula:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Here, TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (FOOTPRINT, in square feet), b and a are the function's lower and upper asymptotes (also in mpg), respectively, c is the slope (in gallons per mile per square foot) of the sloped portion of the function, and d is the intercept (in gallons per mile) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet). The MIN and MAX functions take the minimum and maximum, respectively of the included values.

NHTSA is proposing, consistent with the standards for MYs 2011–2016, that the CAFE level required of any given manufacturer be determined by calculating the production-weighted harmonic average of the fuel economy targets applicable to each vehicle model:

$$CAFE_{required} = \frac{\sum_i PRODUCTION_i}{\sum_i \frac{PRODUCTION_i}{TARGET_i}}$$

PRODUCTION$_i$ is the number of units produced for sale in the United States of each i^{th} unique footprint within each model type, produced for sale in the United States, and *TARGET*$_i$ is the corresponding fuel economy target (according to the equation shown above and based on the corresponding

[734] *Ibid.,* 1181.

[735] 5 U.S.C. 553.

[736] Required CAFE levels shown here are estimated required levels based on NHTSA's current projection of manufacturers' vehicle fleets in MYs 2017–2025. Actual required levels are not determined until the end of each model year, when all of the vehicles produced by a manufacturer in that model year are known and their compliance obligation can be determined with certainty. The target curves, as defined by the constrained linear function, and as embedded in the function for the sales-weighted harmonic average, are the real ''standards'' being proposed today.

footprint), and the summations in the numerator and denominator are both performed over all unique footprint and model type combinations in the fleet in question.

The proposed standards for passenger cars are, therefore, specified by the four coefficients defining fuel economy targets:

a = upper limit (mpg)

b = lower limit (mpg)

c = slope (gallon per mile per square foot)

d = intercept (gallon per mile)

For light trucks, NHTSA is proposing to define fuel economy targets in terms of a mathematical function under which the target is the maximum of values determined under each of two constrained linear functions. The second of these establishes a "floor" reflecting the MY 2016 standard, after accounting for estimated adjustments reflecting increased air conditioner efficiency. This prevents the target at any footprint from declining between model years. The resultant mathematical function is as follows:

$$TARGET = MAX\left(\frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}, \frac{1}{MIN\left[MAX\left(g \times FOOTPRINT + h, \frac{1}{e}\right), \frac{1}{f}\right]}\right)$$

The proposed standards for light trucks are, therefore, specified by the eight coefficients defining fuel economy targets:

a = upper limit (mpg)

b = lower limit (mpg)

c = slope (gallon per mile per square foot)

d = intercept (gallon per mile)

e = upper limit (mpg) of "floor"

f = lower limit (mpg) of "floor"

g = slope (gallon per mile per square foot) of "floor"

h = intercept (gallon per mile) of "floor"

2. Passenger Car Standards for MYs 2017–2025

For passenger cars, NHTSA is proposing CAFE standards defined by the following coefficients during MYs 2017–2025:

Table IV-11. Coefficients Defining Proposed MYs 2017–2025 Fuel Economy Targets For Passenger Cars

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a (mpg)	43.61	45.21	46.87	48.74	50.83	53.21	55.71	58.32	61.07
b (mpg)	32.65	33.84	35.07	36.47	38.02	39.79	41.64	43.58	45.61
c (gpm/sf)	0.0005131	0.0004954	0.0004783	0.0004603	0.0004419	0.0004227	0.0004043	0.0003867	0.0003699
d (gpm)	0.001896	0.001811	0.001729	0.001643	0.001555	0.001463	0.001375	0.001290	0.001210

For reference, the coefficients defining the MYs 2012–2016 passenger car standards are also provided below:

Table IV-12. Coefficients Defining Final MYs 2012–2016 Fuel Economy Targets For Passenger Cars

Coefficient	2012	2013	2014	2015	2016
a (mpg)	36.18	37.16	38.31	40.06	42.03
b (mpg)	28.09	28.67	29.35	30.37	31.49
c (gpm/sf)	0.00053	0.00053	0.00053	0.00053	0.00053
d (gpm)	0.00588	0.00515	0.00434	0.00320	0.00203

Also for reference, the following table presents the coefficients based on 2-cycle CAFE only for easier comparison to the MYs 2012–2016 coefficients presented above. We emphasize, again, that the coefficients in Table IV–11 define the proposed standards.

Table IV-13. Coefficients Based Only on 2-Cycle CAFE for MYs 2017–2025 Passenger Cars

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a (mpg)	42.57	44.09	45.66	47.44	49.42	51.66	54.01	56.47	59.04
b (mpg)	32.06	33.21	34.39	35.73	37.22	38.92	40.69	42.54	44.47
c (gpm/sf)	0.00051	0.00050	0.00048	0.00046	0.00044	0.00042	0.00040	0.00039	0.00037
d (gpm)	0.00246	0.00237	0.00229	0.00221	0.00212	0.00203	0.00194	0.00185	0.00177

Section II.C above and Chapter 2 of the draft Joint TSD discusses how the coefficients in Table IV–11 were developed for this proposed rule. The proposed coefficients result in the footprint-dependent targets shown graphically below for MYs 2017–2025. The MY 2012–2016 final standards are also shown for comparison.

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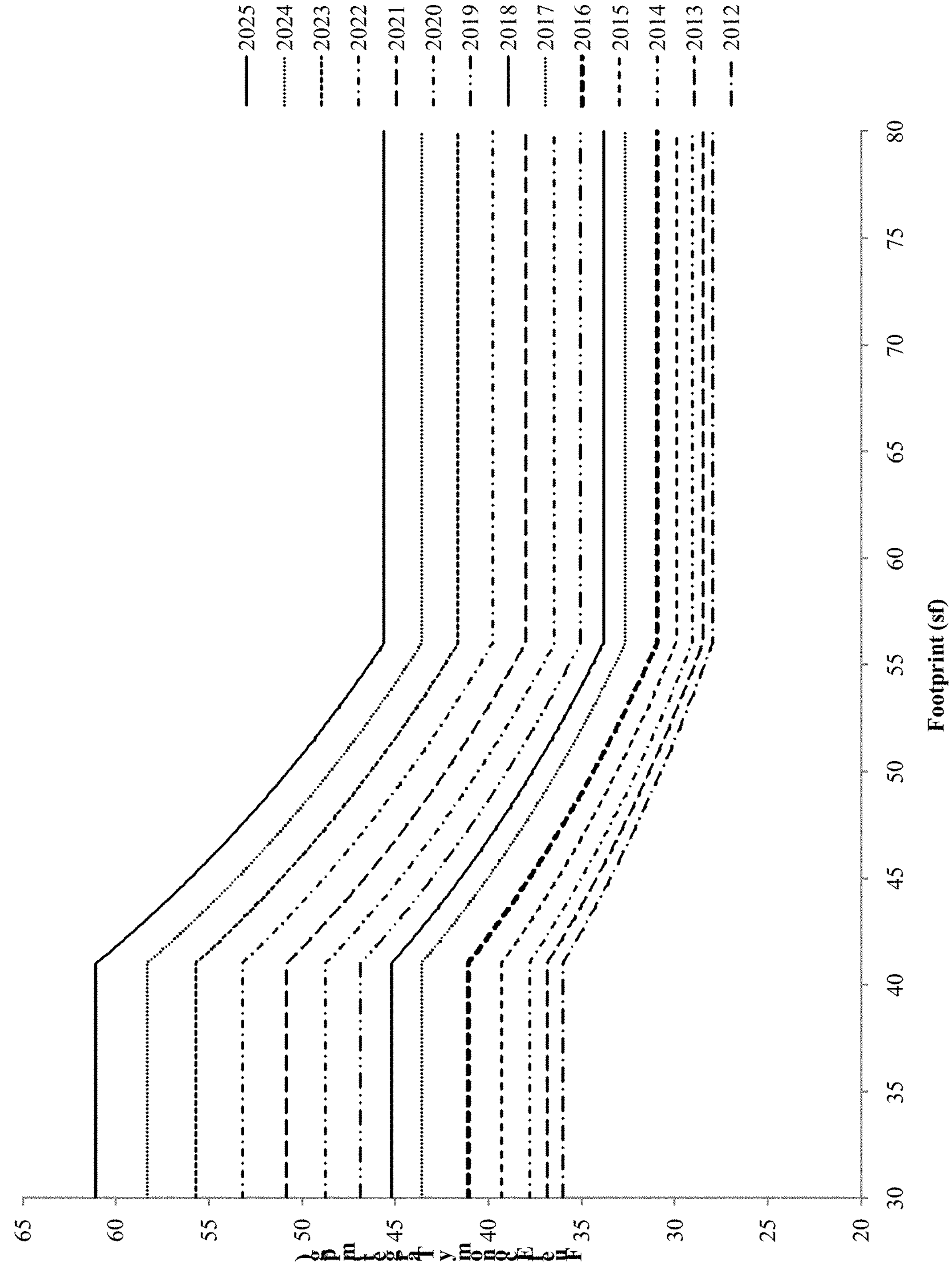
Figure IV-1. Fuel Economy Targets for MYs 2012–2016 and 2017–2025 Passenger Cars



As discussed, the CAFE levels ultimately required of individual manufacturers will depend on the mix of vehicles they produce for sale in the United States. Based on the market forecast of future sales that NHTSA has used to examine today's proposed CAFE standards, the agency currently estimates that the target curves shown above will result in the following average required fuel economy levels for individual manufacturers during MYs 2017–2025 (an updated estimate of the average required fuel economy level under the final MY 2016 standard is also shown for comparison): [737]

[737] In the May 2010 final rule establishing MY 2016 standards for passenger cars and light trucks, NHTSA estimated that the required fuel economy levels for passenger cars would average 37.8 mpg under the MY 2016 passenger car standard. Based on the agency's current forecast of the MY 2016 passenger car market, NHTSA again estimates that the average required fuel economy level for passenger cars will be 37.8 mpg in MY 2016.

[738] For purposes of CAFE compliance, ''Chrysler/Fiat'' is assumed to include Ferrari and Maserati in addition to the larger-volume Chrysler and Fiat brands.

Table IV-14. Estimated Average Fuel Economy Required Under Final MY 2016 and Proposed MYs 2017–2025 CAFE Standards For Passenger Cars

Manufacturer	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	38.2	40.5	41.9	43.5	45.2	47.2	49.4	51.7	54.1	56.6
BMW	37.3	39.4	40.9	42.4	44.1	46.0	48.1	50.4	52.7	55.2
Daimler	35.9	37.8	39.1	40.5	42.2	44.0	46.1	48.2	50.4	52.8
Chrysler/Fiat[738]	36.6	39.2	40.7	42.2	43.7	45.7	48.0	50.2	52.7	55.1
Ford	37.1	39.1	40.6	42.1	43.7	45.6	47.7	49.9	52.3	54.7
Geely (Volvo)	36.6	38.8	40.3	41.7	43.4	45.3	47.4	49.6	51.9	54.4
General Motors	36.9	39.3	40.7	42.3	43.9	45.8	48.0	50.2	52.6	55.1
Honda	38.3	40.5	42.0	43.6	45.3	47.3	49.5	51.7	54.2	56.7
Hyundai	38.2	40.3	41.8	43.4	45.1	47.1	49.3	51.5	54.0	56.5
Kia	37.9	40.0	41.5	43.1	44.8	46.7	48.9	51.2	53.6	56.1
Lotus	41.1	43.6	45.2	46.9	48.7	50.8	53.2	55.7	58.3	61.1
Mazda	38.3	40.5	41.9	43.5	45.2	47.1	49.2	51.5	54.0	56.6
Mitsubishi	38.7	41.1	42.6	44.2	45.9	47.9	50.1	52.5	54.9	57.5
Nissan	37.7	39.7	41.2	42.7	44.4	46.3	48.4	50.7	53.1	55.5
Porsche	41.1	43.6	45.2	46.9	48.7	50.8	53.2	55.7	58.3	61.1
Spyker (Saab)	38.3	40.6	42.1	43.6	45.3	47.3	49.5	51.8	54.2	56.8
Subaru	39.3	41.7	43.2	44.8	46.6	48.6	50.9	53.3	55.8	58.4
Suzuki	40.8	43.3	44.9	46.5	48.4	50.5	52.8	55.3	57.9	60.6
Tata (Jaguar, Rover)	34.7	36.8	38.1	39.6	41.1	42.9	44.9	47.0	49.2	51.5

Tesla	41.1	43.6	45.2	46.9	48.7	50.8	53.2	55.7	58.3	61.1
Toyota	38.4	40.7	42.2	43.8	45.5	47.5	49.7	52.0	54.4	57.0
VW[739]	38.9	41.2	42.7	44.2	46.0	48.0	50.2	52.6	55.0	57.6
Average	37.8	40.0	41.4	43.0	44.7	46.6	48.8	51.0	53.5	56.0

Because a manufacturer's required average fuel economy level for a model year under the final standards will be based on its actual production numbers in that model year, its official required fuel economy level will not be known until the end of that model year. However, because the targets for each vehicle footprint will be established in advance of the model year, a manufacturer should be able to estimate its required level accurately. Readers should remember that the mpg levels describing the ''estimated required standards'' shown throughout this section are not necessarily the ultimate mpg level with which manufacturers will have to comply, for the reasons explained above, and that the mpg level designated as ''estimated required'' is exactly that, an estimate.

Additionally, again for reference, the following table presents estimated mpg levels based on 2-cycle CAFE for easier comparison to the MYs 2012–2016 standards.

[739] For purposes of CAFE compliance, VW is assumed to include Audi-Bentley, Bugatti, and Lamborghini, along with the larger-volume VW brand.

Table IV-15. Estimated Average Fuel Economy Required Under Final MY 2016 and Using 2-Cycle CAFE for MYs 2017-2025 For Passenger Cars

Manufacturer	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	38.2	39.6	41.0	42.4	44.1	45.9	48.0	50.2	52.5	54.9
BMW	37.3	38.6	40.0	41.4	43.0	44.8	46.8	49.0	51.2	53.5
Daimler	35.9	37.0	38.2	39.6	41.2	42.9	44.9	46.9	49.0	51.2
Chrysler/Fiat[740]	36.6	38.3	39.7	41.2	42.7	44.6	46.7	48.8	51.2	53.5
Ford	37.1	38.3	39.7	41.1	42.7	44.4	46.5	48.6	50.8	53.1
Geely (Volvo)	36.6	38.0	39.4	40.8	42.4	44.1	46.1	48.2	50.5	52.8
General Motors	36.9	38.4	39.8	41.3	42.9	44.7	46.7	48.8	51.1	53.4
Honda	38.3	39.6	41.1	42.5	44.2	46.0	48.1	50.3	52.6	55.0
Hyundai	38.2	39.5	40.9	42.3	44.0	45.8	47.9	50.1	52.4	54.8
Kia	37.9	39.2	40.6	42.0	43.7	45.5	47.6	49.7	52.0	54.4
Lotus	41.1	42.6	44.1	45.7	47.4	49.4	51.7	54.0	56.5	59.0
Mazda	38.3	39.6	41.0	42.5	44.1	45.9	47.9	50.1	52.4	54.8
Mitsubishi	38.7	40.1	41.6	43.1	44.8	46.6	48.8	51.0	53.3	55.7
Nissan	37.7	38.9	40.3	41.7	43.3	45.1	47.2	49.3	51.5	53.9
Porsche	41.1	42.6	44.1	45.7	47.4	49.4	51.7	54.0	56.5	59.0
Spyker (Saab)	38.3	39.7	41.1	42.6	44.2	46.1	48.2	50.3	52.6	55.0
Subaru	39.3	40.7	42.2	43.7	45.4	47.3	49.5	51.7	54.1	56.5
Suzuki	40.8	42.2	43.8	45.3	47.1	49.1	51.3	53.6	56.1	58.6
Tata (Jaguar, Rover)	34.7	36.0	37.3	38.6	40.1	41.8	43.7	45.7	47.7	49.9
Tesla	41.1	42.6	44.1	45.7	47.4	49.4	51.7	54.0	56.5	59.0
Toyota	38.4	39.8	41.2	42.7	44.4	46.2	48.3	50.5	52.8	55.2
VW[741]	38.9	40.2	41.7	43.1	44.8	46.7	48.9	51.1	53.4	55.8
Average	37.8	39.1	40.5	42.0	43.6	45.4	47.5	49.6	51.9	54.3

3. Minimum Domestic Passenger Car Standards

EISA expressly requires each manufacturer to meet a minimum fuel economy standard for domestically manufactured passenger cars in addition to meeting the standards set by NHTSA. According to the statute (49 U.S.C. 32902(b)(4)), the minimum standard shall be the greater of (A) 27.5 miles per gallon; or (B) 92 percent of the average fuel economy projected by the Secretary for the combined domestic and nondomestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in

[740] For purposes of CAFE compliance, "Chrysler/Fiat" is assumed to include Ferrari and Maserati in addition to the larger-volume Chrysler and Fiat brands.

[741] For purposes of CAFE compliance, VW is assumed to include Audi-Bentley, Bugatti, and Lamborghini, along with the larger-volume VW brand.

the model year. The agency must publish the projected minimum standards in the **Federal Register** when the passenger car standards for the model year in question are promulgated. As a practical matter, as standards for both cars and trucks continue to rise over time, 49 U.S.C. 32902(b)(4)(A) will likely eventually cease to be relevant.

As discussed in the final rule establishing the MYs 2012–2016 CAFE standards, because 49 U.S.C. 32902(b)(4)(B) states that the minimum domestic passenger car standard shall be 92 percent of the projected average fuel economy for the passenger car fleet, ''which projection shall be published in the **Federal Register** when the standard for that model year is promulgated in accordance with this section,'' NHTSA interprets EISA as indicating that the minimum domestic passenger car standard should be based on the agency's fleet assumptions when the passenger car standard for that year is promulgated.

However, we note that we do not read this language to preclude any change, ever, in the minimum standard after it is first promulgated for a model year. As long as the 18-month lead-time requirement of 49 U.S.C. 32902(a) is respected, NHTSA believes that the language of the statute suggests that the 92 percent should be determined anew any time the passenger car standards are revised. This issue will be particularly relevant for the current rulemaking, given the considerable leadtime involved and the necessity of a mid-term review for the MYs 2022–2025 standards. We seek comment on this interpretation, and on whether or not the agency should consider instead for MYs 2017–2025 designating the minimum domestic passenger car standards proposed here as ''estimated,'' just as the passenger car standards are ''estimated,'' and waiting until the end of each model year to finalize the 92 percent mpg value.

We note also that in the MYs 2012–2016 final rule, we interpreted EISA as indicating that the 92 percent minimum standard should be based on the estimated required CAFE level rather than, as suggested by the Alliance, the estimated achieved CAFE level (which would likely be lower than the estimated required level if it reflected manufacturers' use of dual-fuel vehicle credits under 49 U.S.C. 32905, at least in the context of the MYs 2012–2016 standards). NHTSA continues to believe that this interpretation is appropriate.

Based on NHTSA's current market forecast, the agency's estimates of these minimum standards under the proposed MYs 2017–2025 CAFE standards (and, for comparison, the final MY 2016 minimum domestic passenger car standard) are summarized below in Table IV–16.

Table IV-16. Estimated Minimum Standard For Domestically Manufactured Passenger Cars Under Final MY 2016 and Proposed MYs 2017–2025 CAFE Standards For Passenger Cars

2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
34.7	36.8	38.1	39.6	41.1	42.9	44.9	47.0	49.2	51.5

Again, for the reader's reference, the following table the following table presents estimated mpg levels based on 2-cycle CAFE for easier comparison to the MYs 2012–2016 standards.

Table IV-17. Estimated Minimum Standard For Domestically Manufactured Passenger Cars Under Final MY 2016 and Using 2-Cycle CAFE Only for MYs 2017–2025 Passenger Cars

2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
34.7	35.9	37.2	38.6	40.1	41.7	43.7	45.6	47.7	49.9

As discussed in Section IV.D above, NHTSA is also seeking comment on whether to consider, for the final rule, the possibility of minimum standards for imported passenger cars and light trucks. Although we are not proposing such standards, we believe it may be prudent to explore this concept again given the considerable amount of time between now and 2017–2025 (particularly the later years), and the accompanying uncertainty in our market forecast and other assumptions, that might make such minimum standards relevant to help ensure that currently-expected fuel economy improvements occur during that time frame. To help commenters' consideration of this question, illustrative levels of minimum standards for those other fleets are presented below.

Table IV-18. Illustrative Estimated Minimum Standard For Imported Passenger Cars Under Proposed MYs 2017–2025 CAFE Standards For Passenger Cars

2017	2018	2019	2020	2021	2022	2023	2024	2025
36.8	38.1	39.6	41.1	42.9	44.9	47.0	49.2	51.5

Table IV-19. Illustrative Estimated Minimum Standard For Light Trucks Under Proposed MYs 2017–2025 CAFE Standards For Light Trucks

2017	2018	2019	2020	2021	2022	2023	2024	2025
27.1	27.6	28.1	28.7	30.7	32.1	33.7	35.4	37.1

NHTSA emphasizes again that we are not proposing additional minimum standards for imported passenger cars and light trucks at this time, but we may consider including them in the final rule if it seems reasonable and appropriate to do so based on the information provided by commenters and the agency's analysis. NHTSA also may wait until we are able to observe potential market changes during the implementation of the MYs 2012–2016 standards and consider additional minimum standards in a future rulemaking action. Any additional minimum standards for MYs 2022–2025 that may be set in the future would, like the primary standards, be subject to the mid-term review discussed in Section IV.B above, and potentially revised at that time.

4. Light Truck Standards

For light trucks, NHTSA is proposing CAFE standards defined by the following coefficients during MYs 2017–2025:

Table IV-20. Coefficients Defining Proposed MYs 2017–2025 Fuel Economy Targets For Light Trucks

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a (mpg)	36.26	37.36	38.16	39.11	41.80	43.79	45.89	48.09	50.39
b (mpg)	25.09	25.20	25.25	25.25	25.25	26.29	27.53	28.83	30.19
c (gpm/sf)	0.0005484	0.0005358	0.0005265	0.0005140	0.0004820	0.0004607	0.0004404	0.0004210	0.0004025
d (gpm)	0.005097	0.004797	0.004623	0.004494	0.004164	0.003944	0.003735	0.003534	0.003343
e (mpg)	35.10	35.31	35.41	35.41	35.41	35.41	35.41	35.41	35.41
f (mpg)	25.09	25.20	25.25	25.25	25.25	25.25	25.25	25.25	25.25
g (gpm/sf)	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546
h (gpm)	0.009851	0.009682	0.009603	0.009603	0.009603	0.009603	0.009603	0.009603	0.009603

For reference, the coefficients defining the MYs 2012–2016 light truck standards (which did not include a ''floor'' term defined by coefficients *e, f, g,* and *h*) are also provided below:

Table IV-21. Coefficients Defining Final MYs 2012–2016 Fuel Economy Targets For Light Trucks

Coefficient	2012	2013	2014	2015	2016
a (mpg)	36.18	37.16	38.31	40.06	42.03
b (mpg)	28.09	28.67	29.35	30.37	31.49
c (gpm/sf)	0.00053	0.00053	0.00053	0.00053	0.00053
d (gpm)	0.00588	0.00515	0.00434	0.00320	0.00203

The proposed coefficients result in the footprint-dependent targets shown graphically below for MYs 2017–2025. MYs 2012–2016 final standards are shown for comparison.

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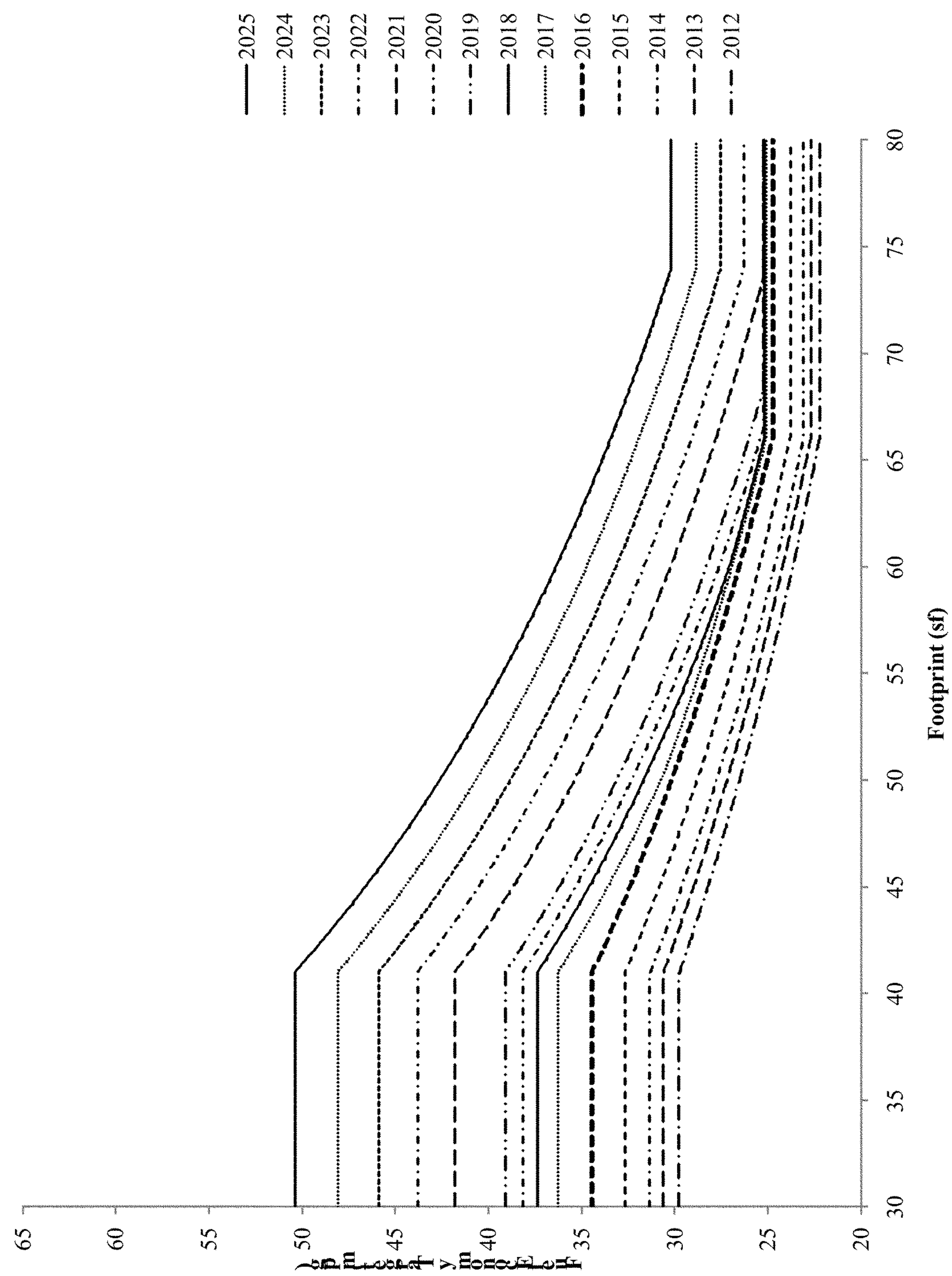

Figure IV-2. Fuel Economy Targets for MYs 2012–2016 and 2017–2025 Light Trucks

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Also for reference, the following table presents the coefficients based on2-cycle CAFE only for easier comparison to the MYs 2012–2016 coefficients presented above. We emphasize, again, that the coefficients in Table IV–20 define the proposed standards.

Table IV-22. Coefficients Based Only on 2-Cycle CAFE for MYs 2017–2025 Light Trucks

Coefficient	2017	2018	2019	2020	2021	2022	2023	2024	2025
a (mpg)	35.53	36.37	37.01	37.91	40.43	42.29	44.24	46.28	48.42
b (mpg)	24.74	24.74	24.74	24.74	24.74	25.74	26.93	28.17	29.47
c (gpm/sf)	0.00055	0.00054	0.00053	0.00051	0.00048	0.00046	0.00044	0.00042	0.00040
d (gpm)	0.00566	0.00553	0.00543	0.00530	0.00497	0.00475	0.00454	0.00434	0.00415

Again, given these targets, the CAFE levels required of individual manufacturers will depend on the mix of vehicles they produce for sale in the United States. Based on the market forecast NHTSA has used to examine today's proposed CAFE standards, the agency currently estimates that the targets shown above will result in the following average required fuel economy levels for individual manufacturers during MYs 2017–2025 (an updated estimate of the average required fuel economy level under the final MY 2016 standard is shown for comparison): [742]

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[742] In the May 2010 final rule establishing MYs 2012–2016 standards for passenger cars and light trucks, NHTSA estimated that the required fuel economy levels for light trucks would average 28.8 mpg under the MY 2016 light truck standard. Based on the agency's current forecast of the MY 2016 light truck market, NHTSA again estimates that the required fuel economy levels will average 28.8 mpg in MY 2016. However, the agency's market forecast reflects less of a future market shift away from light trucks than reflected in the agency's prior market forecast; as a result, NHTSA currently estimates that the combined (*i.e.*, passenger car and light truck) average required fuel economy in MY 2016 will be 33.8 mpg, 0.3 mpg lower than the agency's earlier estimate of 34.1 mpg. The agency has made no changes to MY 2016 standards and projects no changes in fleet-specific average requirements (although within-fleet market shifts could, under an attribute-based standard, produce such changes).

Table IV-23. Estimated Average Fuel Economy Required Under Final MY 2016 and Proposed MYs 2017–2025 CAFE Standards For Light Trucks

Manufacturer	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	-	-	-	-	-	-	-	-	-	-
BMW	30.2	30.6	31.4	32.1	32.9	35.1	36.7	38.4	40.2	42.1
Daimler	29.1	29.1	29.6	30.2	30.9	32.9	34.5	36.1	37.8	39.5
Chrysler/Fiat[743]	29.0	29.6	30.2	30.8	31.6	33.7	35.3	37.0	38.8	40.7
Ford	28.0	28.4	29.0	29.4	29.9	31.8	33.3	35.0	36.8	38.6
Geely (Volvo)	30.5	31.1	32.1	32.7	33.5	35.8	37.5	39.3	41.2	43.1
General Motors	27.4	28.1	28.7	29.2	29.8	31.9	33.4	35.1	36.8	38.6
Honda	30.4	31.0	31.8	32.4	33.2	35.5	37.1	38.9	40.8	42.7
Hyundai	30.7	31.3	32.1	32.8	33.6	35.9	37.6	39.4	41.3	43.2
Kia	29.5	30.0	30.6	31.2	32.0	34.2	35.8	37.5	39.3	41.1
Lotus	-	-	-	-	-	-	-	-	-	-
Mazda	31.5	31.9	32.9	33.5	34.3	36.5	38.1	39.8	41.8	43.8
Mitsubishi	31.7	32.6	33.5	34.2	35.1	37.5	39.3	41.1	43.1	45.2
Nissan	29.1	29.6	30.3	30.9	31.6	33.5	35.1	36.9	38.7	40.6
Porsche	29.8	30.3	31.2	31.8	32.6	34.8	36.5	38.2	40.0	41.9
Spyker (Saab)	30.5	31.2	32.1	32.8	33.6	35.9	37.6	39.4	41.3	43.3
Subaru	31.9	33.0	34.0	34.7	35.5	38.0	39.8	41.7	43.6	45.7
Suzuki	31.4	32.2	33.2	33.9	34.7	37.1	38.9	40.7	42.7	44.7
Tata (Jaguar, Rover)	31.3	32.1	33.1	33.8	34.6	37.0	38.8	40.6	42.6	44.6
Tesla	-	-	-	-	-	-	-	-	-	-
Toyota	29.1	29.7	30.4	31.0	31.6	33.8	35.4	37.1	39.0	40.9
VW[2]	29.2	29.5	30.1	30.8	31.5	33.5	35.1	36.7	38.5	40.3
Average	28.8	29.4	30.0	30.6	31.2	33.3	34.9	36.6	38.5	40.3

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As discussed above with respect to the proposed passenger cars standards, we note that a manufacturer's required light truck fuel economy level for a model year under the ultimate final standards will be based on its actual production numbers in that model year.

Additionally, again for reference, the following table presents estimated mpg levels based on 2-cycle CAFE for easier comparison to the MYs 2012–2016 standards.

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[743] For purposes of CAFE compliance, "Chrysler/Fiat" is assumed to include Ferrari and Maserati in addition to the larger-volume Chrysler and Fiat brands.

[744] For purposes of CAFE compliance, VW is assumed to include Audi-Bentley, Bugatti, and Lamborghini, along with the larger-volume VW brand.

Table IV-24. Estimated Average Fuel Economy Required Under Final MY 2016 and Using 2-Cycle CAFE for MYs 2017-2025 For Light Trucks

Manufacturer	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	-	-	-	-	-	-	-	-	-	-
BMW	30.2	30.1	30.7	31.3	32.0	34.1	35.7	37.3	39.0	40.8
Daimler	29.1	28.6	29.0	29.5	30.2	32.1	33.5	35.0	36.6	38.3
Chrysler/Fiat[745]	29.0	29.1	29.6	30.0	30.8	32.8	34.3	35.9	37.6	39.4
Ford	28.0	28.0	28.4	28.8	29.2	31.0	32.4	34.0	35.7	37.4
Geely (Volvo)	30.5	30.6	31.3	31.9	32.6	34.8	36.4	38.1	39.9	41.7
General Motors	27.4	27.7	28.1	28.5	29.1	31.1	32.5	34.1	35.7	37.4
Honda	30.4	30.5	31.0	31.6	32.3	34.5	36.1	37.7	39.5	41.3
Hyundai	30.7	30.8	31.4	31.9	32.7	34.9	36.5	38.1	39.9	41.8
Kia	29.5	29.5	29.9	30.4	31.2	33.3	34.8	36.4	38.1	39.8
Lotus	-	-	-	-	-	-	-	-	-	-
Mazda	31.5	31.3	32.1	32.7	33.4	35.4	37.0	38.6	40.4	42.3
Mitsubishi	31.7	32.0	32.7	33.3	34.1	36.4	38.1	39.8	41.6	43.6
Nissan	29.1	29.2	29.7	30.2	30.8	32.7	34.1	35.8	37.6	39.3
Porsche	29.8	29.8	30.5	31.0	31.8	33.9	35.4	37.1	38.8	40.6
Spyker (Saab)	30.5	30.7	31.4	32.0	32.7	34.9	36.5	38.2	40.0	41.8
Subaru	31.9	32.4	33.1	33.7	34.5	36.8	38.5	40.3	42.2	44.1
Suzuki	31.4	31.7	32.4	33.0	33.8	36.0	37.7	39.4	41.3	43.2
Tata (Jaguar, Rover)	31.3	31.5	32.3	32.9	33.7	35.9	37.6	39.3	41.2	43.1
Tesla	-	-	-	-	-	-	-	-	-	-
Toyota	29.1	29.2	29.8	30.3	30.8	32.9	34.4	36.0	37.8	39.5
VW[2]	29.2	29.0	29.5	30.0	30.7	32.7	34.1	35.7	37.3	39.1
Average	28.8	29.0	29.4	29.9	30.4	32.5	33.9	35.6	37.3	39.0

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F. How do the proposed standards fulfill NHTSA's statutory obligations?

The discussion that follows is necessarily complex, but the central points are straightforward. NHTSA has tentatively concluded that the standards presented above in Section IV.E are the maximum feasible standards for passenger cars and light trucks in MYs 2017–2025. EPCA/EISA requires NHTSA to consider four statutory factors in determining the maximum feasible CAFE standards in a rulemaking: Specifically, technological

[745] For purposes of CAFE compliance, ''Chrysler/Fiat'' is assumed to include Ferrari and Maserati in addition to the larger-volume Chrysler and Fiat brands.

[746] for purposes of CAFE compliance, VW is assumed to include Audi-Bentley, Bugatti, and Lamborghini, along with the larger-volume VW brand.

feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the nation to conserve energy. The agency considered a number of regulatory alternatives in its analysis of potential CAFE standards for those model years, including several that increase stringency on average at set percentages each year, one that approximates the point at which the modeled net benefits are maximized in each model year, and one that approximates the point at which the modeled total costs equal total benefits in each model year. Some of those alternatives represent standards that would be more stringent than the proposed standards,[747] and some are less stringent.[748] As the discussion below explains, we tentatively conclude that the correct balancing of the relevant factors that the agency must consider in determining the maximum feasible standards recognizes economic practicability concerns as discussed below, and sets standards accordingly. We expect that the proposed standards will enable further research and development into the more advanced fuel economy-improving technologies, and enable significant fuel savings and environmental benefits throughout the program, with particularly substantial benefits in the later years of the program and beyond. Additionally, consistent with Executive Order 13563, the agency believes that the benefits of the preferred alternative amply justify the costs; indeed, the monetized benefits exceed the monetized costs by $358 billion over the lifetime of the vehicles covered by the proposed standards. In full consideration of all of the information currently before the agency, we have weighed the statutory factors carefully and selected proposed passenger car and light truck standards that we believe are the maximum feasible for MYs 2017–2025.

1. What are NHTSA's statutory obligations?

As discussed above in Section IV.D, NHTSA sets CAFE standards under EPCA, as amended by EISA, and is also subject to the APA and NEPA in developing and promulgating CAFE standards.

NEPA requires the agency to develop and consider the findings of an Environmental Impact Statement (EIS) for ''major Federal actions significantly affecting the quality of the human environment.'' NHTSA has determined that this action is such an action and therefore that an EIS is necessary, and has accordingly prepared a Draft EIS to inform its development and consideration of the proposed standards. The agency has evaluated the environmental impacts of a range of regulatory alternatives in our proposal, and integrated the results of that consideration into our balancing of the EPCA/EISA factors, as discussed below.

The APA and relevant case law requires our rulemaking decision to be rational, based on consideration of the relevant factors, and within the scope of the authority delegated to the agency by EPCA/EISA. The relevant factors are those required by EPCA/EISA and the additional factors approved in case law as ones historically considered by the agency in determining the maximum feasible CAFE standards, such as safety. The statute requires us to set standards at the maximum feasible level for passenger cars and light trucks for each model year, and the agency tentatively concludes that the standards, if adopted as proposed, would satisfy this requirement. NHTSA has carefully examined the relevant data and other considerations, as discussed below in our explanation of our tentative conclusion that the proposed standards are the maximum feasible levels for those model years based on our evaluation of the information before us for this NPRM.

As discussed in Section IV.D, EPCA/EISA requires that NHTSA establish separate passenger car and light truck standards at ''the maximum feasible average fuel economy level that it decides the manufacturers can achieve in that model year,'' based on the agency's consideration of four statutory factors: Technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy.[749] NHTSA has developed definitions for these terms over the course of multiple CAFE rulemakings[750] and determines the appropriate weight and balancing of the terms given the circumstances in each CAFE rulemaking. For MYs 2011–2020, EPCA further requires that separate standards for passenger cars and for light trucks be set at levels high enough to ensure that the CAFE of the industry-wide combined fleet of new passenger cars and light trucks reaches at least 35 mpg not later than MY 2020. For model years after 2020, standards need simply be set at the maximum feasible level.

The agency thus balances the relevant factors to determine the maximum feasible level of the CAFE standards for each fleet, in each model year. The next section discusses how the agency balanced the factors for this proposal, and why we believe the proposed standards are the maximum feasible.

2. How did the agency balance the factors for this NPRM?

There are numerous ways that the relevant factors can be balanced (and thus weight given to each factor) depending on the agency's policy priorities and on the information before the agency regarding any given model year, and the agency therefore considered a range of alternatives that represent different regulatory options that we thought were potentially reasonable for purposes of this rulemaking. For this proposal, the regulatory alternatives considered in the agency's analysis include several alternatives for fuel economy levels that increase annually, on average, at set rates—specifically, 2%/year, 3%/year, 4%/year, 5%/year, 6%/year, and 7%/

[747] We recognize that higher standards would help the need of the nation to conserve more energy and might potentially be technologically feasible (in the narrowest sense) during those model years, but based on our analysis and the evidence presented by the industry, we tentatively conclude that higher standards would not represent the proper balancing for MYs 2017–2025 cars and trucks, because they would raise serious questions about economic practicability. As explained above, NHTSA's modeled estimates necessarily do not perfectly capture all of the factors of economic practicability, and this conclusion regarding net benefits versus economic practicability is similar to the conclusion reached in the 2012–2016 analysis.

[748] We also recognize that lower standards might be less burdensome on the industry, but considering the environmental impacts of the different regulatory alternatives as required under NEPA and the need of the nation to conserve energy, we do not believe they would have represented the appropriate balancing of the relevant factors, because they would have left technology, fuel savings, and emissions reductions on the table unnecessarily, and not contributed as much as possible to reducing our nation's energy security and climate change concerns. They would also have lower net benefits than the Preferred Alternative.

[749] As explained in Section IV.D, EPCA also provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several statutory provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance. Specifically, in determining the maximum feasible level of fuel economy for passenger cars and light trucks, NHTSA cannot consider the fuel economy benefits of ''dedicated'' alternative fuel vehicles (like battery electric vehicles or natural gas vehicles), must consider dual-fueled automobiles to be operated only on gasoline or diesel fuel (at least through MY 2019), and may not consider the ability of manufacturers to use, trade, or transfer credits. This provision limits, to some extent, the fuel economy levels that NHTSA can find to be ''maximum feasible''—if NHTSA cannot consider the fuel economy of electric vehicles, for example, NHTSA cannot set standards predicated on manufacturers' usage of electric vehicles to meet the standards.

[750] These factors are defined in Section IV.D; for brevity, we do not repeat those definitions here.

year.[751] Analysis of these various rates of increase effectively encompasses the entire range of fuel economy improvements that, based on information currently available to the agency, could conceivably fall within the statutory boundary of ''maximum feasible'' standards. The regulatory alternatives also include two alternatives based on benefit-cost criteria, one in which standards would be set at the point where the modeled net benefits would be maximized for each fleet in each year (MNB), and another in which standards would be set at the point at which total costs would be most nearly equal to total benefits for each fleet in each year (TC=TB),[752] as well as the preferred alternative, which is within the range of the other alternatives. These alternatives are discussed in more detail in Chapter III of the PRIA accompanying this NPRM, which also contains an extensive analysis of the relative impacts of the alternatives in terms of fuel savings, costs (both per-vehicle and aggregate), carbon dioxide emissions avoided, and many other metrics. Because the agency could conceivably select any of the regulatory alternatives above, all of which fall between 2%/year and 7%/year, inclusive, the Draft EIS that accompanies this proposal analyzes these lower and upper bounds as well as the preferred alternative. Additionally, the Draft EIS analyzes a ''No Action Alternative,'' which assumes that, for MYs 2017 and beyond, NHTSA would set standards at the same level as MY 2016. The No Action Alternative provides a baseline for comparing the environmental impacts of the other alternatives.

NHTSA believes that this approach clearly communicates the level of stringency of each alternative and allows us to identify alternatives that represent different ways to balance NHTSA's statutory factors under EPCA/EISA. Each of the listed alternatives represents, in part, a different way in which NHTSA could conceivably balance different policies and considerations in setting the standards that achieve the maximum feasible levels. For example, the 2% Alternative, the least stringent alternative, would represent a balancing in which economic practicability—which include concerns about availability of technology, capital, and consumer preferences for vehicles built to meet the future standards—weighs more heavily in the agency's consideration, and the need of the nation to conserve energy would weigh less heavily. In contrast, under the 7% Alternative, one of the most stringent, the need of the nation to conserve energy—which includes energy conservation and climate change considerations—would weigh more heavily in the agency's consideration, and other factors would weigh less heavily. Balancing and assessing the feasibility of different alternative can also be influenced by differences and uncertainties in the way in which key economic factors (*e.g.,* the price of fuel and the social cost of carbon) and technological inputs could be assessed and estimated or valued. While NHTSA believes that our analysis conducted in support of this NPRM uses the best and most transparent technology-related inputs and economic assumption inputs that the agencies could derive for MYs 2017–2025, we recognize that there is uncertainty in these inputs, and the balancing could be different if, for example, the inputs are adjusted in response to new information.

This is the first CAFE rulemaking in which the agency has looked this far into the future, which makes our traditional approach to balancing more challenging than in past (even recent past) rulemakings. NHTSA does not presently believe, for example, that technological feasibility as the agency defines it is as constraining in this rulemaking as it has been in the past in light of the time frame of this rulemaking. ''Technological feasibility'' refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established. In previous CAFE rulemakings, it has been more difficult for the agency to say that the most advanced technologies would be available for commercial application in the model years for which standards were being established. For this rulemaking, which is longer term, NHTSA has considered all types of technologies that improve real-world fuel economy, including air-conditioner efficiency and other off-cycle technology, PHEVs, EVs, and highly-advanced internal combustion engines not yet in production, but all of which the agencies' expect to be commercially applicable by the rulemaking time frame. On the one hand, we recognize that some technologies that currently have limited commercial use cannot be deployed on every vehicle model in MY 2017, but require a realistic schedule for widespread commercialization to be feasible. On the other hand, however, the agency expects, based on our analysis, that all of the alternatives could narrowly be considered as technologically feasible, in that they could be achieved based on the existence or projected future existence of technologies that could be incorporated on future vehicles, and enable any of the alternatives to be achieved on a technical basis alone if the level of resources that might be required to implement the technologies is not considered. If all alternatives are at least theoretically technologically feasible in the MY 2017–2025 timeframe, and the need of the nation is best served by pushing standards as stringent as possible, then the agency might be inclined to select the alternative that results in the very most stringent standards considered.

However, the agency must also consider what is required to practically implement technologies, which is part of economic practicability, and to which the most stringent alternatives give little weight. ''Economic practicability'' refers to whether a standard is one ''within the financial capability of the industry, but not so stringent as to lead to adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice.'' Consumer acceptability is also an element of economic practicability, one that is particularly difficult to gauge during times of uncertain fuel prices.[753] In a rulemaking such as the present one,

[751] This is an approach similar to that used by the agency in the MY 2012–2016 rulemaking, in which we also considered several alternatives that increased annually, on average, at 3%, 4%, 5%, 6% and 7%/year. The ''percent-per-year'' alternatives in this proposal are somewhat different from those considered in the MY 2012–2016 rulemaking, however, in terms of how the annual rate of increase is applied. For this proposal, the stringency curves are themselves advanced directly by the annual increase amount, without reference to any yearly changes in the fleet mix. In the 2012–2016 rule, the annual increases for the stringency alternatives reflected the estimated required fuel economy of the fleet which accounted for both the changes in the target curves and changes in the fleet mix.

[752] We included the MNB and TC=TB alternatives in part for the reference of commenters familiar with NHTSA's past several CAFE rulemakings—these alternatives represent balancings carefully considered by the agency in past rulemaking actions as potentially maximum feasible—and because Executive Orders 12866 and 13563 focus attention on an approach that maximizes net benefits. The assessment of maximum net benefits is challenging in the context of setting CAFE standards, in part because standards which maximize net benefits for each fleet, for each model year, would not necessarily be the standards that lead to the greatest net benefits over the entire rulemaking period.

[753] *See, e.g., Center for Auto Safety* v. *NHTSA* (*CAS*), 793 F.2d 1322 (DC Cir. 1986) (Administrator's consideration of market demand as component of economic practicability found to be reasonable); Public Citizen v. NHTSA, 848 F.2d 256 (Congress established broad guidelines in the fuel economy statute; agency's decision to set lower standard was a reasonable accommodation of conflicting policies).

determining economic practicability requires consideration of the uncertainty surrounding relatively distant future market conditions and consumer demand for fuel economy in addition to other vehicle attributes. In an attempt to evaluate the economic practicability of attribute-based standards, NHTSA includes a variety of factors in its analysis, including the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology, the specific fleet mixes of different manufacturers, and assumptions about the cost of the standards to consumers and consumers' valuation of fuel economy, among other things. Ensuring that a reasonable amount of lead time exists to make capital investments and to devote the resources and time to design and prepare for commercial production of a more fuel efficient fleet is also relevant to the agency's consideration of economic practicability. Yet there are some aspects of economic practicability that the agency's analysis is not able to capture at this time—for example, the computer model that we use to analyze alternative standards does not account for all aspects of uncertainty, in part because the agency cannot know what we cannot know. The agency must thus account for uncertainty in the context of economic practicability as best as we can based on the entire record before us.

Both technological feasibility and economic practicability enter into the agency's determination of the maximum feasible levels of stringency, and economic practicability concerns may cause the agency to decide that standards that might be technologically feasible are, in fact, beyond maximum feasible. Standards that require aggressive application of and widespread deployment of advanced technologies could raise serious issues with the adequacy of time to coordinate such significant changes with manufacturers' redesign cycles, as well as with the availability of engineering resources to develop and integrate the technologies into products, and the pace at which capital costs can be incurred to acquire and integrate the manufacturing and production equipment necessary to increase the production volume of the technologies. Moreover, the agency must consider whether consumers would be likely to accept a specific technological change under consideration, and how the cost to the consumer of making that change might affect their acceptance of it. The agency maintains, as it has in prior CAFE rulemakings, that there is an important distinction between considerations of technological feasibility and economic practicability. As explained above, a given level of performance may be technologically feasible (*i.e.,* setting aside economic constraints) for a given vehicle model. However, it would not be economically practicable to require a level of fleet average performance that assumes every vehicle will in the first year of the standards perform at the highest technologically feasible level, because manufacturers do not have unlimited access to the financial resources or may not practically be able to hire enough engineers, build enough facilities, and install enough tooling.

NHTSA therefore believes, based on the information currently before us, that economic practicability concerns render certain standards that might otherwise be technologically feasible to be beyond maximum feasible within the meaning of the statute for the 2017–2025 standards. Our analysis indicated that technologies seem to exist to meet the stringency levels required by future standards under nearly all of the regulatory alternatives; but it also indicated that manufacturers would not be able to apply those technologies quickly enough, given their redesign cycles, and the level of the resources that would be required to implement those technologies widely across their products, to meet all applicable standards in every model year under some of the alternatives.

Another consideration for economic practicability is incremental per-vehicle increases in technology cost. In looking at the incremental technology cost results from our modeling analysis, the agency saw that in progressing from alternatives with lower stringencies to alternatives with higher stringencies, technology cost increases (perhaps predictably) at a progressively higher rate, until the model projects that manufacturers are unable to comply with the increasing standards and enter (or deepen) non-compliance. Table IV–25 and Table IV–26 show estimated cumulative lifetime fuel savings and estimated average vehicle cost increase for passenger cars and light trucks. The results show that there is a significant increase in technology cost between the 4% alternatives and the 5% alternatives.

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Table IV-25. Estimated Passenger Car Cumulative Lifetime Fuel Savings and Average Vehicle Cost Increase

	Cumulative Lifetime Fuel Savings 2017-2021 (billion gallons)	Average Vehicle Cost Increase in 2021 (2009 $)	Cumulative Lifetime Fuel Savings 2017-2025 (billion gallons)	Average Vehicle Cost Increase in 2025 (2009 $)
2%	22	$451	58	$684
3%	32	$775	85	$1,367
MNB	54	$1,060	108	$1,313
Preferred Alternative	39	$1,108	104	$2,023
4%	42	$1,252	110	$2,213
TC=TB	62	$1,607	135	$2,515
5%	51	$1,844	130	$3,040
6%	57	$1,789	140	$3,229
7%	61	$1,930	144	$3,304

Table IV-26. Estimated Light Truck Cumulative Lifetime Fuel Savings and Average Vehicle Cost Increase

	Cumulative Lifetime Fuel Savings 2017-2021 (billion gallons)	Average Vehicle Cost Increase in 2021 (2009 $)	Cumulative Lifetime Fuel Savings 2017-2025 (billion gallons)	Average Vehicle Cost Increase in 2025 (2009 $)
2%	22	$498	53	$706
3%	33	$909	77	$1,308
Preferred Alternative	22	$965	69	$1,578
4%	41	$1,619	98	$2,423
MNB	62	$2,262	126	$3,427
TC=TB	62	$2,232	126	$3,416
5%	50	$2,154	116	$3,444
6%	56	$2,298	123	$3,611
7%	59	$2,482	127	$3,692

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Thus, if technological feasibility and the need of the nation are not particularly limiting in a given rulemaking, then maximum feasible standards would be represented by the mpg levels that we could require of the industry to improve fuel economy before we reach a tipping point that presents risk of significantly adverse economic consequences. Standards that are lower than that point would likely not be maximum feasible, because such standards would leave fuel-saving technologies on the table unnecessarily; standards that are higher than that point would likely be beyond what the agency would consider economically practicable, and therefore beyond what we would consider maximum feasible, even if they might be technologically feasible or better meet the need of the nation to conserve energy. The agency does not believe that standards are balanced if they weight one or two factors so heavily as to ignore another.

We explained above that part of the way that we try to evaluate economic practicability is through a variety of model inputs, such as phase-in caps (the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology) and redesign schedules to account for needed lead time. These inputs limit how much technology can be applied to a manufacturer's fleet in the agency's analysis attempting to simulate a way for the manufacturer to comply with standards set under different regulatory alternatives. If the limits (and technology cost-effectiveness) prevent enough manufacturers from meeting the required levels of stringency, the agency may decide that the standards under consideration may not be economically practicable. The difference between the required fuel economy level that applies to a manufacturer's fleet and the level of fuel economy that the agency projects the manufacturer would achieve in that year, based on our analysis, is called a "compliance shortfall." [754]

We underscore again that the modeling analysis does not dictate the "answer," it is merely one source of information among others that aids the agency's balancing of the standards. These considerations, shortfalls and increases in incremental technology costs, do not entirely define economic practicability, but we believe they are symptomatic of it. In looking at the projected compliance shortfall results from our modeling analysis, the agency preliminarily concluded, based on the information before us at the time, that for both passenger car and for light trucks, the MNB and TC=TB alternatives, and the 5%, 6% and 7% alternatives did not appear to be economically practicable, and were thus likely beyond maximum feasible levels for MYs 2017–2025. In other words, despite the theoretical technological feasibility of achieving these levels, various manufacturers would likely lack the financial and engineering resources and sufficient lead time to do so.

The analysis showed that for the passenger car 5% alternative, there were significant compliance shortfalls for Chrysler in MY 2025, Ford in MYs 2021 and 2023–2025, GM in MYs 2022 and 2024–2025, Mazda in MYs 2021 and 2024–2025, and Nissan in MY 2025. For light trucks, the analysis showed the 5% alternative had significant compliance shortfalls for Chrysler in MYs 2022–2025, Ford in MY 2025, GM in MYs 2023–2025, Kia in MY 2025, Mazda in MYs 2022 and 2025, and Nissan in MYs 2023–2025. However, the 4%, 3% and 2% alternatives did not appear, based on shortfalls, to be beyond the level of economic practicability, and thus appeared potentially to be within the range of alternatives that might yet be maximum feasible.

Table IV-27. Estimated Passenger Car Compliance Shortfall for the 5%/Year Alternative (MPG)

Estimated Compliance Shortfall for Passenger Car (mpg)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025
Chrysler	-	-	-	-	-	1.7	-	-	2.3
Ford	-	-	-	0.2	-	-	1.5	2.9	5.2
General Motors	-	-	-	-	-	2.3	0.8	2.1	2.5
Honda	-	-	-	-	-	-	-	-	-
Hyundai	-	-	-	-	-	-	-	-	-
Kia	-	-	-	-	-	-	-	-	-
Mazda	-	-	-	-	1.9	-	-	1.6	1.9
Nissan	-	-	-	-	-	-	-	-	1.3
Toyota	-	-	-	-	-	-	-	-	-

[754] The agency's modeling estimates how the application of technologies could increase vehicle costs, reduce fuel consumption, and reduce CO_2 emissions, and affect other factors. As CAFE standards are performance-based, NHTSA does not mandate that specific technologies be used for compliance. CAFE modeling, therefore projects one way that manufacturers could comply. Manufacturers may choose a different mix of technologies based on their unique circumstances and products.

Table IV-28. Estimated Light Truck Compliance Shortfall for the 5%/Year Alternative (MPG)

Estimated Compliance Shortfall for Light Truck (mpg)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025
Chrysler	-	-	-	-	-	1.8	0.9	3.2	0.9
Ford	-	-	-	-	-	-	-	0.1	1.8
General Motors	-	-	-	-	-	0.1	1.8	3.2	2.9
Honda	-	-	-	-	-	-	-	-	0.6
Hyundai	-	-	-	-	-	-	0.6	-	-
Kia	-	-	-	-	-	-	-	-	2.1
Mazda	-	-	-	-	-	1.0	-	-	2.1
Nissan	-	-	-	-	-	-	1.1	2.1	4.6
Toyota	-	-	-	-	-	-	-	-	-

The preliminary analysis referred to above, in which the agency tentatively concluded that the 5%, 6%, 7%, MNB, and TC=TB alternatives were likely beyond the level of economic practicability based on the information available to the agency at the time, was conducted following the first SNOI and prior to the second SNOI—thus, between the end of 2010 and July 2011. The agencies stated in the first SNOI that we had not conducted sufficient analysis at the time to narrow the range of potential stringencies that had been discussed in the initial NOI and in the Interim Joint TAR, and that we would be conducting more analyses and continuing extensive dialogue with stakeholders in the coming months to refine our proposal. Based on our initial consideration of how the factors might be balanced to determine the maximum feasible standards to propose for MYs 2017–2025 (*i.e.,* where technological feasibility did not appear to be particularly limiting and the need of the nation would counsel for choosing more stringent alternatives, but economic practicability posed significant limitations), NHTSA's preliminary analysis indicated that the alternatives including up to 4% per year for cars and 4% per year for trucks should reasonably remain under consideration.

With that preliminary estimate of 4%/year for cars and trucks as the upper end of the range of alternatives that should reasonably remain under consideration for MYs 2017–2025, the agencies began meeting again intensely with stakeholders, including many individual manufacturers, between June 21, 2011 and July 27, 2011 to determine whether additional information would aid NHTSA in further consideration. Beginning in the June 21, 2011 meeting, NHTSA and EPA presented the 4% alternative target curves as a potential concept along with preliminary program flexibilities and provisions, in order to get feedback from the manufacturer stakeholders. Manufacturer stakeholders provided comments, much of which was confidential business information, which included projections of how they might comply with concept standards, the challenges that they expected, and their recommendations on program stringency and provisions.[755]

Regarding passenger cars, several manufacturers shared projections that they would be capable of meeting stringency levels similar to NHTSA's preliminary CAFE modeling projections for the 4% alternative in MY 2020 or in 2021, with some of those arguing that they faced challenges in the earlier years of that period with meeting a constant 4% rate throughout the entire period. Some manufacturers shared projections that they could comply with stringencies that ramped up, increasing more slowly in MY 2017 and then progressively increasing through MY 2021. Most manufacturers provided limited projections beyond MY 2021, although some stated that they could meet the agency's concept stringency targets in MY 2025. Manufacturers generally suggested that the most significant challenges to meeting a constant 4% (or faster) year-over-year increase in the passenger car standards related to their ability to implement the

[755] Feedback from these stakeholder meetings is summarized in section IV.B and documents that are referenced in that section.

new technologies quickly enough to achieve the required levels, given their need to implement fuel economy improvements in both the passenger car and light truck fleets concurrently; challenges related to the cadence of redesign and refresh schedules; the pace at which new technology can be implemented considering economic factors such as availability of engineering resources to develop and integrate the technologies into products; and the pace at which capital costs can be incurred to acquire and integrate the manufacturing and production equipment necessary to increase the production volume of the technologies. Manufacturers often expressed concern that the 4% levels could require greater numbers of advanced technology vehicles than they thought they would be able to sell in that time frame, given their belief that the cost of some technologies was much higher than the agencies had estimated and their observations of current consumer acceptance of and willingness to pay for advanced technology vehicles that are available now in the marketplace. A number of manufacturers argued that they did not believe that they could create a sustainable business case under passenger car standards that increased at the rate required by the 4% alternative.

Regarding light trucks, most manufacturers expressed significantly greater concerns over the 4% alternative for light trucks than for passenger cars. Many manufacturers argued that increases in light truck standard stringency should be slower than increases in passenger car standard stringency, based on, among other things, the greater payload, cargo capacity and towing utility requirements of light trucks, and what they perceived to be lower consumer acceptance of certain (albeit not all) advanced technologies on light trucks. Many manufacturers also commented that redesign cycles are longer on trucks than they are on passenger cars, which reduces the frequency at which significant changes can be made cost-effectively to comply with increasing standards, and that the significant increases in stringency in the MY 2012–2016 program [756] in combination with redesign schedules would not make it possible to comply with the 4% alternative in the earliest years of the MY 2017–2025 program, such that only significantly lower stringencies in those years would be feasible in their estimation. As for cars, most manufacturers provided limited projections beyond MY 2021. Manufacturers generally stated that the most significant challenges to meeting a constant 4% (or faster) year-over-year increase in the light truck standards were similar to what they had described for passenger cars as enumerated in the paragraph above, but were compounded by concerns that applying technologies to meet the 4% alternative standards would result in trucks that were more expensive and provided less utility to consumers. As was the case for cars, manufacturers argued that their technology cost estimates were higher than the agencies' and consumers are less willing to accept/pay for some advanced technologies in trucks, but manufacturers argued that these concerns were more significant for trucks than for cars, and that they were not optimistic that they could recoup the costs through higher prices for vehicles with the technologies that would be needed to comply with the 4% alternative. Given their concerns about having to reduce utility and raise truck prices, and about their ability to apply technologies quickly enough given the longer redesign periods for trucks, a number of manufacturers argued that they did not believe that they could create a sustainable business case under light truck standards that increased at the rate required by the 4% alternative.

Other stakeholders, such as environmental and consumer groups, consistently stated that stringent standards are technically achievable and critical to important national interests, such as improving energy independence, reducing climate change, and enabling the domestic automobile industry to remain competitive in the global market. Labor interests stressed the need to carefully consider economic impacts and the opportunity to create and support new jobs, and consumer advocates emphasized the economic and practical benefits to consumers of improved fuel economy and the need to preserve consumer choice. In addition, a number of stakeholders stated that the standards under development should not have an adverse impact on safety.

NHTSA, in collaboration with EPA and in coordination with CARB, carefully considered the inputs received from all stakeholders, conducted additional independent analyses, and deliberated over the feedback received on the agencies' analyses. NHTSA considered individual manufacturers' redesign cycles and, where available, the level of technologies planned for their future products that improve fuel economy, as well as some estimation of the resources that would likely be needed to support those plans and the potential future standards. The agency also considered whether we agreed that there could conceivably be compromises to vehicle utility depending on the technologies chosen to meet the potential new standards, and whether a change in the cadence of the rate at which standards increase could provide additional opportunity for industry to develop and implement technologies that would not adversely affect utility. NHTSA considered feedback on consumer acceptance of some advanced technologies and consumers' willingness to pay for improved fuel economy. In addition, the agency carefully considered whether manufacturer assertions about potential uncertainties in the agency's technical, economic, and consumer acceptance assumptions and estimates were potentially valid, and if so, what the potential effects of these uncertainties might be on economic practicability.

Regarding passenger cars, after considering this feedback from stakeholders, the agency considered further how it thought the factors should be balanced to determine the maximum feasible passenger car standards for MYs 2017–2025. Based on that reconsideration of the information before the agency and how it informs our balancing of the factors, NHTSA tentatively concludes that the points raised may indicate that the agency's preliminary analysis supporting consideration of standards that increased up to 4%/year may not have captured fully the level of uncertainty that surrounds economic practicability in these future model years. Nevertheless, while we believe there may be some uncertainty, we do not agree that it is nearly as significant as a number of manufacturers maintained, especially for passenger cars. The most persuasive information received from stakeholders for passenger cars concerned practicability issues in the first phase of the MY 2017–2025 standards. We therefore tentatively conclude that the maximum feasible stringency levels for passenger cars are only slightly different from the 4%/year levels suggested as the high end preliminarily considered by the agency; increasing on average 3.7%/year in MYs 2017–2021, and on average 4.5%/year in MYs 2022–2025. For the overall MY 2017–2025 period, the maximum feasible stringency curves increase on average at 4.1%/year, and our analysis

[756] Some manufacturers indicated that their light truck fleet fuel economy would be below what they anticipated their required fuel economy level would be in MY 2016, and that they currently expect that they will need to employ available flexibilities to comply with that standard.

indicates that the costs and benefits attributable to the 4% alternative and the preferred alternative for passenger cars are very similar: The preferred alternative is 8.8 percent less expensive for manufacturers than the 4% alternative (estimated total costs are $113 billion for the preferred alternative and $124 billion for the 4% alternative), and achieves only $20 billion less in total benefits than the 4% alternative (estimated total benefits are $310 billion for the preferred alternative and $330 billion for the 4% alternative), a very small difference given that benefits are spread across the entire lifetimes of all vehicles subject to the standards. The analysis also shows that the lifetime cumulative fuel savings is only 5 percent higher for the 4% alternative than the preferred alternative (the estimated fuel savings is 104 billion gallons for the preferred alternative, and 110 billion gallons for the 4% alternative).

At the same time, the increase in average vehicle cost in MY 2025 is 9.4 percent higher for the 4% alternative (the estimated cost increase for the average vehicle is $2,023 for the preferred alternative, and $2,213 for the 4% alternative). The rates of increase in stringency for each model year are summarized in Table IV–29. NHTSA emphasizes that under 49 U.S.C. 32902(b), the standards must be maximum feasible in each model year without reference to other model years, but we believe that the small amount of progressiveness in the proposed standards for MYs 2017–2021, which has very little effect on total benefits attributable to the proposed passenger car standards, will help to enable the continuation of, or increases in, research and development into the more advanced technologies that will enable greater stringency increases in MYs 2022–2025, and help to capture the considerable fuel savings and environmental benefits similar to the 4% alternative beginning in MY 2025.

We are concerned that requiring manufacturers to invest that capital to meet higher standards in MYs 2017–2021, rather than allowing them to increase fuel economy in those years slightly more slowly, would reduce the levels that would be feasible in the second phase of the program by diverting research and development resources to those earlier model years. Thus, after considerable deliberation with EPA and consultation with CARB, NHTSA selected the preferred alternative as the maximum feasible alternative for MYs 2017–2025 passenger cars based on consideration of inputs from manufacturers and the agency's independent analysis, which reaches the stringency levels of the 4% alternative in MY 2025, but has a slightly slower ramp up rate in the earlier years.

Table IV-29. Annual Rate Of Increase in the Stringency of the Preferred Alternative for Each Model Year

Model Year	Passenger Car	Light Truck
2017	3.6%	0.6%
2018	3.6%	2.1%
2019	3.6%	1.7%
2020	3.7%	2.0%
2021	4.2%	6.4%
2022	4.5%	4.5%
2023	4.4%	4.7%
2024	4.5%	4.7%
2025	4.5%	4.6%

Table IV-30. Annual Rate Of Increase in the Stringency of the Preferred Alternative Over Various Periods

Model Years	Passenger Car	Light Truck
2017-2021	3.7%	2.6%
2022-2025	4.5%	4.6%
2017-2025	4.1%	3.5%

Regarding light trucks, while NHTSA does not agree with the manufacturer's overall cost assessments and believe that our technology cost and effectiveness assumptions should allow the most capable manufacturers to preserve all necessary vehicle utility, the agencies do believe there is merit to some of the concerns raised in stakeholder feedback. Specifically, concerns about longer redesign schedules for trucks, compounded by the need to invest simultaneously in raising passenger car fuel economy, may not have been fully captured in our preliminary analysis. This could lead manufacturers to implement technologies that do not maintain vehicle utility, based on the cadence of the standards under the 4% alternative. A number of manufacturers repeatedly stated, in providing feedback, that the MYs 2012–2016 standards for trucks, while feasible, required significant investment to reach the required levels, and that given the redesign schedule for trucks, that level of investment throughout the entire MYs 2012–2025 time period was not sustainable. Based on the confidential business information that manufacturers provided to us, we believe that this point may be valid. If the agency pushes CAFE increases that require considerable sustained investment at a faster rate than industry redesign cycles, adverse economic consequences could ensue. The best information that the agency has at this time, therefore, indicates that requiring light truck fuel economy improvements at the 4% annual rate could create potentially severe economic consequences.

Thus, evaluating the inputs from stakeholders and the agency's independent analysis, the agency also considered further how it thought the factors should be balanced to determine the maximum feasible light truck standards for MYs 2017–2025. Based on that consideration of the information before the agency and how it informs our balancing of the factors, NHTSA tentatively concludes that 4%/year CAFE stringency increases for light trucks in MYs 2017–2021 are likely beyond maximum feasible, and in fact, in the earliest model years of the MY 2017–2021 period, that the 3%/year and 2%/year alternatives for trucks are also likely beyond maximum feasible. NHTSA therefore tentatively concludes that the preferred alternative, which would in MYs 2017–2021 increase on average 2.6%/year, and in MYs 2022–2025 would increase on average 4.6%/year, is the maximum feasible level that the industry can reach in those model years. For the overall MY 2017–2025 period, the maximum feasible stringency curves would increase on average 3.5%/year. The rates of increase in stringency for each model year are summarized in Table IV–29 and Table IV–30.

Our analysis indicates that the preferred alternative has 48 percent lower cost than the 4% alternative (estimated total costs are $44 billion for the preferred alternative and $83 billion for the 4% alternative), and the total benefits of the preferred alternative are 30 percent lower ($87 billion lower) than the 4% alternative (estimated total benefits are $206 billion for the preferred alternative and $293 billion for the 4% alternative), spread across the entire lifetimes of all vehicles subject to the standards. The analysis also shows that the lifetime cumulative fuel savings is 42 percent higher for the 4% alternative than the preferred alternative (the estimated fuel savings is 69 billion gallons for the preferred alternative, and 98 billion gallons for the 4% alternative). At the same time, the increase in average vehicle cost in MY 2025 is 54 percent higher for the 4% alternative (the estimated cost increase for the average vehicle is $1,578 for the preferred alternative, and $2,423 for the 4% alternative).

While these differences are larger than for passenger cars, NHTSA believes that standards set at these levels for these model years will help address concerns raised by manufacturer stakeholders and reduce the risk for adverse economic consequences, while at the same time ensuring most of the substantial improvements in fuel efficiency initially envisioned over the entire period and supported by other stakeholders. NHTSA believes that these stringency levels, along with the provisions for incentives for advanced technologies to encourage their development and implementation, and the agencies' expectation that some of the uncertainties surrounding consumer acceptance of new technologies in light trucks should have resolved themselves by that time frame based on consumers' experience with the advanced technologies, will enable these increases in stringency over the entire MY 2017–2025 period. Although, as stated above, the light truck standards must be maximum feasible in each model year without reference to other model years, we believe that standards set at the stated levels for MYs 2017–2021 and the incentives for advanced technologies for pickup trucks will create the best opportunity to ensure that the MY 2022–2025 standards are economically practicable, and avoid adverse consequences. The first phase of light truck standards, in that respect, acts as a kind of bridge to the second phase, in which industry should be able to realize considerable additional improvements in fuel economy.

The proposed standards also account for the effect of EPA's standards, in light of the agencies' close coordination and the fact that both sets of standards were developed together to harmonize as part of the National Program. Given the close relationship between fuel economy and CO_2 emissions, and the efforts NHTSA and EPA have made to conduct joint analysis and jointly deliberate on information and tentative conclusions,[757] the agencies have sought to harmonize and align their proposed standards to the greatest extent possible, consistent with their respective statutory authorities. In comparing the proposed standards, the agencies' stringency curves are equivalent, except for the fact that the stringency of EPA's proposed passenger car standards reflect the ability to improve GHG emissions through reductions in A/C system refrigerant leakage and the use of lower GWP refrigerants (direct A/C improvements),[758] and that EPA provides incentives for PHEV, EV and FCV vehicles, which NHTSA does not provide because statutory incentives have already been defined for these technologies. The stringency of NHTSA's proposed standards for passenger cars for MYs 2017–2025 align with the stringency of EPA's equivalent standards when these differences are considered.[759] NHTSA is proposing the preferred alternative based on the tentative determination of maximum feasibility as described earlier in the section, but, based on efforts NHTSA and EPA have made to conduct joint analysis and jointly deliberate on information and tentative conclusions, NHTSA has also aligned the proposed CAFE standards with EPA's proposed standards.

Thus, consistent with President Obama's announcement on July 29, 2011, and with the August 9, 2011 SNOI, NHTSA has tentatively concluded that the standards represented by the preferred alternative are the maximum feasible standards for passenger cars and light trucks in MYs 2017–2025. We recognize that higher standards would help the need of the nation to conserve more energy and might potentially be technologically feasible (in the narrowest sense) during those model years, but based on our analysis and the evidence presented by the industry, we tentatively conclude that higher standards would not represent the proper balancing for MYs 2017–2025 cars and trucks.[760] We

[757] NHTSA and EPA conducted joint analysis and jointly deliberated on information and tentative conclusions related to technology cost, effectiveness, manufacturers' capability to implement technologies, the cadence at which manufacturers might support the implementation of technologies, economic factors, and the assessment of comments from manufacturers.

[758] As these A/C system improvements do not influence fuel economy, the stringency of NHTSA's preferred alternatives do not reflect the availability of these technologies.

[759] We note, however, that the alignment is based on the assumption that manufacturers implement the same level of direct A/C system improvements as EPA currently forecasts for those model years, and on the assumption of PHEV, EV, and FCV penetration at specific levels. If a manufacturer implements a higher level of direct A/C improvement technology and/or a higher penetration of PHEVs, EVs and FCVs, then NHTSA's proposed standards would effectively be more stringent than EPA's. Conversely, if a manufacturer implements a lower level of direct A/C improvement technology and/or a lower penetration of PHEVs, EVs and FCVs, then EPA's proposed standards would effectively be more stringent than NHTSA's.

[760] We note, for example, that while Executive Orders 12866 and 13563 focus attention on an approach that maximizes net benefits, both Executive Orders recognize that this focus is subject to the requirements of the governing statute. In this rulemaking, the standards represented by the ''MNB'' alternative are more stringent than what NHTSA has tentatively concluded would be maximum feasible for MYs 2017–2025, and thus setting standards at that level would be inconsistent

Continued

tentatively conclude that the correct balancing recognizes economic practicability concerns as discussed above, and sets standards at the levels that the agency is proposing in this NPRM.[761] In the same vein, lower standards might be less burdensome on the industry, but considering the environmental impacts of the different regulatory alternatives as required under NEPA and the need of the nation to conserve energy, we do not believe they would have represented the appropriate balancing of the relevant factors, because they would have left technology, fuel savings, and emissions reductions on the table unnecessarily, and not contributed as much as possible to reducing our nation's energy security and climate change concerns. Standards set at the proposed levels for MYs 2017–2021 will provide the additional benefit of helping to promote further research and development into the more advanced fuel economy-improving technologies to provide a bridge to more stringent standards in MYs 2022–2025, and enable significant fuel savings and environmental benefits throughout the program, and particularly substantial benefits in the later years of the program and beyond. Additionally, consistent with Executive Order 13563, the agency believes that the benefits of the preferred alternative amply justify the costs; indeed, the monetized benefits exceed the monetized costs by $358 billion over the lifetime of the vehicles covered by the proposed standards. In full consideration of all of the information currently before the agency, we have weighed the statutory factors carefully and selected proposed passenger car and light truck standards that we believe are the maximum feasible for MYs 2017–2025.

G. Impacts of the Proposed CAFE Standards

1. How will these standards improve fuel economy and reduce GHG emissions for MY 2017–2025 vehicles?

As discussed above, the CAFE level required under an attribute-based standard depends on the mix of vehicles produced for sale in the U.S. Based on the market forecast that NHTSA and EPA have used to develop and analyze the proposed CAFE and CO_2 emissions standards, NHTSA estimates that the proposed new CAFE standards would lead average required fuel consumption (fuel consumption is the inverse of fuel economy) levels to increase by an average of 4.0 percent annually through MY 2025, reaching a combined average fuel economy requirement of 49.6 mpg in that model year:

Table IV-31. Estimated Required Average Fuel Economy (mpg) under the Proposed Standards – MYs 2017-2021

Model Year	2017	2018	2019	2020	2021
Passenger cars	40.0	41.4	43.0	44.7	46.6
Light trucks	29.4	30.0	30.6	31.2	33.3
Combined	35.3	36.4	37.5	38.8	40.9

Table IV-32. Estimated Required Average Fuel Economy (mpg) under the Proposed Standards – MYs 2022-2025

Model Year	2022	2023	2024	2025
Passenger cars	48.8	51.0	53.5	56.0
Light trucks	34.9	36.6	38.5	40.3
Combined	42.9	45.0	47.3	49.6

with the requirements of EPCA/EISA to set maximum feasible standards.

[761] We underscore that the agency's tentative decision regarding what standards would be maximum feasible for MYs 2017–2025 is made with reference to the rulemaking time frame and circumstances of this proposal. Each CAFE rulemaking (indeed, each stage of any given CAFE rulemaking) presents the agency with new information that may affect how we balance the relevant actors.

Accounting for differences between fuel economy levels under laboratory conditions, NHTSA estimates that these requirements would translate into the following required average levels under real-world operating conditions:

Table IV-33. Estimated Required Average Fuel Economy (real-world mpg) under the Proposed Standards – MYs 2017-2021

Model Year	2017	2018	2019	2020	2021
Passenger cars	32.0	33.1	34.4	35.8	37.3
Light trucks	23.5	24.0	24.5	25.0	26.6
Combined	28.2	29.1	30.0	31.0	32.7

Table IV-34. Estimated Required Average Fuel Economy (real-world mpg) under the Proposed Standards – MYs 2022-2025

Model Year	2022	2023	2024	2025
Passenger cars	39.0	40.8	42.8	44.8
Light trucks	27.9	29.3	30.8	32.2
Combined	34.3	36.0	37.8	39.7

If manufacturers apply technology only as far as necessary to comply with CAFE standards, NHTSA estimates that, setting aside factors the agency cannot consider for purposes of determining maximum feasible CAFE standards,[762] average achieved fuel economy levels would correspondingly increase through MY 2025, but that manufacturers would, on average, under-comply[763] in some model years and over-comply[764] in others, reaching a combined average fuel economy of 47.4 mpg (taking into account estimated adjustments reflecting improved air conditioner efficiency) in MY 2025:

[762] 49 U.S.C. 32902(h) states that NHTSA may not consider the fuel economy of dedicated alternative fuel vehicles, the alternative-fuel portion of dual-fueled automobile fuel economy, or the ability of manufacturers to earn and use credits for over-compliance, in determining the maximum feasible stringency of CAFE standards.

[763] ''Under-compliance'' with CAFE standards can be mitigated either through use of FFV credits, use of existing or ''banked'' credits, or through fine payment. Although, as mentioned above, NHTSA cannot consider availability of statutorily-provided credits in setting standards, NHTSA is not prohibited from considering fine payment. Therefore, the estimated achieved CAFE levels presented here include the assumption that Aston Martin, BMW, Daimler (*i.e.,* Mercedes), Geely (*i.e.,* Volvo), Lotus, Porsche, Spyker (*i.e.,* Saab), and, Tata (*i.e.,* Jaguar and Rover), and Volkswagen will only apply technology up to the point that it would be less expensive to pay civil penalties.

[764] In NHTSA's analysis, ''over-compliance'' occurs through multi-year planning: manufacturers apply some ''extra'' technology in early model years (*e.g.,* MY 2014) in order to carry that technology forward and thereby facilitate compliance in later model years (*e.g.,* MY 2016).

Table IV-35. Estimated Achieved Average Fuel Economy (mpg) under the Proposed Standards – MYs 2017-2021

Model Year	2017	2018	2019	2020	2021
Passenger cars	39.6	41.7	43.6	45.4	47.1
Light trucks	29.5	30.6	32.4	33.6	35.6
Combined	35.2	36.8	38.8	40.4	42.3

Table IV-36. Estimated Achieved Average Fuel Economy (mpg) under the Proposed Standards – MYs 2022-2025

Model Year	2022	2023	2024	2025
Passenger cars	48.2	49.5	51.3	52.7
Light trucks	36.6	37.7	38.6	39.6
Combined	43.5	44.7	46.2	47.5

Accounting for differences between fuel economy levels under laboratory conditions, NHTSA estimates that these requirements would translate into the following required average levels under real-world operating conditions:

Table IV-37. Estimated Achieved Average Fuel Economy (real-world mpg) under the Proposed Standards – MYs 2017-2021

Model Year	2017	2018	2019	2020	2021
Passenger cars	31.7	33.4	34.9	36.3	37.7
Light trucks	23.6	24.5	25.9	26.9	28.5
Combined	28.2	29.4	31.0	32.3	33.8

Table IV-38. Estimated Achieved Average Fuel Economy (real-world mpg) under the Proposed Standards – MYs 2022-2025

Model Year	2022	2023	2024	2025
Passenger cars	38.6	39.6	41.0	42.2
Light trucks	29.4	30.2	30.9	31.7
Combined	34.8	35.8	37.0	38.0

Setting aside the potential to produce additional EVs (or, prior to MY 2020, PHEVs) or take advantage of EPCA's provisions regarding CAFE credits, NHTSA estimates that today's proposed standards could increase achieved fuel economy levels by average amounts of up to 0.5 mpg during the few model years leading into MY 2017, as manufacturers apply technology during redesigns leading into model years covered by today's new standards.[765] As shown below, these ''early'' fuel economy increases yield corresponding reductions in fuel consumption and greenhouse gas emissions, and incur corresponding increases in technology outlays.

Within the context EPCA requires NHTSA to apply for purposes of determining maximum feasible stringency of CAFE standards (*i.e.,* setting aside EVs, pre-MY 2020 PHEVs, and all statutory CAFE credit provisions), NHTSA estimates that these fuel economy increases would lead to fuel savings totaling 173 billion gallons during the useful lives of vehicles manufactured in MYs 2017–2025 and the few MYs preceding MY 2017:

[765] This outcome is a direct result of revisions, made to DOT's CAFE model in preparation for the MY 2012–2016 rule, to simulate ''multiyear planning'' effects—that is, the potential that manufacturers will apply ''extra'' technology in one model year if doing so will be sufficiently advantageous with respect to the ability to comply with CAFE standards in later model years. For example, for today's rulemaking analysis, NHTSA has estimated that Ford will redesign the F–150 pickup truck in MY 2015, and again in MY 2021. As explained in Chapter V of the PRIA, NHTSA expects that many technologies would be applied as part of a vehicle redesign. Therefore, in NHTSA's analysis, if Ford does not anticipate ensuing standards when redesigning the MY 2015 F–150, Ford may find it more difficult to comply with light truck standard during MY 2016–2020. Through simulation of multiyear planning effects, NHTSA's analysis indicates that Ford could apply more technology to the MY 2015 F–150 if standards continue to increase after MY 2016 than Ford need apply if standards remain unchanged after MY 2016, and that this additional technology would yield further fuel economy improvements of up to 1.3 mpg, depending on pickup configuration.

Table IV-39. Estimated Fuel Saved (billion gallons) under the Proposed Standards

Model year	Pre-2017	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
PC	4	2	5	7	9	11	13	15	17	19	104
LT	0	0	2	5	6	9	10	11	12	13	69
Combined	4	3	7	12	16	20	23	26	30	33	173

The agency also estimates that these new CAFE standards would lead to corresponding reductions of CO_2 emissions totaling 1,834 million metric tons (mmt) during the useful lives of vehicles sold in MYs 2017–2025 and the few MYs preceding MY 2017:

Table IV-40. Carbon Dioxide Emissions Avoided (mmt) under the Proposed Standards

Model year	Pre-2017	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
PC	41	26	52	76	100	122	139	158	184	202	1,100
LT	4	5	22	49	65	93	108	118	129	141	734
Combined	45	31	74	124	165	215	246	276	313	343	1,834

2. How will these standards improve fleet-wide fuel economy and reduce GHG emissions beyond MY 2025?

Under the assumption that CAFE standards at least as stringent as those being proposed today for MY 2025 would be established for subsequent model years, the effects of the proposed standards on fuel consumption and GHG emissions will continue to increase for many years. This will occur because over time, a growing fraction of the U.S. light-duty vehicle fleet will be comprised of cars and light trucks that meet at least the MY 2025 standard. The impact of the new standards on fuel use and GHG emissions would therefore continue to grow through approximately 2060, when virtually all cars and light trucks in service will have met standards as stringent as those established for MY 2025.

As Table IV–41 shows, NHTSA estimates that the fuel economy increases resulting from the proposed standards will lead to reductions in total fuel consumption by cars and light trucks of 3 billion gallons during 2020, increasing to 40 billion gallons by 2060. Over the period from 2017, when the proposed standards would begin to take effect, through 2050, cumulative fuel savings would total 1,232 billion gallons, as Table IV–41 also indicates.

Table IV-41. Reduction in Fleet-Wide Fuel Use (billion gasoline gallon equivalents) under the Proposed Standards

Calendar year	2020	2030	2040	2050	2060	Total, 2017-2060
PC	1.6	10.9	16.5	19.1	21.6	596.6
LT	1.4	11.2	17.3	20.7	23.7	635.2
Combined	3.0	22.1	33.8	39.9	39.9	1,231.8

The energy security analysis conducted for this rule estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products outside the U.S., which would in turn lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. While additional information would be needed to analyze this ''leakage effect'' in detail, NHTSA provides a sample estimate of its potential magnitude in its Draft EIS. This analysis indicates that the leakage effect is likely to offset only a very small fraction of the reductions in fuel use and emissions projected to result from the rule.

As a consequence of these reductions in fleet-wide fuel consumption, the agency also estimates that the new CAFE standards for MYs 2017–2025 would lead to corresponding reductions in CO_2 emissions from the U.S. light-duty vehicle fleet. Specifically, NHTSA estimates that total annual CO_2 emissions associated with passenger car and light truck use in the U.S. use would decline by 32 million metric tons (mmt) in 2020 as a consequence of the new CAFE standards, as Table IV–42 reports. The table also shows that this annual reduction is estimated to grow to nearly 488 million metric tons by the year 2060, and will total over 13 billion metric tons over the period from 2017, when the proposed standards would take effect, through 2060.

Table IV-42. Reduction in Fleet-Wide Carbon Dioxide Emissions (mmt) from Passenger Car and Light Truck Use under the Proposed Standards

Calendar year	2020	2030	2040	2050	2060	Total, 2017-2060
PC	17.0	116.9	176.6	204.1	230.7	6,382.2
LT	15.2	121.8	187.2	224.8	257.0	6,885.3
Combined	32.2	238.7	363.8	428.9	487.7	13,267.5

These reductions in fleet-wide CO_2 emissions, together with corresponding reductions in other GHG emissions from fuel production and use, would lead to small but significant reductions in projected changes in the future global climate. These changes, based on analysis documented in the draft Environmental Impact Statement (EIS) that informed the agency's decisions regarding this proposal, are summarized in Table IV–43 below.

Table IV-43. Effects of Reduction in Fleet-Wide Carbon Dioxide Emissions (mmt) on Projected Changes in Global Climate

Measure	Units	Date	Projected change in measure		
			No action	With proposed standards	Difference
Atmospheric CO2 concentration	Ppm	2100	784.9	781.8	3.1
Increase in global mean surface temperature	°C	2100	3.064	3.053	0.011
Sea level rise	Cm	2100	37.40	37.30	0.10
Global mean precipitation	% change from 1980-1999 avg.	2090	4.50%	4.48%	0.02%

3. How will these proposed standards impact non-GHG emissions and their associated effects?

Under the assumption that CAFE standards at least as stringent as those proposed for MY 2025 would be established for subsequent model years, the effects of the new standards on air quality and its associated health effects will continue to be felt over the foreseeable future. This will occur because over time a growing fraction of the U.S. light-duty vehicle fleet will be comprised of cars and light trucks that meet the MY 2025 standard, and this growth will continue until approximately 2060.

Increases in the fuel economy of light-duty vehicles required by the new CAFE standards will cause a slight increase in the number of miles they are driven, through the fuel economy ''rebound effect.'' In turn, this increase in vehicle use will lead to increases in emissions of criteria air pollutants and some airborne toxics, since these are products of the number of miles vehicles are driven.

At the same time, however, the projected reductions in fuel production and use reported in Table IV–40 and IV–41 above will lead to corresponding reductions in emissions of these pollutants that occur during fuel production and distribution (''upstream'' emissions). For most of these pollutants, the reduction in upstream emissions resulting from lower fuel production and distribution will outweigh the increase in emissions from vehicle use, resulting in a net decline in their total emissions.[766]

Tables IV–44 and IV–45 report estimated reductions in emissions of selected criteria air pollutants (or their chemical precursors) and airborne toxics expected to result from the proposed standards during calendar year 2040. By that date, cars and light trucks meeting the MY 2025 CAFE standards will account for the majority of light-duty vehicle use, so these reductions provide a useful index of the long-term impact of the final standards on air pollution and its consequences for human health. In the tables below, positive values indicate increases in emissions, while negative values indicate reductions.

[766] As stated elsewhere, while the agency's analysis assumes that all changes in upstream emissions result from a decrease in petroleum production and transport, the analysis of non-GHG emissions in future calendar years also assumes that retail gasoline composition is unaffected by this rule; as a result, the impacts of this rule on downstream non-GHG emissions (more specifically, on air toxics) may be underestimated. See also Section III.G above for more information.

Table IV-44. Projected Changes in Emissions of Criteria Air Pollutants from Passenger Car and Light Truck Use (calendar year 2040; tons)

Vehicle class	Source of emissions	Criteria air pollutant			
		Nitrogen oxides (NO_X)	Particulate matter ($PM_{2.5}$)	Sulfur oxides (SO_X)	Volatile organic compounds (VOC)
Passenger cars	Vehicle use	14,742.6	-126.9	-2,412.2	334.8
	Fuel production and distribution	-17,464.3	-1,910.1	-6,968.9	-39,230.5
	All sources	-2,721.7	-2,036.9	-9,381.1	-38,895.7
Light trucks	Vehicle use	6,097.1	202.9	-2,180.3	2,014.8
	Fuel production and distribution	-18,978.4	-2,100.3	-9,544.7	-32,679.8
	All sources	-12,881.3	-1,897.3	-11,725.0	-30,665.0
Total	Vehicle use	15,600	-204	-4,275	-221
	Fuel production and distribution	-33,928	-3,735	-15,427	-67,161
	All sources	-15,603.0	-3,934.2	-21,106.1	-69,560.7

Table IV-45. Projected Changes in Emissions of Airborne Toxics from Passenger Car and Light Truck Use (calendar year 2040; tons)

Vehicle class	Source of emissions	Toxic air pollutant		
		Benzene	1,3-Butadiene	Formaldehyde
Passenger cars	Vehicle use	-114.6	5.0	379.8
	Fuel production and distribution	-172.0	-1.5	-50.6
	All sources	-286.6	3.6	329.2
Light trucks	Vehicle use	44.6	11.9	92.2
	Fuel production and distribution	-145.3	-1.5	-51.4
	All sources	-100.7	10.4	40.8
Total	Vehicle use	-147	2.1	412
	Fuel production and distribution	-296	-2.8	
	All sources	-387.3	14.0	370.0

In turn, the reductions in emissions reported in Tables IV–44 and IV–45 are projected to result in significant declines in the adverse health effects that result from population exposure to these pollutants. Table IV–46 reports the estimated reductions in selected $PM_{2.5}$-related human health impacts that are expected to result from reduced population exposure to unhealthful atmospheric concentrations of $PM_{2.5}$. The estimates reported in Table IV–46, based on analysis documented in the draft Environmental Impact Statement (EIS) that informed the agency's decisions regarding this proposed rule, are derived from $PM_{2.5}$-related dollar-per-ton estimates that reflect the quantifiable reductions in health impacts likely to result from reduced population exposure to particular matter ($PM_{2.5}$). They do not include all health impacts related to reduced exposure to PM, nor do they include any reductions in health impacts resulting from lower population exposure to other criteria air pollutants (particularly ozone) and air toxics.

There may be localized air quality and health impacts associated with this rulemaking that are not reflected in the estimates of aggregate air quality changes and health impacts reported in this analysis. Emissions changes and dollar-per-ton estimates alone are not necessarily a good indication of local or regional air quality and health impacts, because the atmospheric chemistry governing formation and accumulation of ambient concentrations of $PM_{2.5}$, ozone, and air toxics is very complex. Full-scale photochemical modeling would provide the necessary spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. NHTSA intends to conduct such modeling for purposes of the final rule, but it was not available in time to inform these proposed standards or to be included in the Draft EIS.

Table IV-46. Projected Reductions in Health Impacts from Exposure to Criteria Air Pollutants Due to Proposed Standards (calendar year 2040)

Health impact	Measure	Projected reduction (2040)
Mortality (ages 30 and older)	premature deaths per year	380-970[767]
Chronic bronchitis	cases per year	240
Emergency room visits for asthma	number per year	330
Work loss	workdays per year	42,000

4. What are the estimated costs and benefits of these proposed standards?

NHTSA estimates that the proposed standards could entail significant additional technology beyond the levels that could be applied under baseline CAFE standards (*i.e.,* the application of MY 2016 CAFE standards to MYs 2017–2025). This additional technology will lead to increases in costs to manufacturers and vehicle buyers, as well as fuel savings to vehicle buyers. Also, as discussed above, NHTSA estimates that today's proposed standards could induce manufacturers to apply technology during redesigns leading into model years covered by today's new standards, and to incur corresponding increases in technology outlays.

Technology costs are assumed to change over time due to the influence of cost learning and the conversion from short- to long-term ICMs. Table I–47 represents the CAFE model inputs for MY 2012, MY 2017, MY 2021 and MY 2025 approximate net (accumulated) technology costs for some of the key enabling technologies as applied to Midsize passenger cars.[768] Additional details on technology cost estimates can be found in Chapter V of NHTSA's PRIA and Chapter 3 of the Joint Draft TSD.

[768] The net (accumulated) technology costs represent the costs from a baseline vehicle (i.e. the top of the decision tree) to each of the technologies listed in the table. The baseline vehicle is assumed to utilize a fixed-valve naturally aspirated inline 4 cylinder engine, 5-speed transmission and no electrification/hybridization improvements.

Table IV-47. Approximate Net (Accumulated) Technology Costs, Midsize PC

APPROXIMATE ICM NET COSTS PER VEHICLE (2009 dollars) FOR MIDSIZE PC SUBCLASS FOR KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		MY 2012	MY 2017	MY 2021	MY 2025
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$688	$631	$564	$535
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$1,225	$1,120	$980	$929
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,243	$1,146	$1,000	$934
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	n/a	$1,449	$1,285	$1,181
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	n/a	$1,969	$1,776	$1,606
Advanced Diesel	ADSL	n/a	$2,842	$2,672	$2,295
6-speed DCT	DCT	-$71	-$51	-$61	-$52
8-Speed Trans (Auto or DCT)	8SPD	$212	$204	$160	$157
Shift Optimizer	SHFTOPT	n/a	$453	$386	$357
12V Micro-Hybrid (Stop-Start)	MHEV	$836	$631	$548	$503
Strong Hybrid - Level 2	SHEV2	n/a	$6,758	$5,821	$5,220
Plug-in Hybrid - 30 mi range	PHEV1	n/a	$18,622	$14,661	$12,282
Electric Vehicle (Early Adopter) - 75 mile range	EV1	n/a	$22,342	$17,312	$13,517
Electric Vehicle (Broad Market) - 150 mile range	EV4	n/a	$31,552	$24,032	$18,450

In order to pay for this additional technology (and, for some manufacturers, civil penalties), NHTSA estimates that the cost of an average passenger car and light truck will increase relative to levels resulting from compliance with baseline (MY 2016) standards by $228–$2,023 and $44–$1,578, respectively, during MYs 2017–2025. The following tables summarize the agency's estimates of average cost increases for each manufacturer's passenger car, light truck, and overall fleets (with corresponding averages for the industry):

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Table IV-48. Average Passenger Car Incremental Cost Increases ($) under Proposed Standards – MYs 2017-2021

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Average	228	467	652	885	1,108
Aston Martin	2	2	2	2	2
BMW	2	3	1	1	(34)
Daimler (Mercedes)	2	2	1	11	11
Fiat (Chrysler)	310	748	755	1,471	1,503
Ford	434	784	954	1,213	1,448
Geely (Volvo)	2	4	108	113	229
General Motors	284	707	918	1,335	1,713
Honda	155	469	518	549	1,160
Hyundai	303	370	719	735	960
Kia	179	243	508	1,048	1,418
Lotus	2	2	2	2	2
Mazda	631	905	871	1,411	1,387
Mitsubishi	2	458	461	710	1,078
Nissan	367	474	1,020	1,161	1,232
Porsche	(4)	(4)	(3)	10	16
Spyker (Saab)	2	2	2	2	(5)
Subaru	2	35	336	932	898
Suzuki	624	612	1,920	1,924	1,880
Tata (Jaguar, Rover)	44	43	40	39	106
Tesla	2	2	2	2	2
Toyota	114	375	552	780	969
Volkswagen	4	4	4	6	9

Table IV-49. Average Passenger Car Incremental Cost Increases ($) under Proposed Standards – MYs 2022-2025

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Average	1,259	1,536	1,927	2,023
Aston Martin	2	2	2	2
BMW	(42)	(41)	126	119
Daimler (Mercedes)	11	243	243	645
Fiat (Chrysler)	1,564	2,310	2,462	2,638
Ford	1,658	2,349	3,261	2,897
Geely (Volvo)	222	329	609	595
General Motors	1,702	2,269	2,575	2,734
Honda	1,271	1,531	1,615	1,754
Hyundai	1,492	1,560	2,158	2,043
Kia	1,522	1,704	1,688	1,836
Lotus	2	2	2	2
Mazda	1,848	2,089	2,480	3,474
Mitsubishi	1,047	1,022	1,402	3,869
Nissan	1,676	1,853	2,293	2,233
Porsche	2	2	2	2
Spyker (Saab)	(6)	1	1	1
Subaru	883	868	1,599	3,057
Suzuki	1,869	1,839	3,831	3,347
Tata (Jaguar, Rover)	338	550	543	547
Tesla	2	2	2	2
Toyota	1,084	1,078	1,539	1,631
Volkswagen	83	106	129	302

Table IV-50. Average Light Truck Incremental Cost Increases ($) under Proposed Standards – MYs 2017-2021

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Average	44	187	427	688	965
Aston Martin	-	-	-	-	-
BMW	36	48	95	220	326
Daimler (Mercedes)	48	59	63	178	168
Fiat (Chrysler)	238	234	289	1,137	1,252
Ford	(6)	270	279	423	1,435
Geely (Volvo)	1	68	69	68	66
General Motors	(5)	198	595	1,188	1,242
Honda	154	163	340	373	757
Hyundai	262	269	714	712	696
Kia	60	73	192	321	907
Lotus	-	-	-	-	-
Mazda	(3)	472	450	480	550
Mitsubishi	322	347	319	431	2,668
Nissan	21	50	288	431	820
Porsche	1	45	49	48	48
Spyker (Saab)	1	13	18	18	446
Subaru	176	505	1,366	1,337	1,334
Suzuki	293	301	1,793	1,763	1,996
Tata (Jaguar, Rover)	1	13	49	50	15
Tesla	-	-	-	-	-
Toyota	(13)	179	445	462	656
Volkswagen	1	41	350	358	421

Table IV-51. Average Light Truck Incremental Cost Increases ($) under Proposed Standards – MYs 2022-2025

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Average	1,102	1,284	1,428	1,578
Aston Martin	-	-	-	-
BMW	746	738	787	735
Daimler (Mercedes)	1,134	1,130	1,096	1,050
Fiat (Chrysler)	1,296	1,588	1,665	1,948
Ford	1,482	1,981	2,005	2,064
Geely (Volvo)	357	770	759	707
General Motors	1,285	1,456	1,511	1,863
Honda	1,279	1,263	1,296	1,370
Hyundai	1,207	1,191	1,693	1,687
Kia	891	1,020	1,149	1,150
Lotus	-	-	-	-
Mazda	540	1,108	1,393	1,315
Mitsubishi	2,606	2,564	2,526	2,356
Nissan	1,169	1,213	1,469	1,677
Porsche	75	640	629	568
Spyker (Saab)	440	435	429	395
Subaru	1,376	1,358	1,606	1,532
Suzuki	2,000	1,965	1,935	2,252
Tata (Jaguar, Rover)	15	16	16	15
Tesla	-	-	-	-
Toyota	663	858	1,175	1,253
Volkswagen	426	555	959	884

Table IV-52. Average Incremental Cost Increases ($) by Manufacturer under Proposed Standards – MYs 2017-2021

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Average	161	365	572	815	1,058
Aston Martin	2	2	2	2	2
BMW	12	16	27	59	61
Daimler (Mercedes)	13	15	16	51	50
Fiat (Chrysler)	275	496	532	1,317	1,391
Ford	271	597	718	943	1,444
Geely (Volvo)	2	24	95	98	179
General Motors	144	455	756	1,262	1,480
Honda	155	370	462	494	1,035
Hyundai	295	349	718	730	906
Kia	151	203	431	881	1,304
Lotus	2	2	2	2	2
Mazda	523	827	796	1,246	1,239
Mitsubishi	119	418	411	612	1,633
Nissan	250	335	787	934	1,105
Porsche	(2)	9	9	19	23
Spyker (Saab)	2	4	4	4	59
Subaru	47	156	595	1,031	1,002
Suzuki	559	552	1,882	1,895	1,901
Tata (Jaguar, Rover)	22	28	44	44	61
Tesla	2	2	2	2	2
Toyota	61	297	511	659	847
Volkswagen	4	12	78	79	92

Table IV-53. Average Incremental Cost Increases ($) by Manufacturer under Proposed Standards – MYs 2022-2025

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Average	1,205	1,450	1,760	1,876
Aston Martin	2	2	2	2
BMW	166	162	307	282
Daimler (Mercedes)	290	467	451	738
Fiat (Chrysler)	1,442	1,981	2,109	2,343
Ford	1,599	2,231	2,866	2,640
Geely (Volvo)	264	462	654	629
General Motors	1,498	1,877	2,067	2,319
Honda	1,274	1,451	1,522	1,641
Hyundai	1,435	1,485	2,064	1,972
Kia	1,384	1,555	1,572	1,690
Lotus	2	2	2	2
Mazda	1,617	1,919	2,294	3,115
Mitsubishi	1,583	1,553	1,781	3,367
Nissan	1,521	1,659	2,046	2,068
Porsche	19	152	142	124
Spyker (Saab)	56	59	57	52
Subaru	998	981	1,601	2,714
Suzuki	1,892	1,861	3,501	3,159
Tata (Jaguar, Rover)	178	287	292	300
Tesla	2	2	2	2
Toyota	923	995	1,406	1,493
Volkswagen	151	198	300	416

These cost estimates reflect the potential that a given manufacturer's efforts to minimize overall regulatory costs could focus technology where the most fuel can be saved at the least cost, and not necessarily, for example, where the cost to add technology would be smallest relative to baseline production costs. Therefore, if average incremental vehicle cost increases (including any civil penalties) are measured as increases relative to baseline prices (estimated by adding baseline costs to MY 2008 prices), the agency's analysis shows relative cost increases declining as baseline vehicle price increases. Figure IV–3 shows the trend for MY 2025, for vehicles with estimated baseline prices up to $100,000:

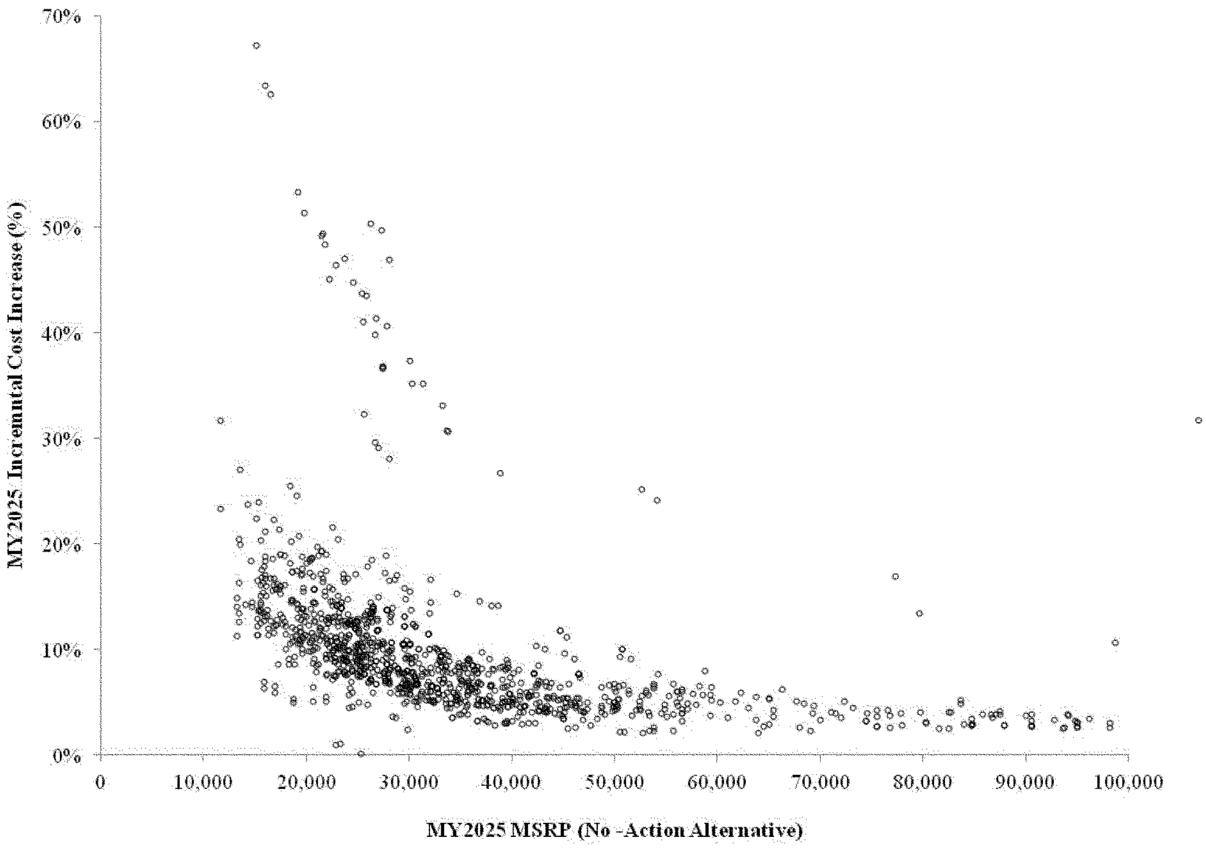

Figure IV-3. Estimated Incremental Cost Increases in MY 2025

If manufacturers pass along these costs rather than reducing profits, and pass these costs along where they are incurred rather than ''cross-subsidizing'' among products, the quantity of vehicles produced at different price levels would change. Shifts in production may potentially occur, which could create marketing challenges for manufacturers that are active in certain segments. We recognize, however, that many manufacturers do in fact cross-subsidize to some extent, and take losses on some vehicles while continuing to make profits from others. NHTSA has no evidence to indicate that manufacturers will inevitably shift production plans in response to these proposed standards, but nevertheless believes that this issue is worth monitoring in the market going forward. NHTSA seeks comment on potential market effects related to this issue.

As mentioned above, these estimated costs derive primarily from the additional application of technology under the proposed standards. The following three tables summarize the incremental extent to which the agency estimates technologies could be added to the passenger car, light truck, and overall fleets in each model year in response to the proposed standards. Percentages reflect the technology's additional application in the market, relative to the estimated application under baseline standards (*i.e.,* application of MY 2016 standards through MY 2025), and are negative in cases where one technology is superseded (*i.e.,* displaced) by another. For example, the agency estimates that manufacturers could apply many improvements to transmissions (*e.g.,* dual clutch transmissions, denoted below by ''DCT'') through MY 2025 under baseline standards. However, the agency also estimates that manufacturers could apply even more advanced high efficiency transmissions (denoted below by ''HETRANS'') under the proposed standards, and that these transmissions would supersede DCTs and other transmission advances. Therefore, as shown in the following three tables, the *incremental* application of DCTs under the proposed standards is negative.

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Table IV-54. Incremental Application of Technologies to Passenger Car Fleet under Proposed Standards – MYs 2017-2025

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
LUB1	8%	16%	16%	16%	16%	16%	16%	16%	16%
EFR1	20%	25%	28%	28%	27%	28%	28%	28%	28%
LUB2_EFR2	2%	10%	21%	28%	38%	43%	46%	52%	53%
CCPS	3%	4%	6%	6%	6%	6%	6%	7%	6%
DVVLS				1%	1%	1%	1%	1%	1%
DEACS							(1%)	(1%)	(1%)
ICP									
DCP	6%	11%	13%	15%	18%	19%	19%	18%	17%
DVVLD	12%	16%	21%	25%	29%	34%	33%	32%	32%
DEACD									
SGDI	11%	15%	22%	28%	36%	43%	46%	54%	55%
DEACO			(1%)	(2%)	(2%)	(2%)	(2%)	(2%)	(2%)
VVA									
SGDIO			1%	2%	2%	2%	2%	2%	2%
TRBDS1_SD	6%	8%	8%	9%	13%	9%	7%	4%	2%
TRBDS1_MD	3%	3%	5%	6%	7%	6%	2%	(4%)	(7%)
TRBDS1_LD									
TRBDS2_SD			3%	3%	3%	3%	4%	1%	
TRBDS2_MD	(2%)	(2%)	(2%)	(3%)	(3%)	(3%)	(3%)	(3%)	(3%)
TRBDS2_LD									
CEGR1_SD	1%	2%	2%	5%	9%	16%	18%	28%	32%

CEGR1_MD	3%	5%	5%	7%	4%	6%	6%	10%	12%
CEGR1_LD									
CEGR2_SD				1%	2%	2%	2%	5%	4%
CEGR2_MD					3%	4%	6%	7%	6%
CEGR2_LD		1%	1%	2%	2%	2%	2%	2%	1%
ADSL_SD			1%	2%	2%	3%	3%	4%	5%
ADSL_MD		1%	1%	1%	1%	1%	2%	2%	3%
ADSL_LD									
6MAN	1%	1%		(1%)	(1%)	(1%)	(1%)	(1%)	(1%)
HETRANSM		1%	1%	3%	4%	5%	5%	6%	7%
IATC		(1%)	(1%)	(1%)	(1%)	(1%)	(1%)	(1%)	(1%)
NAUTO	(3%)	(4%)	(6%)	(7%)	(7%)	(7%)	(7%)	(7%)	(7%)
DCT	(6%)	(17%)	(29%)	(35%)	(44%)	(45%)	(46%)	(46%)	(46%)
8SPD	3%	3%	1%	(4%)	(7%)	(8%)	(9%)	(10%)	(14%)
HETRANS	5%	20%	31%	43%	49%	53%	51%	48%	49%
SHFTOPT	9%	27%	37%	49%	65%	68%	64%	60%	56%
EPS	8%	10%	13%	17%	29%	32%	35%	35%	34%
IACC1	13%	16%	18%	23%	41%	46%	49%	52%	52%
IACC2	13%	21%	31%	40%	50%	55%	65%	70%	70%
MHEV	3%	6%	11%	22%	29%	34%	36%	37%	33%
SHEV1									
SHEV1_2									1%
SHEV2							4%	6%	10%
PHEV1							1%	3%	4%

MR1	5%	11%	14%	14%	14%	14%	15%	14%	14%
MR2	2%	15%	27%	30%	30%	30%	30%	30%	29%
MR3	1%	4%	5%	7%	7%	7%	8%	9%	9%
MR4	2%	4%	4%	6%	6%	7%	8%	10%	10%
MR5		2%	2%	3%	4%	4%	5%	8%	9%
ROLL1		2%	2%	3%	3%	3%	3%	3%	3%
ROLL2	5%	23%	36%	45%	56%	66%	67%	68%	68%
LDB	2%	2%	2%	2%	2%	3%	3%	3%	3%
SAX									
AERO1		3%	3%	3%	3%	3%	3%	3%	3%
AERO2	6%	15%	29%	35%	47%	51%	51%	51%	51%

Table IV-55. Incremental Application of Technologies to Light Truck Fleet under Proposed Standards – MYs 2017-2025

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
LUB1									
EFR1									
LUB2_EFR2	2%	8%	21%	35%	49%	61%	77%	83%	84%
CCPS			2%	1%	4%	4%	4%	4%	4%
DVVLS					1%	1%	1%	1%	1%
DEACS	2%	2%	2%	2%	(2%)	(5%)	(5%)	(5%)	(5%)
ICP									
DCP	4%	4%	4%	4%	4%	4%	5%	5%	3%
DVVLD		1%	6%	2%	8%	9%	12%	14%	13%

DEACD			(1%)	(1%)	(2%)	(2%)	(2%)	(2%)	(2%)
SGDI			8%	4%	19%	25%	29%	33%	33%
DEACO			(1%)	(6%)	(7%)	(6%)	(8%)	(8%)	(8%)
VVA			4%	4%	3%	3%	3%	3%	3%
SGDIO			2%	6%	7%	7%	8%	8%	9%
TRBDS1_SD									
TRBDS1_MD		(2%)	4%	(2%)	4%	3%	(3%)	(14%)	(18%)
TRBDS1_LD					3%	3%	5%	5%	5%
TRBDS2_SD			1%	1%	1%	3%	3%	6%	6%
TRBDS2_MD					1%	1%	1%	2%	1%
TRBDS2_LD									
CEGR1_SD			1%	1%			1%	2%	3%
CEGR1_MD									
CEGR1_LD									
CEGR2_SD									
CEGR2_MD									
CEGR2_LD			1%	1%	3%	6%	7%	7%	7%
ADSL_SD									
ADSL_MD				5%	6%	6%	7%	6%	8%
ADSL_LD									
6MAN									
HETRANSM	0%	1%	1%	1%	1%	1%	2%	2%	2%
IATC			(1%)	(1%)	(1%)	(1%)	(1%)	(1%)	(1%)
NAUTO	(2%)	(7%)	(16%)	(17%)	(26%)	(26%)	(25%)	(25%)	(25%)

DCT	(1%)	(7%)	(7%)	(8%)	(9%)	(12%)	(12%)	(12%)	(12%)
8SPD	3%	3%	(9%)	(15%)	(28%)	(28%)	(29%)	(30%)	(34%)
HETRANS		15%	34%	50%	61%	61%	61%	61%	66%
SHFTOPT	4%	14%	27%	39%	61%	77%	78%	79%	79%
EPS	4%	7%	17%	28%	35%	43%	49%	53%	54%
IACC1	3%	5%	5%	12%	18%	21%	21%	25%	29%
IACC2	3%	7%	17%	31%	42%	48%	54%	58%	62%
MHEV			3%	8%	10%	10%	16%	20%	21%
SHEV1_2									
SHEV2									
PHEV1									
MR1	10%	9%	10%	12%	14%	14%	14%	14%	14%
MR2	1%	12%	33%	42%	50%	54%	56%	57%	58%
MR3	(1%)	2%	6%	14%	24%	36%	48%	64%	77%
MR4	1%	1%	1%	4%	10%	12%	16%	20%	39%
MR5						1%	6%	8%	23%
ROLL1									
ROLL2	2%	15%	32%	48%	59%	70%	74%	81%	82%
ROLL3									
LDB		2%	3%	9%	15%	22%	28%	32%	38%
SAX		4%	4%	5%	9%	11%	13%	15%	22%
AERO1									
AERO2	6%	11%	27%	33%	33%	37%	37%	38%	38%

Table IV-56. Incremental Application of Technologies to Overall Fleet under Proposed Standards – MYs 2017-2025

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
LUB1	5%	10%	10%	10%	10%	10%	11%	11%	10%
EFR1	12%	16%	18%	18%	18%	18%	18%	19%	19%
LUB2_EFR2	2%	9%	21%	31%	42%	50%	57%	62%	64%
CCPS	2%	3%	5%	5%	6%	6%	6%	6%	5%
DVVLS					1%	1%	1%	1%	1%
DEACS	1%	1%	1%		(1%)	(2%)	(2%)	(2%)	(2%)
ICP									
DCP	5%	8%	10%	11%	13%	14%	14%	13%	12%
DVVLD	7%	10%	16%	17%	22%	25%	26%	26%	26%
DEACD					(1%)	(1%)	(1%)	(1%)	(1%)
SGDI	7%	10%	17%	19%	30%	37%	40%	47%	48%
DEACO			(1%)	(3%)	(4%)	(4%)	(4%)	(4%)	(4%)
VVA			1%	1%	1%	1%	1%	1%	1%
SGDIO	0%	0%	1%	4%	4%	4%	4%	4%	5%
TRBDS1_SD	4%	5%	5%	6%	9%	6%	5%	3%	1%
TRBDS1_MD	2%	1%	5%	4%	6%	5%		(7%)	(11%)
TRBDS1_LD					1%	1%	2%	2%	1%
TRBDS2_SD			2%	2%	2%	3%	3%	3%	2%
TRBDS2_MD	(1%)	(2%)	(2%)	(2%)	(2%)	(2%)	(2%)	(2%)	(2%)
CEGR1_SD	1%	1%	2%	4%	6%	11%	13%	19%	22%
CEGR1_MD	2%	4%	5%	8%	8%	10%	12%	18%	21%

CEGR1_LD									
CEGR2_SD				1%	1%	1%	2%	3%	2%
CEGR2_MD				0%	2%	3%	4%	5%	5%
CEGR2_LD			1%	2%	3%	3%	4%	4%	3%
ADSL_SD			1%	1%	2%	2%	2%	3%	3%
ADSL_MD		1%	1%	2%	3%	3%	3%	3%	5%
ADSL_LD									
6MAN						(1%)	(1%)	(1%)	(1%)
HETRANSM		1%	1%	2%	3%	4%	4%	5%	5%
IATC		(1%)	(1%)	(1%)	(1%)	(1%)	(1%)	(1%)	(1%)
NAUTO	(3%)	(5%)	(10%)	(10%)	(13%)	(13%)	(13%)	(13%)	(13%)
DCT	(4%)	(14%)	(21%)	(26%)	(32%)	(34%)	(34%)	(35%)	(35%)
8SPD	3%	3%	(3%)	(8%)	(14%)	(15%)	(16%)	(17%)	(21%)
HETRANS	3%	18%	32%	46%	53%	56%	55%	53%	54%
SHFTOPT	7%	22%	34%	46%	64%	71%	69%	67%	64%
EPS	7%	9%	14%	21%	31%	36%	39%	41%	41%
IACC1	9%	12%	13%	19%	33%	37%	39%	43%	45%
IACC2	10%	16%	26%	37%	47%	52%	61%	66%	67%
MHEV	2%	4%	8%	17%	22%	26%	29%	31%	29%
SHEV1_2									
SHEV2							3%	4%	6%
PHEV1							1%	2%	3%
MR1	7%	11%	12%	14%	14%	14%	14%	14%	14%
MR2	2%	14%	29%	34%	37%	38%	39%	39%	39%

MR3		3%	5%	9%	13%	17%	22%	27%	32%
MR4	2%	3%	3%	5%	8%	9%	11%	14%	20%
MR5	0%	1%	1%	2%	3%	3%	5%	8%	14%
ROLL1		1%	1%	2%	2%	2%	2%	2%	2%
ROLL2	4%	20%	34%	46%	57%	67%	70%	73%	73%
LDB	1%	2%	2%	5%	7%	10%	11%	13%	15%
SAX		2%	2%	2%	3%	4%	5%	5%	8%
AERO1		2%	2%	2%	2%	2%	2%	2%	2%
AERO2	6%	14%	28%	34%	42%	46%	46%	47%	47%

Based on the agencies' estimates of manufacturers' future sales volumes, and taking into account early outlays attributable to multiyear planning effects (discussed above), the cost increases associated with this additional application of technology will lead to a total of nearly $157 billion in incremental outlays during MYs 2017–2025 (and model years leading up to MY 2017) for additional technology attributable to the proposed standards:

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Table IV-57. Incremental Technology Outlays ($M) under Proposed Standards – MYs 2017-2021

	Earlier	MY2017	MY2018	MY2019	MY2020	MY2021
Total	3,976	2,537	5,681	8,905	12,957	17,123
Aston Martin	-	0	0	0	0	0
BMW	-	6	7	13	29	30
Daimler (Mercedes)	-	5	5	6	20	20
Fiat (Chrysler)	394	229	393	407	1,031	1,080
Ford	734	559	1,230	1,472	1,976	3,055
Geely (Volvo)	-	0	3	13	13	24
General Motors	1,029	408	1,327	2,266	3,881	4,580
Honda	189	271	622	773	835	1,796
Hyundai	231	220	255	530	549	698
Kia	107	64	83	179	370	556
Lotus	-	0	0	0	0	0
Mazda	360	160	265	258	409	414
Mitsubishi	43	12	42	41	61	165
Nissan	434	328	423	986	1,196	1,459
Porsche	-	0	0	0	1	1
Spyker (Saab)	-	0	0	0	0	1
Subaru	42	14	45	172	305	304
Suzuki	233	63	61	209	216	221
Tata (Jaguar, Rover)	3	3	3	5	5	7
Tesla	-	0	0	0	0	0
Toyota	177	194	907	1,521	2,003	2,643

Volkswagen	0	2	8	54	56	68
Passenger cars	3,641	2,280	4,621	6,521	9,103	11,636
Light trucks	335	257	1,060	2,384	3,853	5,487
Combined	3,976	2,537	5,681	8,905	12,957	17,123

Table IV-58. Incremental Technology Outlays ($M) under Proposed Standards – MYs 2022-2025 (and total through MY 2025)

	MY2022	MY2023	MY2024	MY2025	Total
Total	19,807	24,155	29,798	32,354	157,293
Aston Martin	0	0	0	0	0
BMW	81	79	164	155	564
Daimler (Mercedes)	118	195	198	326	893
Fiat (Chrysler)	1,145	1,569	1,641	1,818	9,708
Ford	3,405	4,851	6,284	5,874	29,440
Geely (Volvo)	35	64	93	90	336
General Motors	4,623	5,824	6,471	7,415	37,823
Honda	2,263	2,615	2,808	3,114	15,285
Hyundai	1,127	1,181	1,701	1,667	8,160
Kia	601	682	704	778	4,124
Lotus	0	(0)	(0)	(0)	(0)
Mazda	552	689	832	1,147	5,085
Mitsubishi	162	160	190	369	1,246
Nissan	2,052	2,275	2,874	2,981	15,009

Porsche	(1)	7	7	6	25
Spyker (Saab)	1	2	1	1	8
Subaru	311	309	516	900	2,919
Suzuki	224	223	426	393	2,272
Tata (Jaguar, Rover)	21	34	35	37	153
Tesla	0	0	0	0	0
Toyota	2,972	3,247	4,622	4,954	23,239
Volkswagen	112	149	229	327	1,004
Passenger cars	11,636	13,519	16,852	21,695	113,218
Light trucks	5,487	6,287	7,303	8,102	44,075
Combined	19,807	24,155	29,798	32,354	157,293

NHTSA notes that these estimates of the economic costs for meeting higher CAFE standards omit certain potentially important categories of costs, and may also reflect underestimation (or possibly overestimation) of some costs that are included. For example, although the agency's analysis is intended—with very limited exceptions[769]—to hold vehicle performance, capacity, and utility constant when applying fuel-saving technologies to vehicles, the analysis imputes no cost to any actual reductions in vehicle performance, capacity, and utility that may result from manufacturers' efforts to comply with the proposed CAFE standards. Although these costs are difficult to estimate accurately, they nonetheless represent a notable category of omitted costs if they have not been adequately accounted for in the cost estimates. Similarly, the agency's estimates of net benefits for meeting higher CAFE standards includes estimates of the economic value of potential changes in motor vehicle fatalities that could result from reductions in the size or weight of vehicles, but not of changes in non-fatal injuries that could result from reductions in vehicle size and/or weight.

Finally, while NHTSA is confident that the cost estimates are the best available and appropriate for purposes of this proposed rule, it is possible that the agency may have underestimated or overestimated manufacturers' direct costs for applying some fuel economy technologies, or the increases in manufacturer's indirect costs associated with higher vehicle manufacturing costs. In either case, the technology outlays reported here will not correctly represent the costs of meeting higher CAFE standards. Similarly, NHTSA's estimates of increased costs of congestion, accidents, and noise associated with added vehicle use are drawn from a 1997 study, and the correct magnitude of these values may have changed since they were developed. If this is the case, the costs of increased vehicle use associated with the fuel economy rebound effect will differ from the agency's estimates in this analysis. Thus, like the agency's estimates of economic benefits, estimates of total compliance costs reported here may underestimate or overestimate the true economic costs of the proposed standards.

However, offsetting these costs, the achieved increases in fuel economy will also produce significant benefits to society. Most of these benefits are attributable to reductions in fuel consumption; fuel savings are valued using forecasts of pretax prices in EIA's reference case forecast from AEO 2011. The total benefits also include other benefits and dis-benefits, examples of which include the social values of reductions in CO_2 and criteria pollutant emissions, the value of additional travel (induced by the rebound effect), and the social costs of additional congestion, accidents, and noise attributable to that additional travel. The PRIA accompanying today's proposed rule presents a detailed analysis of the rule's specific benefits.

As Tables IV–59 and 60 show, NHTSA estimates that at the discount rates of 3 percent prescribed in OMB guidance for regulatory analysis, the present value of total benefits from the proposed CAFE standards over the lifetimes of MY 2017–2025 (and, accounting for multiyear planning effects discussed above, model years leading up to MY 2017) passenger cars and light trucks will be $515 billion.

[769] For example, the agencies have assumed no cost changes due to our assumption that HEV towing capability is not maintained; due to potential drivability issues with the P2 HEV; and due to potential drivability and NVH issues with the shift optimizer.

Table IV-59. Present Value of Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2017-2021[770]

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	11	7	14	21	27	34
LT	1	1	6	13	18	26
Combined	12	8	20	34	45	60

Table IV-60. Present Value of Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2022-2025 (and total through MY 2025)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	39	45	53	59	310
LT	30	33	37	40	206
Combined	69	78	90	100	516

Tables IV–61 and 62 report that the present value of total benefits from requiring cars and light trucks to achieve the fuel economy levels specified in the proposed CAFE standards for MYs 2017–25 will be $419 billion when discounted at the 7 percent rate also required by OMB guidance. Thus the present value of fuel savings and other benefits over the lifetimes of the vehicles covered by the proposed standards is $96 billion—or about 19 percent—lower when discounted at a 7 percent annual rate than when discounted using the 3 percent annual rate.[771]

[770] Unless otherwise indicated, all tables in Section IV report benefits calculated using the Reference Case input assumptions, with future benefits resulting from reductions in carbon dioxide emissions discounted at the 3 percent rate prescribed in the interagency guidance on the social cost of carbon.

[771] For tables that report total or net benefits using a 7 percent discount rate, future benefits from reducing carbon dioxide emissions are discounted at 3 percent in order to maintain consistency with the discount rate used to develop the reference case estimate of the social cost of carbon. All other future benefits reported in these tables are discounted using the 7 percent rate.

Table IV-61. Present Value of Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2017-2021

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	9	6	12	17	22	28
LT	1	1	5	10	14	21
Combined	9	7	16	27	37	49

Table IV-62. Present Value of Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2022-2025 (and total through MY2025)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	32	37	44	49	254
LT	24	27	30	33	165
Combined	56	64	73	81	419

For both the passenger car and light truck fleets, NHTSA estimates that the benefits of today's proposed standards will exceed the corresponding costs in every model year, so that the net social benefits from requiring higher fuel economy—the difference between the total benefits that result from higher fuel economy and the technology outlays required to achieve it—will be substantial. Because the technology outlays required to achieve the fuel economy levels required by the proposed standards are incurred during the model years when the vehicles are produced and sold, however, they are not subject to discounting, so that their present value does not depend on the discount rate used. Thus the net benefits of the proposed standards differ depending on whether the 3 percent or 7 percent discount rate is used, but only because the choice of discount rates affects the present value of total benefits, and not that of technology costs.

As Tables IV–63 and 64 show, over the lifetimes of the affected (MY 2017–2025, and MYs leading up to MY 2017) vehicles, the agency estimates that when the benefits of the proposed standards are discounted at a 3 percent rate, they will exceed the costs of the proposed standards by $358 billion:

Table IV-63. Present Value of Net Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2017-2021

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	7	4	9	14	18	22
LT	1	1	5	11	14	20
Combined	8	6	14	25	32	43

Table IV-64. Present Value of Net Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2022-2025 (and total through MY 2025)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	26	28	31	36	197
LT	24	26	29	31	161
Combined	49	54	60	67	358

As indicated previously, when fuel savings and other future benefits resulting from the proposed standards are discounted at the 7 percent rate prescribed in OMB guidance, they are $96 billion lower than when the 3 percent discount rate is applied. Because technology costs are not subject to discounting, using the higher 7 percent discount rate reduces net benefits by exactly this same amount. Nevertheless, Tables IV–65 and 66 show that the net benefits from requiring passenger cars and light trucks to achieve higher fuel economy are still substantial even when future benefits are discounted at the higher rate, totaling $262 billion over MYs 2017–25. Net benefits are thus about 27 percent lower when future benefits are discounted at a 7 percent annual rate than at a 3 percent rate.

Table IV-65. Present Value of Net Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2017-2021

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	5	3	7	10	13	16
LT	1	1	4	8	10	15
Combined	5	4	11	18	24	31

Table IV-66. Present Value of Net Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2022-2025 (and total through MY 2025)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	18	20	22	25	141
LT	18	20	21	24	121
Combined	36	40	43	49	262

NHTSA's estimates of economic benefits from establishing higher CAFE standards are subject to considerable uncertainty. Most important, the agency's estimates of the fuel savings likely to result from adopting higher CAFE standards depend critically on the accuracy of the estimated fuel economy levels that will be achieved under both the baseline scenario, which assumes that manufacturers will continue to comply with the MY 2016 CAFE standards, and under alternative increases in the standards that apply to MYs 2017–25 passenger cars and light trucks. Specifically, if the agency has underestimated the fuel economy levels that manufacturers would have achieved under the baseline scenario—or is too optimistic about the fuel economy levels that manufacturers will actually achieve under the proposed standards—its estimates of fuel savings and the resulting economic benefits attributable to this rule will be too large.

Another major source of potential overestimation in the agency's estimates of benefits from requiring higher fuel economy stems from its reliance on the Reference Case fuel price forecasts reported in AEO 2011. Although NHTSA believes that these forecasts are the most reliable that are available, they are nevertheless significantly higher than the fuel price projections reported in most previous editions of EIA's Annual Energy Outlook, and reflect projections of world oil prices that are well above forecasts issued by other firms and government agencies. If the future fuel prices projected in AEO 2011 prove to be too high, the agency's estimates of the value of future fuel savings—the major component of benefits from this rule—will also be too high.

However, it is also possible that NHTSA's estimates of economic benefits from establishing higher CAFE standards underestimate the true economic benefits of the fuel savings those standards would produce. If the AEO 2011 forecast of fuel prices proves to be too low, for example, NHTSA will have underestimated the value of fuel savings that will result from adopting higher CAFE standards for MY 2017–25. As another example, the agency's estimate of benefits from reducing the threat of economic damages from disruptions in the supply of imported petroleum to the U.S. applies to calendar year 2020. If the magnitude of this estimate would be expected to grow after 2015 in response to increases in U.S. petroleum imports, growth in the level of U.S. economic activity, or increases in the likelihood of disruptions in the supply of imported petroleum, the agency may have underestimated the benefits from the reduction in petroleum imports expected to result from adopting higher CAFE standards.

NHTSA's benefit estimates could also be too low because they exclude or understate the economic value of certain potentially significant categories of benefits from reducing fuel consumption. As one example, EPA's estimates of the economic value of reduced damages to human health resulting from lower exposure to criteria air pollutants includes only the effects of reducing population exposure to $PM_{2.5}$ emissions. Although this is likely to be the most significant component of health benefits from reduced emissions of criteria air pollutants, it excludes the value of reduced damages to human health and other impacts resulting from lower emissions and reduced population exposure to other criteria air pollutants, including ozone and nitrous oxide (N_2O), as well as to airborne toxics. EPA's estimates exclude these benefits because no reliable dollar-per-ton estimates of the health impacts of criteria pollutants other than $PM_{2.5}$ or of the health impacts of airborne toxics were available to use in developing estimates of these benefits.

Similarly, the agency's estimate of the value of reduced climate-related economic damages from lower emissions of GHGs excludes many sources of potential benefits from reducing the pace and extent of global climate change.[772] For example, none of the three models used to value climate-related economic damages includes those resulting from ocean acidification or loss of species and wildlife. The models also may not adequately capture certain other impacts, including potentially abrupt changes in climate associated with thresholds that govern climate system responses, interregional interactions such as global security impacts of extreme warming, or limited near-term substitutability between damage to natural systems and increased consumption. Including monetized estimates of benefits from reducing the extent of climate change and these associated impacts would increase the agency's estimates of benefits from adopting higher CAFE standards.

The following tables present itemized costs and benefits for the combined passenger car and light truck fleets for each model year affected by the proposed standards and for all model years combined, using both discount rates prescribed by OMB regulatory guidance. Tables IV–67 and 68 report technology outlays, each separate component of benefits (including costs associated with additional driving due to the rebound effect, labeled ''dis-benefits''), the total value of benefits, and net benefits using the 3 percent discount rate. (Numbers in parentheses represent negative values.)

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[772] *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government, February 2010. Available in Docket No. NHTSA–2009–0059.

Table IV-67. Present Value of Net Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2017-2021

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Costs						
Technology costs	4.0	3.0	6.0	9.0	13.0	17.0
Benefits						
Savings in lifetime fuel expenditures	10.2	7.1	17.5	29.6	40.0	52.5
Consumer surplus from additional driving	0.6	0.4	0.7	1.1	1.2	1.7
Value of savings in refueling time	0.1	0.1	0.2	0.5	0.7	1.0
Reduction in petroleum market externalities	0.6	0.4	0.9	1.6	2.1	2.7
Reduction in climate-related damages from lower CO_2 emissions[773]	1.1	0.7	1.8	3.1	4.2	5.6

Reduction in highway fatalities from changes in vehicle mass	(0.6)	(0.0)	0.0	(0.1)	(0.0)	(0.0)
Reduction in health damage costs from lower emissions of criteria air pollutants:						
CO	-	-	-	-	-	-
VOC	0.0	0.0	0.0	0.0	0.1	0.1
NO_X	0.0	0.0	0.0	0.0	0.0	0.0
PM	0.2	0.1	0.1	0.3	0.5	0.8
SO_X	**0.2**	**0.1**	**0.3**	**0.4**	**0.6**	**0.8**
Dis-benefits from increased driving:						
Congestion costs	(0.8)	(0.6)	(1.3)	(2.2)	(2.9)	(3.8)
Noise costs	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.1)
Crash costs	(0.4)	(0.3)	(0.6)	(1.0)	(1.4)	(1.8)
Total benefits	12.0	8.0	20.0	34.0	45.0	60.0
Net benefits	8.0	6.0	14.0	25.0	32.0	43.0

Table IV-68. Present Value of Net Benefits ($b) under Proposed Standards Using 3 Percent Discount Rate – MYs 2022-2025 and Total for All MYs

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Costs					
Technology costs	20.0	24.0	30.0	32.0	157
Benefits					
Savings in lifetime fuel expenditures	60.6	68.6	78.4	87.0	452
Consumer surplus from additional driving	2.0	2.2	2.5	2.4	14.8
Value of savings in refueling time	1.3	1.6	2.0	2.4	9.9
Reduction in petroleum market externalities	3.1	3.5	4.0	4.4	23.4
Reduction in climate-related damages from lower CO_2 emissions	6.6	7.5	8.7	9.7	49.1
Reduction in highway fatalities from changes in vehicle mass	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)
Reduction in health damage costs from lower emissions of criteria air pollutants:					
CO	-	-	-	-	-

VOC	0.1	0.1	0.1	0.1	0.7
NO_X	0.0	0.0	0.0	0.0	0.2
PM	1.1	1.3	1.4	1.7	8.3
SO_X	0.9	1.0	1.0	1.1	6.3
Dis-benefits from increased driving:					
Congestion costs	(4.3)	(4.9)	(5.6)	(6.2)	(32.7)
Noise costs	(0.1)	(0.1)	(0.1)	(0.1)	(0.6)
Crash costs	(2.1)	(2.3)	(2.7)	(3.0)	(15.5)
Total benefits	69	78	90	100	515
Net benefits	49	54	60	67	358

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Similarly, Tables IV–69 and 70 below report technology outlays, the individual components of benefits (including "dis-benefits" resulting from additional driving) and their total and net benefits using the 7 percent discount rate. (Again, numbers in parentheses represent negative values.)

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Table IV-69. Present Value of Net Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2017-2021

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Costs						
Technology costs	4.0	3	6	9	13	17
Benefits						
Savings in lifetime fuel expenditures	8.1	5.7	13.9	23.4	31.7	41.6
Consumer surplus from additional driving	0.1	0.0	0.2	0.4	0.6	0.8
Value of savings in refueling time	0.4	0.3	0.6	0.9	1.0	1.4
Reduction in petroleum market externalities	0.5	0.3	0.7	1.2	1.7	2.2
Reduction in climate-related damages from lower CO_2 emissions[774]	1.1	0.7	1.8	3.1	4.2	5.6

[774] Using the central value of $22 per metric ton for the SCC, and discounting future benefits from reduced CO_2 emissions at a 3 percent annual rate. Additionally, we note that the $22 per metric ton value for the SCC applies to calendar year 2010, and increases over time. See the interagency guidance on SCC for more information.

Reduction in highway fatalities from changes in vehicle mass	(0.0)	(0.0)	0.0	(0.1)	(0.0)	(0.0)
Reduction in health damage costs from lower emissions of criteria air pollutants:						
CO	-	-	-	-	-	-
VOC	0.0	0.0	0.0	0.0	0.1	0.1
NO_X	0.0	0.0	0.0	0.0	0.0	0.0
PM	0.1	0.1	0.2	0.4	0.6	0.8
SO_X	0.1	0.1	0.2	0.4	0.5	0.6
Dis-benefits from increased driving:						
Congestion costs	(0.7)	(0.4)	(1.1)	(1.7)	(2.3)	(3.0)
Noise costs	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)
Crash costs	(0.3)	(0.2)	(0.5)	(0.8)	(1.1)	(1.4)
Total benefits	9.0	6.6	16.2	27.2	36.8	48.5
Net benefits	5.0	4.0	10.5	18.3	23.8	31.4

Table IV-70. Present Value of Net Benefits ($b) under Proposed Standards Using 7 Percent Discount Rate – MYs 2022-2025 and Total for All MYs

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Costs					
Technology costs	20	24	30	32	157
Benefits					
Savings in lifetime fuel expenditures	48.1	54.4	62.3	69.2	358.3
Consumer surplus from additional driving	1.0	1.3	1.6	1.9	7.9
Value of savings in refueling time	1.6	1.8	2.0	2.0	11.9
Reduction in petroleum market externalities	2.5	2.8	3.2	3.6	18.7
Reduction in climate-related damages from lower CO_2 emissions	6.6	7.5	8.7	9.7	49.1
Reduction in highway fatalities from changes in vehicle mass	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)
Reduction in health damage costs from lower emissions of criteria air pollutants:					

CO	-	-	-	-	-
VOC	0.1	0.1	0.1	0.1	0.6
NO_X	0.0	0.0	0.0	0.0	0.2
PM	0.9	1.0	1.1	1.3	6.6
SO_X	0.7	0.8	0.8	0.9	5.1
Dis-benefits from increased driving:					
Congestion costs	(3.5)	(3.9)	(4.5)	(5.0)	(26.2)
Noise costs	(0.1)	(0.1)	(0.1)	(0.1)	(0.5)
Crash costs	(1.6)	(1.9)	(2.1)	(2.4)	(12.4)
Total benefits	56.2	63.8	73.2	81.2	419.2
Net benefits	36.4	39.7	43.4	48.8	252.2

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These benefit and cost estimates do not reflect the availability and use of certain flexibility mechanisms, such as compliance credits and credit trading, because EPCA prohibits NHTSA from considering the effects of those mechanisms in setting CAFE standards. However, the agency notes that, in reality, manufacturers are likely to rely to some extent on flexibility mechanisms and would thereby reduce the cost of complying with the proposed standards to a meaningful extent.

As discussed in the PRIA, NHTSA has performed an analysis to estimate costs and benefits taking into account EPCA's provisions regarding EVs, PHEVs produced before MY 2020, FFV credits, and other CAFE credit provisions. Accounting for these provisions indicates that achieved fuel economies would be 0.5–1.6 mpg lower than when these provisions are not considered:

Table IV-71. Average Achieved Fuel Economy (mpg) under Proposed Standards – MYs 2017-2021

(with EPCA AFV and credit provisions)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	38.8	40.6	42.7	44.6	46.1
Light trucks	29.0	30.1	31.8	33.0	34.8
Combined	34.5	36.0	38.0	39.7	41.4

Table IV-72. Average Achieved Fuel Economy (mpg) under Proposed Standards – MYs 2022-2025

(with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	47.2	48.8	50.5	52.7
Light trucks	35.5	36.3	37.4	38.6
Combined	42.4	43.7	45.2	47.0

As a result, NHTSA estimates that, when EPCA AFV and credit provisions are taken into account, fuel savings will total 163 billion gallons—5.8 percent less than the 173 billion gallons estimated when these flexibilities are not considered:

Table IV-73. Fuel Saved (billion gallons) under Proposed Standards – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	4	2	4	6	9	10
LT	0	1	2	4	6	8
Combined	4	3	6	11	14	19

Table IV-74. Fuel Saved (billion gallons) under Proposed Standards – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	12	14	17	20	98
LT	9	10	11	13	65
Combined	21	24	28	32	153

The agency similarly estimates CO_2 emissions reductions will total 1,742 million metric tons (mmt), 5.0 percent less than the 1,834 mmt estimated when these EPCA provisions are not considered:[775]

[775] Differences in the application of diesel engines and plug-in hybrid electric vehicles lead to differences in the percentage changes in fuel consumption and carbon dioxide emissions between the with- and without-credit cases.

Table IV-75. Avoided Carbon Dioxide Emissions (mmt) under Proposed Standards – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	41	23	43	69	93	111
LT	4	7	22	47	64	89
Combined	45	31	65	116	157	200

Table IV-76. Avoided Carbon Dioxide Emissions (mmt) under Proposed Standards – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	128	151	177	204	1,040
LT	100	109	123	138	702
Combined	227	260	300	341	1,742

This analysis further indicates that significant reductions in outlays for additional technology will result when EPCA's AFV and credit provisions are taken into account. Tables IV–77 and 78 below show that, total technology costs are estimated to decline to $133 billion as a result of manufacturers' use of these provisions, or about 15 percent less than the $157 billion estimated when excluding these flexibilities:

Table IV-77. Incremental Technology Outlays ($ billion) under Proposed Standards – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	1	1	3	5	8	10
LT	0	0	1	2	3	4
Combined	1	2	4	7	11	15

Table IV-78. Incremental Technology Outlays ($ billion) under Proposed Standards – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	12	16	19	22	98
LT	5	6	6	8	35
Combined	17	21	25	30	133

Because NHTSA's analysis indicated that these EPCA provisions will modestly reduce fuel savings and related benefits, the agency's estimate of the present value of total benefits will be $488 billion when discounted at a 3 percent annual rate, as Tables IV–79 and 80 below report. This estimate of total benefits is $27 billion, or 5.2 percent, lower than the $515 billion reported previously for the analysis that excluded these provisions:

Table IVV-79. Present Value of Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	10	6	12	19	26	31
LT	1	2	6	12	17	24
Combined	11	8	17	31	43	55

Table IV-80. Present Value of Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	36	43	51	60	293
LT	28	30	35	39	195
Combined	63	74	86	99	488

Similarly, NHTSA estimates that the present value of total benefits will decline modestly from its previous estimate when future fuel savings and other benefits are discounted at the higher 7 percent rate. Tables IV–81 and 82 report that the present value of benefits from requiring higher fuel economy for MY 2017–25 cars and light trucks will total $397 billion when discounted using a 7 percent rate, about $22 billion (5.3 percent) below the previous $419.2 billion estimate of total benefits when FFV credits were not permitted:

Table IV-81. Present Value of Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	8	5	9	15	21	25
LT	1	2	5	10	14	20
Combined	9	7	14	25	35	45

Table IV-82. Present Value of Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	29	35	42	49	240
LT	22	24	28	32	157
Combined	52	60	70	81	397

Although the discounted present value of total benefits will be modestly lower when EPCA AFV and credit provisions are taken into account, the agency estimates that these provisions will reduce net benefits by a smaller proportion. As Tables IV–83 and 84 show, the agency estimates that these will reduce net benefits from the proposed CAFE standards to $355 billion from the previously-reported estimate of $358 billion without those credits, or by only about 1 percent.

Table IV-83. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	9	5	8	13	18	21
LT	1	2	5	10	14	20
Combined	10	6	13	24	32	41

Table IV-84. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	24	28	32	38	195
LT	23	25	28	31	159
Combined	47	52	60	69	354

Similarly, Tables IV–85 and 86 immediately below show that NHTSA estimates manufacturers' use of EPCA AFV and credit provisions will increase net benefits from requiring higher fuel economy for MY 2017–25 cars and light trucks, but very slightly—to $264 billion—if a 7 percent discount rate is applied to future benefits. This estimate is $2 billion—or 0.8 percent—higher than the previously-reported $262 billion estimate of net benefits without the availability of EPCA AFV and credit provisions using that same discount rate.

Table IV-85. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2017-2021 (with EPCA AFV and credit provisions)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	7	4	6	10	13	15
LT	1	1	4	8	11	15
Combined	8	5	10	18	24	30

Table IV-86. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2022-2025 (with EPCA AFV and credit provisions)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
PC	17	20	23	27	142
LT	17	19	21	24	121
Combined	35	39	44	51	263

The agency has performed several sensitivity analyses to examine important assumptions. All sensitivity analyses were based on the ''standard setting'' output of the CAFE model. We examine sensitivity with respect to the following economic parameters:

(1) The price of gasoline: The main analysis (*i.e.,* the Reference Case) uses the AEO 2011 Reference Case estimate for the price of gasoline. In this sensitivity analysis we examine the effect of using the AEO 2011 High Price Case or Low Price Case forecast estimates instead.

(2) The rebound effect: The main analysis uses a rebound effect of 10 percent to project increased miles traveled as the cost per mile driven decreases. In the sensitivity analysis, we examine the effect of using a 5, 15, or 20 percent rebound effect instead.

(3) The value of CO_2 benefits: The main analysis uses $22 per ton discounted at a 3 percent discount rate to quantify the benefits of reducing CO_2 emissions and $0.174 per gallon to quantify the benefits of reducing fuel consumption. In the sensitivity analysis, we examine the following values and discount rates applied only to the social cost of carbon to value carbon benefits, considering low, high, and very high valuations of approximately $5, $36, and $67 per ton, respectively with regard to the benefits of reducing CO_2 emissions.[776] These are the 2010 values, which increase over time. These values can be translated into cents per gallon by multiplying by 0.0089,[777] giving the following values:

($4.86 per ton CO_2) × 0.0089 = $0.043 per gallon discounted at 5%

($22.00 per ton CO_2) × 0.0089 = $0.196 per gallon discounted at 3% (used in the main analysis)

($36.13 per ton CO_2) ×0.0089 = $0.322 per gallon discounted at 2.5%

And a 95th percentile estimate of

($66.88 per ton CO_2) × 0.0089 = $0.595 per gallon discounted at 3%

(4) Military security: The main analysis does not assign a value to the military security benefits of reducing fuel consumption. In the sensitivity analysis, we examine the impact of using a value of 12 cents per gallon instead.

(5) Consumer Benefit: The main analysis assumes there is no loss in value to consumers resulting from vehicles that have an increase in price and higher fuel economy. This sensitivity analysis assumes that there is a 25, or 50 percent loss in value to consumers—equivalent to the assumption that consumers will only value the calculated benefits they will achieve at 75, or 50 percent,

[776] The low, high, and very high valuations of $5, $36, and $67 are rounded for brevity; the exact values are $4.86, $36.13, and $66.88, respectively. While the model uses the unrounded values, the use of unrounded values is not intended to imply that the chosen values are precisely accurate to the nearest cent; rather, they are average levels resulting from the many published studies on the topic.

[777] The molecular weight of Carbon (C) is 12, the molecular weight of Oxygen (O) is 16, thus the molecular weight of CO_2 is 44. 1 gallon of gas weighs 2,819 grams, of that 2,433 grams are carbon. One ton of CO_2/One ton of C (44/12)* 2433grams C/gallon *1 ton/1000kg * 1 kg/1000g = (44 * 2433*1*1)/(12*1*1000 * 1000) = 0.0089. Thus, one ton of CO_2*0.0089 = 1 gallon of gasoline.

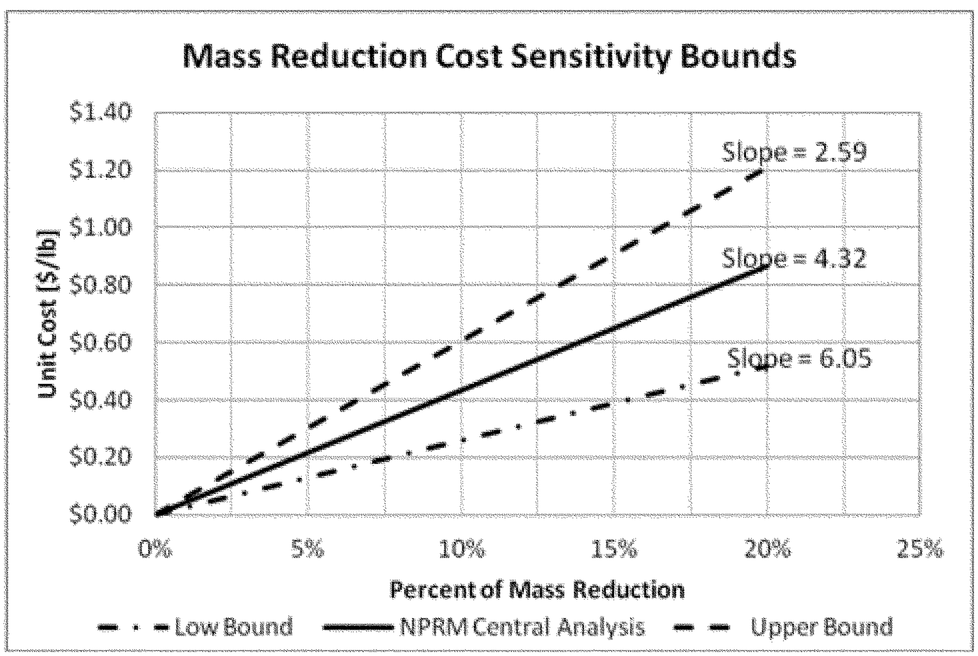
respectively, of the main analysis estimates.

(6) Battery cost: The agency conducted a sensitivity analysis of technology cost in relation to battery costs for HEV, PHEV, and EV batteries. The ranges are based on recommendations from technical experts in the field of battery energy storage technologies at the Department of Energy (DOE) and at Argonne National Laboratories (ANL), and were developed using the Battery Performance and Cost (BatPac) model developed by ANL and funded by DOE.[778] The values for these ranges are shown in the table below and are calculated with 95 percent confidence intervals after analyzing the confidence bound using the BatPac model.

Suggested Confidence Bounds as a Percentage of the Calculated Point Estimate for a Graphite-Based Li-ion Battery Using the Default Inputs in BatPac

Battery Type	Cathodes	Confidence Interval	
		Lower	Upper
HEV	LMO, LFP, NCA, NMC	-10%	10%
PHEV, EV	NMC, NCA	-10%	20%
PHEV, EV	LMO, LFP	-20%	35%

(7) Mass reduction cost: Due to the wide range of mass reduction costs as discussed in Chapter 3 of the draft joint TSD, a sensitivity analysis was performed examining the impact of the cost of vehicle mass reduction to the total technology cost. The direct manufacturing cost (DMC) for mass reduction is represented as a linear function between the unit DMC versus percent of mass reduction, as shown in the figure below:



The slope of the line used in the central analysis for this NPRM is $4.32 per pound per percent of mass reduction. The slope of the line is varied + 40% as the upper and lower bound for this sensitivity study. The resultant values

[778] Section 3.4.3.9 in Chapter 3 of the draft Joint TSD has a detailed description of the history of the BatPac model and how the agencies used it in this NPRM analysis.

for the range of mass reduction cost are shown in the table below:

Bounds for Mass Reduction Direct Manufacturing Cost

Sensitivity Bound	Slope of Mass Reduction Line [$/(lb / %MR)]	Example Unit Direct Manufacturing Cost[1] [$/lb]	Example Total Direct Manufacturing Cost[2] [$/lb]
Lower bound	$2.59	$0.39	$233
NPRM central analysis	$4.32	$0.65	$389
Upper bound	$6.05	$0.91	$544

[1]Example is based on 15% mass reduction

[2]Example is based on 15% mass reduction for a 4,000 lb vehicle

(8) Market-driven response: The baseline for the central analysis is based on the MY 2016 CAFE standards and assumes that manufacturers will make no changes in the fuel economy from that level through MY 2025. A sensitivity analysis was performed to simulate potential increases in fuel economy over the compliance level required if MY 2016 standards were to remain in place. The assumption is that the market would drive manufacturers to put technologies into their vehicles that they believe consumers would value and be willing to pay for. Using parameter values consistent with the central analysis, the agency simulated a market-driven response by applying a payback period of one year for purposes of calculating the value of future fuel savings when simulating whether manufacturers would apply additional technology to an already CAFE-compliant fleet. In other words we assumed that manufacturers that were above their MY 2016 CAFE level would compare the cost to consumers to the fuel savings in the first year of operation and decide to voluntarily apply those technologies to their vehicles when benefits for the first year exceeded costs for the consumer. For a manufacturer's fleet that has not yet achieved compliance with CAFE standards, the agency continued to apply a five-year payback period. In other words, for this sensitivity analysis the agency assumed that manufacturers that have not yet met CAFE standards for future model years will apply technology as if buyers were willing to pay for the technologies as long as the fuel savings throughout the first five years of vehicle ownership exceeded their costs. Once having complied with those standards, however, manufacturers are assumed to consider making further improvements in fuel economy as if buyers were only willing to pay for fuel savings to be realized during the first year of vehicle ownership. The 'market-driven response' assumes that manufacturers will overcomply if additional technology is sufficiently cost-effective. Because this assumption has a greater impact under the baseline standards, its application reduces the incremental costs, effects, and benefits attributable to the new standards. This does not mean that costs, effects, and benefits would actually be smaller with a market-driven response; rather, it means that costs, effects, and benefits would be at least as great, but would be partially attributable not to the new standards, but instead to the market.

Varying each of these eight parameters in isolation results in a variety of economic scenarios, in addition to the Reference case. These are listed in Table IV–87 below.

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Table IV-87. Sensitivity Analyses Evaluated in NHTSA's PRIA

Name	Fuel Price	Discount Rate	Rebound Effect	SCC	Military Security
Reference	Reference	3%	10%	$22	0¢/gal
High Fuel Price	High	3%	10%	$22	0¢/gal
Low Fuel Price	Low	3%	10%	$22	0¢/gal
5% Rebound Effect	Reference	3%	5%	$22	0¢/gal
15% Rebound Effect	Reference	3%	15%	$22	0¢/gal
20% Rebound Effect	Reference	3%	20%	$22	0¢/gal
12¢/gal Military Security Value	Reference	3%	10%	$22	12¢/gal
$5/ton CO_2 Value	Reference	3%	10%	$5	0¢/gal
$36/ton CO_2 Value	Reference	3%	10%	$36	0¢/gal
$67/ton CO_2 Value	Reference	3%	10%	$67	0¢/gal
50% Consumer Benefit	Reference	3%	10%	$22	0¢/gal
75% Consumer Benefit	Reference	3%	10%	$22	0¢/gal
Low Battery Cost	Reference	3%	10%	$22	0¢/gal
High Battery Cost	Reference	3%	10%	$22	0¢/gal
Low Cost Mass Reduction	Reference	3%	10%	$22	0¢/gal
High Cost Mass Reduction	Reference	3%	10%	$22	0¢/gal
Market-Driven Response	Reference	3%	10%	$22	0¢/gal

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The basic results of this sensitivity analysis are contained in Chapter X of the PRIA, but several selected findings are as follows:

(1) Varying the economic assumptions has almost no impact on achieved mpg. The mass reduction cost sensitivities, battery cost reduction sensitivities, and the market-based baseline are the only cases in which achieved mpg differs from the Reference Case of the Preferred Alternative. None of these alter the outcome by more than 0.2 mpg for either fleet.

(2) Varying the economic assumptions has, at most, a small impact on per-vehicle costs, fuel saved, and CO_2 emissions reductions, with none of the variations impacting the outcomes by more than 10 percent from their central analysis levels, save for several exceptions including alternate fuel price sensitivities and the sensitivity involving a 20 percent rebound effect.

(3) The category most affected by variations in the economic parameters considered in these sensitivity analyses is net benefits. The sensitivity analyses examining the AEO Low and High fuel price scenarios demonstrate the potential to negatively impact net benefits by up to 40.3 percent or to increase net benefits by 29.5 percent relative to those of the Preferred Alternative. Other large impacts on net benefits occurred with the 20 percent rebound effect (-38.4%), valuing benefits at 50 and 75 percent (−63.0% and −31.5%, respectively), and valuing the reduction in CO_2 emissions at $67/ton (+28.1%).

(4) Even if consumers value the benefits achieved at 50% of the main analysis assumptions, total benefits still exceed costs.

Regarding the lower fuel savings and CO_2 emissions reductions predicted by the sensitivity analysis as fuel price increases, which initially may seem counterintuitive, we note that there are some counterbalancing factors occurring. As fuel price increases, people will drive less and so fuel savings and CO_2 emissions reductions may decrease.

The agency performed two additional sensitivity analyses presented in Tables IV–88 and IV–89. First, the agency analyzed the impact that having a retail price equivalent (RPE) factor of 1.5 for all technologies would have on the various alternatives instead of using the indirect cost methodology (ICM). The ICM methodology in an overall markup factor of 1.2 to 1.25 compared to the RPE markup factor from variable cost of 1.5. Next, the agency conducted a separate sensitivity analysis using values that were derived from the 2011 NAS Report. This analysis used an RPE markup factor of 1.5 for non-electrification technologies, which is consistent with the NAS estimation for technologies manufactured by suppliers, and an RPE markup factor of 1.33 for electrification technologies (HEV, PHEV, and EV); three types of learning which include no learning for mature technologies, 1.25 percent annual learning for evolutionary technologies, and 2.5 percent annual learning for revolutionary technologies; technology cost estimates for 52 percent (33 out of 63) technologies; and technology effectiveness estimates for 56 percent (35 out of 63) technologies. Cost learning was applied to technology costs in a manner similar to how cost learning is applied in the central analysis for many technologies which have base costs that are applicable to recent or near-term future model years. As noted above, the cost learning factors used for the sensitivity case are different from the values used in the central analysis. For the other inputs in the sensitivity case, where the NAS study has inconsistent information or lacks projections, NHTSA used the same input values that were used in the central analysis.

Table IV-88. Achieved mpg Level, MY 2025, Comparing Different Cost Mark-up Methodologies (3% Discount Rate)

	ICM Method (Main Analysis Costs)	RPE Method (Main Analysis Costs)	Difference (mpg)
Passenger Cars			
Preferred Alternative	52.70	52.24	-0.46
Max Net Benefits	49.09	48.47	-0.61
Light trucks			
Preferred Alternative	39.59	39.38	-0.21
Max Net Benefits	44.31	44.17	-0.14

Table IV-89. Achieved mpg level, MY 2025, Comparing ICM Method with Main Analysis Costs vs. NAS Costs (3% Discount Rate)

	ICM Method (Main Analysis Costs)	ICM Method (NAS Cost Estimates)	Difference (mpg)
Passenger Cars			
Preferred Alternative	52.70	52.11	-0.59
Max Net Benefits	49.09	48.28	-0.80
Light trucks			
Preferred Alternative	39.59	39.08	-0.51
Max Net Benefits	44.31	44.48	0.18

Table IV-90. Sensitivity Analyses (Achieved mpg, Per-Vehicle Cost, Net Benefits, Fuel Saved, & CO_2 Emissions Reduced)

Cost Method and Set of Cost Estimates	MY 2025 Achieved mpg	Average MY 2025 Per-Vehicle Technology Cost	MY 2017-2025 Net Benefits, Discounted 3%, in Billions of $	MY 2017-2025 Fuel Saved, in Billions of Gallons	MY 2017-2025 CO2 Emissions Reduced, in mmT
Passenger Cars					
ICM w/Main Analysis Costs	52.70	$2,023	$190	100	1,059
RPE w/Main Analysis Costs	52.24	$2,509	$164	101	1,062
ICM w/NAS Costs	52.11	$2,811	$149	101	1,074
Light trucks					
ICM w/Main Analysis Costs	39.59	$1,578	$161	69	729
RPE w/Main Analysis Costs	39.38	$2,038	$148	68	722
ICM w/NAS Costs	39.08	$2,405	$139	66	660

For today's rulemaking analysis, the agency has also performed a sensitivity analysis where manufacturers are allowed to voluntarily apply more technology than would be required to comply with CAFE standards for each model year. Manufacturers are assumed to do so as long as applying each additional technology would increase vehicle production costs (including markup) by less than it would reduce buyers' fuel costs during the first year they own the vehicle. This analysis makes use of the ''voluntary overcompliance'' simulation capability DOT has recently added to its CAFE model. This capability, which is discussed further above in section IV.C.4.c and in the CAFE model documentation, is a logical extension of the model's simulation of some manufacturers' decisions to respond to EPCA by paying civil penalties once additional technology becomes economically unattractive. It attempts to simulate manufacturers' responses to buyers' demands for higher fuel economy levels than prevailing CAFE standards would require when fuel costs are sufficiently high, and technologies that manufacturers have not yet fully utilized are available to improve fuel economy at relatively low costs.

NHTSA performed this analysis because some stakeholders commenting on the recently-promulgated standards for medium- and heavy-duty vehicles indicated that it would be unrealistic for the agency to assume that in the absence of new regulations, technology and fuel economy would not improve at all in the future. In other words, these stakeholders argued that market forces are likely to result in some fuel economy improvements over time, as potential vehicle buyers and manufacturers respond to changes in fuel prices and in the availability and costs of technologies to increase fuel economy. NHTSA agrees that, in principle, its analysis should estimate a potential that manufacturers will apply technology as if buyers place some value on fuel economy improvements. Considering current uncertainties discussed below regarding the *degree* to which manufacturers will do so, the agency currently judges it appropriate to conduct its central rulemaking analysis without attempting to simulate these effects. Nonetheless, the agency believes that voluntary overcompliance is sufficiently plausible that corresponding sensitivity analysis is warranted.

NHTSA performed this analysis by simulating potential overcompliance under the no-action alternative, the preferred alternative, and other regulatory alternatives. In doing so, the agency used all the same parameter values as in the agency's central analysis, but applied a payback period of one year for purposes of calculating the value of future fuel savings when simulating whether a manufacturer would apply additional technology to an already CAFE-compliant fleet. For technologies applied to a manufacturer's fleet that has not yet achieved compliance with CAFE standards, the agency continued to apply a five-year payback period.

In other words, for this sensitivity analysis the agency assumed that manufacturers that have not yet met CAFE standards for future model years will apply technology as if buyers were willing to pay for fuel savings throughout the first five years of vehicle ownership. Once having complied with those standards, however, manufacturers are assumed to consider making further improvements in fuel economy as if buyers were only willing to pay for fuel savings to be realized during the first year of vehicle ownership. This reflects the agency's assumptions for this sensitivity analysis, that (1) civil penalties, though legally available, carry a stigma that manufacturers will strive to avoid, and that (2) having achieved compliance with CAFE standards, manufacturers will avoid competitive risks entailed in charging higher prices for vehicles that offer additional fuel economy, rather than offering additional performance or utility.

Since CAFE standards were first introduced, some manufacturers have consistently exceeded those standards, and the industry as a whole has consistently overcomplied with both the passenger car and light truck standards. Although the combined average fuel economy of cars and light trucks declined in some years, this resulted from buyers shifting their purchases from passenger cars to light trucks, not from undercompliance with either standard. Even with those declines, the industry still overcomplied with both passenger car and light truck standards. In recent years, between MYs 1999 and 2009, fuel economy overcompliance has been increasing on average for both the passenger car and the light truck fleets. NHTSA considers it impossible to say with certainty why past fuel economy levels have followed their observed path. If the agency could say with certainty how fuel economy would have changed in the absence of CAFE standards, it might be able to answer this question; however, NHTSA regards this ''counterfactual'' case as simply unknowable.

NHTSA has, however, considered other relevant indications regarding manufacturers' potential future decisions. Published research regarding how vehicle buyers have previously viewed fuel economy suggests that they have only a weak quantitative understanding of the relationship between fuel economy and future fuel outlays, and that potential buyers value fuel economy improvements by less than theoretical present-value calculations of lifetime fuel savings would suggest. These findings are generally consistent with manufacturers' confidential and, in some cases, public statements. Manufacturers have tended to communicate not that buyers absolutely ''don't care'' about fuel economy, but that buyers have, in the past, not been willing to pay the full cost of most fuel economy improvements. Manufacturers have also tended to indicate that sustained high fuel prices would provide a powerful incentive for increased fuel economy; this implies that manufacturers believe buyers are willing to pay for some fuel economy increases, but that buyers' willingness to do so depends on their expectations for future fuel prices. In their confidential statements to the agency, manufacturers have also tended to indicate that in their past product planning processes, they have assumed buyers would only be willing to pay for technologies that ''break even'' within a relatively short time—generally the first two to four years of vehicle ownership.

NHTSA considers it not only feasible but appropriate to simulate such effects by calculating the present value of fuel savings over some ''payback period.'' The agency also believes it is appropriate to assume that specific improvements in fuel economy will be implemented voluntarily if manufacturers' costs for adding the technology necessary to implement them to specific models would be lower than potential buyers' willingness to pay for the resulting fuel savings. This approach takes fuel costs directly into account, and is therefore responsive to manufacturers' statements regarding the role that fuel prices play in influencing buyers' demands and manufacturers' planning processes. Under this approach, a short payback period can be employed if manufacturers are expected to act as if buyers place little value on fuel economy. Conversely, a longer payback period can be used if manufacturers are expected to act as if buyers will place comparatively greater value on fuel economy.

NHTSA cannot be certain to what extent vehicle buyers will, in the future, be willing to pay for fuel economy improvements, or to what extent manufacturers would, in the future, voluntarily apply more technology than needed to comply with fuel economy standards. The agency is similarly hopeful that future vehicle buyers will be more willing to pay for fuel economy improvements than has historically been the case. In meetings preceding today's proposed standards, two manufacturers stated they expected fuel economy to increase two percent to three percent per year after MY 2016, absent more stringent regulations. And in August 2010, one manufacturer stated its combined fleet would achieve 50 mpg by MY 2025, supporting that at a minimum some manufacturers believe that exceeding fuel economy standards will provide them a competitive advantage. The agency is hopeful that future vehicle buyers will be better-informed than has historically been the case, in part because recently-promulgated requirements regarding vehicle labels will provide clearer information regarding fuel economy and the dollar value of resulting fuel savings. The agency is similarly hopeful that future vehicle buyers will be more willing to pay for fuel economy improvements than past buyers. In meetings preceding today's proposed standards, many manufacturers indicated significant shifts in their product plans—shifts consistent with expectations that compared to past buyers, future buyers will ''care more'' about fuel economy.

Nevertheless, considering the uncertainties mentioned above, NHTSA continues to consider it appropriate to conduct its central rulemaking analysis in a manner that ignores the possibility that in the future, manufacturers will voluntarily apply more technology than the minimum necessary to comply with CAFE standards. Also, in conducting its sensitivity analysis to simulate voluntary overcompliance with the proposed standards, the agency has applied the extremely conservative assumption that when considering whether to employ ''extra'' technology, manufacturers will act as if buyers' value the resulting savings in fuel costs only during their first year of ownership (*i.e.,* as if a 1-year payback period applies).

Results of the agency's analysis simulating this potential for voluntary overcompliance are summarized below. Compared to results from the agencies' central analysis presented above, differences are greatest for the baseline scenario (*i.e.,* the No-Action Alternative), under which CAFE standards remain unchanged after MY 2016. These results also suggest, as the agency would expect, that because increasingly stringent standards require progressively more technology than the market will demand, the likelihood of voluntary overcompliance will decline with increasing stringency. Achieved fuel economy levels under baseline standards are as follows:

Table IV-91. Average Achieved Fuel Economy (mpg) under Baseline Standards – MYs 2017-2021 (including voluntary overcompliance)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
PC	37.2	38.4	38.7	38.9	39.0
LT	29.3	29.6	29.8	29.9	30.0
Combined	34.3	34.7	35.0	35.1	35.3

Table IV-92. Average Achieved Fuel Economy (mpg) under Baseline Standards – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025
PC	39.1	39.1	39.2	39.3
LT	30.0	30.2	30.4	30.8
Combined	35.4	35.6	35.8	36.0

With no change in standards after MY 2016, while combined average fuel economy is the same in MY 2017 both with and without simulated voluntary overcompliance, differences grow over time, reaching 0.8 mpg in MY 2025. In other words, without simulating voluntary overcompliance, the agency estimated that combined average achieved fuel economy would reach 35.2 mpg in MY 2025, whereas the agency estimates that it would reach 36.0 mpg in that year if voluntary overcompliance occurred.

In contrast, the effect on achieved fuel economy levels of allowing voluntary overcompliance with the proposed standards was minimal. Allowing manufacturers to overcomply with the proposed standards for MY 2025 led to combined average achieved fuel economy levels approximately equal to levels of values obtained without simulating voluntary overcompliance:

Table IV-93. Average Achieved Fuel Economy (mpg) under Proposed Standards – MYs 2017-2021 (including voluntary overcompliance)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	39.5	41.6	43.6	45.3	47.0
Light trucks	29.6	30.8	32.6	33.9	35.8
Combined	35.2	36.9	38.9	40.5	42.3

Table IV-94. Average Achieved Fuel Economy (mpg) under Proposed Standards – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	48.2	49.4	51.2	52.6
Light trucks	36.8	37.7	38.6	39.6
Combined	43.5	44.7	46.2	47.5

As a result, NHTSA estimates that, when the potential for voluntary overcompliance is taken into account, fuel savings attributable to more stringent standards will total 162 billion gallons—6.4 percent less than the 173 billion gallons estimated when potential voluntary overcompliance is not taken into account:

Table IV-95. Fuel Saved (billion gallons) under Proposed Standards – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	4	2	5	7	9	11
Light trucks	1	0	2	4	6	8
Combined	5	3	7	11	15	19

Table IV-96. Fuel Saved (billion gallons) under Proposed Standards – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	12	14	17	18	99
Light trucks	9	10	11	11	63
Combined	22	24	27	30	162

The agency is not projecting, however, that fuel consumption will be greater when voluntary overcompliance is taken into account. Rather, under today's proposed standards, the agency's analysis shows virtually identical fuel consumption (0.2 percent less over the useful lives of MY 2017–2025 vehicles) when potential voluntary overcompliance is taken into account. Simulation of voluntary overcompliance, therefore, does not reduce the agency's estimate of future fuel savings over the baseline scenario. Rather it changes the attribution of those fuel savings to the proposed standards, because voluntary overcompliance attributes some of the fuel savings to the market. The same holds for the attribution of costs, other effects, and monetized benefits—inclusion of voluntary overcompliance does not necessarily change their amounts, but it does attribute some of each cost, effect, or benefit to the workings of the market, rather than to the proposed standards.

The agency similarly estimates CO_2 emissions reductions attributable to today's proposed standards will total 1,726 million metric tons (mmt), 5.8 percent less than the 1,834 mmt estimated when potential voluntary overcompliance is not taken into account: [779]

[779] Differences in the application of diesel engines and plug-in hybrid electric vehicles lead to differences in the incremental percentage changes in fuel consumption and carbon dioxide emissions.

Table IV-97. Avoided Carbon Dioxide Emissions (mmt) under Proposed Standards – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	41	25	48	72	94	116
Light trucks	6	5	22	45	63	88
Combined	47	30	70	117	157	204

Table IV-98. Avoided Carbon Dioxide Emissions (mmt) under Proposed Standards – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	133	150	174	192	1,047
Light trucks	101	110	118	122	679
Combined	234	260	292	314	1,726

Conversely, this analysis indicates slightly greater outlays for additional technology under the proposed standards when potential voluntary overcompliance is taken into account. This increase is attributable to slight increases in technology application when potential voluntary overcompliance is taken into account. Tables IV–99 and 100 below show that total technology costs attributable to today's proposed standards are estimated to increase to $159 billion, or 1.3 percent more than the $157 billion estimated when potential voluntary overcompliance was not taken into account:

Table IV-99. Incremental Technology Outlays ($ billion) under Proposed Standards – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	3.5	2	5	7	9	12
Light trucks	0	0	1	2	4	5
Combined	4	3	6	9	13	18

Table IV-100. Incremental Technology Outlays ($ billion) under Proposed Standards – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	14	18	22	24	116
Light trucks	6	7	8	9	43
Combined	21	25	30	33	159

Because NHTSA's analysis indicated that voluntary overcompliance with baseline standards will slightly reduce the share of fuel savings attributable to today's standards, the agency's estimate of the present value of total benefits will be $484 billion when discounted at a 3 percent annual rate, as Tables IV–101 and 102 following report. This estimate of total benefits is $31 billion, or about 6 percent, lower than the $515 billion reported previously for the analysis in which potential voluntary overcompliance was not taken into account:

Table IV-101. Present Value of Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	10	7	13	20	26	32
Light trucks	2	1	6	12	17	24
Combined	12	8	19	32	43	56

Table IV-102. Present Value of Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	38	43	50	56	295
Light trucks	28	31	33	35	189
Combined	66	74	84	91	484

Similarly, when accounting for potential voluntary overcompliance, NHTSA estimates that the present value of total benefits will decline from its previous estimate when future fuel savings and other benefits are discounted at the higher 7 percent rate. Tables IV–103 and 104 report that the present value of benefits from requiring higher fuel economy for MY 2017–25 cars and light trucks will total $394 billion when discounted using a 7 percent rate, about $25 billion (or 6 percent) below the previous $419 billion estimate of total benefits when potential voluntary overcompliance is not taken into account:

Table IV-103. Present Value of Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	8	5	11	16	21	26
Light trucks	1	1	5	10	14	19
Combined	10	6	15	26	35	46

Table IV-104. Present Value of Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	31	35	41	46	242
Light trucks	23	25	27	28	152
Combined	53	60	68	74	397

Based primarily on the reduction of benefits attributable to the proposed standards when voluntary overcompliance is taken into account, the agency estimates, as shown in Tables IV–105 and 106, that net benefits from the proposed CAFE standards will be $325 billion—or 9.2 percent—less than the previously-reported estimate of $358 billion, which did not incorporate the potential for voluntary overcompliance.

Table IV-105. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	7	4	8	13	17	20
Light trucks	1	1	5	10	13	19
Combined	8	5	13	23	30	39

Table IV-106. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 3 Percent Discount Rate – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	23	26	29	33	180
Light trucks	22	23	25	26	145
Combined	45	49	54	59	325

Similarly, Tables IV–107 and 108 immediately below show that NHTSA estimates voluntary overcompliance could reduce net benefits attributable to today's proposed standards to $235 billion if a 7 percent discount rate is applied to future benefits. This estimate is $24 billion—or 10.3 percent—lower than the previously-reported $262 billion estimate of net benefits when potential voluntary overcompliance is not taken into account, using that same discount rate.

Table IV-108. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2017-2021 (including voluntary overcompliance)

	Earlier	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger cars	5	3	6	9	12	14
Light trucks	1	1	4	7	10	14
Combined	6	4	9	17	22	28

Table IV-109. Present Value of Net Benefits ($ billion) under Proposed Standards Using a 7 Percent Discount Rate – MYs 2022-2025 (including voluntary overcompliance)

	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger cars	17	18	20	23	126
Light trucks	16	18	19	19	108
Combined	33	35	39	42	234

As discussed above, these reductions in fuel savings and avoided CO_2 emissions (and correspondingly, in total and net benefits) attributable to today's proposed standards, do not indicate that fuel consumption and CO_2 emissions will be higher when potential voluntary overcompliance with standards is taken into account than when it is set aside. Rather, these reductions reflect differences in attribution; when potential voluntary overcompliance is taken into account, portions of the avoided fuel consumption and CO_2 emissions (and, correspondingly, in total and net benefits) are effectively attributed to the actions of the market, rather than to the proposed CAFE standards.

NHTSA invites comment on this sensitivity analysis, in particular regarding the following questions:

Is it reasonable to assume that, having achieved compliance with CAFE standards, a manufacturer might consider further fuel economy improvements, depending on technology costs and fuel prices?

If so, does the agency's approach—comparing technology costs to the present value of fuel savings over some payback period—provide a reasonable means to simulate manufacturers' decisions? DOT's consideration of any alternative methods will be facilitated by specific suggestions regarding their integration into DOT's CAFE model.

Is it appropriate to assume different effective payback periods before and after compliance has been achieved? Why, or why not?

What payback period is (or, if more than one, are) most likely to reflect manufacturers' decisions regarding technology application through MY 2025?

For more detailed information regarding NHTSA's sensitivity analyses for this proposed rule, please see Chapter X of NHTSA's PRIA.

Additionally, due to the uncertainty and difficulty in projecting technology cost and efficacy through 2025, and consistent with Circular A–4, NHTSA conducted a full probabilistic uncertainty analysis, which is included in Chapter XII of the PRIA. Results of the uncertainty analysis are summarized below for model years 2017–2025 passenger car and light truck fleets combined:

Total Benefits at 7% discount rate: Societal benefits will total $46 billion to $725 billion, with a mean estimate of $373 billion.

Total Benefits at 3% discount rate: Societal benefits will total $53 billion to $877 billion, with a mean estimate of $453 billion.

Total Costs at 7% discount rate: Costs will total between $125 billion and $247 billion, with a mean estimate of $175 billion.

Total Costs at 3% discount rate: Costs will total between $109 billion and $294 billion, with a mean estimate of $175 billion

5. How would these proposed standards impact vehicle sales?

In past fuel economy analyses, the agency has made estimates of sales impacts comparing increases in vehicle price to the savings in fuel over a 5 year period. We chose 5 years because this is the average length of time of a financing agreement.[780] As discussed below, for this analysis we have conducted a fresh search of the literature for additional estimates of consumer valuation of fuel savings, in order to determine whether the 5 year assumption was accurate or whether it should be revised. That search has led us to the conclusion for this proposed rule that consumer valuation of future fuel savings is highly uncertain. A negative impact on sales is certainly possible, because the proposed rule will lead to an increase in the initial price of vehicles. A positive impact is also possible, because the proposed rule will lead to a significant decrease in the lifetime cost of vehicles, and with consumer learning over time, this effect may produce an increase in sales. In light of the relevant uncertainties, the agency therefore decided not to include a quantitative sales estimate and requests comments on all of the discussion here, including the question whether a quantitative estimate (or range) is possible.

The effect of this rule on sales of new vehicles depends largely on how potential buyers evaluate and respond to its effects on vehicle prices and fuel economy. The rule will make new cars and light trucks more expensive, as manufacturers attempt to recover their costs for complying with the rule by raising vehicle prices. At the same time, the rule will require manufacturers to improve the fuel economy of many of their models, which will lower their operating costs. The initial cost of vehicles will increase but the overall cost will decrease. The net effect on sales will depend on the extent to which consumers are willing to pay for fuel economy.

The earlier discussion of consumer welfare suggests that by itself, a net decrease in overall cost may not produce a net increase in sales, because many consumers are more affected by upfront cost than by overall cost, and will not be willing to purchase vehicles with greater fuel economy even when it appears to be in their economic interest to do so (assuming standard discount rates). But there is considerable uncertainty in the economics literature about the extent to which consumers value fuel savings from increased fuel economy, and there is still more uncertainty about possible changes in consumer behavior over time (especially with the likelihood of consumer learning). The effect of this proposed regulation on vehicle sales will depend upon whether the overall value that potential buyers place on the increased fuel economy is greater or less than the increase in vehicle prices and how automakers factor that into price setting for the various models.

Two economic concepts bear on how consumers might value fuel savings. The first relates to the length of time that consumers consider when valuing fuel savings and the second relates to the discount rate that consumers apply to future savings. These two concepts are used together to determine consumer valuation of future fuel savings. The length of time that consumers consider when valuing future fuel savings can significantly affect their decision when they compare their estimates of fuel savings with the increased cost of purchasing higher fuel economy. There is a significant difference in fuel savings if you consider the savings over 1 year, 3 years, 5 years, 10 years, or the lifetime of the vehicle. The discount rate that consumers use to discount future fuel savings to present value can also have a significant impact. If consumers value fuel savings over a short period, such as 1 to 2 years, then the discount rate is less important. If consumers value fuel savings over a long period, then the discount rate is important.

The Length of Time Consumers Consider When Valuing Fuel Savings

Information regarding the number of years that consumers value fuel savings (or undervalue fuel savings) come from several sources. In past analyses NHTSA has used five years as representing the average new vehicle loan. A recent paper by David Greene[781] examined studies from the past 20 years of consumers' willingness to pay for fuel economy and found that ''the available literature does not provide a reasonable consensus.'' In his paper Greene states that ''manufacturers have repeatedly stated that consumers will pay, in increased vehicle price, for only 2–4 years in fuel savings.'' These estimates were derived from manufacturer's own market research. And the National Research Council[782] used a 3 year payback period as one of its ways to compare benefits to a full lifetime discounting. A survey conducted for the Department of Energy in 2004,[783] which asked 1,000 households how much they would pay for a vehicle that saved them $400 or $1,200 per year in fuel costs, found implied payback periods of 1.5 to 2.5 years In reviewing this survey, Greene concluded: ''The striking similarity of the implied payback periods from the two subsamples would seem to suggest that consumers understand the questions and are giving consistent and reliable responses: They require payback in 1.5 to 2.5 years.''

However, Turrentine and Kurani's[784] in-depth interviews of 57 households found almost no evidence that consumers think about fuel economy in terms of payback periods. When asked such questions, some consumers became confused while others offered time periods that were meaningful to them for other reasons, such as the length of their car loan or lease.

The Discount Rate That Consumers Apply to Future Fuel Savings

The effective discount rate that consumers have used in the past to value future fuel economy savings has been studied in many different ways and by many different economists. Greene[785] examined and compiled many of these analyses and found: ''Implicit consumer discount rates were estimated by Greene (1983) based on eight early mutinomial logit choice models. * * * The estimates range from 0 to 73% * * * Most fall between 4 and 40%.'' Greene added: ''The more recent studies exhibit as least a wide a range as the earlier studies.''

With such uncertainty about how consumers value future fuel savings and the discount rates they might use to determine the present value of future fuel savings, NHTSA would utilize the standard 3 and 7 percent discount rates. It is true that some consumers appear to show higher discount rates, which would affect the analysis of likely sales consequences; NHTSA invites comments on the nature and extent of that effect.

In past analyses, NHTSA assumed that consumers would consider the fuel savings they would obtain over the first

[780] National average financing terms for automobile loans are available from the Board of Governors of the Federal Reserve System G.19 ''Consumer Finance'' release. *See http://www.federalreserve.gov/releases/g19/* (last accessed August 25, 2011). The average new car loan at an auto finance company in the first quarter of 2011 is for 62 months at 4.73%.

[781] ''Why the Market for New Passenger Cars Generally Undervalues Fuel Economy'', David Greene, Oak Ridge National Laboratory, 2010, Pg. 17, *http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP201006.pdf*

[782] National Research Council (2002) ''Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards'', National Academies Press, Washington DC.

[783] Opinion Research Corporation (2004), ''CARAVAN'' ORC study #7132218, for the National Renewable Energy Laboratory Princeton, New Jersey, May 20, 2004.

[784] Turrentine, T.S. and K.S. Kurani, 2007. ''Car Buyers and Fuel Economy,'' *Energy Policy,* vol. 35, pp. 1213–1223.

[785] ''Why the Market for New Passenger Cars Generally Undervalues Fuel Economy'', David Greene, Oak Ridge National Laboratory, 2010.

five years of vehicle ownership, which is consistent with the average loan rates and the average length of first vehicle ownership. The five-year span is somewhat longer than the period found to be used by consumers in some studies, but use of a shorter period may also reflect a lack of salience or related factors, and as noted, use of the five-year span has the advantage of tracking the average length of first vehicle ownership. NHTSA continues to use the five-year period here. As with discount rates, NHTSA invites comments on this issue and in particular on the possible use of a shorter period.

It is true that the payback period and discount rate are conceptual proxies for consumer decisions that may often be made without any corresponding explicit quantitative analysis. For example, some buyers choosing among some set of vehicles may know what they have been paying recently for gasoline, may know what they are likely to pay to buy each of the vehicles consider, and may know some of the attributes—including labeled fuel economies—of those vehicles. Such buyers may then make a choice without actually trying to estimate how much they would pay to fuel each of the vehicles they are considering buying. In other words, for such buyers, the idea of a payback period and discount rate may have no explicit meaning. This does not, however, limit the utility of these concepts for the agency's analysis. If, as a group, buyers behave as if they value fuel consumption considering a payback period and discount rate, these concepts remain useful as a basis for estimating the market response to increases in fuel economy accompanied by increases in price.

NHTSA's Previous Analytical Approach Updated

There is a broad consensus in the economic literature that the price elasticity for demand for automobiles is approximately –1.0.[786] [787] [788] Thus, every one percent increase in the price of the vehicle would reduce sales by one percent. Elasticity estimates assume no perceived change in the quality of the product. However, in this case, vehicle price increases result from adding technologies that improve fuel economy. This elasticity is generally considered to be a short-run elasticity, reflecting the immediate impacts of a price change on vehicle sales.

For a durable good such as an auto, the elasticity may be smaller in the long run: though people may be able to change the timing of their purchase when price changes in the short run, they must eventually make the investment. Using a smaller elasticity would reduce the magnitude of the estimates presented here for vehicle sales, but it would not change the direction. A short-run elasticity is more valid for initial responses to changes in price, but, over time, a long-run elasticity may better reflect behavior; thus, the results presented for the initial years of the program may be more appropriate for modeling with the short-run elasticity than the later years of the program. A search of the literature has not found studies more recent than the 1970s that specifically investigate long-run elasticities.[789]

One approach to determine the breakeven point between vehicle prices and fuel savings is to look at the payback periods shown earlier in this analysis. For example at a 3 percent discount rate, the payback period for MY 2025 vehicles is 2 years for light trucks and 4 years for passenger cars.

In determining the payback period we make several assumptions. For example, we follow along with the calculations that are used for a 5 year payback period, as we have used in previous analyses. For the fuel savings part of the equation, we assumed as a starting point that the average purchaser considers the fuel savings they would receive over a 5 year timeframe. The present values of these savings were calculated using a 3 and 7 percent discount rate. We used a fuel price forecast (see Table VIII–3) that included taxes, because this is what consumers must pay. Fuel savings were calculated over the first 5 years and discounted back to a present value.

The agency believes that consumers may consider several other factors over the 5 year horizon when contemplating the purchase of a new vehicle. The agency added these factors into the calculation to represent how an increase in technology costs might affect consumers' buying considerations.

First, consumers might consider the sales taxes they have to pay at the time of purchasing the vehicle. We took sales taxes in 2010 by state and weighted them by population by state to determine a national weighted-average sales tax of 5.5 percent.[790]

Second, we considered insurance costs over the 5 year period. More expensive vehicles will require more expensive collision and comprehensive (*e.g.,* theft) car insurance. The increase in insurance costs is estimated from the average value of collision plus comprehensive insurance as a proportion of average new vehicle price. Collision plus comprehensive insurance is the portion of insurance costs that depend on vehicle value. The Insurance Information Institute [791] provides the average value of collision plus comprehensive insurance in 2006 as $448, which is $480 in 2009$. The average consumer expenditure for a new passenger car in 2010, according to the Bureau of Economic Analysis was $24,092 and the average price of a new light truck $30,641 in $2009.[792] Using sales volumes from the Bureau, we determined an average passenger car and an average light truck price was $27,394 in $2009 dollars. Average prices and estimated sales volumes are needed because price elasticity is an estimate of how a percent increase in price affects the percent decrease in sales.

Dividing the insurance cost by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.75% of the price of a vehicle. If we assume that this premium is proportional to the new vehicle price, it represents about 1.75 percent of the new vehicle price and insurance is paid each year for the five year period we are considering for payback. Discounting that stream of insurance costs back to present value indicates that the present value of the component of insurance costs that vary with vehicle price is equal to 8.0 percent of the vehicle's price at a 3 percent discount rate.

Third, we considered that 70 percent of new vehicle purchasers take out loans

[786] Kleit, A.N. (1990). ''The Effect of Annual Changes in Automobile Fuel Economy Standards,'' *Journal of Regulatory Economics,* vol. 2, pp 151–172. Docket EPA–HQ–OAR–2009–0472–0015.

[787] Bordley, R. (1994). ''An Overlapping Choice Set Model of Automotive Price Elasticities,'' *Transportation Research B,* vol 28B, no 6, pp 401–408. Docket NHTSA–2009–0059–0153.

[788] McCarthy, P.S. (1996). ''Market Price and Income Elasticities of New Vehicle Demands,'' *The Review of Economics and Statistics,* vol. LXXVII, no. 3, pp. 543–547. Docket NHTSA–2009–0059–0039

[789] E.g., Hymans, Saul H. ''Consumer Durable Spending: Explanation and Prediction.'' Brookings Papers on Economic Activity 1 (1970): 173–206.

http://www.brookings.edu/~/media/Files/Programs/ES/BPEA/1970_2_bpea_papers/1970b_bpea_hymans_ackley_juster.pdf finds a short-run elasticity of auto expenditures (not sales) with respect to price of 0.78 to 1.17, and a long-run elasticity of 0.3 to 0.46.

[790] Based on data found in *http://www.api.org/statistics/fueltaxes/*

[791] Insurance Information Institute, 2008, ''Average Expenditures for Auto Insurance By State, 2005–2006,'' *available at http://www.iii.org/media/facts/statsbyissue/auto/* (last accessed March 4, 2010).

[792] U.S. Department of Commerce, Bureau of Economic Analysis, Table 7.2.5S. Auto and Truck Unit Sales, Production, Inventories, Expenditures, and Price, available at *http://www.bea.gov/national/nipaweb/nipa_underlying/TableView.asp?SelectedTable=55&ViewSeries=NO&Java=.*

to finance their purchase. The average new vehicle loan in the first quarter of 2011 is 5.3 percent.[793] At these terms the average person taking a loan will pay 14 percent more for their vehicle over the 5 years than a consumer paying cash for the vehicle at the time of purchase.[794] Discounting the additional 2.8 percent (14 percent/5 years) per year over the 5 years using a 3 percent mid-year discount rate[795] results in a discounted present value of 12.73 percent higher for those taking a loan. Multiplying that by the 70 percent that take a loan, means that the average consumer would pay 8.9 percent more than the retail price for loans the consumer discounted at a 3 percent discount rate.

Fourth, we considered the residual value (or resale value) of the vehicle after 5 years and expressed this as a percentage of the new vehicle price. If the price of the vehicle increases due to fuel economy technologies, the resale value of the vehicle will go up proportionately. The average resale price of a vehicle after 5 years is about 35%[796] of the original purchase price. Discounting the residual value back 5 years using a 3 percent discount rate (35 percent * .8755) gives an effective residual value of 30.6 percent. Note that added CAFE technology could also result in more expensive or more frequent repairs. However, we do not have data to verify the extent to which this would be a factor during the first 5 years of vehicle life.

We add these four factors together. At a 3 percent discount rate, the consumer considers he could get 30.6 percent back upon resale in 5 years, but will pay 5.5 percent more for taxes, 8.1 percent more in insurance, and 8.9 percent more for loans, results in a 8.1 percent return on the increase in price for fuel economy technology (30.6 percent − 5.5 percent − 8.1 percent − 8.9 percent). Thus, the increase in price per vehicle would be multiplied by 0.919 (1 − 0.081) before subtracting the fuel savings to determine the overall net consumer valuation of the increase of costs on this purchase decision. This process results in estimates of the payback period for MY 2025 vehicles of 2 years for light trucks and 4 years for passenger cars at a 3 percent discount rate.

A General Discussion of Consumer Considerations

If consumers do not value improved fuel economy at all, and consider nothing but the increase in price in their purchase decisions, then the estimated impact on sales from price elasticity could be applied directly. However, the agency anticipates that consumers will place some value improved fuel economy, because they reduce the operating cost of the vehicles, and because, based on recently-promulgated EPA and DOT regulations, vehicles sold during through 2025 will display labels that more clearly communicate to buyers the fuel savings, economic, and environmental benefits of more efficient vehicles. The magnitude of this effect remains unclear, and how much consumers value fuel economy is an ongoing debate. We know that different consumers value different aspects of their vehicle purchase,[797] but we do not have reliable evidence of consumer behavior on this issue. Several past consumer surveys lead to different conclusions (and surveys themselves, as opposed to actual behavior, may not be entirely informative). We also expect that consumers will consider other factors that affect their costs, and have included these in the analysis.

One issue that significantly affects this sales analysis is: How much of the retail price increase needed to cover the fuel economy technology investments will manufacturers be able to pass on to consumers? NHTSA typically assumes that manufacturers will be able to pass all of their costs to improve fuel economy on to consumers. Consumer valuation of fuel economy improvements often depends upon the price of gasoline, which has recently been very volatile.

Sales losses would occur only if consumers fail to value fuel economy improvements at least as much as they pay in higher prices. If manufacturers are unable to raise prices beyond the level of consumer's valuation of fuel savings, then manufacturer's profit levels would fall but there would be no impact on sales. Likewise, if fuel prices rise beyond levels used in this analysis, consumer's valuation of improved fuel economy could increase to match or exceed their initial investment, resulting in no impact or even an increase in sales levels.

The agency has been exploring the question why there is not more consumer demand for higher fuel economy today when linked with our methodology that results in projecting increasing sales for the future when consumers are faced with rising vehicle prices and rising fuel economy. Some of the discussion of salience, focus on the short-term, loss aversion, and related factors (see above) bears directly on that question. It is possible, in that light, that consumers will not demand increased fuel economy even when such increases would produce net benefits for them.

Nonetheless, some current vehicle owners, including those who currently drive gas guzzlers, will undoubtedly realize the net benefits to be gained by purchasing a more efficient vehicle. Some vehicle owners may also react to persistently higher vehicle costs by owning fewer vehicles, and keeping existing vehicles in service for somewhat longer. For these consumers, the possibility exists that there may be permanent sales losses, compared with a situation in which vehicle prices are lower.

There is a wide variety in the number of miles that owners drive per year. Some drivers only drive 5,000 miles per year and others drive 25,000 miles or more. Rationally those that drive many miles have more incentive to buy vehicles with high fuel economy levels

In summary, there are a variety of types of consumers that are in different financial situations and drive different mileages per year. Since consumers are different and use different reasoning in purchasing vehicles, and we do not yet have an account of the distribution of their preferences or how that may change over time as a result of this rulemaking — in other words, the answer is quite ambiguous. Some may be induced by better fuel economy to purchase vehicles more often to keep up with technology, some may purchase no new vehicles because of the increase in vehicle price, and some may purchase fewer vehicles and hold onto their vehicles longer. There is great uncertainty about how consumers value fuel economy, and for this reason, the impact of this fuel economy proposal on sales is uncertain.

For years, consumers have been learning about the benefits that accrue to them from owning and operating vehicles with greater fuel efficiency. Consumer demand has thus shifted towards such vehicles, not only because of higher fuel prices but also because

[793] New car loan rates in the first quarter of 2011 averaged 5.86 percent at commercial banks and 4.73 percent at auto finance companies, so their average is close to 5.3 percent.

[794] Based on *www.bankrate.com* auto loan calculator for a 5 year loan at 5.3 percent.

[795] For a 3 percent discount rate, the summation of 2.8 percent × 0.9853 in year one, 2.8 × 0.9566 in year two, 2.8 × 0.9288 in year three, 2.8 × 0.9017 in year 4, and 2.8 × 0.8755 in year five.

[796] Consumer Reports, August 2008,''What That Car Really Costs to Own,'' *available at http://www.consumerreports.org/cro/cars/pricing/what-that-car-really-costs-to-own-4–08/overview/what-that-car-really-costs-to-own-ov.htm* (last accessed March 4, 2010).

[797] For some consumers there will be a cash-flow problem in that the vehicle is purchased at a higher price on day 1 and fuel savings occur over the lifetime of the vehicle. Increases in prices have sometimes led to longer loan periods, which would lead to higher overall costs of the loan.

many consumers are learning about the value of purchases based not only on initial costs but also on the total cost of owning and operating a vehicle over its lifetime. This type of learning is expected to continue before and during the model years affected by this rule, particularly given the new fuel economy labels that clarify potential economic effects and should therefore reinforce that learning. Therefore, some increase in the demand for, and production of, more fuel efficient vehicles is incorporated in the alternative baseline (*i.e.,* without these rules) developed by NHTSA. The agency requests comment on the appropriateness of using a flat or rising baseline after 2016.

Today's proposed rule, combined with the new and easier-to-understand fuel economy label required to be on all new vehicles beginning in 2012, may increase sales above baseline levels by hastening this very type of consumer learning. As more consumers experience, as a result of the rule, the savings in time and expense from owning more fuel efficient vehicles, demand may shift yet further in the direction of the vehicles mandated under the rule. This social learning can take place both within and across households, as consumers learn from one another.

First and most directly, the time and fuel savings associated with operating more fuel efficient vehicles will be more salient to individuals who own them, causing their subsequent purchase decisions to shift closer to minimizing the total cost of ownership over the lifetime of the vehicle. Second, this appreciation may spread across households through word of mouth and other forms of communications. Third, as more motorists experience the time and fuel savings associated with greater fuel efficiency, the price of used cars will better reflect such efficiency, further reducing the cost of owning more efficient vehicles for the buyers of new vehicles (since the resale price will increase).

If these induced learning effects are strong, the rule could potentially increase total vehicle sales over time. These increased sales would not occur in the model years first affected by the rule, but they could occur once the induced learning takes place. It is not possible to quantify these learning effects years in advance and that effect may be speeded or slowed by other factors that enter into a consumer's valuation of fuel efficiency in selecting vehicles.

The possibility that the rule will (after a lag for consumer learning) increase sales need not rest on the assumption that automobile manufacturers are failing to pursue profitable opportunities to supply the vehicles that consumers demand. In the absence of the rule, no individual automobile manufacturer would find it profitable to move toward the more efficient vehicles mandated under the rule. In particular, no individual company can fully internalize the future boost to demand resulting from the rule. If one company were to make more efficient vehicles, counting on consumer learning to enhance demand in the future, that company would capture only a fraction of the extra sales so generated, because the learning at issue is not specific to any one company's fleet. Many of the extra sales would accrue to that company's competitors.

In the language of economics, consumer learning about the benefits of fuel efficient vehicles involves positive externalities (spillovers) from one company to the others.[798] These positive externalities may lead to benefits for manufacturers as a whole.

We emphasize that this discussion has been tentative and qualified. To be sure, social learning of related kinds has been identified in a number of contexts.[799] Comments are invited on the discussion offered here, with particular reference to any relevant empirical findings.

How does NHTSA plan to address this issue for the final rule?

NHTSA seeks comment on how to attempt to quantify sales impacts of the proposed MYs 2017–2025 CAFE standards in light of the uncertainty discussed above. The agency is currently sponsoring work to develop a vehicle choice model for potential use in the agency's future rulemaking analysis—this work may help to better estimate the market's effective valuation of future fuel economy improvements. The agency hopes to evaluate those potential impacts through use of a ''market shift'' or ''consumer vehicle choice'' model, discussed in Section IV of the NPRM preamble. With an integrated market share model, the CAFE model would then estimate how the sales volumes of individual vehicle models would change in response to changes in fuel economy levels and prices throughout the light vehicle market, possibly taking into account interactions with the used vehicle market. Having done so, the model would replace the sales estimates in the original market forecast with those reflecting these model-estimated shifts, repeating the entire modeling cycle until converging on a stable solution. We seek comment on the potential for this approach to help the agency estimate sales effects for the final rule.

Others Studies of the Sales Effect of This CAFE Proposal

We outline here other relevant studies and seek comment on their assumptions and projections.

A recent study on the effects on sales, attributed to regulatory programs, including the fuel economy program was undertaken by the Center for Automotive Research (CAR).[800] CAR examined the impacts of alternative fuel economy increases of 3%, 4%, 5%, and 6% per year on the general outlook for the U.S. motor vehicle market, the likely increase in costs for fuel economy (based on the NAS report, which estimates higher costs than NHTSA's current estimates) and required safety features, the technologies used and how they would affect the market, production, and automotive manufacturing employment in the year 2025. The required safety mandates were assumed to cost $1,500 per vehicle in 2025, but CAR did not value the safety benefits from those standards. NHTSA does not believe that the assumed safety mandates should be a part of this analysis without estimating the benefits achieved by the safety mandates.

There are many factors that go into the CAR analysis of sales. CAR assumes a 22.0 mpg baseline, two gasoline price scenarios of $3.50 and $6.00 per gallon, VMT schedules by age, and a rebound rate of 10 percent (although it appears that the CAR report assumes a rebound effect even for the baseline and thus negates the impact of the rebound effect). Fuel savings are assumed to be valued by consumers over a 5 year period at a 10 percent discount rate. The impact on sales varies by scenario, the estimates of the cost of technology, the price of gasoline, etc. At $3.50 per gallon, the net change in consumer savings (costs minus the fuel savings

[798] Industry-wide positive spillovers of this type are hardly unique to this situation. In many industries, companies form trade associations to promote industry-wide public goods. For example, merchants in a given locale may band together to promote tourism in that locale. Antitrust law recognizes that this type of coordination can increase output.

[799] See Hunt Alcott, Social Norms and Energy Conservation, Journal of Public Economics (forthcoming 2011), available at *http://web.mit.edu/allcott/www/Allcott%202011%20JPubEc%20-%20Social%20Norms%20and%20Energy%20Conservation.pdf*; Christophe Chamley, Rational Herds: Economic Models of Social Learning (Cambridge, 2003).

[800] ''The U.S. Automotive Market and Industry in 2025'', Center for Automotive Research, June 2011. *http://www.cargroup.org/pdfs/ami.pdf.*

valued by consumers) is a net cost to consumers of $359 for the 3% scenario, a net cost of $1,644 for the 4% scenario, a net cost of $2,858 for the 5% scenario, and a net consumer cost of $6,525 for the 6% scenario. At $6.00 per gallon, the net change in consumer savings (costs minus the fuel savings valued by consumers) is a net savings to consumers of $2,107 for the 3% scenario, a net savings of $1,131 for the 4% scenario, a net savings of $258 for the 5% scenario, and a net consumer cost of $3,051 for the 6% scenario. Thus, the price of gasoline can be a significant factor in affecting how consumers view whether they are getting value for their expenditures on technology.

Table 14 on page 42 of the CAR report presents the results of their estimates of the 4 alternative mpg scenarios and the 2 prices of gasoline on light vehicle sales and automotive employment. The table below shows these estimates. The baseline for the CAR report is 17.9 million sales and 877,075 employees. The price of gasoline at $6.00 per gallon, rather than $3.50 per gallon results in about 2.1 million additional sales per year and 100,000 more employees in year 2025.

Gasoline at $3.50	CAFE requirement of a 3% increase in mpg per year	CAFE requirement of a 4% increase in mpg per year	CAFE requirement of a 5% increase in mpg per year	CAFE requirement of a 6% increase in mpg per year
Sales (millions)	16.4	15.5	14.7	12.5
Employment	803,548	757,700	717,626	612,567
Gasoline at $6.00				
Sales	18.5	17.6	16.9	14.5
Employment	903,135	861,739	826,950	711,538

Figure 13 on page 44 of the CAR report shows a graph of historical automotive labor productivity, indicating that there has been a long term 0.4 percent productivity growth rate from 1960–2008, to indicate that there will be 12.26 vehicles produced in the U.S. per worker in 2025 (which is higher than NHTSA's estimate—see below). In addition, the CAR report discusses the jobs multiplier. For every one automotive manufacturing job, they estimate the economic contribution to the U.S. economy of 7.96 jobs [801] stating "In 2010, about 1 million direct U.S. jobs were located at an auto and auto parts manufacturers; these jobs generated an additional 1.966 million supplier jobs, largely in non-manufacturing sectors of the economy. The combined total of 2.966 million jobs generated a further spin-off of 3.466 million jobs that depend on the consumer spending of direct and supplier employees, for a total jobs contribution from U.S. auto manufacturing of 6.432 million jobs in 2010. The figure actually rises to 7.96 million when direct jobs located at new vehicle dealerships (connected to the sale and service of new vehicles) are considered."

CAR uses econometric estimates of the sensitivity of new vehicle purchases to prices and consumer incomes and forecasts of income growth through 2025 to translate these estimated changes in net vehicle prices to estimates of changes in sales of MY 2025 vehicles; higher net prices—which occur when increases in vehicle prices exceeds the value of fuel savings—reduce vehicle sales, while lower net prices increase new vehicle sales in 2025. We do not have access to the statistical models that CAR develops to estimate the effects of price and income changes on vehicle sales. CAR's analysis assumes continued increases in labor productivity over time and then translates the estimated impacts of higher CAFE standards on net vehicle prices into estimated impacts on sales and employment in the automobile production and related industries. The agency disagrees with the cost estimates in the CAR report for new technologies, the addition of safety mandates into the costs, and various other assumptions.

An analysis conducted by Ceres and Citigroup Global Markets Inc.[802] examined the impact on automotive sales in 2020, with a baseline assumption of an industry fuel economy standard of 42 mpg, a $4.00 price of

[801] Kim Hill, Debbie Menk, and Adam Cooper, "Contribution of the Automotive Industry to the Economies of All Fifty States and the United States", The Center for Automotive Research, Ann Arbor MI, April 2010.

[802] "U.S. Autos, CAFE and GHG Emissions", March 2011, Citi Ceres, UMTRI, Baum and Associates, Meszler Engineering Services, and the Natural Resources Defense Council. *http://www.ceres.org/resources/reports/fuel-economy-focus.*

gasoline, a 12.2 percent discount rate and an assumption that buyers value 48% of fuel savings over seven years in purchasing vehicles. The main finding on sales was that light vehicle sales were predicted to increase by 6% from 16.3 million to 17.3 million in 2020. Elasticity is not provided in the report but it states that they use a complex model of price elasticity and cross elasticities developed by GM. A fuel price risk factor [803] was utilized. Little rationale was provided for the baseline assumptions, but sensitivity analyses were examined around the price of fuel ($2, $4, and $7 per gallon), the discount rate (5.2%, 12.2%, 17.2%), purchasers consider fuel savings over (3, 7, or 15 years), fuel price risk factor of (30%, 70%, or 140%), and VMT of (10,000, 15,000, and 20,000 in the first year and declining thereafter).

6. Social Benefits, Private Benefits, and Potential Unquantified Consumer Welfare Impacts of the Proposed Standards

There are two viewpoints for evaluating the costs and benefits of the increase in CAFE standards: the private perspective of vehicle buyers themselves on the higher fuel economy levels that the rule would require, and the economy-wide or ''social'' perspective on the costs and benefits of requiring higher fuel economy. In order to appreciate how these viewpoints may diverge, it is important to distinguish between costs and benefits that are ''private'' and costs and benefits that are ''social,'' The agency's analysis of benefits and costs from requiring higher fuel efficiency, presented above, includes several categories of benefits (identified as ''social benefits'') that are not limited to automobile purchasers, and that extend throughout the U.S. economy. Examples of these benefits include reductions in the energy security costs associated with U.S. petroleum imports, and in the economic damages expected to result from air pollution (including, but not limited to, climate change). In contrast, other categories of benefits—principally future fuel savings projected to result from higher fuel economy, but also, for example, time savings—will be experienced exclusively by the initial purchasers and subsequent owners of vehicle models whose fuel economy manufacturers elect to improve (''private benefits'').

The economy-wide or ''social'' benefits from requiring higher fuel economy represent an important share of the total economic benefits from raising CAFE standards. At the same time, NHTSA estimates that benefits to vehicle buyers themselves will significantly exceed vehicle manufacturers' costs for complying with the stricter fuel economy standards this rule establishes. In short, consumers will benefit on net. Since the agency also assumes that the costs of new technologies manufacturers will employ to improve fuel economy will ultimately be borne by vehicle buyers in the form of higher purchase prices, NHTSA concludes that the benefits to potential vehicle buyers from requiring higher fuel efficiency will far outweigh the costs they will be required to pay to obtain it. NHTSA also recognizes that this conclusion raises certain issues, addressed directly below; NHTSA also seeks public comment on its discussion here.

As an illustration, Tables IV–110 and 111 report the agency's estimates of the average lifetime values of fuel savings for MY 2017–2025 passenger cars and light trucks calculated using projected future retail fuel prices. The table compares NHTSA's estimates of the average lifetime value of fuel savings for cars and light trucks to the price increases it expects to occur as manufacturers attempt to recover their costs for complying with increased CAFE standards. As the table shows, the agency's estimates of the present value of lifetime fuel savings (discounted using the OMB-recommended 3% rate) substantially outweigh projected vehicle price increases for both cars and light trucks in every model year, even under the assumption that all of manufacturers' technology outlays are passed on to buyers in the form of higher selling prices for new cars and light trucks. By model year 2025, NHTSA projects that average lifetime fuel savings will exceed the average price increase by more than $2,900 for cars, and by more than $5,200 for light trucks.

[802] ''U.S. Autos, CAFE and GHG Emissions'', March 2011, Citi Ceres, UMTRI, Baum and Associates, Meszler Engineering Services, and the Natural Resources Defense Council. *http://www.ceres.org/resources/reports/fuel-economy-focus.*

Table IV-110. Value of Lifetime Fuel Savings vs. Vehicle Price Increases – MYs 2017-2021

Fleet	Measure	Model year				
		2017	2018	2019	2020	2021
Passenger cars	Value of fuel savings	$668	$1,409	$2,035	$2,643	$3,186
	Average price increase	$228	$467	$652	$885	$1,108
	Difference	$440	$942	$1,383	$1,758	$2,078
Light trucks	Value of fuel savings	$228	$999	$2,278	$3,104	$4,400
	Average price increase	$44	$187	$427	$688	$965
	Difference	$184	$812	$1,851	$2,416	$3,435

Table IV-111. Value of Lifetime Fuel Savings vs. Vehicle Price Increases – MYs 2022-2025

Fleet	Measure	Model year			
		2022	2023	2024	2025
Passenger cars	Value of fuel savings	$3,568	$4,010	$4,600	$4,999
	Average price increase	$1,259	$1,536	$1,927	$2,023
	Difference	$2,309	$2,474	$2,673	$2,976
Light trucks	Value of fuel savings	$5,114	$5,675	$6,215	$6,804
	Average price increase	$1,102	$1,284	$1,428	$1,578
	Difference	$4,012	$4,391	$4,787	$5,226

The comparisons above immediately raise the question of why current vehicle purchasing patterns do not already result in average fuel economy levels approaching those that this rule would require, and why raising CAFE standards should be necessary to increase the fuel economy of new cars and light trucks. They also raise the question of whether it is appropriate to assume that manufacturers would not elect to provide higher fuel economy even in the absence of increases in CAFE standards, since the comparisons in Tables IV–109 and 110 suggest that doing so would increase the market value (and thus the selling prices) of many new vehicle models by far more than it would raise the cost of producing them. Thus, increasing fuel economy would be expected to increase sales of new vehicles and manufacturers' profits. More specifically, why would potential buyers of new vehicles hesitate to purchase models offering higher fuel economy, when doing so would produce the substantial economic returns illustrated by the comparisons presented in Tables IV–109 and 110? And why would manufacturers voluntarily forego opportunities to increase the attractiveness, value, and competitive positioning of their car and light truck models—and thus their own profits—by improving their fuel economy?

One explanation for why this situation might persist is that the market for vehicle fuel economy does not appear to work perfectly, in which case properly designed CAFE standards would be expected to increase consumer welfare. Some of these imperfections might stem from standard market failures, such as limited availability of information to consumers about the value of higher fuel economy. It is true, of course, that such information is technically available and that new fuel economy and environment vehicle labels, emphasizing economic effects, will provide a wide range of relevant information. Other explanations would point to phenomena observed elsewhere in the field of behavioral economics, including loss aversion, inadequate consumer attention to long-term savings, or a lack of salience of relevant benefits (such as fuel savings, or time savings associated with refueling) to consumers at the time they make purchasing decisions. Both theoretical and empirical research suggests that many consumers are unwilling to make energy-efficient investments even when those investments appear to pay off in the relatively short-term.[804] This research is in line with related findings that consumers may undervalue benefits or costs that are less salient, or that they will realize only in the future.[805]

Previous research provides some support for the agency's conclusion that the benefits buyers will receive from requiring manufacturers to increase fuel economy outweigh the costs they will pay to acquire those benefits, even if private markets have not provided that amount of fuel economy. This research identifies aspects of normal behavior that may explain the market not providing vehicles whose higher fuel economy appears to offer an attractive economic return. For example, consumers' aversion to the prospect of losses (''loss aversion'') and especially immediate, certain losses, may affect their decisions when they also have a sense of uncertainty about the value of future fuel savings. Loss aversion, accompanied with a sense of uncertainty about gains, may make purchasing a more fuel-efficient vehicle seem unattractive to some potential buyers, even when doing so is likely to be a sound economic decision. As an illustration, Greene et al. (2009) calculate that the expected net present value of increasing the fuel economy of a passenger car from 28 to 35 miles per gallon falls from $405 when calculated using standard net present value calculations, to nearly zero when uncertainty regarding future cost savings and buyers' reluctance to accept the risk of losses are taken into account.[806]

The well-known finding that as gas prices rise, consumers show more willingness to pay for fuel-efficient vehicles is not necessarily inconsistent with the possibility that many consumers undervalue potential savings in gasoline costs and fuel economy when purchasing new vehicles. In ordinary circumstances, such costs may be a relatively ''shrouded'' attribute in consumers' decisions, in part because the savings from purchasing a more fuel efficient vehicle are cumulative and extend over a significant period of time. At the same time, it may be difficult for potential buyers to disentangle the cost of purchasing a more fuel-efficient vehicle from its overall purchase price, or to isolate the value of higher fuel economy form accompanying differences in other vehicle attributes. This possibility is consistent with recent evidence to the effect that many consumers are willing to pay less than $1 upfront to obtain a $1 reduction in the discounted present value of future gasoline costs.[807]

Some research suggests that the market's apparent unwillingness to provide more fuel efficient vehicles stems from consumers' inability to value future fuel savings correctly. For example, Larrick and Soll (2008) find evidence that consumers do not understand how to translate changes in fuel economy, which is denominated in miles per gallon (MPG), into resulting changes in fuel consumption, measured for example in gallons 100 miles traveled or per month or year.[808] It is true that the recently redesigned fuel economy and environment label should help overcome this difficulty, because it draws attention to purely economic effects of fuel economy, but MPG remains a prominent measure. Sanstad and Howarth (1994) argue that consumers often resort to imprecise but convenient rules of thumb to compare vehicles that offer different fuel economy ratings, and that this can cause many buyers to underestimate the value of fuel savings, particularly from significant increases in fuel economy.[809] If the behavior identified in these studies is widespread, then the agency's estimates suggesting that the benefits to vehicle owners from requiring higher fuel economy significantly exceed the costs of providing it may be consistent with private markets not providing that fuel economy level.

The agency projects that the typical vehicle buyer will experience net savings from the proposed standards, yet it is not simple to reconcile this projection with the fact that the average fuel economy of new vehicles sold currently falls well short of the level those standards would require. The foregoing discussion offers several possible explanations. One possible explanation for this apparent inconsistency is that many of the technologies projected by the agency to be available through MY 2025 offer significantly improved efficiency per unit of cost, but were not available for application to new vehicles sold currently. Another is that the perceived and real values of future savings resulting from the proposed standards will vary widely among potential

[803] Fuel price risk factor measures the rate at which consumers are willing to trade reductions in fuel costs for increases in purchase price. For example, a fuel price risk factor of 1.0 would indicate the consumers would be willing to pay $1 for an improvement in fuel economy that resulted in reducing by $1 the present value of the savings in fuel costs.

[804] Jaffe, A. B., and Stavins, R. N. (1994). The Energy Paradox and the Diffusion of Conservation Technology. Resource and Energy Economics, 16(2); see Hunt Alcott and Nathan Wozny, Gasoline Prices, Fuel Economy, and the Energy Paradox (2009), available at *http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf* (last accessed Sept. 26, 2011). For relevant background, with an emphasis on the importance of salience and attention, see Kahneman, D. Thinking, Fast and Slow (2011).

[805] Mutulinggan, S., C. Corbett, S. Benzarti, and B. Oppenheim. ''Investment in Energy Efficiency by Small and Medium-Size Firms: An Empirical Analysis of the Adoption of Process Improvement Recommendations'' (2011), *available at http://papers.ssrn.com/sol3/papers/cfm?abstract_id=1947330.* Hossain, Janjim, and John Morgan (2009). '' * * * Plus Shipping and Handling: Revenue (Non)Equivalence in Field Experiments on eBay,'' Advances in Economic Analysis and Policy vol. 6; Barber, Brad, Terrence Odean, and Lu Zheng (2005). ''Out of Sight, Out of Mind: The Effects of Expenses on Mutual Fund Flows,'' Journal of Business vol. 78, no. 6, pp. 2095–2020.

[807] *See, e.g.,* Alcott and Wozny. On shrouded attributes and their importance, see Gabaix, Xavier, and David Laibson, 2006. ''Shrouded Attributes, Consumer Myopia, and Information Suppression in Competitive Markets.'' *Quarterly Journal of Economics* 121(2): 505–540.

[808] Larrick, R. P., and J. B. Soll (2008). ''The MPG illusion'' *Science* 320: 1593–1594.

[809] Sanstad, A., and R. Howarth (1994). '' 'Normal' Markets, Market Imperfections, and Energy Efficiency.'' Energy Policy 22(10): 811–818.

vehicle buyers. When they purchase a new vehicle, some buyers value fuel economy very highly, and others value fuel economy very little, if at all. These differences undoubtedly reflect variation in the amount they drive, differences in their driving styles affect the fuel economy they expect to achieve, and varying expectations about future fuel prices, but they may also partly reflect differences in buyers' understanding of what increased fuel economy is likely to mean to them financially, or in buyers' preferences for paying lower prices today versus anticipated savings over the future.

Unless the agency has overestimated their average value, however, the fact that the value of fuel savings varies among potential buyers cannot explain why typical buyers do not currently purchase what appear to be cost-saving increases in fuel economy. A possible explanation for this situation is that the effects of differing fuel economy levels are relatively modest when compared to those provided by other, more prominent features of new vehicles, such as passenger and cargo-carrying capacity, performance, or safety. In this situation, it may simply not be in many shoppers' interest to spend the time and effort necessary to determine the economic value of higher fuel economy, to isolate the component of a new vehicle's selling price that is related to its fuel economy, and compare these two. (This possibility is consistent with the view that fuel economy is a relatively ''shrouded'' attribute.) In this case, the agency's estimates of the average value of fuel savings that will result from requiring cars and light trucks to achieve higher fuel economy may be correct, yet those savings may not be large enough to lead a sufficient number of buyers to purchase vehicles with higher fuel economy to raise average fuel economy above its current levels.

Defects in the market for cars and light trucks could also lead manufacturers to undersupply fuel economy, even in cases where many buyers were willing to pay the increased prices necessary to compensate manufacturers for providing it. To be sure, the market for new automobiles as a whole exhibits a great deal of competition. But this apparently vigorous competition among manufacturers may not extend to the provision of some individual vehicle attributes. Incomplete or ''asymmetric'' access to information about vehicle attributes such as fuel economy—whereby manufacturers of new cars and light trucks or sellers of used models have more complete knowledge about vehicles' actual fuel economy performance than is available to their potential buyers—may also prevent sellers of new or used vehicles from being able to capture its full value. In this situation, the level of fuel efficiency provided in the markets for new or used vehicles might remain persistently lower than that demanded by well-informed potential buyers.

Constraints on the combinations of fuel economy, carrying capacity, and performance that manufacturers can offer in individual vehicle models using current technologies undoubtedly limit the range of fuel economy available within certain vehicle classes, particularly those including larger vehicles. However, it is also possible that deliberate decisions by manufacturers of cars and light trucks further limit the range of fuel economy available to buyers within individual vehicle market segments, such as large automobiles, SUVs, or minivans. Manufacturers may deliberately limit the range of fuel economy levels they offer in those market segments (by choosing not to invest in fuel economy and investing instead in providing a range of other vehicle attributes) because they underestimate the premiums that prospective buyers of those models are willing to pay for improved fuel economy, and thus mistakenly believe it will be unprofitable for them to offer more fuel-efficient models within those segments. Of course, this possibility is most realistic if it is also assumed that buyers are imperfectly informed, or if fuel economy savings are not sufficiently salient to shoppers in those particular market segments. As an illustration, once a potential buyer has decided to purchase a minivan, the range of highway fuel economy ratings among current models extends from 22 to 28 mpg, while their combined city and highway ratings extend only from 18 to 20 mpg.[810] If this phenomenon is widespread, the average fuel efficiency of their entire new vehicle fleet could remain below the levels that potential buyers demand and are willing to pay for.

Another possible explanation for the paradox posed by buyers' apparent unwillingness to invest in higher fuel economy when it appears to offer such large financial returns is that NHTSA's estimates of benefits and costs from requiring manufacturers to improve fuel efficiency do not match potential buyers' assessment of the likely benefits and costs from purchasing models with higher fuel economy ratings. This could occur because the agency's underlying assumptions about some of the factors that affect the value of fuel savings differ from those made by potential buyers, because NHTSA has used different estimates for some components of the benefits from saving fuel from those of buyers, or simply because the agency has failed to account for some potential costs of achieving higher fuel economy.

For example, buyers may not value increased fuel economy as highly as the agency's calculations suggest, because they have shorter time horizons than the full vehicle lifetimes NHTSA uses in these calculations, or because they discount future fuel savings using higher rates than those prescribed by OMB for evaluating Federal regulations. Potential buyers may also anticipate lower fuel prices in the future than those forecast by the Energy Information Administration, or may expect larger differences between vehicles' MPG ratings and their own actual on-road fuel economy than the 20 percent gap (30 percent for HEVs) the agency estimates.

To illustrate the first of these possibilities, Table IV–111 shows the effect of differing assumptions about vehicle buyers' time horizons on their assessment of the value of future fuel savings. Specifically, the table reports the value of fuel savings consumers might consider when purchasing a MY 2025 car or light truck that features the higher fuel economy levels required by the proposed rule, when those fuel savings are evaluated over different time horizons. The table then compares these values to the agency's estimates of the increases in these vehicles' prices that are likely to result from the standards proposed for MY 2025. This table shows that when fuel savings are evaluated over the average lifetime of a MY 2025 car (approximately 14 years) or light truck (about 16 years), their present value (discounted at 3 percent) exceeds the estimated average price increase by more than $2,500 for cars and by over $4,500 for light trucks.

If buyers are instead assumed to consider fuel savings over only a 10-year time horizon, Table IV–112 shows that this reduces the difference between the present value of fuel savings and the projected price increase for a MY 2025 car to about $1,800, and to about $3,350 for a MY 2025 light truck. Finally, Table IV–112 shows that if buyers consider fuel savings only over the length of time for which they typically finance new car

[810] This is the range of combined city and highway fuel economy levels from lowest (Toyota Sienna AWD) to highest (Honda Odyssey) available for model year 2010; *http://www.fueleconomy.gov/feg/bestworstEPAtrucks.htm* (last accessed September 26, 2011).

purchases (slightly more than 5 years during 2011), the value of fuel savings exceeds the estimated increase in the price of a MY 2025 car by only about $200, while the corresponding difference is reduced to slightly more than $1,200 for a MY 2025 light truck.

Table IV-2. Current Baseline CAFE Levels in MY 2016 versus MY 2012-2016 Rulemaking CAFE Levels

Manufacturer	MY 2012-2016 Final Rule[619]		Current Baseline	
	Passenger	Non passenger	Passenger	Non passenger
Aston Martin			18.83	
BMW	27.19	23.04	27.19	23.03
Daimler	25.25	21.12	25.50	21.13
Fiat/Chrysler	28.69	22.19	27.74	22.19
Ford	28.14	21.31	28.24	21.32
Geely/Volvo			25.89	21.08
General Motors	28.42	21.45	28.38	21.45
Honda	33.98	25.05	33.83	25.02
Hyundai	32.02	24.30	31.74	24.29
Kia	32.98	23.74	32.70	23.74
Lotus			29.66	
Mazda	30.94	26.41	30.77	26.40
Mitsubishi	28.94	23.59	28.86	23.57
Nissan	32.04	22.11	31.98	22.10
Porsche	26.22	19.98	26.22	19.98
Spyker/Saab			26.54	19.79
Subaru	29.44	26.91	29.59	27.37
Suzuki	30.84	23.29	30.77	23.29
Tata	24.58	19.74	24.58	19.71
Tesla			244.00	
Toyota	35.33	24.25	35.22	24.26
Volkswagen	28.99	20.23	28.90	20.24
Total/Average	30.73	22.59	30.65	22.56

Potential vehicle buyers may also discount future fuel savings using higher rates than those typically used to evaluate Federal regulations. OMB guidance prescribes that future benefits and costs of regulations that mainly affect private consumption decisions, as will be the case if manufacturers' costs for complying with higher fuel economy standards are passed on to vehicle buyers, should be discounted using a consumption rate of time preference.[811] OMB estimates that savers currently discount future consumption at an average real or inflation-adjusted rate of about 3 percent when they face little risk about its likely level, which makes it a reasonable estimate of the consumption rate of time preference.

However, vehicle buyers may view the value of future fuel savings that results from purchasing a vehicle with higher fuel economy as risky or uncertain, or they may instead discount future consumption at rates reflecting their costs for financing the higher capital outlays required to purchase more fuel-efficient models. In either case, buyers comparing models with different fuel economy ratings are likely to discount the future fuel savings from purchasing one that offers higher fuel economy at rates well above the 3% assumed in NHTSA's evaluation.

Table IV–113 shows the effects of higher discount rates on vehicle buyers' evaluation of the fuel savings projected to result from the CAFE standards proposed in this NPRM, again using MY 2025 passenger cars and light trucks as an example. As Table IV–112 showed previously, average future fuel savings discounted at the OMB 3 percent consumer rate exceed the agency's estimated price increases by more than $2,500 for MY 2025 passenger cars and by about $4,500 for MY 2025 light trucks. If vehicle buyers instead discount future fuel savings at the typical new-car loan rate prevailing during 2010 (approximately 5.2 percent), however, these differences decline to slightly more than $2,000 for cars and $3,900 for light trucks, as Table IV–113 illustrates. This is a plausible alternative assumption, because buyers are likely to finance the increases in purchase prices resulting from compliance with higher CAFE standards as part of the process of financing the vehicle purchase itself.

Finally, as the table also shows, discounting future fuel savings using a consumer credit card rate (which averaged almost 14 percent during 2010) reduces these differences to less than $900 for a MY 2025 passenger car and about $2,250 for the typical MY 2025 light truck. Even at these significantly higher discount rates, however, the table shows that the private net benefits from purchasing new vehicles with the levels of fuel economy this rule would

[811] Office of Management and Budget, Circular A–4, ''Regulatory Analysis,'' September 17, 2003, 33. Available at *http://www.whitehouse.gov/omb/assets/regulatory_matters_pdf/a-4.pdf* (last accessed Sept. 26, 2010).

require—rather than those that would result from simply extending the MY 2016 CAFE standards to apply to future model years—remain large.

Category	NAICS Codes[A]	Examples of Potentially Regulated Entities
Industry	336111 336112	Motor Vehicle Manufacturers
Industry	811111 811112 811198 423110	Commercial Importers of Vehicles and Vehicle Components
Industry	335312 336312 336399 811198	Alternative Fuel Vehicle Converters

[A] North American Industry Classification System (NAICS)

Some evidence also suggests that vehicle buyers may employ combinations of high discount rates and short time horizons in their purchase decisions. For example, consumers surveyed by Kubik (2006) reported that fuel savings would have to be adequate to pay back the additional purchase price of a more fuel-efficient vehicle in less than 3 years to persuade them to purchase it, and that even over this short time horizon they were likely to discount fuel savings using credit card-like rates.[814] Combinations of a shorter time horizon and a higher discount rate could further reduce—or potentially even eliminate—the difference between the value of fuel savings and the agency's estimates of increases in vehicle prices. One plausible combination would be for buyers to discount fuel savings over the term of a new car loan, using the interest rate on that loan as a discount rate. Doing so would reduce the amount by which future fuel savings exceed the estimated increase in the prices of MY 2025 vehicles considerably further, to about $117 for passenger cars and $1,250 for light trucks.

As these comparisons illustrate, reasonable alternative assumptions about how consumers might evaluate future fuel savings, the major private benefit from requiring higher fuel economy, can significantly affect the benefits they consider when deciding whether to purchase more fuel-efficient vehicles. Readily imaginable combinations of shorter time horizons, higher discount rates, and lower expectations about future fuel prices or annual vehicle use and fuel savings could make potential buyers hesitant—or perhaps even unwilling—to purchase vehicles offering the increased fuel economy levels this proposed rule would require manufacturers to provide in future model years. Thus, vehicle buyers' assessment of the benefits and costs of this proposal in their purchase decisions may differ markedly from NHTSA's estimates.

[812] Interest rates on 48-month new vehicle loans made by commercial banks during 2010 averaged 6.21%, while new car loan rates at auto finance companies averaged 4.26%; *See* Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.19, Consumer Credit. *Available at http://www.federalreserve.gov/releases/g19/Current* (last accessed September 27, 2011).

[813] The average rate on consumer credit card accounts at commercial banks during 2010 was 13.78%; *See* Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.19, Consumer Credit. *Available at http://www.federalreserve.gov/releases/g19/Current* (last accessed September 27, 2011).

[814] Kubik, M. (2006). Consumer Views on Transportation and Energy. Second Edition. Technical Report: National Renewable Energy Laboratory. *Available at* Docket No. NHTSA–2009–0059–0038.

If consumers' views about critical variables such as future fuel prices or the appropriate discount rate differ sufficiently from the assumptions used by the agency, some or perhaps many potential vehicle buyers might conclude that the value of fuel savings and other benefits from higher fuel economy they are considering are not sufficient to justify the increase in purchase prices they expect to pay. In conjunction with the possibility that manufacturers misinterpret potential buyers' willingness to pay for improved fuel economy, this might explain why the current choices among available models do not result in average fuel economy levels approaching those this rule would require.

Another possibility is that achieving the fuel economy improvements required by stricter fuel economy standards might lead manufacturers to forego planned future improvements in performance, carrying capacity, safety, or other features of their vehicle models that provide important sources of utility to their owners, even if it is technologically feasible to have both improvements in those other features and improved fuel economy. Although the specific economic values that vehicle buyers attach to individual vehicle attributes such as fuel economy, performance, passenger- and cargo-carrying capacity, or other features are difficult to infer from vehicle prices or buyers' choices among competing models, changes in vehicle attributes can significantly affect the overall utility that vehicles offer to potential buyers. Thus if requiring manufacturers to provide higher fuel economy leads them to sacrifice improvements in these or other highly-valued attributes, potential buyers are likely to view these sacrifices as an additional cost of improving fuel economy. If those attributes are of sufficient value, or if the range of vehicles offered ensures that vehicles with those attributes will continue to be offered, then vehicle buyers will still have the opportunity to choose those attributes, though at increased cost compared to models without the fuel economy improvements.

As indicated in its previous discussion of technology costs, NHTSA has approached this potential problem by attempting to develop cost estimates for fuel economy-improving technologies that include allowances for any additional costs that would be necessary to maintain the reference fleet (or baseline) levels of performance, comfort, capacity, or safety of light-duty vehicle models to which those technologies are applied. In doing so, the agency followed the precedent established by the 2002 NAS Report on improving fuel economy, which estimated ''constant performance and utility'' costs for technologies that manufacturers could employ to increase the fuel efficiency of cars or light trucks. Although NHTSA has revised its estimates of manufacturers' costs for some technologies significantly for use in this rulemaking, these revised estimates are still intended to represent costs that would allow manufacturers to maintain the performance, safety, carrying capacity, and utility of vehicle models while improving their fuel economy, in the majority of cases. The agency's continued specification of footprint-based CAFE standards also addresses this concern, by establishing less demanding fuel economy targets for larger cars and light trucks.

Finally, vehicle buyers may simply prefer the choices of vehicle models they now have available to the combinations of price, fuel economy, and other attributes that manufacturers are likely to offer when required to achieve the higher overall fuel economy levels proposed in this NPRM. This explanation assumes that auto makers decide to change vehicle attributes other than price and fuel economy in response to this rule. If this is the case, their choices among models—and even some buyers' decisions about whether to purchase a new vehicle—will respond accordingly, and their responses to these new choices will reduce their overall welfare. Some may buy models with combinations of price, fuel efficiency, and other attributes that they consider less desirable than those they would otherwise have purchased, while others may simply postpone buying a new vehicle. It leaves open the question, though, why auto makers would change those other vehicle characteristics if consumers liked them as they were; as noted, the assumption of ''constant performance and utility'' built into the cost estimates means that these changes are not necessary.

As the foregoing discussion makes clear, the agency cannot offer a complete answer to the question of why the apparently large differences between its estimates of private benefits from requiring higher fuel economy and the costs of supplying it would not result in higher fuel economy for new cars and light trucks in the absence of this rule. One explanation is that these estimates are reasonable, but that for the reasons outlined above, the market for fuel economy is not operating efficiently. NHTSA believes the existing literature offers some support for the view that various failures in the market for fuel economy prevent it from providing an economically desirable outcome, which implies that on balance there are likely to be substantial private gains from the proposed rule. The agency will continue to investigate new empirical literature addressing this question as it becomes available, and seeks comment on all of the relevant questions.

NHTSA acknowledges the possibility that it has incorrectly characterized the impact on the market of the CAFE standards this rule proposes, and that this could cause its estimates of benefits and costs to misrepresent the effects of the proposed rule. To recognize this possibility, this section presents an alternative accounting of the benefits and costs of CAFE standards for MYs 2017–2025 passenger cars and light trucks and discusses its implications. Table IV–114 displays the economic impacts of the rule as viewed from the perspective of potential buyers.

As the table shows, the proposed rule's total benefits to vehicle buyers (line 4) consist of the value of fuel savings over vehicles' full lifetimes at retail fuel prices (line 1), the economic value of vehicle occupants' savings in refueling time (line 2), and the economic benefits from added rebound-effect driving (line 3). As the zero entries in line 5 of the table suggest, no losses in consumer welfare from changes in vehicle attributes (other than those from increases in vehicle prices) are assumed to occur. Thus there is no reduction in the total private benefits to vehicle owners, so that net private benefits to vehicle buyers (line 6) are equal to total private benefits (reported previously in line 4).

As Table IV–114 also shows, the decline in fuel tax revenues (line 7) that results from reduced fuel purchases is a transfer of funds between consumers and government and is thus not a social cost.[815] (Thus the sum of lines 1 and 7 equals the savings in fuel production costs that were reported previously as the value of fuel savings at pre-tax prices in the agency's previous accounting of benefits and costs.) Lines 8 and 9 of Table IV–114 report the value of reductions in air pollution and climate-related externalities resulting from lower emissions of criteria air

[815] Strictly speaking, fuel taxes represent a transfer of resources from consumers of fuel to government agencies and not a use of economic resources. Reducing the volume of fuel purchases simply reduces the value of this transfer, and thus cannot produce a real economic cost or benefit. Representing the change in fuel tax revenues in effect as an economy-wide cost is necessary to offset the portion of fuel savings included in line 1 that represents savings in fuel tax payments by consumers. This prevents the savings in tax revenues from being counted as a benefit from the economy-wide perspective.

pollutants and GHGs during fuel production and consumption, while line 10 reports the savings in energy security externalities to the U.S. economy from reduced consumption and imports of petroleum and refined fuel. Line 12 reports the costs of increased congestion delays, accidents, and noise that result from additional driving due to the fuel economy rebound effect. Net external benefits from the proposed CAFE standards (line 13) are thus the sum of the change in fuel tax revenues, the reduction in environmental and energy security externalities, and increased external costs from added driving.

Line 14 of Table IV–114 shows manufacturers' technology outlays for meeting higher CAFE standards for passenger cars and light trucks, which represent the principal private and social cost of requiring higher fuel economy. The net social benefits (line 15 of the table) resulting from the proposed rule consist of the sum of private (line 6) and external (line 13) benefits, minus technology costs (line 14). As expected, the figures reported in line 15 of the table are identical to those reported previously in Table IV–63.

Table IV–114 highlights several important features of this rule's economic impacts. First, comparing the rule's net private (line 6) and external (line 13) benefits makes it clear that a very large proportion of the proposed rule's benefits would be experienced by vehicle buyers, while the small remaining fraction would be experienced throughout the remainder of the U.S. economy. In turn, the vast majority of private benefits resulting from the higher fuel economy levels the proposed rule would require stem from fuel savings to vehicle buyers. Net external benefits from the proposed rule are expected to be small, because the value of reductions in environmental and energy security externalities is likely almost exactly offset by the increased costs associated with added vehicle use. As a consequence, the net social benefits of the rule mirror almost exactly its net private benefits to vehicle buyers, under the assumption that manufacturers will recover their technology outlays for achieving higher fuel economy by raising new car and light truck prices. Once again, this result highlights the extreme importance of accounting for any other effects of the rule on the economic welfare of vehicle buyers.

Table IV-114. Private, Social, and Total Benefits and Costs of MYs 2017-2021 CAFE Standards – Passenger Cars Plus Light Trucks (3% discount rate)

Entry	Model Year				
	2017	2018	2019	2020	2021
1. Value of fuel savings (at retail prices)	\$8.0	\$19.6	\$33.1	\$44.6	\$58.5
2. Savings in refueling time	\$0.4	\$0.7	\$1.1	\$1.2	\$1.7
3. Consumer surplus from added driving	\$0.1	\$0.2	\$0.5	\$0.7	\$1.0
4. Total private benefits (= 1 + 2 + 3)	\$8.50	\$20.50	\$34.70	\$46.50	\$61.20
5. Reduction in private benefits from changes in other vehicle attributes	\$0.0	\$0.0	\$0.0	\$0.0	\$0.0
6. Net private benefits (= 4 + 5)	\$8.50	\$20.50	\$34.70	\$46.50	\$61.20
7. Change in fuel tax revenues	(\$0.9)	(\$2.1)	(\$3.5)	(\$4.6)	(\$6.0)
8. Reduced health damages from criteria emissions	\$0.2	\$0.4	\$0.8	\$1.2	\$1.5
9. Reduced climate damages from CO_2 emissions	\$0.7	\$1.8	\$3.1	\$4.2	\$5.6
10. Reduced energy security externalities	\$0.4	\$0.9	\$1.6	\$2.1	\$2.7
11. Reduction in externalities (= 8 + 9 + 10)	\$1.3	\$3.1	\$5.5	\$7.5	\$9.8
12. Increased costs of congestion, etc.	(\$0.9)	(\$1.9)	(\$3.2)	(\$4.4)	(\$5.7)
13. Net external benefits (= 7 + 11 + 12)	(\$0.50)	(\$0.90)	(\$1.20)	(\$1.50)	(\$1.90)
14. Technology costs	(\$2.0)	(\$4.4)	(\$7.7)	(\$11.3)	(\$15.2)
15. Net social benefits (= 6 + 13 – 14)	\$5.50	\$13.90	\$24.60	\$32.00	\$42.20

Table IV-115. Private, Social, and Total Benefits and Costs of MYs 2022-2025 and Total MYs 2017-2025 CAFE Standards – Passenger Cars Plus Light Trucks

Entry	Model Year				
	2022	2023	2024	2025	Total,2017-2025
1. Value of fuel savings (at retail fuel prices)	$67.5	$76.3	$87.1	$96.5	$491.1
2. Savings in refueling time	$2.0	$2.2	$2.5	$2.4	$14.3
3. Consumer surplus from added driving	$1.3	$1.6	$2.0	$2.4	$9.9
4. Total private benefits (= 1 + 2 + 3)	$70.80	$80.10	$91.60	$101.30	$515.30
5. Reduction in private benefits from changes in other vehicle attributes	$0.0	$0.0	$0.0	$0.0	$0.0
6. Net private benefits (= 4 +52)	$70.80	$80.10	$91.60	$101.30	$515.30
7. Change in fuel tax revenues	($6.8)	($7.7)	($8.7)	($9.5)	($49.9)
8. Reduced health damages from criteria emissions	$1.7	$1.9	$2	$2.3	$12.5
9. Reduced climate damages from CO_2 emissions	$6.6	$7.5	$8.7	$9.7	$48.0
10. Reduced energy security externalities	$3.1	$3.5	$4.0	$4.4	$22.8
11. Reduction in externalities (= 8 + 9 + 10)	$11.4	$12.9	$14.7	$16.4	$83.3
12. Increased costs of congestion, etc.	($6.5)	($7.3)	($8.4)	($9.3)	($48.8)
13. Net external benefits (= 7 + 11 + 12)	($1.90)	($2.10)	($2.40)	($2.40)	($15.40)
14. Technology costs	($19.8)	($24.2)	($29.8)	($32.4)	($153.3)
15. Net social benefits (= 6 + 13 – 14)	$49.10	$53.80	$59.40	$66.50	$346.60

As discussed in detail previously, NHTSA believes that the aggregate benefits from this proposed rule amply justify its total costs, but it remains possible that the agency has overestimated the role of fuel savings to buyers and subsequent owners of the cars and light trucks to which the higher CAFE standards it proposes would apply. It is also possible that the agency has failed to develop cost estimates that do not require manufacturers to make changes in vehicle attributes as part of their efforts to achieve higher fuel economy. To acknowledge these possibilities, NHTSA has examined their potential impact on its estimates of the proposed rule's benefits and costs. This analysis, which appears in Chapter VIII of the Preliminary RIA accompanying this proposed rule, shows the rule's economic impacts under alternative assumptions about the private benefits from higher fuel economy, and the value of potential changes in other vehicle attributes. One conclusion is that even if the private savings are significantly overstated, the benefits of the proposed standards continue to exceed the costs. We seek comment on that analysis and the discussion above.

7. What other impacts (quantitative and unquantifiable) will these proposed standards have?

In addition to the quantified benefits and costs of fuel economy standards, the final standards will have other impacts that we have not quantified in monetary terms. The decision on whether or not to quantify a particular impact depends on several considerations:

How likely is it to occur, and can the magnitude of the impact reasonably be attributed to the outcome of this rulemaking?

Would quantification of its physical magnitude or economic value help NHTSA and the public evaluate the CAFE standards that may be set in rulemaking?

Is the impact readily quantifiable in physical terms?

If so, can it readily be translated into an economic value?

Is this economic value likely to be material?

Can the impact be quantified with a sufficiently narrow range of uncertainty so that the estimate is useful?

NHTSA expects that this rulemaking will have a number of genuine, material impacts that have not been quantified due to one or more of these considerations. In some cases, further research may yield estimates that are useful for future rulemakings.

Technology Forcing

The proposed rule will improve the fuel economy of the U.S. new vehicle fleet, but it will also increase the cost (and presumably, the price) of new passenger cars and light trucks built during MYs 2017–2025. We anticipate that the cost, scope, and duration of this rule, as well as the steadily rising standards it requires, will cause automakers and suppliers to devote increased attention to methods of improving vehicle fuel economy.

This increased attention will stimulate additional research and engineering, and we anticipate that, over time, innovative approaches to reducing the fuel consumption of light duty vehicles will emerge. These innovative approaches may reduce the cost of the proposed rule in its later years, and also increase the set of feasible technologies in future years. We have attempted to estimate the effect of learning effects on the costs of producing known technologies within the period of the rulemaking, which is one way that technologies become cheaper over time, and may reflect innovations in application and use of existing technologies to meet the proposed future. However, we have not attempted to estimate the extent to which not-yet-invented technologies will appear, either within the time period of the current rulemaking or that might be available after MY 2016, or whether technologies considered but not applied in the current rulemaking, due to concern about the likelihood of their commercialization in the rulemaking timeframe, will in fact be helped towards commercialization as a result of the proposed standards. NHTSA seeks comment on whether there are quantifiable costs and benefits associated with the potential technology forcing effects of the proposed standards, and if so, how the agency should consider attempting to account for them in the final rule analysis.

Effects on Vehicle Costs

Actions that increases the cost of new vehicles could subsequently make such vehicles more costly to maintain, repair, and insure. In general, NHTSA expects that this effect to be a positive linear function of vehicle costs. In its central analysis, NHTSA estimates that the proposed rule could raise average vehicle technology costs by over $1,800 by 2025, and for some manufacturers, average costs will increase by more than $3,000 (for some specific vehicle models, we estimate that the proposed rule could increase technology costs by more than $10,000). Depending on the retail price of the vehicle, this could represent a significant increase in the overall vehicle cost and subsequently increase insurance rates, operation costs, and maintenance costs. Comprehensive and collision insurance costs are likely to be directly related to price increases, but liability premiums will go up by a smaller proportion because the bulk of liability coverage reflects the cost of personal injury. Also, although they represent economic transfers, sales and excise taxes would also increase with increases in vehicle prices (unless rates are reduced). The impact on operation and maintenance costs is less clear, because the maintenance burden and useful life of each technology are not known. However, one of the common consequences of using more complex or innovative technologies is a decline in vehicle reliability and an increase in maintenance costs. These costs are borne in part by vehicle manufacturers (through warranty costs, which are included in the indirect costs of production), and in part by vehicle owners. NHTSA believes that this effect is difficult to quantify for purposes of this proposed rule, but we seek comment on how we might attempt to do so for the final rule.

Related, to the extent that the proposed standards require manufacturers to build and sell more PHEVs and EVs, vehicle manufacturers and owners may face additional costs for charging infrastructure and battery disposal. While Chapter 3 of the draft Joint TSD discusses the costs of charging infrastructure, neither of these costs have been incorporated into the rulemaking analysis due to time constraints. We intend to attempt to quantify these additional costs for the final rule stage, but we believe that doing so will be difficult and we seek comment on how we might go about it. We also seek comment on other costs or cost savings that are not accounted for in this analysis and how we might go about quantifying them for the final rule.

And finally on the subject of vehicle operation, NHTSA has received comments in the past that premium (higher octane) fuel may be necessary if certain advanced fuel economy-improving technologies are required by stringent CAFE standards. The agencies have not assumed in our development of technology costs that premium fuel would be required. We seek comment on this assumption.

Effects on Vehicle Miles Traveled (VMT)

While NHTSA has estimated the impact of the rebound effect on the use of MY 2017–25 vehicles, we have not estimated how a change in new vehicle sales would impact aggregate vehicle use. Changes in new vehicle sales may be accompanied by complex but difficult-to-quantify effects on overall vehicle use and its composition by vehicle type and age, because the same factors affecting sales of new vehicles are also likely to influence their use, as well as how intensively older vehicles are used and when they are retired from service. These changes may have important consequences for total fleet-wide fuel consumption. NHTSA believes that this effect is difficult to quantify for purposes of this proposed rule, but we seek comment on how we might attempt to do so for the final rule, if commenters agree that attempting quantification of this effect could be informative.

Effect on Composition of Passenger Car and Light Truck Sales

To the extent that manufacturers pass on costs to buyers by raising prices for new vehicle models, they may distribute these price increases across their model lineups in ways that affect the composition of their total sales. To the extent that changes in the composition of sales occur, this could affect fuel savings to some degree. However, NHTSA's view is that the scope for such effects is relatively small, since most vehicles will to some extent be impacted by the standards. Compositional effects might be important with respect to compliance costs for individual manufacturers, but are unlikely to be material for the rule as a whole.

NHTSA is continuing to develop methods of estimating the effects of these proposed standards on the sales of individual vehicle models, and plans to apply these methods in analyzing the impacts of its final CAFE standards for MY 2017–25. In the meantime, the agency seeks comment on the possibility that significant shifts in the composition of new vehicle sales by type or model could occur, the potential effects of such shifts on fuel consumption and fuel savings from the proposed standards, and methods for analyzing the potential extent and patterns of shifts in sales.

Effects on the Used Vehicle Market

The effect of this rule on the lifetimes, use, and retirement dates (''scrappage'') of older vehicles will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, and total sales of new vehicles. If the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' prices, sales of new vehicles will rise, while scrappage rates of used vehicles will increase slightly. This will cause the ''turnover'' of the vehicle fleet—that is, the retirement of used vehicles and their replacement by new models—to accelerate slightly, thus accentuating the anticipated effect of the rule on fleet-wide fuel consumption and CO_2 emissions. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles will decline, as will the rate at which used vehicles are retired from service. This effect will slow the replacement of used vehicles by new models, and thus partly offset the anticipated effects of the final rules on fuel use and emissions.

Because the agencies are uncertain about how the value of projected fuel savings from the final rules to potential buyers will compare to their estimates of increases in new vehicle prices, we have not attempted to estimate explicitly the effects of the rule on scrappage of older vehicles and the turnover of the vehicle fleet.

Impacts of Changing Fuel Composition on Costs, Benefits, and Emissions

EPAct, as amended by EISA, creates a Renewable Fuels Standard that sets targets for greatly increased usage of renewable fuels over the next decade. The law requires fixed volumes of renewable fuels to be used—volumes that are not linked to actual usage of transportation fuels.

Ethanol and biodiesel (in the required volumes) may increase or decrease the cost of blended gasoline and diesel, depending on crude oil prices and tax subsidies offered for renewable fuels. The potential extra cost of renewable fuels would be borne through a cross-subsidy: the price of every gallon of blended gasoline could rise sufficiently to pay for any extra cost of using renewable fuels in these blends. However, if the price of gasoline or diesel increases enough, the consumer could actually realize a savings through the increased usage of renewable fuels. By reducing total fuel consumption, the CAFE standards proposed in this rule could tend to increase any necessary cross-subsidy per gallon of fuel, and hence raise the market price of transportation fuels, while there would be no change in the volume or cost of renewable fuels used.

These effects are indirectly incorporated in NHTSA's analysis of the proposed CAFE rule because they are reflected in EIA's projections of future gasoline and diesel prices in the Annual Energy Outlook, which incorporates in its baseline both a Renewable Fuel Standard and an CAFE standards.

The net effect of incorporating an RFS then might be to slightly reduce the benefits of the rule because affected vehicles might be driven slightly less if the RFS makes blended gasoline relatively more expensive, and because fuels blended with more ethanol emit slightly fewer greenhouse gas emissions per gallon. In addition, there might be corresponding benefit losses from the induced reduction in VMT. All of these effects are difficult to estimate, because of uncertainty in future crude oil prices, uncertainty in future tax policy, and uncertainty about how petroleum marketers will actually comply with the RFS, but they are likely to be small, because the cumulative deviation from baseline fuel consumption induced by the final rule will itself be small.

Distributional Effects

The agency's analysis of the proposed rule reports impacts only as nationwide aggregate or per-vehicle average values. NHTSA also shows the effects of the EIA high and low fuel price forecasts on the aggregate benefits in its sensitivity analysis. Generally, this proposed rule would have its largest effects on individuals who purchase new vehicles produced during the model years it would affect (2017–25). New vehicle buyers who drive more than the agency's estimates of average vehicle use will experience larger fuel savings and economic benefits than the average values reported in this NPRM, while those who drive less than our average estimates will experience smaller fuel savings and benefits. NHTSA believes that this effect is difficult to quantify for purposes of this proposed rule, but we seek comment on how we might attempt to do so for the final rule, if commenters agree that attempting quantification of this effect could be informative.

H. Vehicle Classification

Vehicle classification, for purposes of the CAFE program, refers to whether NHTSA considers a vehicle to be a passenger car or a light truck, and thus subject to either the passenger car or the light truck standards.[816] As NHTSA explained in the MY 2011 rulemaking and in the MYs 2012–2016 rulemaking, vehicle classification is based in part on EPCA/EISA, and in part on NHTSA's regulations. EPCA categorizes some light 4-wheeled vehicles as ''passenger automobiles'' (cars) and the balance as ''non-passenger automobiles'' (light trucks). EPCA defines passenger

[816] For the purpose of the MYs 2012–2016 standards and this NPRM for the MYs 2017–2025 standards, EPA has agreed to use NHTSA's regulatory definitions for determining which vehicles would be subject to which CO_2 standards.

automobiles as any automobile (other than an automobile capable of off-highway operation) which NHTSA decides by rule is manufactured primarily for use in the transportation of not more than 10 individuals.[817] NHTSA created regulatory definitions for passenger automobiles and light trucks, found at 49 CFR Part 523, to guide the agency and manufacturers in classifying vehicles.

Under EPCA, there are two general groups of automobiles that qualify as non-passenger automobiles or light trucks: (1) Those defined by NHTSA in its regulations as other than passenger automobiles due to their having design features that indicate they were not manufactured ''primarily'' for transporting up to ten individuals; and (2) those expressly excluded from the passenger category by statute due to their capability for off-highway operation, regardless of whether they might have been manufactured primarily for passenger transportation.[818] 49 CFR 523 directly tracks those two broad groups of non-passenger automobiles in subsections (a) and (b), respectively. We note that NHTSA tightened the definition of light truck in the MY 2011 rulemaking to ensure that only vehicles that actually have 4WD will be classified as off-highway vehicles by reason of having 4WD (to prevent 2WD SUVs that also come in a 4WD ''version'' from qualifying automatically as ''off-road capable'' simply by reason of the existence of the 4WD version), which resulted in the reclassification of over 1 million vehicles from the truck fleet to the car fleet.

Since the original passage of EPCA, and consistently through the passage of EISA, Congress has expressed its intent that different vehicles with different characteristics and capabilities should be subject to different CAFE standards in two ways: first, through whether a vehicle is classified as a passenger car or as a light truck, and second, by requiring NHTSA to set separate standards for passenger cars and for light trucks.[819] Creating two categories of vehicles and requiring separate standards for each, however, can lead to two issues which may either detract from the fuel savings that the program is able to achieve, or increase regulatory burden for manufacturers simply because they are trying to meet market demand. Specifically,

(1) If the stringency of the standards that NHTSA establishes seems to favor either cars or trucks, manufacturers may have incentive to change their vehicles' characteristics in order to reclassify them and average them into the ''easier'' fleet; and

(2) ''Like'' vehicles, such as the 2WD and 4WD versions of the same CUV, may have generally similar fuel economy-achieving capabilities, but different targets due to differences in the car and truck curves.

NHTSA recognizes that manufacturers may have an incentive to classify vehicles as light trucks if the fuel economy target for light trucks with a given footprint is less stringent than the target for passenger cars with the same footprint. This is often the case given the current fleet. Because of characteristics like 4WD and towing and hauling capacity (and correspondingly, although not necessarily, heavier weight), the vehicles in the current light truck fleet are generally less capable of achieving higher fuel economy levels as compared to the vehicles in the passenger car fleet. 2WD SUVs are the vehicles that could be most readily redesigned so that they can be ''moved'' from the passenger car to the light truck fleet. A manufacturer could do this by adding a third row of seats, for example, or boosting GVWR over 6,000 lbs for a 2WD SUV that already meets the ground clearance requirements for ''off-road capability.'' A change like this may only be possible during a vehicle redesign, but since vehicles are redesigned, on average, every 5 years, at least some manufacturers could possibly choose to make such changes before or during the model years covered by this rulemaking, either because of market demands or because of interest in changing the vehicle's classification.

NHTSA continues to believe that the definitions as they currently exist are consistent with the text of EISA and with Congress' original intent. However, the time frame of this rulemaking is longer than any CAFE rulemaking that NHTSA has previously undertaken, and no one can predict with certainty how the market will change between now and 2025. The agency therefore has less assurance than in prior rulemakings that manufacturers will not have greater incentives and opportunities during that time frame to make more deliberate redesign efforts to move vehicles out of the car fleet and into the truck fleet in order to obtain the lower target, and potentially reducing overall fuel savings. Recognizing this possibility, we seek comment on how best to avoid it while still classifying vehicles appropriately based on their characteristics and capabilities.

One of the potential options that we explored in the MYs 2012–2016 rulemaking for MYs 2017 and beyond was changing the definition of light truck to remove paragraph (5) of 49 CFR 523.5(a), which allows vehicles to be classified as light trucks if they have three or more rows of seats that can either be removed or folded flat to allow greater cargo-carrying capacity. NHTSA has received comments in the past arguing that vehicles with three or more rows of seats, unless they are capable of transporting more than 10 individuals, should be classified as passenger cars rather than as light trucks because they would not need to have so many seats if they were not intended primarily to carry passengers.

NHTSA recognizes that there are arguments both for and against maintaining the definition as currently written for MYs 2017 and beyond. The agency continues to believe that three or more rows of seats that can be removed or folded flat is a reasonable proxy for a vehicle's ability to provide expanded cargo space, consistent with the agency's original intent in developing the light truck definitions that expanded cargo space is a fundamentally ''truck-like'' characteristic. Much of the public reaction to this definition, which is mixed, tends to be visceral and anecdotal—for example, for parents with minivans and multiple children, the ability of seats to fold flat to provide more room for child-related cargo may have been a paramount consideration in purchasing the vehicle, while for CUV owners with cramped and largely unused third rows, those extra seats may seem to have sprung up entirely in response to the regulation, rather than in response to the consumer's need for utility. If we believe, for the sake of argument, that the agency's decision might be reasonable from both a policy and a legal perspective whether we decided to change the definition or to leave it alone, the most important questions in making the decision become (1) whether removing

[817] EPCA 501(2), 89 Stat. 901, codified at 49 U.S.C. 32901(a).

[818] 49 U.S.C. 32901(a)(18). The statute refers both to vehicles that are 4WD and to vehicles over 6,000 lbs GVWR as potential candidates for off-road capability, if they also meet the ''significant feature * * * designed for off-highway operation'' as defined by the Secretary. We note that we consider ''AWD'' vehicles as 4WD for purposes of this determination—they send power to all wheels of the vehicle all the time, while 4WD vehicles may only do so part of the time, which appears to make them equal candidates for off-road capability given other necessary characteristics. We also underscore, as we have in the past, that despite comments in prior rulemakings suggesting that any vehicle that appears to be manufactured ''primarily'' for transporting passengers must be classified as a passenger car, the statute as currently written clearly provides that vehicles that are off-highway capable are not passenger cars.

[819] *See, e.g.,* discussion of legislative history in 42 FR 38362, 38365–66 (Jul. 28, 1977).

523.5(a)(5), and thus causing vehicles with three or more rows to be classified as passenger cars in the future, will save more fuel, and (2) if more fuel will be saved, at what cost.

In considering these questions in the MYs 2012–2016 rulemaking, NHTSA conducted an analysis in the final rule to attempt to consider the impact of moving these vehicles. We identified all of the 3-row vehicles in the baseline (MY 2008) fleet,[820] and then considered whether any could be properly classified as a light truck under a different provision of 49 CFR 523.5—about 40 vehicles were classifiable under § 523.5(b) as off-highway capable. We then transferred those remaining 3-row vehicles from the light truck to the passenger car input sheets for the CAFE model, re-estimated the relative stringency of the passenger car and light truck standards, shifted the curves to obtain the same overall average required fuel economy as under the final standards, and ran the model to evaluate potential impacts (in terms of costs, fuel savings, etc.) of moving these vehicles. The agency's hypothesis had been that moving 3-row vehicles from the truck to the car fleet would tend to bring the achieved fuel economy levels down in both fleets—the car fleet achieved levels could theoretically fall due to the introduction of many more vehicles that are relatively heavy for their footprint and thus comparatively less fuel economy-capable, while the truck fleet achieved levels could theoretically fall due to the characteristics of the vehicles remaining in the fleet (4WDs and pickups, mainly) that are often comparatively less fuel economy-capable than 3-row vehicles, although more vehicles would be subject to the relatively more stringent passenger car standards, assuming the curves were not refit to the data.

As the agency found, however, moving the vehicles reduced the stringency of the passenger car standards by approximately 0.8 mpg on average for the five years of the rule, and reduced the stringency of the light truck standards by approximately 0.2 mpg on average for the five years of the rule, but it also resulted in approximately 676 million fewer gallons of fuel consumed (equivalent to about 1 percent of the reduction in fuel consumption under the final standards) and 7.1 mmt fewer CO_2 emissions (equivalent to about 1 percent of the reduction in CO_2 emissions under the final standards) over the lifetime of the MYs 2012–2016 vehicles. This result was attributable to slight differences (due to rounding precision) in the overall average required fuel economy levels in MYs 2012–2014, and to the retention of the relatively high lifetime mileage accumulation (compared to ''traditional'' passenger cars) of the vehicles moved from the light truck fleet to the passenger car fleet. The net effect on technology costs was approximately $200 million additional spending on technology each year (equivalent to about 2 percent of the average increase in annual technology outlays under the final standards). Assuming manufacturers would pass that cost forward to consumers by increasing vehicle costs, NHTSA estimated that vehicle prices would increase by an average of approximately $13 during MYs 2012–2016. With less fuel savings and higher costs, and a substantial disruption to the industry, removing 523.5(a)(5) did not seem advisable in the context of the MYs 2012–2016 rulemaking.

Looking forward, however, and given the considerable uncertainty regarding the incentive to reclassify vehicles in the MYs 2017 and beyond timeframe, the agency considered whether a fresh attempt at this analysis would be warranted, but did not believe that it would be informative given the uncertainty. One important point to note in the comparative analysis in the MYs 2012–2016 rulemaking is that, due to time constraints, the agency did not attempt to refit the respective fleet target curves or to change the intended required stringency in MY 2016 of 34.1 mpg for the combined fleets. If we had refitted curves, considering the vehicles in question, we might have obtained a somewhat steeper passenger car curve, and a somewhat flatter light truck curve, which could have affected the agency's findings. The same is true today. Without refitting the curves and changing the required levels of stringency for cars and trucks, simply moving vehicles from one fleet to another will not inform the agency in any substantive way as to the impacts of a change in classification. Moreover, even if we did attempt to make those changes, the results would be somewhat speculative; for example, the agencies continue to use the same MY 2008 baseline used in the MYs 2012–2016 rulemaking, which may have limited utility for predicting relatively small changes (moving only 40 vehicles, as noted above) in the fleet makeup during the rulemaking timeframe. As a result, NHTSA did not attempt to quantify the impact of such a reclassification of 3-row vehicles, but we seek comment on whether and how we should do so for the final rule. If commenters believe that we should attempt to quantify the impact, we specifically seek comment on how to refit the footprint curves and how the agency should consider stringency levels under such a scenario.

Another potential option that we explored in the MYs 2012–2016 rulemaking for MYs 2017 and beyond was classifying ''like'' vehicles together. Many commenters objected in the rulemaking for the MY 2011 standards to NHTSA's regulatory separation of ''like'' vehicles. Industry commenters argued that it was technologically inappropriate for NHTSA to place 4WD and 2WD versions of the same SUV in separate classes. They argued that the vehicles are the same, except for their drivetrain features, thus giving them similar fuel economy improvement potential. They further argued that all SUVs should be classified as light trucks. Environmental and consumer group commenters, on the other hand, argued that 4WD SUVs and 2WD SUVs that are ''off-highway capable'' by virtue of a GVWR above 6,000 pounds should be classified as passenger cars, since they are primarily used to transport passengers. In the MY 2011 rulemaking, NHTSA rejected both of these sets of arguments. NHTSA concluded that 2WD SUVs that were neither ''off-highway capable'' nor possessed ''truck-like'' functional characteristics were appropriately classified as passenger cars. At the same time, NHTSA also concluded that because Congress explicitly designated vehicles with GVWRs over 6,000 pounds as ''off-highway capable'' (if they meet the ground clearance requirements established by the agency), NHTSA did not have authority to move these vehicles to the passenger car fleet.

NHTSA continues to believe that this would not be an appropriate solution for addressing either the risk of gaming or perceived regulatory inequity going forward. As explained in the MYs 2012–2016 final rule, with regard to the first argument, that ''like'' vehicles should be classified similarly (*i.e.,* that 2WD SUVs should be classified as light trucks because, besides their drivetrain, they are ''like'' the 4WD version that qualifies as a light truck), NHTSA continues to believe that 2WD SUVs that do not meet any part of the existing regulatory definition for light trucks should be classified as passenger cars. However, NHTSA recognizes the additional point raised by industry commenters in the MY 2011 rulemaking that manufacturers may respond to this tighter classification by ceasing to build 2WD versions of SUVs, which could

[820] Of the 430 light truck models in the fleet, 175 of these had 3 rows.

reduce fuel savings. In response to that point, NHTSA stated in the MY 2011 final rule that it expects that manufacturer decisions about whether to continue building 2WD SUVs will be driven in much greater measure by consumer demand than by NHTSA's regulatory definitions. If it appears, in the course of the next several model years, that manufacturers are indeed responding to the CAFE regulatory definitions in a way that reduces overall fuel savings from expected levels, it may be appropriate for NHTSA to review this question again. At this time, however, since so little time has passed since our last rulemaking action, we do not believe that we have enough information about changes in the fleet to ascertain whether this is yet ripe for consideration. We seek comment on how the agency might go about reviewing this question as more information about manufacturer behavior is accumulated over time.

I. Compliance and Enforcement

1. Overview

NHTSA's CAFE enforcement program is largely established by statute—unlike the CAA, EPCA, as amended by EISA, is very prescriptive with regard to enforcement. EPCA and EISA also clearly specify a number of flexibilities that are available to manufacturers to help them comply with the CAFE standards. Some of those flexibilities are constrained by statute—for example, while Congress required that NHTSA allow manufacturers to transfer credits earned for over-compliance from their car fleet to their truck fleet and vice versa, Congress also limited the amount by which manufacturers could increase their CAFE levels using those transfers.[821] NHTSA believes Congress balanced the energy-saving purposes of the statute against the benefits of certain flexibilities and incentives and intentionally placed some limits on certain statutory flexibilities and incentives. With that goal in mind, of maximizing compliance flexibility while also implementing EPCA/EISA's overarching purpose of energy conservation as fully as possible, NHTSA has done its best in crafting the credit transfer and trading regulations authorized by EISA to ensure that total fuel savings are preserved when manufacturers exercise their statutorily-provided compliance flexibilities.

Furthermore, to achieve the level of standards described in this proposal for the 2017–2025 program, NHTSA expects automakers to continue increasing the use of innovative and advanced technologies as they evolve. Additional incentive programs may encourage early adoption of these innovative and advanced technologies and help to maximize both compliance flexibility and energy conservation. These incentive programs for CAFE compliance would not be under NHTSA's EPCA/EISA authority, but under EPA's EPCA authority—as discussed in more detail below and in Section III of this preamble, EPA measures and calculates manufacturer compliance with the CAFE standards, and it would be in the calculation of fuel economy levels that additional incentives would most appropriately be applied, as a practical matter. Specifically, to be included in the CAFE program, EPA is proposing: (1) Fuel economy performance adjustments due to improvements in air conditioning system efficiency; (2) utilization of ''game changing'' technologies installed on full size pick-up trucks including hybridization; and (3) installation of ''off-cycle'' technologies. In addition, for model years 2020 and later, EPA is proposing calculation methods for dual-fueled vehicles, to fill the gap left in EPCA/EISA by the expiration of the dual-fuel incentive. A more thorough description of the basis for the new incentive programs can be found in Section III.

The following sections explain how NHTSA determines whether manufacturers are in compliance with the CAFE standards for each model year, and how manufacturers may address potential non-compliance situations through the use of compliance flexibilities or fine payment. The following sections also explain, for the reader's reference, the proposed new incentives and calculations, but we also refer readers to Section III.C for EPA's explanation of its authority and more specific detail regarding these proposed changes to the CAFE program.

2. How does NHTSA determine compliance?

a. Manufacturer Submission of Data and CAFE Testing by EPA

NHTSA begins to determine CAFE compliance by reviewing projected estimates in pre- and mid-model year reports submitted by manufacturers pursuant to 49 CFR part 537, Automotive Fuel Economy Reports.[822] Those reports for each compliance model year are submitted to NHTSA by December of the calendar year prior to the corresponding subsequent model year (for the pre-model year report) and in July of the given model year (for the mid-model year report). NHTSA has already received pre-and mid-model year reports from manufacturers for MY 2011. NHTSA uses these reports for reference to help the agency, and the manufacturers who prepare them, anticipate potential compliance issues as early as possible, and help manufacturers plan compliance strategies. NHTSA also uses the reports for auditing and testing purposes, which helps manufacturers correct errors prior to the end of the model year and facilitates acceptance of their final CAFE report by EPA. In addition, NHTSA issues reports to the public twice a year that provide a summary of manufacturers' fleet fuel economy projected performances using pre- and mid model year data. Currently, NHTSA receives manufacturers' CAFE reports in paper form. In order to facilitate submission by manufacturers, NHTSA amended part 537 to allow for electronic submission of the pre- and mid-model year CAFE reports in 2010 (see 75 FR 25324). Electronic reports are optional and must be submitted in a pdf format. NHTSA proposes to modify these provisions in this NPRM, as described below, in order to eliminate hardcopy submissions and help the agency more readily process and utilize the electronically-submitted data.

Throughout the model year, NHTSA audits manufacturers' reports and conducts vehicle testing to confirm the accuracy of track width and wheelbase measurements as a part of its footprint validation program,[823] which helps the agency understand better how manufacturers may adjust vehicle characteristics to change a vehicle's footprint measurement, and thus its fuel economy target. NHTSA resolve discrepancies with the manufacturer prior to the end of the calendar year corresponding to the respective model year with the primary goal of manufacturers submitting accurate final reports to EPA. NHTSA makes its ultimate determination of a manufacturer's CAFE compliance obligation based on official reported and verified CAFE data received from EPA. Pursuant to 49 U.S.C. 32904(e), EPA is responsible for calculating manufacturers' CAFE values so that NHTSA can determine compliance with its CAFE standards. The EPA-verified data is based on any considerations from NHTSA testing, its own vehicle testing, and final model year data

[821] See 49 U.S.C. 32903(g).

[822] 49 CFR part 537 is authorized by 49 U.S.C. 32907.

[823] See *http://www.nhtsa.gov/DOT/NHTSA/Vehicle%20Safety/Test%20Procedures/Associated%20Files/TP–537–01.pdf*

submitted by manufacturers to EPA pursuant to 40 CFR 600.512. A manufacturer's final model year report must be submitted to EPA no later than 90 days after December 31st of the model year. EPA test procedures including those used to establish the new incentive fuel economy performance values for model year 2017 to 2025 vehicles are contained in sections 40 CFR Part 600 and 40 CFR Part 86.

b. NHTSA Then Analyzes EPA–Certified CAFE Values for Compliance

NHTSA's determination of CAFE compliance is fairly straightforward: after testing, EPA verifies the data submitted by manufacturers and issues final CAFE reports sent to manufacturers and to NHTSA in a pdf format between April and October of each year (for the previous model year), and NHTSA then identifies the manufacturers' compliance categories (fleets) that do not meet the applicable CAFE fleet standards. NHTSA plans to construct a new, more automated database system in the near future to store manufacturer data and the EPA data. The new database is expected to simplify data submissions to NHTSA, improve the quality of the agency's data, expedite public reporting, improve audit verifications and testing, and enable more efficient tracking of manufacturers' CAFE credits with greater transparency.

NHTSA uses the verified data from EPA to compare fleet average standards with performance. A manufacturer complies with NHTSA's fuel economy standard if its fleet average performance is greater than or equal to its required standard, or if it is able to use available compliance flexibilities to resolve its non-compliance difference. NHTSA calculates a cumulative credit status for each of a manufacturer's vehicle compliance categories according to 49 U.S.C. 32903. If a manufacturer's compliance category exceeds the applicable fuel economy standard, NHTSA adds credits to the account for that compliance category. The amount of credits earned in a given year are determined by multiplying the number of tenths of an mpg by which a manufacturer exceeds a standard for a particular category of automobiles by the total volume of automobiles of that category manufactured by the manufacturer for that model year. Credits may be used to offset shortfalls in other model years, subject to the three year ''carry-back'' and five-year ''carry-forward'' limitations specified in 49 U.S.C. 32903(a); NHTSA does not have authority to allow credits to be carried forward or back for periods longer than that specified in the statute. A manufacturer may also transfer credits to another compliance category, subject to the limitations specified in 49 U.S.C. 32903(g)(3), or trade them to another manufacturer. The value of each credit received via trade or transfer, when used for compliance, is adjusted using the adjustment factor described in 49 CFR 536.4, pursuant to 49 U.S.C. 32903(f)(1). As part of this rulemaking, NHTSA is proposing to set the VMT values that are part of the adjustment factor for credits earned in MYs 2017–2025 at a single level that does not change from model year to model year, as discussed further below.

If a manufacturer's vehicles in a particular compliance category fall below the standard fuel economy value, NHTSA will provide written notification to the manufacturer that it has not met a particular fleet standard. The manufacturer will be required to confirm the shortfall and must either submit a plan indicating it will allocate existing credits, or if it does not have sufficient credits available in that fleet, how it will earn, transfer and/or acquire credits, or pay the appropriate civil penalty. The manufacturer must submit a plan or payment within 60 days of receiving agency notification. Credit allocation plans received from the manufacturer will be reviewed and approved by NHTSA. NHTSA will approve a credit allocation plan unless it finds the proposed credits are unavailable or that it is unlikely that the plan will result in the manufacturer earning sufficient credits to offset the subject credit shortfall. If a plan is approved, NHTSA will revise the manufacturer's credit account accordingly. If a plan is rejected, NHTSA will notify the manufacturer and request a revised plan or payment of the appropriate fine.

In the event that a manufacturer does not comply with a CAFE standard even after the consideration of credits, EPCA provides for the assessment of civil penalties. The Act specifies a precise formula for determining the amount of civil penalties for noncompliance.[824] The penalty, as adjusted for inflation by law, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year multiplied by the total volume of those vehicles in the affected fleet (*i.e.,* import or domestic passenger car, or light truck), manufactured for that model year. The amount of the penalty may not be reduced except under the unusual or extreme circumstances specified in the statute. All penalties are paid to the U.S. Treasury and not to NHTSA itself.

Unlike the National Traffic and Motor Vehicle Safety Act, EPCA does not provide for recall and remedy in the event of a noncompliance. The presence of recall and remedy provisions[825] in the Safety Act and their absence in EPCA is believed to arise from the difference in the application of the safety standards and CAFE standards. A safety standard applies to individual vehicles; that is, each vehicle must possess the requisite equipment or feature that must provide the requisite type and level of performance. If a vehicle does not, it is noncompliant. Typically, a vehicle does not entirely lack an item or equipment or feature. Instead, the equipment or features fails to perform adequately. Recalling the vehicle to repair or replace the noncompliant equipment or feature can usually be readily accomplished.

In contrast, a CAFE standard applies to a manufacturer's entire fleet for a model year. It does not require that a particular individual vehicle be equipped with any particular equipment or feature or meet a particular level of fuel economy. It does require that the manufacturer's fleet, as a whole, comply. Further, although under the attribute-based approach to setting CAFE standards fuel economy targets are established for individual vehicles based on their footprints, the vehicles are not required to comply with those targets on a model-by-model or vehicle-by-vehicle basis. However, as a practical matter, if a manufacturer chooses to design some vehicles so they fall below their target levels of fuel economy, it will need to design other vehicles so they exceed their targets if the manufacturer's overall fleet average is to meet the applicable standard.

Thus, under EPCA, there is no such thing as a noncompliant vehicle, only a noncompliant fleet. No particular vehicle in a noncompliant fleet is any more, or less, noncompliant than any other vehicle in the fleet.

After enforcement letters are sent, NHTSA continues to monitor receipt of credit allocation plans or civil penalty payments that are due within 60 days from the date of receipt of the letter by the vehicle manufacturer, and takes further action if the manufacturer is delinquent in responding. If NHTSA receives and approves a manufacturer's carryback plan to earn future credits within the following three years in order to comply with current regulatory

[824] See 49 U.S.C. 32912.

[825] 49 U.S.C. 30120, Remedies for defects and noncompliance.

obligations, NHTSA will defer levying fines for non-compliance until the date(s) when the manufacturer's approved plan indicates that credits will be earned or acquired to achieve compliance, and upon receiving confirmed CAFE data from EPA. If the manufacturer fails to acquire or earn sufficient credits by the plan dates, NHTSA will initiate compliance proceedings. 49 CFR part 536 contains the detailed regulations governing the use and application of CAFE credits authorized by 49 U.S.C. 32903.

3. What compliance flexibilities are available under the CAFE program and how do manufacturers use them?

There are three basic flexibilities outlined by EPCA/EISA that manufacturers can currently use to achieve compliance with CAFE standards beyond applying fuel economy-improving technologies: (1) Building dual- and alternative-fueled vehicles; (2) banking (carry-forward and carry-back), trading, and transferring credits earned for exceeding fuel economy standards; and (3) paying civil penalties. We note that while these flexibility mechanisms will reduce compliance costs to some degree for most manufacturers, 49 U.S.C. 32902(h) expressly prohibits NHTSA from considering the availability of statutorily-established credits (either for building dual- or alternative-fueled vehicles or from accumulated transfers or trades) in determining the level of the standards. Thus, NHTSA may not raise CAFE standards because manufacturers have enough of those credits to meet higher standards. This is an important difference from EPA's authority under the CAA, which does not contain such a restriction, and which allows EPA to set higher standards as a result.

a. Dual- and Alternative-Fueled Vehicles

As discussed at length in prior rulemakings, EPCA encourages manufacturers to build alternative-fueled and dual- (or flexible-) fueled vehicles by providing special fuel economy calculations for "dedicated" (that is, 100 percent) alternative fueled vehicles and "dual-fueled" (that is, capable of running on either the alternative fuel or gasoline/diesel) vehicles. Consistent with the overarching purpose of EPCA/EISA, these statutory incentives help to reduce petroleum usage and thus improve our nation's energy security. Per EPCA, the fuel economy of a dedicated alternative fuel vehicle is determined by dividing its fuel economy in equivalent miles per gallon of gasoline or diesel fuel by 0.15.[826] Thus, a 15 mpg dedicated alternative fuel vehicle would be rated as 100 mpg.

For dual-fueled vehicles, EPA measures the vehicle's fuel economy rating by determining the average of the fuel economy on gasoline or diesel and the fuel economy on the alternative fuel vehicle divided by 0.15.[827] This calculation procedure, provided in EPCA, turns a dual-fueled vehicle that averages 25 mpg on gasoline or diesel into a 40 mpg vehicle for CAFE purposes. This assumes that (1) the vehicle operates on gasoline or diesel 50 percent of the time and on alternative fuel 50 percent of the time; (2) fuel economy while operating on alternative fuel is 15 mpg (15/.15 = 100 mpg); and (3) fuel economy while operating on gas or diesel is 25 mpg. Thus:

$$\text{CAFE FE} = 1/\{0.5/(\text{mpg gas}) + 0.5/(\text{mpg alt fuel})\} = 1/\{0.5/25 + 0.5/100\} = 40 \text{ mpg}$$

[826] 49 U.S.C. 32905(a).

[827] 49 U.S.C. 32905(b).

In the case of natural gas, EPA's calculation is performed in a similar manner. The fuel economy is the weighted average while operating on natural gas and operating on gas or diesel. The statute specifies that 100 cubic feet (ft^3) of natural gas is equivalent to 0.823 gallons of gasoline. The CAFE fuel economy while operating on the natural gas is determined by dividing its fuel economy in equivalent miles per gallon of gasoline by 0.15.[828] Thus, if a vehicle averages 25 miles per 100 ft^3 of natural gas, then:

$$\text{CAFE FE} = (25/100) * (100/.823)*(1/0.15) = 203 \text{ mpg}$$

Congress extended the dual-fueled vehicle incentive in EISA for dual-fueled automobiles through MY 2019, but provided for its phase-out between MYs 2015 and 2019.[829] The maximum fleet fuel economy increase attributable to this statutory incentive is thus as follows:

[828] 49 U.S.C. 32905(c).

[829] 49 U.S.C. 32906(a). NHTSA notes that the incentive for dedicated alternative-fuel automobiles, automobiles that run exclusively on an alternative fuel, at 49 U.S.C. 32905(a), was not phased-out by EISA.

We note additionally and for the reader's reference that EPA will be treating dual- and alternative-fueled vehicles under its GHG program similarly to the way EPCA/EISA provides for CAFE through MY 2015, but for MY 2016, EPA established CO_2 emission levels for alternative fuel vehicles based on measurement of actual CO_2 emissions during testing, plus a manufacturer demonstration that the vehicles are actually being run on the alternative fuel. The manufacturer would then be allowed to weight the gasoline and alternative fuel test results based on the proportion of actual usage of both fuels. Because EPCA/EISA provides the explicit CAFE measurement methodology for EPA to use for dedicated vehicles and dual-fueled vehicles through MY 2019, we explained in the MYs 2012–2016 final rule that the CAFE program would not require that vehicles manufactured for the purpose of obtaining the credit actually be run on the alternative fuel.

Model year	mpg increase
MYs 1993-2014	1.2
MY 2015	1.0
MY 2016	0.8
MY 2017	0.6
MY 2018	0.4
MY 2019	0.2
After MY 2019	0

49 CFR part 538 codifies in regulation the statutory alternative-fueled and dual-fueled automobile manufacturing incentive.

Given that the statutory incentive for dual-fueled vehicles in 49 U.S.C. 32906 and the measurement methodology specified in 49 U.S.C. 32905(b) and (d) expire in MY 2019, the question becomes, how should the fuel economy of dual-fueled vehicles be determined for CAFE compliance in MYs 2020 and beyond? NHTSA and EPA believe that the expiration of the dual-fueled vehicle measurement methodology in the statute leaves a gap to be filled, to avoid the absurd result of dual-fueled vehicles' fuel economy being measured like that of conventional gasoline vehicles. If the overarching purpose of the statute is energy conservation and reducing petroleum usage, the agencies believe that that goal is best met by continuing to reflect through CAFE calculations the reduced petroleum usage that dual-fueled vehicles achieve.

As discussed in more detail in Section III.B.10, for MYs 2020 and beyond, to fill the gap left by the expiration of the statutory CAFE measurement methodology for dual-fueled vehicles, EPA is proposing to harmonize with the approach it uses under the GHG program to measure the emissions of dual-fueled vehicles, to reflect the real-world percentage of usage of alternative fuels by dual-fueled vehicles, but also to continue to incentivize the use of certain alternative fuels in dual-fueled vehicles as appropriate under EPCA/EISA to reduce petroleum usage. Specifically, for MYs 2020 and beyond, EPA will calculate the fuel economy test values for a plug-in hybrid electric vehicle (PHEV, that runs on both gasoline and electricity) and for CNG-gasoline vehicles on both the alternative fuel and on gasoline, but rather than assuming that the dual-fueled vehicle runs on the alternative fuel 50 percent of the time as the current statutory measurement methodology requires, EPA will instead use the Society of Automotive Engineers (SAE) ''utility factor'' methodology (based on vehicle range on the alternative fuel and typical daily travel mileage) to determine the assumed percentage of operation on gasoline/diesel and percentage of operation on the alternative fuel for those vehicles. Using the utility factor, rather than making an a priori assumption about the amount of alternative fuel used by dual-fueled vehicles, recognizes that once a consumer has paid several thousand dollars to be able to use a fuel that is considerably cheaper than gasoline or diesel, it is very likely that the consumer will seek to use the cheaper fuel as much as possible. Consistent with this approach, however, EPA is not proposing to extend the utility factor method to flexible fueled vehicles (FFVs) that use E–85 and gasoline, since there is not a significant cost differential between an FFV and conventional gasoline vehicle and historically consumers have only fueled these vehicles with E85 a very small percentage of the time. Therefore, EPA is proposing for CAFE compliance in MYs 2020 and beyond to continue treatment of E85 and other FFVs as finalized in the MY 2016 GHG program, based on actual usage of the alternative fuel which represents a real-world reduction attributed to alternative fuels. For clarification in our regulations, NHTSA is proposing to add Part 536.10(d) which states that for model years 2020 and beyond a manufacturer must calculate the fuel economy of dual fueled vehicles in accordance with 40 CFR 600.500–12(c), (2)(v) and (vii), the sections of EPA's calculation regulations where EPA is proposing to incorporate these changes.

Additionally, to avoid manufacturers building only dedicated alternative fuel vehicles (which may be harder to refuel in some instances) because of the continued statutory 0.15 CAFE divisor under 49 U.S.C. 32905(a) and the calculation for EV fuel economy under 49 U.S.C. 32904, and declining to build dual-fueled vehicles which might not get a similar bonus, EPA is proposing to use the Petroleum Equivalency Factor (PEF) and a 0.15 divisor for calculating the fuel economy of PHEVs' electrical operation and for natural gas operation of CNG-gasoline vehicles.[830] This is consistent with the statutory approach for dedicated alternative fuel vehicles, and continues to incentivize the usage of alternative fuels and reduction of petroleum usage, but when combined with the utility factor approach described above, does not needlessly over-incentivize their usage—it gives credit for what is used, and does not give credit for what is not used. Because it does not give credit for what is not used, EPA would propose that manufacturers may increase their calculated fleet fuel economy for dual-

[830] EPA is also seeking comment on an approach that would not use the PEF and 0.15 multiplier, as discussed above in Section III.

fueled vehicles by an unlimited amount using these flexibilities.

As an example, for MYs 2020 and beyond, the calculation procedure for a dual-fueled vehicle that uses both gasoline and CNG could result in a combined fuel economy value of 150 mpg for CAFE purposes. This assumes that (1) the ''utility factor'' for the alternative fuel is found to be 95 percent, and so the vehicle operates on gasoline for the remaining 5 percent of the time; (2) fuel economy while operating on natural gas is 203 mpg [(25/100) * (100/.823) * (1/0.15)] as shown above utilizing the PEF and the .15 incentive factor; and (3) fuel economy while operating on gasoline is 25 mpg. Thus:

CAFE FE = 1/{0.05/(mpg gas) + 0.95/(mpg CNG)} = 1/{0.05/25 + 0.95/203} = 150 mpg

The agencies seek comment on this approach.

b. Credit Trading and Transfer

As part of the MY 2011 final rule, NHTSA created 49 CFR part 536 for credit trading and transfer. Part 536 implements the provisions in EISA authorizing NHTSA to establish by regulation a credit trading program and directing it to establish by regulation a credit transfer program.[831] Since its enactment, EPCA has permitted manufacturers to earn credits for exceeding the standards and to carry those credits backward or forward. EISA extended the ''carry-forward'' period from three to five model years, and left the ''carry-back'' period at three model years. Under part 536, credit holders (including, but not limited to, manufacturers) will have credit accounts with NHTSA, and will be able to hold credits, use them to achieve compliance with CAFE standards, transfer them between compliance categories, or trade them. A credit may also be cancelled before its expiration date, if the credit holder so chooses. Traded and transferred credits are subject to an ''adjustment factor'' to ensure total oil savings are preserved, as required by EISA. EISA also prohibits credits earned before MY 2011 from being transferred, so NHTSA has developed several regulatory restrictions on trading and transferring to facilitate Congress' intent in this regard. As discussed above, EISA establishes a ''cap'' for the maximum increase in any compliance category attributable to transferred credits: for MYs 2011–2013, transferred credits can only be used to increase a manufacturer's CAFE level in a given compliance category by 1.0 mpg; for MYs 2014–2017, by 1.5 mpg; and for MYs 2018 and beyond, by 2.0 mpg.

As part of this rulemaking, NHTSA is proposing to set the VMT estimates used in the credit adjustment factor at 195,264 miles for passenger car credits and 225,865 miles for light truck credits for credits earned in MYs 2017–2025. The VMT estimates for MYs 2012–2016 would not change. NHTSA is proposing these values in the interest of harmonizing with EPA's GHG program, and seeks comment on this approach as compared to the prior approach of adjustment factors with VMT estimates that vary by year. Additionally, NHTSA is proposing to include VMT estimates for MY 2011 which the agency neglected to include in Part 536 as part of the MYs 2012–2016 rulemaking. The proposed MY 2011 VMT estimate for passenger cars is 152,922 miles, and for light trucks is 172,552 miles.

c. Payment of Civil Penalties

If a manufacturer's average miles per gallon for a given compliance category (domestic passenger car, imported passenger car, light truck) falls below the applicable standard, and the manufacturer cannot make up the difference by using credits earned or acquired, the manufacturer is subject to penalties. The penalty, as mentioned, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year, multiplied by the total volume of those vehicles in the affected fleet, manufactured for that model year. NHTSA has collected $794,921,139.50 to date in CAFE penalties, the largest ever being paid by DaimlerChrysler for its MY 2006 import passenger car fleet, $30,257,920.00. For their MY 2009 fleets, six manufacturers paid CAFE fines for not meeting an applicable standard—Fiat, which included Ferrari, Maserati, and Alfa Romeo; Daimler (Mercedes-Benz); Porsche; and Tata (Jaguar Land Rover)—for a total of $9,148,425.00. As mentioned above, civil penalties paid for CAFE non-compliance go to the U.S. Treasury, and not to DOT or NHTSA.

NHTSA recognizes that some manufacturers may use the option to pay civil penalties as a CAFE compliance flexibility—presumably, when paying civil penalties is deemed more cost-effective than applying additional fuel economy-improving technology, or when adding fuel economy-improving technology would fundamentally change the characteristics of the vehicle in ways that the manufacturer believes its target consumers would not accept. NHTSA has no authority under EPCA/EISA to prevent manufacturers from turning to payment of civil penalties if they choose to do so. This is another important difference from EPA's authority under the CAA, which allows EPA to revoke a manufacturer's certificate of conformity that permits it to sell vehicles if EPA determines that the manufacturer is in non-compliance, and does not permit manufacturers to pay fines in lieu of compliance with applicable standards.

NHTSA has grappled repeatedly with the issue of whether civil penalties are motivational for manufacturers, and whether raising them would increase manufacturers' compliance with the standards. EPCA authorizes increasing the civil penalty very slightly up to $10.00, exclusive of inflationary adjustments, if NHTSA decides that the increase in the penalty ''will result in, or substantially further, substantial energy conservation for automobiles in the model years in which the increased penalty may be imposed; and will not have a substantial deleterious impact on the economy of the United States, a State, or a region of a State.'' 49 U.S.C. 32912(c).

To support a decision that increasing the penalty would result in ''substantial energy conservation'' without having ''a substantial deleterious impact on the economy,'' NHTSA would likely need to provide some reasonably certain quantitative estimates of the fuel that would be saved, and the impact on the economy, if the penalty were raised. Comments received on this issue in the past have not explained in clear quantitative terms what the benefits and drawbacks to raising the penalty might be. Additionally, it may be that the range of possible increase that the statute provides, *i.e.,* up to $10 per tenth of a mpg, is insufficient to result in substantial energy conservation, although changing this would require an amendment to the statute by Congress. NHTSA continues to seek to gain information on this issue and requests that commenters wishing to address this issue please provide, as specifically as possible, estimates of how raising or not raising the penalty amount will or will not substantially raise energy conservation and impact the economy.

[831] Congress required that DOT establish a credit ''transferring'' regulation, to allow individual manufacturers to move credits from one of their fleets to another (e.g., using a credit earned for exceeding the light truck standard for compliance with the domestic passenger car standard). Congress allowed DOT to establish a credit ''trading'' regulation, so that credits may be bought and sold between manufacturers and other parties.

4. What new incentives are being added to the CAFE program for MYs 2017–2025?

All of the CAFE compliance incentives discussed below are being proposed by EPA under its EPCA authority to calculate fuel economy levels for individual vehicles and for fleets. Because they are EPA proposals, we refer the reader to Section III for more details, as well as Chapter 5 of the draft Joint TSD for more information on the precise mechanics of the incentives, but we present them here in summary form so that the reader may understand more comprehensively what compliance options are proposed to be available for manufacturers for meeting the MYs 2017–2025 CAFE standards.

As mentioned above with regard to EPA's proposed changes for the calculation of dual-fueled automobile fuel economy for MYs 2020 and beyond, NHTSA is proposing to modify its own regulations to reflect the fact that these incentives may be used as part of the determination of a manufacturer's CAFE level. The requirements for determining the vehicle and fleet average performance for passenger cars and light trucks inclusive of the proposed incentives are defined in 49 CFR part 531 and 49 CFR part 533, respectively. Part 531.6(a) specifies that the average fuel economy of all passenger automobiles that are manufactured by a manufacturer in a model year shall be determined in accordance with procedures established by the Administrator of the Environmental Protection Agency under 49 U.S.C. 32904 of the Act and set forth in 40 CFR part 600. Part 533.6 (b) specifies that the average fuel economy of all non-passenger automobiles is required to be determined in accordance with the procedures established by the Administrator of the Environmental Protection Agency under 49 U.S.C. 32904 and set forth in 40 CFR part 600. Proposed changes to these sections would simply clarify that in model years 2017 to 2025, manufacturers may adjust their vehicle fuel economy performance values in accordance with 40 CFR Part 600 for improvements due to the new incentives. We seek comment on this proposed change.

a. ''Game Changing'' Technologies For Full Size Pick-Up Trucks

EPA is proposing to adopt two new types of incentives for improving the fuel economy performance of full size pickup trucks. The first incentive would provide a credit to manufacturers that employ significant quantities of hybridization on full size pickup trucks. The second incentive would provide a performance-based incentive for full size pickup trucks that achieve a significant reduction in fuel consumption as compared to the applicable fuel economy target for the vehicle in question. These incentives are proposed due to the significant difficulty of large trucks, including full size pickup trucks, in meeting CAFE standards while still maintaining the levels of utility to which consumers have become accustomed, which require higher payload and towing capabilities and greater cargo volumes than other light-duty vehicles. Technologies that provide substantial fuel economy benefits are often not attractive to manufacturers of large trucks due to these tradeoffs in utility purposes, and therefore have not been taken advantage of to the same extent as they have in other vehicle classes. The goal of these incentives is to facilitate the application of these ''game changing'' technologies for large pickups, both to save more fuel and to help provide a bridge for industry to more stringent light truck standards in MYs 2022–2025—as manufacturers gain experience with applying more fuel-saving technology for these vehicles and consumers become more accustomed to certain advanced technologies in pickup trucks, the agencies anticipate that higher CAFE levels will be more feasible for the fleet as a whole.[832] In the context of the CAFE program, these incentives would be used as an adjustment to a full size pickup truck's fuel economy performance. The same vehicle would not be allowed to receive an adjustment to its calculated fuel economy for both the hybridization incentive and the performance-based incentive, to avoid double-counting.

To accommodate the proposed changes to the CAFE program, NHTSA is proposing to adopt new definitions into regulation, 49 CFR part 523, ''Vehicle Classification.'' Part 523 was established by NHTSA to include its regulatory definitions for passenger automobiles and trucks and to guide the agency and manufacturers in classifying vehicles. NHTSA proposes to add a definition in Part 523.2 defining the characteristics that identify full size pickup trucks. NHTSA believes that the definition is needed to help explain to readers which characteristics of full size pickup truck make them eligible to gain fuel economy improvement values allowed after a manufacturer meets either a minimum penetration of hybridized technologies or has other technologies that significantly reduce fuel consumption. The proposed improvement would be available on a per-vehicle basis for mild and strong HEVs, as well as for other technologies that significantly improve the efficiency of full sized pickup trucks. The proposed definition would specify that trucks meeting an overall bed width and length as well as a minimum towing or payload capacity could be qualified as full size pickup trucks. NHTSA is also proposing to modify Part 523 to include definitions for mild and strong hybrid electric full size pickup trucks, and to include the references in Part 533 mentioned above.

i. Pickup Truck Hybridization

One proposed incentive would provide an adjustment to the fuel economy of a manufacturer's full size pickup trucks if the manufacturer employs certain defined hybrid technologies on defined significant quantities of its full size pickup trucks. After meeting the minimum production percentages, manufacturers would gain an adjustment to the fuel economy performance for each ''mild'' or ''strong'' hybrid full size pickup truck it produces. Manufacturers producing mild hybrid pickup trucks, as defined in Chapter 5 of the draft Joint TSD, would gain the incentive by applying mild hybrid technology to at least 30 percent of the company's full sized pickups produced in MY 2017, which would increase each year up to at least 80 percent of the company's full size pickups produced in MY 2021, after which point the adjustment is no longer applicable. For strong hybrids, also defined in Chapter 5 of the draft Joint TSD, the strong hybrid technology must be applied to at least 10 percent of a company's full sized pickup production in each year for model years 2017–2025. The fuel economy adjustment for each mild hybrid full size pickup would be a decrease in measured fuel consumption of 0.0011gal/mi; for each strong hybrid full size pickup, the decrease in measured fuel consumption would be 0.0023 gal/mi. These adjustments are consistent with the GHG credits under EPA's program of 10 g/mi CO_2 for mild hybrid pickups and 20 g/mi CO_2 for strong hybrid pickups. A manufacturer would then be allowed to adjust the fuel economy performance of its light truck fleet by converting the benefit gained from those improvements in accordance with the procedures specified in 40 CFR part 600.

[832] NHTSA is not prohibited from considering this availability of this incentive in determining the maximum feasible levels of stringency for the light truck standards, because it is not one of the statutory flexibilities enumerated in 49 U.S.C. 32902(h).

ii. Performance-Based Incentive for Full-Size Pickups

Another proposed incentive for full size pickup trucks would provide an adjustment to the fuel economy of a manufacturer's full sized pickup truck if it achieves a fuel economy performance level significantly above the CAFE target for that footprint. This incentive recognizes that not all manufacturers may wish to pursue hybridization for their pickup trucks, but still rewards them for applying fuel-saving technologies above and beyond what they might otherwise do. The fuel economy adjustment for each full size pickup that exceeds its applicable footprint curve target by 15 percent would be a decrease in measured fuel consumption of 0.0011gal/mi; for each full size pickup that exceeds its applicable footprint curve target by 20 percent, the decrease in measured fuel consumption would be 0.0023 gal/mi. These adjustments are consistent with the GHG credits under EPA's program of 10 g/mi CO_2 and 20 g/mi CO_2, respectively, for beating the applicable CO_2 targets by 15 and 20 percent, respectively.

The 0.0011 gal/mi performance-based adjustment would be available for MYs 2017 to 2021, and a vehicle meeting the requirement in a given model year would continue to receive the credit until MY 2021—that is, the credit remains applicable to that vehicle model if the target is exceeded in only one model year—unless its fuel consumption increases. The 0.0023 gal/mi adjustment would be available for a maximum of 5 years within model years 2017–2025, provided the vehicle model's fuel consumption does not increase. As explained above for the hybrid incentive, a manufacturer would then be allowed to adjust the fuel economy performance of its light truck fleet by converting the benefit gained from those improvements in accordance with the procedures specified in 40 CFR Part 600.

We note that in today's analyses, the agencies have projected that PHEV technology is not available to large pickups. While it is technically possible to electrify such vehicles, there are tradeoffs in terms of cost, electric range, and utility that may reduce the appeal of the vehicle to a narrower market. Due to this consideration, the agencies have not considered giving credit to PHEVs for large pickup truck. However, the agencies seek comments on this and will give further consideration during the final rule. Also, the agencies note that under today's proposal, a PHEV that captures a sufficient proportion of braking energy could quality for the HEV adjustment; alternatively, a PHEV pickup achieving sufficiently high fuel economy and low CO_2 emission could qualify for a performance-based adjustment.

b. A/C Efficiency-Improving Technologies

Air conditioning (A/C) use places excess load on an engine, which results in additional fuel consumption. A number of methods related to the A/C system components and their controls can be used to improve A/C system efficiencies. Starting in MY 2017, EPA is proposing to allow manufacturers to include fuel consumption reductions resulting from the use of improved A/C systems in their CAFE calculations. This will more accurately account for achieved real-world fuel economy improvements due to improved A/C technologies, and better fulfill EPCA's overarching purpose of energy conservation. Manufacturers would not be allowed to claim CAFE-related benefits for reducing A/C leakage or switching to an A/C refrigerant with a lower global warming potential, because while these improvements reduce GHGs consistent with the purpose of the CAA, they do not improve fuel economy and thus are not relevant to the CAFE program.

The improvements that manufacturers would likely use to increase A/C efficiency would focus primarily, but not exclusively, on the compressor, electric motor controls, and system controls which reduce load on the A/C system (such as reduced ''reheat'' of the cooled air and increased use of re-circulated cabin air).

Fuel consumption improvement values for CAFE resulting from A/C efficiency improvements would be quantified using a two-step process, the same as for the related CO_2 credits for EPA's GHG program. First, the vehicle with the improved A/C system would be tested in accordance with EPA testing guidelines, and compared with the baseline fuel consumption value for that vehicle. Second, the difference between the baseline fuel consumption value and the value for the vehicle with improved A/C technologies would be calculated, which would determine the fuel consumption improvement value.

In the GHG program for MYs 2012 to 2016, EPA finalized the idle test method for measuring CO_2reductions from improved AC systems. The idle test method measures CO_2 in grams per minute (g/min) while the vehicle is stationary and idling. For MYs 2017–2025, EPA is proposing that a new test called ''A/C 17'' replace the idle test to measure A/C related CO_2emissions reductions. Some aspects of the AC17 test are still being developed and improved, but the basic procedure is sufficiently complete for EPA to propose it as a reporting option alternative to the Idle Test threshold in 2014, and a replacement for the Idle Test in 2017, as a prerequisite for generating Efficiency Credits. Manufacturers will use this test to measure A/C-related CO_2 emissions from vehicles with improved A/C systems, which would be translated to fuel consumption to establish the ratio between the baseline vehicle and the improved-A/C vehicle to determine the value of the fuel consumption improvement. The A/C 17 test procedure is described briefly below.

i. What is the proposed testing approach?

The A/C 17 test is a more extensive test than the idle test and has four elements, including two drive cycles, US03 and the highway fuel economy cycle, which capture steady state and transient operating conditions. It also includes a solar soak period to measure the energy required to cool down a car that has been sitting in the sun, as well as a pre-conditioning cycle. The A/C 17 test cycle will be able to capture improvements in all areas related to efficient operation of a vehicle's A/C system. The A/C 17 test cycle measures CO_2 emissions in grams per mile (g/mi), and requires that baseline emissions be measured in addition to emissions from vehicles with improved A/C systems. EPA is taking comment on whether the A/C 17 test is appropriate for estimating the effectiveness of new efficiency-improving A/C technologies.

ii. How are fuel consumption improvement values then estimated?

Manufacturers would run the A/C 17 test procedure on each vehicle platform that incorporates the new technologies, with the A/C system off and then on, and then report these test results to the EPA. In addition to reporting the test results, EPA will require that manufacturers provide detailed vehicle and A/C system information for each vehicle tested (*e.g.* vehicle class, model type, curb weight, engine size, transmission type, interior volume, climate control type, refrigerant type, compressor type, and evaporator/condenser characteristics). For vehicle models which manufacturers are seeking to earn A/C related fuel consumption improvement values, the A/C 17 test would be run to validate that the performance and efficiency of a vehicle's A/C technology is commensurate to the level of improvement value that is being earned. To determine whether the efficiency improvements of these technologies are being realized, the results of an A/C 17 test performed on a new vehicle model will be compared to a ''baseline'' vehicle which does not incorporate the efficiency-improving technologies. The baseline vehicle is defined as one with characteristics which are similar to the new vehicle, only it is not equipped with efficiency-improving technologies (or they are de-activated).

Manufacturers then take the results of the A/C 17 test and access a credit menu (shown in the table below) to determine A/C related fuel consumption improvement values. The maximum value possible is limited to 0.000563 gal/mi for cars and 0.000810 gal/mi for trucks. As an example, a manufacturer uses two technologies listed in the table, for which the combined improvement value equals 0.000282 gal/mi. If the results of the A/C 17 tests for the baseline and vehicle with improved A/C system demonstrates a 0.000282 gal/mi improvement, then the full fuel consumption improvement value for those two technologies can be taken. If the A/C 17 test result falls short of the improvement value for the two technologies, then a fraction of the improvement value may be counted in CAFE calculations. The improvement value fraction is calculated in the following way: The A/C 17 test result for both the baseline vehicle and the vehicle with an improved A/C system are measured. The difference in the test result of the baseline and the improved vehicle is divided by the test result of the baseline vehicle. This fraction is multiplied by the fuel consumption improvement value for the specific technologies. Thus, if the A/C 17 test yielded an improvement equal to ⅔ of the summed values listed in the table, then ⅔ of the summed fuel consumption improvement values can be counted.

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Table IV-116. Efficiency Improving A/C Technologies and Improvement Values

Technology Description	A/C Fuel Consumption Reduction (% of total A/C improvement)	Car A/C Fuel Efficiency Improvement Value (gals/mi)	Truck A/C Fuel Efficiency Improvement Value (gals/mi)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	0.000169 (*30% of 5.0 g/mi impact*)	0.000248 (*30% of 7.2 g/mi impact*)
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	0.000113	0.000158
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher	30%	0.000169	0.000248

Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher	20%	0.000113	0.000156
Blower motor control which limit wasted electrical energy (e.g. pulsewidth modulated power controller)	15%	0.000090	0.000124
Internal heat exchanger (or suction line heat exchanger)	20%	0.000113	0.000156

As stated above, if more than one technology is utilized by a manufacturer for a given vehicle model, the A/C fuel consumption improvement values can be added, but the maximum value possible is limited to 0.000563 gal/mi for cars and 0.000810 gal/mi for trucks. More A/C related fuel consumption improvement values are discussed in the off-cycle credits section of this chapter. The approach for determining the manufacturers' adjusted fleet fuel economy performance due to improvements in A/C efficiency is described in 40 CFR Part 600.

The agencies seek comment on the proposal to allow manufacturers to estimate fuel consumption reductions from the use of A/C efficiency-improving technologies and to apply these reductions to their CAFE calculations.

c. Off-Cycle Technologies and Adjustments

For MYs 2012–2016, EPA provided an optional credit for new and innovative ''off-cycle'' technologies that reduce vehicle CO_2 emissions, but for which the CO_2 reduction benefits are not recognized under the 2-cycle test procedure used to determine compliance with the fleet average standards. The off-cycle credit option was intended to encourage the introduction of off-cycle technologies that achieve real-world benefits. The off-cycle credits were to be determined using the 5-cycle methodology currently used to determine fuel economy label values, which EPA established to better represent real-world factors impacting fuel economy, including higher speeds and more aggressive driving, colder temperature operation, and the use of air conditioning. A manufacturer must determine whether the benefit of the technology could be captured using the 5-cycle test; if this determination is affirmative, the manufacture must follow the 5-cycle procedures to determine the CO_2 reductions. If the manufacturer finds that the technology is such that the benefit is not adequately captured using the 5-cycle approach, then the manufacturer would have to develop a robust methodology, subject to EPA approval, to demonstrate the benefit and determine the appropriate CO_2 gram per mile credit. The demonstration program must be robust, verifiable, and capable of demonstrating the real-world emissions benefit of the technology with strong statistical significance. The non-5-cycle approach includes an opportunity for public comment as part of the approval process.

EPA has been encouraged by automakers' interest in off-cycle credits since the program was finalized and believes that extending the program to MY 2017 and beyond may continue to encourage automakers to invest in off-cycle technologies that could have the benefit of realizing additional reductions in the light-duty fleet over the longer-term. Therefore, EPA is proposing to extend the off-cycle credits program to 2017 and later model years. EPA is also proposing, under its EPCA authority, to make available a comparable off-cycle technology incentive under the CAFE program beginning in MY 2017. However, instead of manufacturers gaining credits as done under the GHG program, a direct adjustment would be made to the manufacturer's fuel economy performance value.

Starting with MY 2017, manufacturers may generate fuel economy improvements by applying technologies listed on the pre-defined and pre-approved technology list provided in Table IV–117. These credits would be verified and approved as part of certification, with no prior approval process needed. This new option should significantly simplify the program for manufacturers and provide certainty that improvement values may be generated through the use of pre-approved technologies. For improvements from technologies not on the pre-defined list, EPA is proposing to clarify the step-by-step application process for demonstration of fuel consumption reductions and approval.

Table IV-117. Off-cycle technologies and proposed improvement values for passenger cars and light trucks

Technology	Improvement value for passenger cars(gal/mi)	Improvement value for light trucks (gal/mi)
High Efficiency Exterior Lighting	0.000124	0.000124
Engine Heat Recovery	0.000778	0.000778
Solar Roof Panels	0.000338	0.000338
Active Grill Shutters	0.000113	0.000113
Active Suspension Lowering		
Engine Start-Stop	0.000326	0.000506
Electric Heater Circulation Pump	0.000123	0.000169
Active Transmission Warm-Up	0.000203	0.000203
Active Engine Warm-Up	0.000203	0.000203
Solar Control	0.000338	0.000338
High Efficiency Exterior Lighting	0.0001	0.0001
Engine Heat Recovery	0.0001	0.0001
Solar Roof Panels	0.0003	0.0003
Active Grill Shutters	0.0001	0.0001
Active Suspension Lowering		
Engine Start-Stop	0.0003	0.0005
Electric Heater Circulation Pump	0.0001	0.0002
Active Transmission Warm-Up	0.0002	0.0002
Active Engine Warm-Up		
Solar Control	0.0002	0.0002

An example of technologies that could be used to generate off-cycle improvements are those that reduce electrical load and as a result, fuel consumption. The 2-cycle test does not require that all electrical components be turned on during testing. Headlights, for example, are always turned off during testing. Turning the headlights on during normal driving will add an additional load on the vehicle's electrical system and will affect fuel economy. More efficient electrical systems or technologies that offset electrical loads will have a real-world impact on fuel economy but are not captured in the 2-cycle test. Therefore, technologies that reduce or offset electrical loads related to the operation or safety of the vehicle should merit consideration for off-cycle improvements. Reducing the electrical load on a vehicle by 100W will result in an average of 0.000337 gallons/mile reduction in fuel consumption over the course of a 2-cycle test, or 0.00042 gallons/mile over a 5-cycle test. To determine the off-cycle benefit of certain 100W electrical load reduction technologies, the benefit of the technology on the 2-cycle test is subtracted from the benefit of the technology on the 5-cycle test. This determines the actual benefit of the technology not realized in the 2-cycle test methodology, which in this case is 0.000416 gal/mi minus 0.000337 gal/mi, or 0.000078 gal/mi. This method will avoid double-counting the benefit of the electrical load reduction, which is already counted on the 2-cycle test.

Regardless of whether the off-cycle technology fuel consumption benefit is obtained from the table (columns 2 or 3) above or is based on an approved testing protocol as indicated in the preceding example, under the CAFE program the benefit or credit is treated as an adjustment and subtracted from the subject vehicle's fuel consumption performance value determined from the required CAFE program 2-cycle test results. A manufacturer would then be allowed to adjust the fuel economy performance of its fleets by converting the benefit gained from those improvements in accordance with the procedures specified in 40 CFR Part 600.

Since one purpose of the off-cycle improvement incentive is to encourage market penetration of the technologies (see 75 FR at 25438), EPA is proposing to require minimum penetration rates for non-hybrid based listed technologies as a condition for generating improvements from the list as a way to further encourage their widespread adoption by MY 2017 and later. At the end of the model year for which the off-cycle improvement is claimed, manufacturers would need to demonstrate that production of vehicles equipped with the technologies for that model year exceeded the percentage thresholds in order to receive the listed improvement. EPA proposes to set the threshold at 10 percent of a manufacturer's overall combined car and light truck production for all technologies not specific to HEVs. 10 percent would seem to be an appropriate threshold as it would encourage manufacturers to develop technologies for use on larger volume models and bring the technologies into the mainstream. For solar roof panels and electric heat circulation pumps, which are HEV-specific, EPA is not proposing a minimum penetration rate threshold for credit generation. Hybrids may be a small subset of a manufacturer's fleet, less than 10 percent in some cases, and EPA does not believe that establishing a threshold for hybrid-based technologies would be useful and could unnecessarily complicate the introduction of these technologies. The agencies request comments on applying this type of threshold, the appropriateness of 10 percent as the threshold for listed technologies that are not HEV-specific, and the proposed treatment of hybrid-based technologies.

Because the proposed improvements are based on limited data, however, and because some uncertainty is introduced when credits are provided based on a general assessment of off-cycle performance as opposed to testing on the individual vehicle models, as part of the incentive EPA is proposing to cap the amount of improvement a manufacturer could generate using the above list to 0.001125 gal/mile per year on a combined car and truck fleet-wide average basis. The cap would not apply on a vehicle model basis, allowing manufacturers the flexibility to focus off-cycle technologies on certain vehicle models and generate improvements for that vehicle model in excess of 0.001125 gal/mile. If manufacturers wish to generate improvements in excess of the 0.001125 gal/mile limit using listed technologies, they could do so by generating necessary data and going through the approval process.

For more details on the testing protocols used for determining off-cycle technology benefits and the step-by-step EPA review and approval process, refer to Section III.C.5.b.iii and v. The approach for determining a manufacturer's adjusted fuel economy performance for off-cycle technologies is described in 40 CFR Part 600. NHTSA also proposes to incorporate references in Part 531.6 and 533.6 to allow manufacturers to adjust their fleet performance for off-cycle technologies as described above.

5. Other CAFE Enforcement Issues

a. Electronic Reporting

Pursuant to 49 CFR part 537, manufacturers submit pre-model year fuel economy reports to NHTSA by December 31st prior to the model year, and mid-model year reports by July 31st of the model year. Manufacturers may also provide supplemental reports whenever changes are needed to a previously submitted CAFE report. NHTSA receives both non-confidential and confidential versions of reports, the basic difference being the inclusion of projected upcoming production sales volumes in reports seeking confidentiality. Manufacturers must include a request for confidentiality, in accordance with 49 CFR part 512, along with the report for which confidential treatment is sought.[833] Manufacturers may submit reports either in paper form or electronically to a secure email address, *cafe@dot.gov*, that allows for the safe handling of confidential materials. All electronic submissions submitted to the CAFE email must be provided in a pdf format. NHTSA added electronic reporting to the 2012–2016 CAFE rule as an approach to simplify reporting for manufacturers and NHTSA alike. Currently, most manufacturers submit both electronic and paper reports.[834]

NHTSA is proposing to modify its reporting requirements to receive all CAFE reports in electronic format, thereby eliminating the requirement for paper submissions. In the revised requirements, a manufacturer could either submit its reports on a CD–ROM or through the existing email procedures. Under the proposal, the contents of the CD must include the manufacturer's request for confidentiality, the cover letter, and any other supporting documents in a pdf format. Any data included in the report must be provided in a Microsoft Excel spreadsheet format. The same approach is also proposed for submitting information by email. NHTSA emphasizes that submitting reports to the CAFE email address is completely voluntary, but if the option is selected, the manufacturer must follow the normal deadline dates as specified in 49 CFR 537.5. NHTSA believes that receiving CAFE data through electronic reports would be a significant improvement, improving the quality of its CAFE data, simplifying enforcement activities (*e.g.,* auditing the data), and helping to expedite the tracking and reporting of CAFE credits. The agency also plans to eventually develop an XML schema for submitting CAFE reports electronically that will available through its Web site. Ultimately, the XML schema would be used as part of the new database system NHTSA plans to construct in the future to store its

[833] Pursuant to § 537.12, NHTSA's Office of Chief Counsel normally grants confidentiality to reports with projected production sales volumes until after the model year ends.

[834] For model year 2011, NHTSA received electronic mid-model year reports from 12 manufacturers. Each of the manufacturers also provided hardcopy reports.

CAFE data. NHTSA seeks comments on the appropriateness of ending paper submissions, as well as information on any other electronic formats that should be considered for submissions.

b. Reporting of How a Vehicle Is Classified as a Light Truck

As part of the reporting provisions in 49 CFR part 537, NHTSA requires manufacturers to provide information on some, but not all, of the functions and features that a manufacturer uses to classify an automobile as a light truck. The required data is distributed throughout the report, making it difficult for the agency to clearly and easily determine exactly what functions or features a manufacturer is actually using to make this determination. For example, related to the functions specified in 49 CFR 523.5(a) and discussed in Section IV.H above, manufacturers must provide the vehicles' passenger and cargo carrying volumes,[835] and identify whether their vehicles are equipped with three rows of seats that can be removed or folded flat for expanded cargo carrying purposes or if the vehicle includes temporary living quarters.[836] Manufacturers are not required to identify whether the vehicles can transport more than 10 persons or if the vehicles are equipped with an open cargo bed. Related to the functions specified in Section 523.5(b), for each model type classified as an automobile capable of off-highway operation, manufacturers are required to provide the five suspension parameter measurements and indicate the existence of 4-wheel drive,[837] but they are not required to identify a vehicle's GVWR, which is necessary for off-road determination when the vehicle is not equipped with 4-wheel drive. NHTSA proposes to eliminate the language requesting vehicle attribute information in Sections 537.7(c)(4)(xvi)(A)(3) to (6) and (B)(3) to (6) and to relocate that language into a revised Section 537.7(c)(5) to include identification of all the functions and features that can be used by a manufacturer for making a light truck classification determination. By incorporating all the requirements into one section, the agency believes the classification process will become significantly more accurate and efficient. NHTSA seeks comment on this proposed change.

[835] 49 CFR 537.7(c)(4)(xvi)(B).

[836] 49 CFR 537.7(c)(4)(xvii) and (xviii).

[837] 49 CFR 537.7(c)(5).

c. Base Tire Definition

Beginning in model year 2011, manufacturers of light trucks and passenger cars are required to use vehicle footprint to determine the CAFE standards applicable to each of their vehicle fleets. To determine the appropriate footprint-based standards, a manufacturer must calculate each vehicle's footprint value, which is the product of the vehicle track width and wheelbase dimensions. Vehicle track width dimensions are determined with a vehicle equipped with ''base tires,'' [838] which NHTSA defines as the tire specified as standard equipment by a manufacturer on each vehicle configuration of a model type.

NHTSA is concerned that the definition for ''base tire'' is insufficiently descriptive, and may lead to inconsistencies among manufacturers' base tire selections. In meetings relating to CAFE enforcement, manufacturers have stated that various approaches in selecting base tires exist due to differences in the tires considered as standard equipment.[839] Standard equipment is defined by EPA regulation as those features or equipment which are marketed on a vehicle over which the purchaser can exercise no choice,[840] but NHTSA regulations have no comparable definition. NHTSA considered whether adding a definition for ''standard equipment'' would clarify and strengthen the NHTSA regulations, but some manufacturers indicated that the definition of standard equipment provided by EPA does not effectively prevent differences in their interpretations. Some manufacturers, for example, view the base tire as the tire equipped as standard equipment for each trim level of a model type, as each trim level has standard equipment over which the purchaser cannot exercise a choice. This view can allow multiple base tires and footprint values within each model type: A manufacturer may have two vehicle configurations for a particular model type, with each configuration having three trim levels with different standard tires sizes. In that scenario, the model type could have 6 different trim level vehicle configurations, each having three or more unique footprint values with slightly different targets. The additional target fuel economy values could allow the manufacturer to reduce its required fleet standard despite a vehicle model type not having any inherent differences in physical feature between vehicle configurations other than the tire sizes. Other manufacturers, in contrast, avoid designating multiple base tires and choose the standard tire equipped on the most basic vehicle configuration of a model type, even if the most basic vehicle is rarely actually sold. In this scenario, the tires being used to derive a manufacturer fleet standard are not the same size tire equipped on the representative number of vehicles being sold. Yet others designate the base tire as the tire most commonly installed on a model type having the highest production volume. This approach most realistically reflects the manufacturer's sales production fleet.

[838] See 49 CFR 523.2.

[839] NHTSA has confirmed these differences in approach for the designating base tire exist through review of manufacturer-submitted CAFE reports.

[840] In the EPA regulation 40 CFR 600.002–08, standard equipment means those features or equipment which are marketed on a vehicle over which the purchaser can exercise no choice.

To attempt to reconcile the varied approaches for designating base tires, NHTSA is proposing to modify its definition for base tire in 49 CFR 523.2. The proposed modification changes the definition of the base tire by dropping the reference to ''standard equipment'' and adding a reference to the ''the tire installed by the vehicle manufacturer that is used on the highest production sales volume of vehicles within the configuration.'' This modification should ensure that the tires installed on the vehicle most commonly sold within a vehicle configuration become the basis for setting a manufacturer's fuel economy standards. It is NHTSA's goal that a change to the definition of base tire for purposes of CAFE will help to reduce inconsistencies and confusion for both the agency and the manufacturers. NHTSA seeks comments on this approach, as well as other approaches that could be used for selecting the base tire(s).

d. Confirming Target and Fleet Standards

NHTSA requires manufacturers to provide reports containing fleet and model type CAFE standards and projections of expected performance results for each model year.[841] The footprint, track width and wheelbase values are provided for each vehicle configuration within the model types making up the manufacturer's fleets, along with other model type-specific information. Because this information is organized by vehicle configuration, instead of by each vehicle with a unique model type and footprint combination, it is not in the format needed to calculate performance standards. EPA, in contrast, requires manufacturers to provide all of the information necessary

[841] 49 CFR part 537.

to calculate footprint values and CAFE standards. EPA provides an additional calculator (in the form of an Excel spreadsheet), which all manufacturers use and submit as part of their end-of-the-year reports, which includes the appropriate breakdown of footprint values for calculating standards.

Since NHTSA only requires a breakdown of footprint values by vehicle configurations, instead of by each unique model type and footprint combination, NHTSA is currently unable to verify manufacturers' reported target standards. By standardizing with EPA's requirements for reported data, NHTSA would both simplify manufacturer reporting efforts and gain the necessary information for calculating attribute-based CAFE standards. Therefore, NHTSA is proposing to eliminate the language requesting information in § 537.7(c)(4)((xvi)(A)(*3*) through (*6*) and (B)(*3*) through (*6*), and to relocate that language into a revised § 537.7(b)(3).

NHTSA requests comment on this proposed change.

J. Regulatory Notices and Analyses

1. Executive Order 12866, Executive Order 13563, and DOT Regulatory Policies and Procedures

Executive Order 12866, ''Regulatory Planning and Review'' (58 FR 51735, Oct. 4, 1993), as amended by Executive Order 13563, ''Improving Regulation and Regulatory Review'' (76 FR 3821, Jan. 21, 2011), provides for making determinations whether a regulatory action is ''significant'' and therefore subject to OMB review and to the requirements of the Executive Order. The Order defines a ''significant regulatory action'' as one that is likely to result in a rule that may:

(1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or Tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

The rulemaking proposed in this NPRM will be economically significant if adopted. Accordingly, OMB reviewed it under Executive Order 12866. The rule, if adopted, would also be significant within the meaning of the Department of Transportation's Regulatory Policies and Procedures.

The benefits and costs of this proposal are described above. Because the proposed rule would, if adopted, be economically significant under both the Department of Transportation's procedures and OMB guidelines, the agency has prepared a Preliminary Regulatory Impact Analysis (PRIA) and placed it in the docket and on the agency's Web site. Further, pursuant to Circular A–4, we have prepared a formal probabilistic uncertainty analysis for this proposal. The circular requires such an analysis for complex rules where there are large, multiple uncertainties whose analysis raises technical challenges or where effects cascade and where the impacts of the rule exceed $1 billion. This proposal meets these criteria on all counts.

2. National Environmental Policy Act

Concurrently with this NPRM, NHTSA is releasing a Draft Environmental Impact Statement (Draft EIS), pursuant to the National Environmental Policy Act, 42 U.S.C. 4321–4347, and implementing regulations issued by the Council on Environmental Quality (CEQ), 40 CFR part 1500, and NHTSA, 49 CFR part 520. NHTSA prepared the Draft EIS to analyze and disclose the potential environmental impacts of the proposed CAFE standards and a range of alternatives. The Draft EIS analyzes direct, indirect, and cumulative impacts and analyzes impacts in proportion to their significance.

Because of the link between the transportation sector and GHG emissions, the Draft EIS considers the possible impacts on climate and global climate change in the analysis of the effects of these proposed CAFE standards. The Draft EIS also describes potential environmental impacts to a variety of resources. Resources that may be affected by the proposed action and alternatives include water resources, biological resources, land use and development, safety, hazardous materials and regulated wastes, noise, socioeconomics, fuel and energy use, air quality, and environmental justice. These resource areas are assessed qualitatively in the Draft EIS.

For additional information on NHTSA's NEPA analysis, please see the Draft EIS.

3. Regulatory Flexibility Act

Pursuant to the Regulatory Flexibility Act (5 U.S.C. 601 *et seq.,* as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), whenever an agency is required to publish a notice of rulemaking for any proposed or final rule, it must prepare and make available for public comment a regulatory flexibility analysis that describes the effect of the rule on small entities (*i.e.,* small businesses, small organizations, and small governmental jurisdictions). The Small Business Administration's regulations at 13 CFR part 121 define a small business, in part, as a business entity ''which operates primarily within the United States.'' 13 CFR 121.105(a). No regulatory flexibility analysis is required if the head of an agency certifies the rule will not have a significant economic impact of a substantial number of small entities.

I certify that the proposed rule would not have a significant economic impact on a substantial number of small entities. The following is NHTSA's statement providing the factual basis for the certification (5 U.S.C. 605(b)).

If adopted, the proposal would directly affect nineteen large single stage motor vehicle manufacturers.[842] Based on our preliminary assessment, the proposal would also affect a total of about 21 entities that fit the Small Business Administration's criteria for a small business. According to the Small Business Administration's small business size standards (see 13 CFR 121.201), a single stage automobile or light truck manufacturer (NAICS code 336111, Automobile Manufacturing; 336112, Light Truck and Utility Vehicle Manufacturing) must have 1,000 or fewer employees to qualify as a small business. There are about 4 small manufacturers, including 3 electric vehicle manufacturers, 8 independent commercial importers, and 9 alternative fuel vehicle converters in the passenger car and light truck market which are small businesses. We believe that the rulemaking would not have a significant economic impact on these small vehicle manufacturers because under 49 CFR part 525, passenger car manufacturers making fewer than 10,000 vehicles per year can petition NHTSA to have alternative standards set for those manufacturers. Manufacturers that produce only electric vehicles, or that modify vehicles to make them electric or some other kind of dedicated alternative fuel vehicle, will have average fuel economy values far beyond

[842] BMW, Daimler (Mercedes), Fiat/Chrysler (which also includes Ferrari and Maserati for CAFE compliance purposes), Ford, Geely (Volvo), General Motors, Honda, Hyundai, Kia, Lotus, Mazda, Mitsubishi, Nissan, Porsche, Subaru, Suzuki, Tata (Jaguar Land Rover), Toyota, and Volkswagen/Audi.

those proposed today, so we would not expect them to need a petition for relief. A number of other small vehicle manufacturers already petition the agency for relief under Part 525. If the standard is raised, it has no meaningful impact on those manufacturers, because they are expected to still go through the same process to petition for relief. Given that there is already a mechanism for handling small businesses, which is the purpose of the Regulatory Flexibility Act, a regulatory flexibility analysis was not prepared, but we welcome comments on this issue for the final rule.

4. Executive Order 13132 (Federalism)

Executive Order 13132 requires NHTSA to develop an accountable process to ensure ''meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications.'' [843] The Order defines the term ''Policies that have federalism implications'' to include regulations that have ''substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government.'' Under the Order, NHTSA may not issue a regulation that has federalism implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by State and local governments, or NHTSA consults with State and local officials early in the process of developing the proposed regulation.

NHTSA solicits comment on this proposed action from State and local officials. The agency believes that it is unnecessary to address the question of preemption further at this time because of the consistent and coordinated Federal standards that would apply nationally under the proposed National Program.

5. Executive Order 12988 (Civil Justice Reform)

Pursuant to Executive Order 12988, ''Civil Justice Reform,'' [844] NHTSA has considered whether this rulemaking would have any retroactive effect. This proposed rule does not have any retroactive effect.

6. Unfunded Mandates Reform Act

Section 202 of the Unfunded Mandates Reform Act of 1995 (UMRA) requires Federal agencies to prepare a written assessment of the costs, benefits, and other effects of a proposed or final rule that includes a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of more than $100 million in any one year (adjusted for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for 2009 results in $134 million (109.729/81.606 = 1.34). Before promulgating a rule for which a written statement is needed, section 205 of UMRA generally requires NHTSA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows NHTSA to adopt an alternative other than the least costly, most cost-effective, or least burdensome alternative if the agency publishes with the final rule an explanation of why that alternative was not adopted.

This proposed rule will not result in the expenditure by State, local, or tribal governments, in the aggregate, of more than $134 million annually, but it will result in the expenditure of that magnitude by vehicle manufacturers and/or their suppliers. In developing this proposal, NHTSA considered a variety of alternative average fuel economy standards lower and higher than those proposed. NHTSA is statutorily required to set standards at the maximum feasible level achievable by manufacturers based on its consideration and balancing of relevant factors, and has tentatively concluded that the proposed fuel economy standards are the maximum feasible standards for the passenger car and light truck fleets for MYs 2017–2025 in light of the statutory considerations.

7. Regulation Identifier Number

The Department of Transportation assigns a regulation identifier number (RIN) to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. You may use the RIN contained in the heading at the beginning of this document to find this action in the Unified Agenda.

8. Executive Order 13045

Executive Order 13045 [845] applies to any rule that: (1) is determined to be economically significant as defined under E.O. 12866, and (2) concerns an environmental, health, or safety risk that NHTSA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, we must evaluate the environmental, health, or safety effects of the proposed rule on children, and explain why the proposed regulation is preferable to other potentially effective and reasonably foreseeable alternatives considered by us.

Chapter 5 of NHTSA's DEIS notes that breathing PM can cause respiratory ailments, heart attack, and arrhythmias (Dockery *et al.* 1993, Samet *et al.* 2000, Pope *et al.* 1995, 2002, 2004, Pope and Dockery 2006, Dominici *et al.* 2006, Laden *et al.* 2006, all in Ebi *et al.* 2008). Populations at greatest risk could include children, the elderly, and those with heart and lung disease, diabetes (Ebi *et al.* 2008), and high blood pressure (Künzli *et al.* 2005, in Ebi *et al.* 2008). Chronic exposure to PM could decrease lifespan by 1 to 3 years (Pope 2000, in American Lung Association 2008). Increasing PM concentrations are expected to have a measurable adverse impact on human health (Confalonieri *et al.* 2007).

Additionally, the DEIS notes that substantial morbidity and childhood mortality has been linked to water- and food-borne diseases. Climate change is projected to alter temperature and the hydrologic cycle through changes in precipitation, evaporation, transpiration, and water storage. These changes, in turn, potentially affect water-borne and food-borne diseases, such as salmonellosis, campylobacter, leptospirosis, and pathogenic species of vibrio. They also have a direct impact on surface water availability and water quality. It has been estimated that more than 1 billion people in 2002 did not have access to adequate clean water (McMichael *et al.* 2003, in Epstein *et al.* 2006). Increased temperatures, greater evaporation, and heavy rain events have been associated with adverse impacts on drinking water through increased waterborne diseases, algal blooms, and toxins (Chorus and Bartram 1999, Levin *et al.* 2002, Johnson and Murphy 2004, all in Epstein *et al.* 2006). A seasonal signature has been associated with water-borne disease outbreaks (EPA 2009b). In the United States, 68 percent of all water-borne diseases between 1948 and 1994 were observed after

[843] 64 FR 43255 (Aug. 10, 1999).

[844] 61 FR 4729 (Feb. 7, 1996).

[845] 62 FR 19885 (Apr. 23, 1997).

heavy rainfall events (Curriero *et al.* 2001a, in Epstein *et al.* 2006).

Climate change could further impact a pathogen by directly affecting its lifecycle (Ebi *et al.* 2008). The global increase in the frequency, intensity, and duration of red tides could be linked to local impacts already associated with climate change (Harvell *et al.* 1999, in Epstein *et al.* 2006); toxins associated with red tide directly affect the nervous system (Epstein *et al.* 2006).

Many people do not report or seek medical attention for their ailments of water-borne or food-borne diseases; hence, the number of actual cases with these diseases is greater than clinical records demonstrate (Mead *et al.* 1999, in Ebi *et al.* 2008). Many of the gastrointestinal diseases associated with water-borne and food-borne diseases can be self-limiting; however, vulnerable populations include young children, those with a compromised immune system, and the elderly.

Thus, as detailed in the DEIS, NHTSA has evaluated the environmental, health, and safety effects of the proposed rule on children. The DEIS also explains why the proposed regulation is preferable to other potentially effective and reasonably foreseeable alternatives considered by the agency.

9. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act (NTTAA) requires NHTSA to evaluate and use existing voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law (*e.g.,* the statutory provisions regarding NHTSA's vehicle safety authority) or otherwise impractical.[846]

Voluntary consensus standards are technical standards developed or adopted by voluntary consensus standards bodies. Technical standards are defined by the NTTAA as ''performance-based or design-specific technical specification and related management systems practices.'' They pertain to ''products and processes, such as size, strength, or technical performance of a product, process or material.''

Examples of organizations generally regarded as voluntary consensus standards bodies include the American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), and the American National Standards Institute (ANSI). If NHTSA does not use available and potentially applicable voluntary consensus standards, we are required by the Act to provide Congress, through OMB, an explanation of the reasons for not using such standards.

There are currently no voluntary consensus standards relevant to today's proposed CAFE standards.

10. Executive Order 13211

Executive Order 13211 [847] applies to any rule that: (1) is determined to be economically significant as defined under E.O. 12866, and is likely to have a significant adverse effect on the supply, distribution, or use of energy; or (2) that is designated by the Administrator of the Office of Information and Regulatory Affairs (OIRA) as a significant regulatory action. If the regulatory action meets either criterion, we must evaluate the adverse energy effects of the proposed rule and explain why the proposed regulation is preferable to other potentially effective and reasonably foreseeable alternatives considered by us.

The proposed rule seeks to establish passenger car and light truck fuel economy standards that will reduce the consumption of petroleum and will not have any adverse energy effects. Accordingly, this proposed rulemaking action is not designated as a significant energy action.

11. Department of Energy Review

In accordance with 49 U.S.C. 32902(j)(1), we submitted this proposed rule to the Department of Energy for review. That Department did not make any comments that we have not addressed.

12. Plain Language

Executive Order 12866 requires each agency to write all rules in plain language. Application of the principles of plain language includes consideration of the following questions:

Have we organized the material to suit the public's needs?

Are the requirements in the rule clearly stated?

Does the rule contain technical jargon that isn't clear?

Would a different format (grouping and order of sections, use of headings, paragraphing) make the rule easier to understand?

Would more (but shorter) sections be better?

Could we improve clarity by adding tables, lists, or diagrams?

What else could we do to make the rule easier to understand?

If you have any responses to these questions, please include them in your comments on this proposal.

13. Privacy Act

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an organization, business, labor union, etc.). You may review DOT's complete Privacy Act statement in the **Federal Register** (65 FR 19477–78, April 11, 2000) or you may visit *http://www.dot.gov/privacy.html.*

List of Subjects

40 CFR Part 85

Confidential business information, Imports, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Research, Warranties.

40 CFR Part 86

Administrative practice and procedure, Confidential business information, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements.

40 CFR Part 600

Administrative practice and procedure, Electric power, Fuel economy, Incorporation by reference, Labeling, Reporting and recordkeeping requirements.

49 CFR Parts 523, 531, and 533

Fuel Economy.

49 CFR Parts 536 and 537

Fuel economy, Reporting and recordkeeping requirements.

Environmental Protection Agency

40 CFR Chapter I

For the reasons set forth in the preamble, the Environmental Protection Agency proposes to amend parts 85, 86, and 600 of title 40, Chapter I of the Code of Federal Regulations as follows:

PART 85—CONTROL OF AIR POLLUTION FROM MOBILE SOURCES

1. The authority citation for part 86 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

Subpart F—[Amended]

2. Section 85.525 is amended by adding paragraph (a)(2)(i)(D) to read as follows:

§ 85.525 Applicable standards.

* * * * *

(a) * * *

[846] 15 U.S.C. 272.

[847] 66 FR 28355 (May 22, 2001).

(2) * * *

(i) * * *

(D) Optionally, compliance with greenhouse gas emission requirements may be demonstrated by comparing the sum of CH_4 plus N_2O plus CO_2 emissions from the before fuel conversion FTP results to the after fuel conversion FTP results. This comparison is based on test results from the emission data vehicle (EDV) from the conversion test group at issue. The summation of the post fuel conversion test results must be lower than the summation of the before conversion greenhouse gas emission results. CO_2 emissions are calculated as specified in 40 CFR 600.113–12. CH_4 and N_2O emissions, before and after fuel conversion, are adjusted by applying multiplicative factors of 25 and 298, respectively, to account for their increased global warming potential. If statements of compliance are applicable and accepted in lieu of measuring N_2O, as permitted by EPA regulation, the comparison of the greenhouse gas results also need not measure or include N_2O in the before and after emission comparisons.

* * * * *

PART 86—CONTROL OF EMISSIONS FROM NEW AND IN–USE HIGHWAY VEHICLES AND ENGINES

3. The authority citation for part 86 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

4. Section 86.1 is revised to read as follows:

§ 86.1 Reference materials.

(a) Certain material is incorporated by reference into this part with the approval of the Director of the Federal Register under 5 U.S.C. 552(a) and 1 CFR part 51. To enforce any edition other than that specified in this section, the Environmental Protection Agency must publish a notice of the change in the **Federal Register** and the material must be available to the public. All approved material is available for inspection at U.S. EPA, Air and Radiation Docket and Information Center, 1301 Constitution Ave. NW., Room B102, EPA West Building, Washington, DC 20460, (202) 202–1744, and is available from the sources listed below. It is also available for inspection at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call (202) 741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html* and is available from the sources listed below:

(b) American Society for Testing and Materials, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA, 19428–2959, (610) 832–9585, *http://www.astm.org/*.

(1) ASTM D 975–04c, Standard Specification for Diesel Fuel Oils, IBR approved for §§ 86.1910, 86.213–11.

(2) ASTM D1945–91, Standard Test Method for Analysis of Natural Gas by Gas Chromatography, IBR approved for §§ 86.113–94, 86.513–94, 86.1213–94, 86.1313–94.

(3) ASTM D2163–91, Standard Test Method for Analysis of Liquefied Petroleum (LP) Gases and Propane Concentrates by Gas Chromatography, IBR approved for §§ 86.113–94, 86.1213–94, 86.1313–94.

(4) ASTM D2986–95a, Reapproved 1999, Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test, IBR approved for §§ 86.1310–2007.

(5) ASTM D5186–91, Standard Test Method for Determination of Aromatic Content of Diesel Fuels by Supercritical Fluid Chromatography, IBR approved for §§ 86.113–07, 86.1313–91, 86.1313–94, 86.1313–98, 1313–2007.

(6) ASTM E29–67, Reapproved 1980, Standard Recommended Practice for Indicating Which Places of Figures Are To Be Considered Significant in Specified Limiting Values, IBR approved for § 86.1105–87.

(7) ASTM E29–90, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications, IBR approved for §§ 86.609–84, 86.609–96, 86.609–97, 86.609–98, 86.1009–84, 86.1009–96, 86.1442, 86.1708–99, 86.1709–99, 86.1710–99, 86.1728–99.

(8) ASTM E29–93a, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications, IBR approved for §§ 86.098–15, 86.004–15, 86.007–11, 86.007–15, 86.1803–01, 86.1823–01, 86.1824–01, 86.1825–01, 86.1837–01.

(9) ASTM F1471–93, Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air-Filter System, IBR approved § 86.1310–2007.

(10) ASTM E903–96, Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres (Withdrawn 2005), IBR approved for § 86.1866–12.

(11) ASTM E1918–06, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field, IBR approved for § 86.1866–12.

(12) ASTM C1549–09, Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer (2009) IBR approved for § 86.1866–12.

(c) Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096–0001, (877) 606–7323 (U.S. and Canada) or (724) 776–4970 (outside the U.S. and Canada), *http://www.sae.org*.

(1) SAE J1151, December 1991, Methane Measurement Using Gas Chromatography, 1994 SAE Handbook—SAE International Cooperative Engineering Program, Volume 1: Materials, Fuels, Emissions, and Noise; Section 13 and page 170 (13.170), IBR approved for §§ 86.111–94; 86.1311–94.

(2) SAE J1349, June 1990, Engine Power Test Code—Spark Ignition and Compression Ignition, IBR approved for §§ 86.094–8, 86.096–8.

(3) SAE J1850, July 1995, Class B Data Communication Network Interface, IBR approved for §§ 86.099–17, 86.1806–01.

(4) SAE J1850, Revised May 2001, Class B Data Communication Network Interface, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(5) SAE J1877, July 1994, Recommended Practice for Bar-Coded Vehicle Identification Number Label, IBR approved for §§ 86.095–35, 86.1806–01.

(6) SAE J1892, October 1993, Recommended Practice for Bar-Coded Vehicle Emission Configuration Label, IBR approved for §§ 86.095–35, 86.1806–01.

(7) SAE J1930, Revised May 1998, Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms, IBR approved for §§ 86.096–38, 86.004–38, 86.007–38, 86.010–38, 86.1808–01, 86.1808–07.

(8) SAE J1930, Revised April 2002, Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviations, and Acronyms—Equivalent to ISO/TR 15031–2: April 30, 2002, IBR approved for §§ 86.005–17, 86.007–17, 86.010–18, 86.1806–04, 86.1806–05.

(9) SAE J1937, November 1989, Engine Testing with Low Temperature Charge Air Cooler Systems in a Dynamometer Test Cell, IBR approved for §§ 86.1330–84, 86.1330–90.

(10) SAE J1939, Revised October 2007, Recommended Practice for a Serial Control and Communications Vehicle Network, IBR approved for §§ 86.010–18.

(11) SAE J1939–11, December 1994, Physical Layer—250K bits/s, Shielded Twisted Pair, IBR approved for §§ 86.005–17, 86.1806–05.

(12) SAE J1939–11, Revised October 1999, Physical Layer—250K bits/s, Shielded Twisted Pair, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(13) SAE J1939–13, July 1999, Off-Board Diagnostic Connector, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(14) SAE J1939–13, Revised March 2004, Off-Board Diagnostic Connector, IBR approved for § 86.010–18.

(15) SAE J1939–21, July 1994, Data Link Layer, IBR approved for §§ 86.005–17, 86.1806–05.

(16) SAE J1939–21, Revised April 2001, Data Link Layer, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(17) SAE J1939–31, Revised December 1997, Network Layer, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(18) SAE J1939–71, May 1996, Vehicle Application Layer, IBR approved for §§ 86.005–17, 86.1806–05.

(19) SAE J1939–71, Revised August 2002, Vehicle Application Layer—J1939–71 (through 1999), IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(20) SAE J1939–71, Revised January 2008, Vehicle Application Layer (Through February 2007), IBR approved for § 86.010–38.

(21) SAE J1939–73, February 1996, Application Layer—Diagnostics, IBR approved for §§ 86.005–17, 86.1806–05.

(22) SAE J1939–73, Revised June 2001, Application Layer—Diagnostics, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(23) SAE J1939–73, Revised September 2006, Application Layer—Diagnostics, IBR approved for §§ 86.010–18, 86.010–38.

(24) SAE J1939–81, July 1997, Recommended Practice for Serial Control and Communications Vehicle Network Part 81—Network Management, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(25) SAE J1939–81, Revised May 2003, Network Management, IBR approved for § 86.010–38.

(26) SAE J1962, January 1995, Diagnostic Connector, IBR approved for §§ 86.099–17, 86.1806–01.

(27) SAE J1962, Revised April 2002, Diagnostic Connector Equivalent to ISO/DIS 15031–3; December 14, 2001, IBR approved for §§ 86.005–17, 86.007–17, 86.010–18, 86.1806–04, 86.1806–05.

(28) SAE J1978, Revised April 2002, OBD II Scan Tool—Equivalent to ISO/DIS 15031–4; December 14, 2001, IBR approved for §§ 86.005–17, 86.007–17, 86.010–18, 86.1806–04, 86.1806–05.

(29) SAE J1979, July 1996, E/E Diagnostic Test Modes, IBR approved for §§ 86.099–17, 86.1806–01.

(30) SAE J1979, Revised September 1997, E/E Diagnostic Test Modes, IBR approved for §§ 86.096–38, 86.004–38, 86.007–38, 86.010–38, 86.1808–01, 86.1808–07.

(31) SAE J1979, Revised April 2002, E/E Diagnostic Test Modes—Equivalent to ISO/DIS 15031–5; April 30, 2002, IBR approved for §§ 86.099–17, 86.005–17, 86.007–17, 86.1806–01, 86.1806–04, 86.1806–05.

(32) SAE J1979, Revised May 2007, (R) E/E Diagnostic Test Modes, IBR approved for § 86.010–18, 86.010–38.

(33) SAE J2012, July 1996, Recommended Practice for Diagnostic Trouble Code Definitions, IBR approved for §§ 86.099–17, 86.1806–01.

(34) SAE J2012, Revised April 2002, (R) Diagnostic Trouble Code Definitions Equivalent to ISO/DIS 15031–6: April 30, 2002, IBR approved for §§ 86.005–17, 86.007–17, 86.010–18, 86.1806–04, 86.1806–05.

(35) SAE J2284–3, May 2001, High Speed CAN (HSC) for Vehicle Applications at 500 KBPS, IBR approved for §§ 86.096–38, 86.004–38, 86.007–38, 86.010–38, 86.1808–01, 86.1808–07.

(36) SAE J2403, Revised August 2007, Medium/Heavy-Duty E/E Systems Diagnosis Nomenclature—Truck and Bus, IBR approved for §§ 86.007–17, 86.010–18, 86.010–38, 86.1806–05.

(37) SAE J2534, February 2002, Recommended Practice for Pass-Thru Vehicle Programming, IBR approved for §§ 86.096–38, 86.004–38, 86.007–38, 86.010–38, 86.1808–01, 86.1808–07.

(38) SAE J2534–1, Revised December 2004, (R) Recommended Practice for Pass-Thru Vehicle Programming, IBR approved for § 86.010–38.

(39) SAE J2064, Revised December 2005, R134a Refrigerant Automotive Air-Conditioned Hose, IBR approved for § 86.166–12.

(40) SAE J2765, October, 2008, Procedure for Measuring System COP [Coefficient of Performance] of a Mobile Air Conditioning System on a Test Bench, IBR approved for § 86.1866–12.

(41) SAE J1711, Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles, June 2010, IBR approved for § 86.1811–04(n).

(42) SAE J1634, Electric Vehicle Energy Consumption and Range Test Procedure, Cancelled October 2002, IBR approved for § 86.1811–04(n).

(43) SAE J1100, November, 2009, Motor Vehicle Dimensions, IBR approved for § 86.1866–12(d).

(44) SAE J2064, Revised December 2005, R134a Refrigerant Automotive Air-Conditioned Hose, IBR approved for § 86.166–12(d).

(d) American National Standards Institute, 25 W 43rd Street, 4th Floor, New York, NY 10036, (212) 642–4900, *http://www.ansi.org*.

(1) ANSI/AGA NGV1–1994, Standard for Compressed Natural Gas Vehicle (NGV) Fueling Connection Devices, IBR approved for §§ 86.001–9, 86.004–9, 86.098–8, 86.099–8, 86.099–9, 86.1810–01.

(2) [Reserved]

(e) California Air Resources Board, (916) 322–2884, *http://www.arb.ca.gov.*

(1) California Regulatory Requirements Applicable to the ''LEV II'' Program, including:

(i) [Reserved]

(ii) California Non-Methane Organic Gas Test Procedures, August 5, 1999, IBR approved for §§ 86.1803–01, 86.1810–01, 86.1811–04.

(2) California Regulatory Requirements Applicable to the National Low Emission Vehicle Program, October 1996, IBR approved for §§ 86.113–04, 86.612–97, 86.1012–97, 86.1702–99, 86.1708–99, 86.1709–99, 86.1717–99, 86.1735–99, 86.1771–99, 86.1775–99, 86.1776–99, 86.1777–99, Appendix XVI, Appendix XVII.

(3) California Regulatory Requirements known as On-board Diagnostics II (OBD–II), Approved on April 21, 2003, Title 13, California Code Regulations, Section 1968.2, Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD–II), IBR approved for § 86.1806–05.

(4) California Regulatory Requirements known as On-board Diagnostics II (OBD–II), Approved on November 9, 2007, Title 13, California Code Regulations, Section 1968.2, Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD–II), IBR approved for §§ 86.007–17, 86.1806–05.

(f) International Organization for Standardization, Case Postale 56, CH–1211 Geneva 20, Switzerland, 41–22–749–01–11, *http://www.iso.org.*

(1) ISO 9141–2, February 1, 1994, Road vehicles—Diagnostic systems—Part 2: CARB requirements for interchange of digital information, IBR approved for §§ 86.099–17, 86.005–17, 86.007–17, 86.1806–01, 86.1806–04, 86.1806–05.

(2) ISO 14230–4:2000(E), June 1, 2000, Road vehicles—Diagnostic systems—

KWP 2000 requirements for Emission-related systems, IBR approved for §§ 86.099–17, 86.005–17, 86.007–17, 86.1806–01, 86.1806–04, 86.1806–05.

(3) ISO 15765–4.3:2001, December 14, 2001, Road Vehicles—Diagnostics on Controller Area Networks (CAN)—Part 4: Requirements for emissions-related systems, IBR approved for §§ 86.005–17, 86.007–17, 86.1806–04, 86.1806–05.

(4) ISO 15765–4:2005(E), January 15, 2005, Road Vehicles—Diagnostics on Controller Area Networks (CAN)—Part 4: Requirements for emissions-related systems, IBR approved for §§ 86.007–17, 86.010–18, 86.1806–05.

(5) ISO 13837:2008, May 30, 2008, Road Vehicles—Safety glazing materials. Method for the determination of solar transmittance, IBR approved for § 86.1866–12.

(g) Government Printing Office, Washington, DC 20402, (202) 512–1800 *http://www.nist.gov.*

(1) NIST Special Publication 811, 1995 Edition, Guide for the Use of the International System of Units (SI), IBR approved for § 86.1901.

(2) [Reserved]

(h) Truck and Maintenance Council, 950 North Glebe Road, Suite 210, Arlington, VA 22203–4181, (703) 838–1754.

(1) TMC RP 1210B, Revised June 2007, WINDOWSTMCOMMUNICATION API, IBR approved for § 86.010–38.

(2) [Reserved]

(i) U.S. EPA, Office of Air and Radiation, 2565 Plymouth Road, Ann Arbor, MI 48105, *http://www.epa.gov*:

(1) EPA Vehicle Simulation Tool, Version x.x, November 2011; IBR approved for § 86.1866–12. The computer code for this model is available as noted in paragraph (a) of this section. A working version of this software is also available for download at *http://www.epa.gov/otaq/climate/ldst.htm.*

(2) [Reserved]

Subpart B—[Amended]

5. Section 86.111–94 is amended by revising paragraph (b) introductory text to read as follows:

§ 86.111–94 Exhaust gas analytical system.

* * * * *

(b) *Major component description.* The exhaust gas analytical system, Figure B94–7, consists of a flame ionization detector (FID) (heated, 235 ±15 F (113 ±8 C) for methanol-fueled vehicles) for the determination of THC, a methane analyzer (consisting of a gas chromatograph combined with a FID) for the determination of CH_4, non-dispersive infrared analyzers (NDIR) for the determination of CO and CO_2, a chemiluminescence analyzer (CL) for the determination of NO_X, and an analyzer meeting the requirements specified in 40 CFR 1065.275 for the determination of N_2O. A heated flame ionization detector (HFID) is used for the continuous determination of THC from petroleum-fueled diesel-cycle vehicles (may also be used with methanol-fueled diesel-cycle vehicles), Figure B94–5 (or B94–6). The analytical system for methanol consists of a gas chromatograph (GC) equipped with a flame ionization detector. The analysis for formaldehyde is performed using high-pressure liquid chromatography (HPLC) of 2,4-dinitrophenylhydrazine (DNPH) derivatives using ultraviolet (UV) detection. The exhaust gas analytical system shall conform to the following requirements:

* * * * *

6. Section 86.135–12 is amended by revising paragraph (a) to read as follows:

§ 86.135–12 Dynamometer procedure.

(a) *Overview.* The dynamometer run consists of two tests, a ''cold'' start test, after a minimum 12-hour and a maximum 36-hour soak according to the provisions of §§ 86.132 and 86.133, and a ''hot'' start test following the ''cold'' start by 10 minutes. Engine startup (with all accessories turned off), operation over the UDDS, and engine shutdown make a complete cold start test. Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test. The exhaust emissions are diluted with ambient air in the dilution tunnel as shown in Figure B94–5 and Figure B94–6. A dilution tunnel is not required for testing vehicles waived from the requirement to measure particulates. Six particulate samples are collected on filters for weighing; the first sample plus backup is collected during the first 505 seconds of the cold start test; the second sample plus backup is collected during the remainder of the cold start test (including shutdown); the third sample plus backup is collected during the hot start test. Continuous proportional samples of gaseous emissions are collected for analysis during each test phase. For gasoline-fueled, natural gas-fueled and liquefied petroleum gas-fueled Otto-cycle vehicles, the composite samples collected in bags are analyzed for THC, CO, CO_2, CH_4, NO_X, and N_2O. For petroleum-fueled diesel-cycle vehicles (optional for natural gas-fueled, liquefied petroleum gas-fueled and methanol-fueled diesel-cycle vehicles), THC is sampled and analyzed continuously according to the provisions of § 86.110–94. Parallel samples of the dilution air are similarly analyzed for THC, CO, CO_2, CH_4, NO_X, and N_2O. For natural gas-fueled, liquefied petroleum gas-fueled and methanol-fueled vehicles, bag samples are collected and analyzed for THC (if not sampled continuously), CO, CO_2, CH_4, NO_X, and N_2O. For methanol-fueled vehicles, methanol and formaldehyde samples are taken for both exhaust emissions and dilution air (a single dilution air formaldehyde sample, covering the total test period may be collected). For ethanol-fueled vehicles, methanol, ethanol, acetaldehyde, and formaldehyde samples are taken for both exhaust emissions and dilution air (a single dilution air formaldehyde sample, covering the total test period may be collected). Parallel bag samples of dilution air are analyzed for THC, CO, CO_2, CH_4, NO_X, and N_2O.

* * * * *

7. Section 86.165–12 is amended by revising paragraphs (c)(1) and (2) to read as follows:

§ 86.165–12 Air conditioning idle test procedure.

* * * * *

(c) * * *

(1) Ambient humidity within the test cell during all phases of the test sequence shall be controlled to an average of 40–60 grains of water/pound of dry air.

(2) Ambient air temperature within the test cell during all phases of the test sequence shall be controlled to 73–80 F on average and 75 ± 5 F as an instantaneous measurement. Air temperature shall be recorded continuously at a minimum of 30 second intervals.

* * * * *

8. Section 86.166–12 is amended as follows:

a. By revising paragraph (b) introductory text.

b. By revising paragraph (b).

c. By revising paragraph (d).

§ 86.166–12 Method for calculating emissions due to air conditioning leakage.

* * * * *

(b) *Rigid pipe connections.* For 2017 and later model years, manufacturers may test the leakage of system connections by pressurizing the system with Helium and using a mass spectrometer to measure the leakage of the connections within the system. Connections that are demonstrated to be free of leaks using Helium mass spectrometry are considered to have a relative emission factor of 10 and are accounted for separately in the equation in paragraph (b)(2) of this section.

(1) The following equation shall be used for the 2012 through 2016 model years, and for 2017 and later model years in cases where the connections are not demonstrated to be leak-free using Helium mass spectrometry:

$$Grams/YR_{RP} = 0.00522 \times [(125 \times SO) + (75 \times SCO) + (50 \times MO) + (10 \times SW) + (5 \times SWO) + (MG)]$$

Where:

$Grams/YR_{RP}$ = Total emission rate for rigid pipe connections in grams per year.
SO = The number of single O-ring connections.
SCO = The number of single captured O-ring connections.
MO = The number of multiple O-ring connections.
SW = The number of seal washer connections.
SWO = The number of seal washer with O-ring connections.
MG = The number of metal gasket connections.

(2) For 2017 and later model years, manufacturers may test the leakage of system connections by pressurizing the system with Helium and using a mass spectrometer to measure the leakage of the connections within the system. Connections that are demonstrated to be free of leaks using Helium mass spectrometry are considered to have a relative emission factor of 10 and are accounted for separately in the following equation:

$$Grams/YR_{RP} = 0.00522 \times [(125 \times SO) + (75 \times SCO) + (50 \times MO) + (10 \times SW) + (10 \times LTO) + (5 \times SWO) + (MG)]$$

Where:

$Grams/YR_{RP}$ = Total emission rate for rigid pipe connections in grams per year.
SO = The number of single O-ring connections.
SCO = The number of single captured O-ring connections.
MO = The number of multiple O-ring connections.
SW = The number of seal washer connections.
LTO = The total number of O-ring connections (single, single captured, and multiple) that have demonstrated no leakage using Helium mass spectrometry. Connections included here should not be counted elsewhere in the equation, and all connections counted here must be tested using Helium mass spectrometry and demonstrated as free of leaks.
SWO = The number of seal washer with O-ring connections.
MG = The number of metal gasket connections.

* * * * *

(d) *Flexible hoses.* Determine the permeation emission rate in grams per year for each segment of flexible hose using the following equation, and then sum the values for all hoses in the system to calculate a total flexible hose emission rate for the system. Hose end connections shall be included in the calculations in paragraph (b) of this section.

$$Grams/YR_{FH} = 0.00522 \times (3.14159 \times ID \times L \times ER)$$

Where:

$Grams/YR_{FH}$ = Emission rate for a segment of flexible hose in grams per year.
ID = Inner diameter of hose, in millimeters.
L = Length of hose, in millimeters.
ER = Emission rate per unit internal surface area of the hose, in g/mm², selected from the following table, or, for 2017 and later model years, calculated according to SAE J2064 ''R134a Refrigerant Automotive Air-Conditioned Hose'' (incorporated by reference; see 86.1):

Material/configuration	ER	
	High-pressure side	Low-pressure side
All rubber hose	0.0216	0.0144
Standard barrier or veneer hose	0.0054	0.0036
Ultra-low permeation barrier or veneer hose	0.00225	0.00167

* * * * *

9. Section 86.167–17 is added to read as follows:

§ 86.167–17 AC17 Air Conditioning Efficiency Test Procedure.

(a) *Overview.* The dynamometer operation consists of four elements: a pre-conditioning cycle, a 30-minute soak period under simulated solar heat, an SC03 drive cycle, and a Highway Fuel Economy Test (HFET) drive cycle. The vehicle is preconditioned with the UDDS to bring the vehicle to a warmed-up stabilized condition. This preconditioning is followed by a 30 minute vehicle soak (engine off) that proceeds directly into the SC03 driving schedule, during which continuous proportional samples of gaseous emissions are collected for analysis. The SC03 driving schedule is followed immediately by the HFET cycle, during which continuous proportional samples of gaseous emissions are collected for analysis. The entire test, including the preconditioning driving, vehicle soak, and SC03 and HFET official test cycles, is conducted in an environmental test facility. The environmental test facility must be capable of providing the following nominal ambient test conditions of: 77 F air temperature, 50 percent relative humidity, a solar heat load intensity of 850 W/m², and vehicle cooling air flow proportional to vehicle speed. Section 86.161–00 discusses the minimum facility requirements and corresponding control tolerances for air conditioning ambient test conditions. The entire test sequence is run twice; with and without the vehicle's air conditioner operating during the SC03 and HFET test cycles. For gasoline-fueled Otto-cycle vehicles, the composite samples collected in bags are analyzed for THC, CO, CO_2, and CH_4. For petroleum-fueled diesel-cycle vehicles, THC is sampled and analyzed continuously according to the provisions of § 86.110. Parallel bag samples of dilution air are analyzed for THC, CO, CO_2, and CH_4. The following figure shows the basic sequence of the test procedure.

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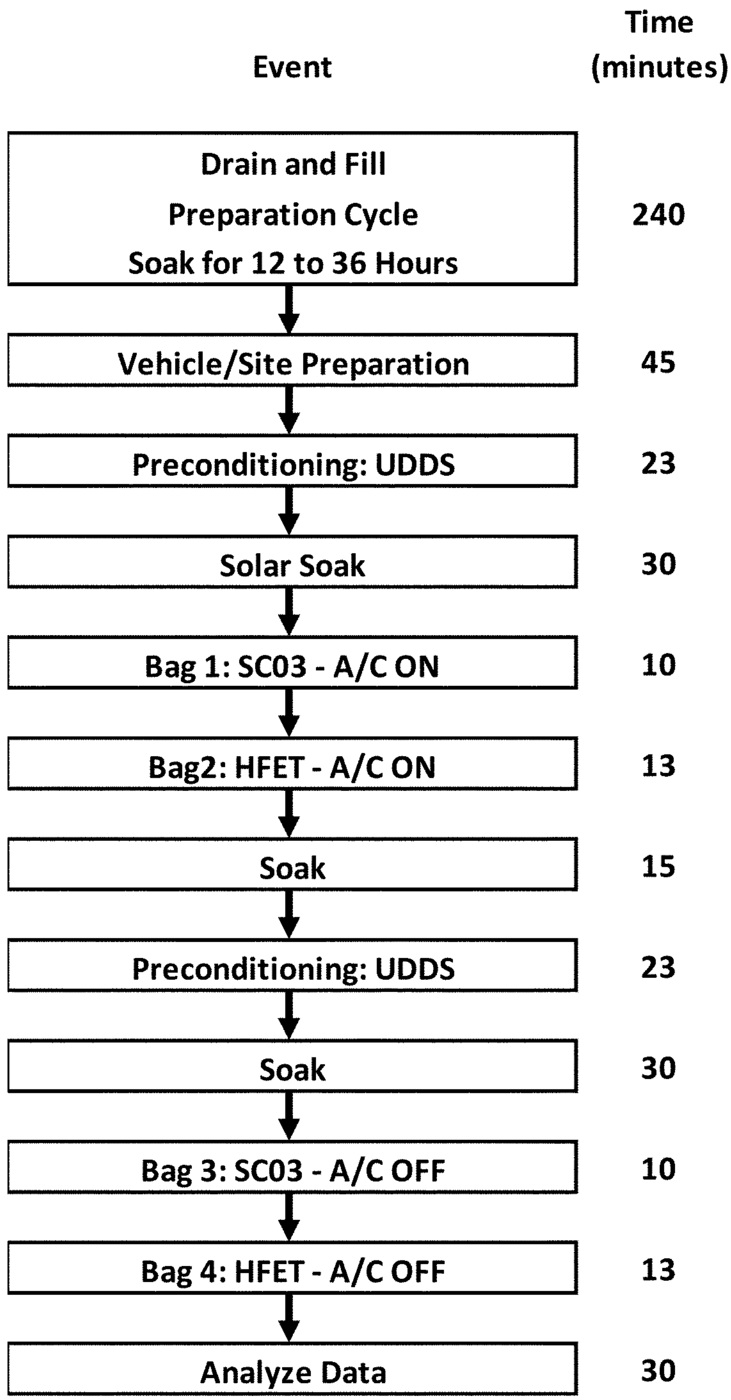

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(b) *Dynamometer requirements.* (1) Tests shall be run on a large single roll electric dynamometer or an equivalent dynamometer configuration that satisfies the requirements of § 86.108–00.

(2) Position (vehicle can be driven) the test vehicle on the dynamometer and restrain.

(3) Required dynamometer inertia weight class selections are determined by the test vehicle's test weight basis and corresponding equivalent weight as listed in the tabular information of § 86.129–00(a) and discussed in § 86.129–00(e) and (f).

(4) Set the dynamometer test inertia weight and roadload horsepower requirements for the test vehicle (see § 86.129–00 (e) and (f)). The dynamometer's horsepower adjustment settings shall be set such that the force imposed during dynamometer operation matches actual road load force at all speeds.

(5) The vehicle speed as measured from the dynamometer rolls shall be used. A speed vs. time recording, as evidence of dynamometer test validity, shall be supplied at request of the Administrator.

(6) The drive wheel tires may be inflated up to a gauge pressure of 45 psi (310 kPa), or the manufacturer's recommended pressure if higher than 45 psi, in order to prevent tire damage. The drive wheel tire pressure shall be reported with the test results.

(7) The driving distance, as measured by counting the number of

dynamometer roll or shaft revolutions, shall be determined for the test.

(8) Four-wheel drive and all-wheel drive vehicles may be tested either in a four-wheel drive or a two-wheel drive mode of operation. In order to test in the two-wheel drive mode, four-wheel drive and all-wheel drive vehicles may have one set of drive wheels disengaged; four-wheel and all-wheel drive vehicles which can be shifted to a two-wheel mode by the driver may be tested in a two-wheel drive mode of operation.

(c) *Test cell ambient conditions.* (1) *Ambient air temperature.* (i) Ambient air temperature is controlled, within the test cell, during all phases of the test sequence to 77 ±2 F on average and 77 ±5 F as an instantaneous measurement.

(ii) Air temperature is recorded continuously at a minimum of 30 second intervals. Records of cell air temperatures and values of average test temperatures are maintained by the manufacturer for all certification related programs.

(2) *Ambient humidity.* (i) Ambient humidity is controlled, within the test cell, during all phases of the test sequence to an average of 69 ±5 grains of water/pound of dry air.

(ii) Humidity is recorded continuously at a minimum of 30 second intervals. Records of cell humidity and values of average test humidity are maintained by the manufacturer for all certification related programs.

(3) *Solar heat loading.* The requirements of 86.161–00(d) regarding solar heat loading specifications shall apply. The solar load of 850 W/m² is applied only during specified portions of the test sequence.

(d) *Interior temperature measurement.* The interior temperature of the vehicle shall be measured during the emission sampling phases of the test(s).

(1) Interior temperatures shall be measured by placement of thermocouples at the following locations:

(i) The outlet of the center duct on the dash.

(ii) Behind the driver and passenger seat headrests. The location of the temperature measuring devices shall be 30 mm behind each headrest and 330 mm below the roof.

(2) The temperature at each location shall be recorded a minimum of every 5 seconds.

(e) *Air conditioning system settings.* For the portion of the test where the air conditioner is required to be operating the settings shall be as follows:

(1) Automatic systems shall be set to automatic and the temperature control set to 72 deg F.

(2) Manual systems shall be set at the start of the SC03 drive cycle to full cool with the fan on the highest setting and the airflow setting to ''recirculation.'' Within the first idle period of the SC03 drive cycle (186 to 204 seconds) the fan speed shall be reduced to the setting closest to 6 volts at the motor, the temperature setting shall be adjusted to provide 55 deg F at the center dash air outlet, and the airflow setting changed to ''outside air.''

(f) *Vehicle and test activities.* The AC17 air conditioning test in an environmental test cell is composed of the following sequence of activities.

(1) Drain and fill the vehicle's fuel tank to 40 percent capacity with test fuel. If a vehicle has gone through the drain and fuel sequence less than 72 hours previously and has remained under laboratory ambient temperature conditions, this drain and fill operation can be omitted (see § 86.132–00(c)(2)(ii)).

(2)(i) Position the variable speed cooling fan in front of the test vehicle with the vehicle's hood down. This air flow should provide representative cooling at the front of the test vehicle (air conditioning condenser and engine) during the driving cycles. See § 86.161–00(e) for a discussion of cooling fan specifications.

(ii) In the case of vehicles with rear engine compartments (or if this front location provides inadequate engine cooling), an additional cooling fan shall be placed in a position to provide sufficient air to maintain vehicle cooling. The fan capacity shall normally not exceed 5300 cfm (2.50 m³/s). If, however, it can be demonstrated that during road operation the vehicle receives additional cooling, and that such additional cooling is needed to provide a representative test, the fan capacity may be increased or additional fans used if approved in advance by the Administrator.

(3) Open all vehicle windows.

(4) Connect the emission test sampling system to the vehicle's exhaust tail pipe(s).

(5) Set the environmental test cell ambient test conditions to the conditions defined in paragraph (c) of this section, except that the solar heat shall be off.

(6) Set the air conditioning system controls to off.

(7) Start the vehicle (with air conditioning system off) and conduct a preconditioning EPA urban dynamometer driving cycle (§ 86.115).

(i) If engine stalling should occur during any air conditioning test cycle operation, follow the provisions of § 86.136–90 (Engine starting and restarting).

(ii) For manual transmission vehicles, the vehicle shall be shifted according the provisions of § 86.128–00.

(8) Following the preconditioning cycle, the test vehicle and cooling fan(s) are turned off, all windows are rolled up, and the vehicle is allowed to soak in the ambient conditions of paragraph (c)(1) of this section for 30 ±1 minutes. The solar heat system must be turned on and generating 850 W/m² within 1 minute of turning the engine off.

(9) *Air conditioning on test.* (i) Start engine (with air conditioning system also running). Fifteen seconds after the engine starts, place vehicle in gear.

(ii) Eighteen seconds after the engine starts, begin the initial vehicle acceleration of the SC03 driving schedule.

(iii) Operate the vehicle according to the SC03 driving schedule, as described in appendix I, paragraph (h), of this part, while sampling the exhaust gas.

(iv) At the end of the deceleration which is scheduled to occur at 594 seconds, simultaneously switch the sample flows from the SC03 bags and samples to the ''HFET'' bags and samples, switch off gas flow measuring device No. 1, switch off the No. 1 petroleum-fueled diesel hydrocarbon integrator, mark the petroleum-fueled diesel hydrocarbon recorder chart, and start gas flow measuring device No. 2, and start the petroleum-fueled diesel hydrocarbon integrator No. 2.

(v) Allow the vehicle to idle for 14–16 seconds. Before the end of this idle period, record the measured roll or shaft revolutions and reset the counter or switch to a second counter. As soon as possible transfer the SC03 exhaust and dilution air samples to the analytical system and process the samples according to § 86.140 obtaining a stabilized reading of the bag exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test. Obtain methanol and formaldehyde sample analyses, if applicable, within 24 hours of the end of the sample collection phase of the test.

(vi) Operate the vehicle according to the HFET driving schedule, as described in 40 CFR 600.109–08, while sampling the exhaust gas.

(vii) Turn the engine off 2 seconds after the end of the last deceleration.

(viii) Five seconds after the engine stops running, simultaneously turn off gas flow measuring device No. 2 and if applicable, turn off the petroleum-fueled diesel hydrocarbon integrator No. 2, mark the hydrocarbon recorder chart, and position the sample selector valves to the ''standby'' position. Record the measured roll or shaft revolutions (both gas meter or flow measurement instrumentation readings), and re-set the counter. As soon as possible, transfer the ''HFET'' exhaust and dilution air samples to the analytical system and process the samples according to § 86.140, obtaining a stabilized reading of the exhaust bag sample on all analyzers within 20 minutes of the end of the sample collection phase of the test. Obtain methanol and formaldehyde sample analyses, if applicable, within 24 hours of the end of the sample period.

(10) *Air conditioning off test.* The air conditioning off test is identical to the steps identified in paragraphs (d)(1) through (9) of this section, except that the air conditioning system and fan speeds are set to complete off or the lowest. It is preferred that the air conditioning off test be conducted sequentially after the air conditioning on test, following a 10–15 minute soak.

(g) *Records required and reporting requirements.* For each test the manufacturer shall record the information specified in 86.142–90. Emission results must be reported for each phase of the test. The manufacturer must also report the following information for each vehicle tested: vehicle class, model type, carline, curb weight engine displacement, transmission class and configuration, interior volume, climate control system type and characteristics, refrigerant used, compressor type, and evaporator/condenser characteristics.

Subpart S—[Amended]

10. Section 86.1801–12 is amended by revising paragraphs (b), (j), and (k) introductory text to read as follows:

§ 86.1801–12 Applicability.

* * * * *

(b) *Clean alternative fuel conversions.* The provisions of this subpart apply to clean alternative fuel conversions as defined in 40 CFR 85.502, of all model year light-duty vehicles, light-duty trucks, medium duty passenger vehicles, and complete Otto-cycle heavy-duty vehicles.

(j) *Exemption from greenhouse gas emission standards for small businesses.* (1) Manufacturers that qualify as a small business under the Small Business Administration regulations in 13 CFR part 121 are exempt from the greenhouse gas emission standards specified in § 86.1818–12 and in associated provisions in this part and in part 600 of this chapter. This exemption applies to both U.S.-based and non-U.S.-based businesses. The following categories of businesses (with their associated NAICS codes) may be eligible for exemption based on the Small Business Administration size standards in 13 CFR 121.201.

(i) Vehicle manufacturers (NAICS code 336111).

(ii) Independent commercial importers (NAICS codes 811111, 811112, 811198, 423110, 424990, and 441120).

(iii) Alternate fuel vehicle converters (NAICS codes 335312, 336312, 336322, 336399, 454312, 485310, and 811198).

(2) Effective for the 2014 and later model years, a manufacturer that would otherwise be exempt under the provisions of paragraph (j)(1) of this section may optionally comply with the greenhouse gas emission standards specified in § 86.1818. A manufacturer making this choice is required to comply with all the applicable standards and provisions in § 86.1818 and in associated provisions in this part and in part 600 of this chapter. Manufacturers may optionally earn early credits in the 2012 and/or 2013 model years by demonstrating CO_2 emission levels below the fleet average CO_2 standard that would have been applicable in those model years if the manufacturer had not been exempt. Manufacturers electing to earn these early credits must comply with the model year reporting requirements in § 600.512–12 for each model year.

(k) *Conditional exemption from greenhouse gas emission standards.* Manufacturers meeting the eligibility requirements described in paragraphs (k)(1) and (2) of this section may request a conditional exemption from compliance with the emission standards described in § 86.1818–12(c) through (e) and associated provisions in this part and in part 600 of this chapter. A conditional exemption under this paragraph (k) may be requested for the 2012 through 2016 model years. The terms ''sales'' and ''sold'' as used in this paragraph (k) shall mean vehicles produced and delivered for sale (or sold) in the states and territories of the United States. For the purpose of determining eligibility the sales of related companies shall be aggregated according to the provisions of § 86.1838–01(b)(3).

* * * * *

11. Section 86.1803–01 is amended as follows:

a. By revising the definition for ''footprint.''

b. By adding a definition for ''good engineering judgment.''

c. By adding a definition for ''gross combination weight rating.''

d. By revising the definition for ''gross vehicle weight rating.''

e. By adding a definition for ''platform.''

The revisions and additions read as follows:

§ 86.1803–01 Definitions.

* * * * *

Footprint is the product of average track width (rounded to the nearest tenth of an inch) and wheelbase (measured in inches and rounded to the nearest tenth of an inch), divided by 144 and then rounded to the nearest tenth of a square foot, where the average track width is the average of the front and rear track widths, where each is measured in inches and rounded to the nearest tenth of an inch.

* * * * *

Good engineering judgment has the meaning given in 40 CFR 1068.30. *See* 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

Gross combination weight rating (GCWR) means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment.

* * * * *

Gross vehicle weight rating (GVWR) means the value specified by the manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment.

* * * * *

Platform means a group of vehicles with common body floor plan and construction, chassis construction and components, basic engine, and transmission class. Platform does not consider any level of décor or opulence, or characteristics such as roof line, number of doors, seats, or windows. A single platform may include multiple fuel economy label classes or car lines, and may include both cars and trucks.

* * * * *

12. Section 86.1818–12 is amended as follows:

a. By adding paragraph (b)(4).

b. By revising paragraphs (c)(2)(i)(A) through (C).

c. By revising paragraphs (c)(3)(i)(A) through (C).

d. By adding paragraph (c)(3)(i)(D).

e. By adding paragraph (c)(4).

f. By revising paragraph (f) introductory text.

g. By revising paragraph (f)(3).

h. By adding paragraph (g).

i. By adding paragraph (h).

The additions and revisions read as follows:

§ 86.1818–12 Greenhouse gas emission standards for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles.

* * * * *

(b) * * *

(4) *Emergency vehicle* means a motor vehicle manufactured primarily for use as an ambulance or combination ambulance-hearse or for use by the United States Government or a State or local government for law enforcement.

(c) * * *

(2) * * *

(i) * * *

(A) For passenger automobiles with a footprint of less than or equal to 41 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	244.0
2013	237.0
2014	228.0
2015	217.0
2016	206.0
2017	195.0
2018	185.0
2019	175.0
2020	166.0
2021	157.0
2022	150.0
2023	143.0
2024	137.0
2025 and later	131.0

(B) For passenger automobiles with a footprint of greater than 56 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	315.0
2013	307.0
2014	299.0
2015	288.0
2016	277.0
2017	263.0
2018	250.0
2019	238.0
2020	226.0
2021	215.0
2022	205.0
2023	196.0
2024	188.0
2025 and later	179.0

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(C) For passenger automobiles with a footprint that is greater than 41 square feet and less than or equal to 56 square feet, the gram/mile CO_2 target value shall be calculated using the following equation and rounded to the nearest 0.1 grams/mile:

Target $CO_2 = [a \times f] + b$

Where:

f is the vehicle footprint, as defined in § 86.1803; and

a and b are selected from the following table for the appropriate model year:

Model year	a	*b*
2012	4.72	50.5
2013	4.72	43.3
2014	4.72	34.8
2015	4.72	23.4
2016	4.72	12.7
2017	4.53	8.9
2018	4.35	6.5
2019	4.17	4.2
2020	4.01	1.9
2021	3.84	-0.4
2022	3.69	-1.1
2023	3.54	-1.8
2024	3.4	-2.5
2025 and later	3.26	-3.2

* * * * *

(3) * * *

(i) * * *

(A) For light trucks with a footprint of less than or equal to 41 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	294.0
2013	284.0
2014	275.0
2015	261.0
2016	247.0
2017	238.0
2018	227.0
2019	220.0
2020	212.0
2021	195.0
2022	186.0
2023	176.0
2024	168.0
2025 and later	159.0

(B) For light trucks with a footprint that is greater than 41 square feet and less than or equal to the maximum footprint value specified in the table below for each model year, the gram/mile CO_2 target value shall be calculated using the following equation and rounded to the nearest 0.1 grams/mile:

Target $CO_2 = (a \times f) + b$

Where:

f is the footprint, as defined in § 86.1803; and
a and b are selected from the following table for the appropriate model year:

Model year	Maximum Footprint	a	b
2012	66.0	4.04	128.6
2013	66.0	4.04	118.7
2014	66.0	4.04	109.4
2015	66.0	4.04	95.1
2016	66.0	4.04	81.1
2017	50.7	4.87	38.3
2018	60.2	4.76	31.6
2019	66.4	4.68	27.7
2020	68.3	4.57	24.6
2021	73.5	4.28	19.8
2022	74.0	4.09	17.8
2023	74.0	3.91	16.0
2024	74.0	3.74	14.2
2025 and later	74.0	3.58	12.5

(C) For light trucks with a footprint that is greater than the minimum footprint value specified in the table below and less than or equal to the maximum footprint value specified in the table below for each model year, the gram/mile CO_2 target value shall be calculated using the following equation and rounded to the nearest 0.1 grams/mile:

Target $CO_2 = (a \times f) + b$

Where:

f is the footprint, as defined in § 86.1803; and

a and b are selected from the following table for the appropriate model year:

Model year	Minimum Footprint	Maximum Footprint	a	b
2017	50.7	66.0	4.04	80.5
2018	60.2	66.0	4.04	75.0

(D) For light trucks with a footprint greater than the minimum value specified in the table below for each model year, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	Minimum Footprint	CO_2 target value (grams/mile)
2012	66.0	395.0
2013	66.0	385.0
2014	66.0	376.0
2015	66.0	362.0
2016	66.0	348.0
2017	66.0	347.0
2018	66.0	342.0
2019	66.4	339.0
2020	68.3	337.0
2021	73.5	335.0
2022	74.0	321.0
2023	74.0	306.0
2024	74.0	291.0
2025 and later	74.0	277.0

* * * * *

(4) *Emergency vehicles.* Emergency vehicles may be excluded from the fleet average CO_2 exhaust emission standards described in paragraph (c) of this section. The manufacturer should notify the Administrator that they are making such an election in the model year reports required under § 600.512 of this chapter. Such vehicles should be excluded from both the calculation of the fleet average standard for a manufacturer under this paragraph (c) and from the calculation of the fleet average carbon-related exhaust emissions in 86.510–12.

* * * * *

(f) *Nitrous oxide (N_2O) and methane (CH_4) exhaust emission standards for passenger automobiles and light trucks.* Each manufacturer's fleet of combined passenger automobile and light trucks must comply with N_2O and CH_4 standards using either the provisions of paragraph (f)(1), (2), or (3) of this section. Except with prior EPA approval, a manufacturer may not use the provisions of both paragraphs (f)(1) and (2) of this section in a model year. For example, a manufacturer may not use the provisions of paragraph (f)(1) of this section for their passenger automobile fleet and the provisions of paragraph (f)(2) for their light truck fleet in the same model year. The manufacturer may use the provisions of both paragraphs (f)(1) and (3) of this section in a model year. For example, a manufacturer may meet the N_2O standard in paragraph (f)(1)(i) of this section and an alternative CH_4 standard determined under paragraph (f)(3) of this section.

* * * * *

(3) *Optional use of alternative N_2O and/or CH_4 standards.* Manufacturers may select an alternative standard applicable to a test group, for either N_2O or CH_4, or both. For example, a manufacturer may choose to meet the N_2O standard in paragraph (f)(1)(i) of this section and an alternative CH_4 standard in lieu of the standard in paragraph (f)(1)(ii) of this section. The alternative standard for each pollutant must be greater than the applicable exhaust emission standard specified in paragraph (f)(1) of this section. Alternative N_2O and CH_4 standards apply to emissions measured according to the Federal Test Procedure (FTP) described in Subpart B of this part for the full useful life, and become the applicable certification and in-use emission standard(s) for the test group. Manufacturers using an alternative standard for N_2O and/or CH_4 must calculate emission debits according to the provisions of paragraph (f)(4) of this section for each test group/alternative standard combination. Debits must be included in the calculation of total credits or debits generated in a model year as required under § 86.1865–12(k)(5). For flexible fuel vehicles (or other vehicles certified for multiple fuels) you must meet these alternative standards when tested on any applicable test fuel type.

* * * * *

(g) *Alternative fleet average standards for manufacturers with limited U.S. sales.* Manufacturers meeting the criteria in this paragraph (g) may request that the Administrator establish alternative fleet average CO_2 standards that would apply instead of the standards in paragraph (c) of this section. The provisions of this paragraph (g) are applicable only to the 2017 and later model years.

(1) *Eligibility for alternative standards.* Eligibility as determined in this paragraph (g) shall be based on the total sales of combined passenger automobiles and light trucks. The terms ''sales'' and ''sold'' as used in this paragraph (g) shall mean vehicles produced and delivered for sale (or sold) in the states and territories of the United States. For the purpose of determining eligibility the sales of related companies shall be aggregated according to the provisions of § 86.1838–01(b)(3). To be eligible for alternative standards established under this paragraph (g), the manufacturer's average sales for the three most recent consecutive model years must remain below 5,000. If a manufacturer's average sales for the three most recent consecutive model years exceeds 4,999, the manufacturer will no longer be eligible for exemption and must meet applicable emission standards starting with the model year according to the provisions in this paragraph (g)(1).

(i) If a manufacturer's average sales for three consecutive model years exceeds 4,999, and if the increase in sales is the result of corporate acquisitions, mergers, or purchase by another manufacturer, the manufacturer shall comply with the emission standards described in § 86.1818–12(c) and (d), as applicable, beginning with the first model year after the last year of the three consecutive model years.

(ii) If a manufacturer's average sales for three consecutive model years exceeds 4,999 and is less than 50,000, and if the increase in sales is solely the result of the manufacturer's expansion in vehicle production (not the result of corporate acquisitions, mergers, or purchase by another manufacturer), the manufacturer shall comply with the emission standards described in § 86.1818–12(c) through (e), as applicable, beginning with the second model year after the last year of the three consecutive model years.

(2) *Requirements for new entrants into the U.S. market.* New entrants are those manufacturers without a prior record of automobile sales in the United States and without prior certification to (or exemption from, under § 86.1801–12(k)) greenhouse gas emission standards in § 86.1818–12. In addition to the eligibility requirements stated in paragraph (g)(1) of this section, new entrants must meet the following requirements:

(i) In addition to the information required under paragraph (g)(4) of this section, new entrants must provide documentation that shows a clear intent by the company to actually enter the U.S. market in the years for which alternative standards are requested. Demonstrating such intent could include providing documentation that shows the establishment of a U.S. dealer network, documentation of work underway to meet other U.S. requirements (*e.g.,* safety standards), or other information that reasonably establishes intent to the satisfaction of the Administrator.

(ii) Sales of vehicles in the U.S. by new entrants must remain below 5,000 vehicles for the first two model years in the U.S. market and the average sales for any three consecutive years within the first five years of entering the U.S. market must remain below 5,000 vehicles. Vehicles sold in violation of these limits will be considered not covered by the certificate of conformity and the manufacturer will be subject to penalties on an individual-vehicle basis for sale of vehicles not covered by a certificate. In addition, violation of these limits will result in loss of eligibility for alternative standards until such point as the manufacturer demonstrates two consecutive model years of sales below 5,000 automobiles.

(iii) A manufacturer with sales in the most recent model year of less than 5,000 automobiles, but where prior model year sales were not less than 5,000 automobiles, is eligible to request alternative standards under this paragraph (g). However, such a manufacturer will be considered a new entrant and subject to the provisions regarding new entrants in this paragraph (g), except that the requirement to demonstrate an intent to enter the U.S. market it paragraph (g)(2)(i) of this section shall not apply.

(3) *How to request alternative fleet average standards.* Eligible manufacturers may petition for alternative standards for up to five consecutive model years if sufficient information is available on which to base such standards.

(i) To request alternative standards starting with the 2017 model year, eligible manufacturers must submit a completed application no later than July 30, 2013.

(ii) To request alternative standards starting with a model after 2017, eligible manufacturers must submit a completed request no later than 36 months prior to the start of the first model year to which the alternative standards would apply.

(iii) The request must contain all the information required in paragraph (g)(4) of this section, and must be signed by a chief officer of the company. If the Administrator determines that the content of the request is incomplete or insufficient, the manufacturer will be notified and given an additional 30 days to amend the request.

(4) *Data and information submittal requirements.* Eligible manufacturers requesting alternative standards under this paragraph (g) must submit the following information to the Environmental Protection Agency. The Administrator may request additional information as she deems appropriate. The completed request must be sent to

the Environmental Protection Agency at the following address: Director, Compliance and Innovative Strategies Division, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, Michigan 48105.

(i) *Vehicle model and fleet information.* (A) The model years to which the requested alternative standards would apply, limited to five consecutive model years.

(B) Vehicle models and projections of production volumes for each model year.

(C) Detailed description of each model, including the vehicle type, vehicle mass, power, footprint, and expected pricing.

(D) The expected production cycle for each model, including new model introductions and redesign or refresh cycles.

(ii) *Technology evaluation information.* (A) The CO_2 reduction technologies employed by the manufacturer on each vehicle model, including information regarding the cost and CO_2-reducing effectiveness. Include technologies that improve air conditioning efficiency and reduce air conditioning system leakage, and any ''off-cycle'' technologies that potentially provide benefits outside the operation represented by the Federal Test Procedure and the Highway Fuel Economy Test.

(B) An evaluation of comparable models from other manufacturers, including CO_2 results and air conditioning credits generated by the models. Comparable vehicles should be similar, but not necessarily identical, in the following respects: vehicle type, horsepower, mass, power-to-weight ratio, footprint, retail price, and any other relevant factors. For manufacturers requesting alternative standards starting with the 2017 model year, the analysis of comparable vehicles should include vehicles from the 2012 and 2013 model years, otherwise the analysis should at a minimum include vehicles from the most recent two model years.

(C) A discussion of the CO_2-reducing technologies employed on vehicles offered outside of the U.S. market but not available in the U.S., including a discussion as to why those vehicles and/or technologies are not being used to achieve CO_2 reductions for vehicles in the U.S. market.

(D) An evaluation, at a minimum, of the technologies projected by the Environmental Protection Agency in a final rulemaking as those technologies likely to be used to meet greenhouse gas emission standards and the extent to which those technologies are employed or projected to be employed by the manufacturer. For any technology that is not projected to be fully employed, explain why this is the case.

(iii) *Alternative fleet average CO_2 standards.* (A) The most stringent CO_2 level estimated to be feasible for each model, in each model year, and the technological basis for this estimate.

(B) For each model year, a projection of the lowest feasible sales-weighted fleet average CO_2 value, separately for passenger automobiles and light trucks, and an explanation demonstrating that these projections are reasonable.

(C) A copy of any application, data, and related information submitted to NHTSA in support of a request for alternative Corporate Average Fuel Economy standards filed under 49 CFR Part 525.

(iv) *Information supporting eligibility.* (A) U.S. sales for the three previous model years and projected sales for the model years for which the manufacturer is seeking alternative standards.

(B) Information regarding ownership relationships with other manufacturers, including details regarding the application of the provisions of § 86.1838–01(b)(3) regarding the aggregation of sales of related companies,

(5) *Alternative standards.* Upon receiving a complete application, the Administrator will review the application and determine whether an alternative standard is warranted. If the Administrator judges that an alternative standard is warranted, the Administrator will publish a proposed determination in the **Federal Register** to establish alternative standards for the manufacturer that the Administrator judges are appropriate. Following a 30 day public comment period, the Administrator will issue a final determination establishing alternative standards for the manufacturer. If the Administrator does not establish alternative standards for an eligible manufacturer prior to 12 months before the first model year to which the alternative standards would apply, the manufacturer may request an extension of the exemption under 86.1801–12(k) or an extension of previously approved alternative standards, whichever may apply.

(6) *Restrictions on credit trading.* Manufacturers subject to alternative standards approved by the Administrator under this paragraph (g) may not trade credits to another manufacturer. Transfers between car and truck fleets within the manufacturer are allowed.

(h) *Mid-term evaluation of standards.* No later than April 1, 2018, the Administrator shall determine whether the standards established in paragraph (c) of this section for the 2022 through 2025 model years are appropriate under section 202(a) of the Clean Air Act, in light of the record then before the Administrator. An opportunity for public comment shall be provided before making such determination. If the Administrator determines they are not appropriate, the Administrator shall initiate a rulemaking to revise the standards, to be either more or less stringent as appropriate.

(1) In making the determination required by this paragraph (h), the Administrator shall consider the information available on the factors relevant to setting greenhouse gas emission standards under section 202(a) of the Clean Air Act for model years 2022 through 2025, including but not limited to:

(i) The availability and effectiveness of technology, and the appropriate lead time for introduction of technology;

(ii) The cost on the producers or purchasers of new motor vehicles or new motor vehicle engines;

(iii) The feasibility and practicability of the standards;

(iv) The impact of the standards on reduction of emissions, oil conservation, energy security, and fuel savings by consumers;

(v) The impact of the standards on the automobile industry;

(vi) The impacts of the standards on automobile safety;

(vii) The impact of the greenhouse gas emission standards on the Corporate Average Fuel Economy standards and a national harmonized program; and

(viii) The impact of the standards on other relevant factors.

(2) The Administrator shall make the determination required by this paragraph (h) based upon a record that includes the following:

(i) A draft Technical Assessment Report addressing issues relevant to the standard for the 2022 through 2025 model years;

(ii) Public comment on the draft Technical Assessment Report;

(iii) Public comment on whether the standards established for the 2022 through 2025 model years are appropriate under section 202(a) of the Clean Air Act; and

(iv) Such other materials the Administrator deems appropriate.

(3) No later than November 15, 2017, the Administrator shall issue a draft Technical Assessment Report addressing issues relevant to the standards for the 2022 through 2025 model years.

(4) The Administrator will set forth in detail the bases for the determination

required by this paragraph (h), including the Administrator's assessment of each of the factors listed in paragraph (h)(1) of this section.

13. Section 86.1823–08 is amended by revising paragraph (m)(2)(iii) to read as follows:

§ 86.1823–08 Durability demonstration procedures for exhaust emissions.

* * * * *

(m) * * *

(2) * * *

(iii) For the 2012 through 2016 model years only, manufacturers may use alternative deterioration factors. For N_2O, the alternative deterioration factor to be used to adjust FTP and HFET emissions is the deterioration factor determined for (or derived from, using good engineering judgment) NO_X emissions according to the provisions of this section. For CH_4, the alternative deterioration factor to be used to adjust FTP and HFET emissions is the deterioration factor determined for (or derived from, using good engineering judgment) NMOG or NMHC emissions according to the provisions of this section.

* * * * *

14. Section 86.1829–01 is amended by revising paragraph (b)(1)(iii) to read as follows:

§ 86.1829–01 Durability and emission testing requirements; waivers.

* * * * *

(b) * * *

(1) * * *

(iii) *Data submittal waivers.* (A) In lieu of testing a methanol-fueled diesel-cycle light truck for particulate emissions a manufacturer may provide a statement in its application for certification that such light trucks comply with the applicable standards. Such a statement shall be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

(B) In lieu of testing an Otto-cycle light-duty vehicle, light-duty truck, or heavy-duty vehicle for particulate emissions for certification, a manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement must be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

(C) A manufacturer may petition the Administrator for a waiver of the requirement to submit total hydrocarbon emission data. If the waiver is granted, then in lieu of testing a certification light-duty vehicle or light-duty truck for total hydrocarbon emissions the manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement shall be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

(D) A manufacturer may petition the Administrator to waive the requirement to measure particulate emissions when conducting Selective Enforcement Audit testing of Otto-cycle vehicles.

(E) In lieu of testing a gasoline, diesel, natural gas, liquefied petroleum gas, or hydrogen fueled Tier 2 or interim non-Tier 2 vehicle for formaldehyde emissions when such vehicles are certified based upon NMHC emissions, a manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement must be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

(F) In lieu of testing a petroleum-, natural gas-, liquefied petroleum gas-, or hydrogen-fueled heavy-duty vehicle for formaldehyde emissions for certification, a manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement must be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

(G) For the 2012 through 2016 model years only, in lieu of testing a vehicle for N_2O emissions, a manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement must be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

* * * * *

15. Section 86.1865–12 is amended as follows:

a. By revising paragraph (k)(5) introductory text.

b. By redesignating paragraph (k)(5)(iv) as paragraph (k)(5)(v).

c. By adding new paragraph (k)(5)(iv).

d. By revising paragraph (k)(6).

e. By revising paragraph (k)(7)(i).

f. By revising paragraph (k)(8)(iv)(A).

g. By revising paragraph (l)(1)(ii) introductory text.

h. By revising paragraph (l)(1)(ii)(F).

The revisions read as follows:

§ 86.1865–12 How to comply with the fleet average CO_2 standards.

* * * * *

(k) * * *

(5) Total credits or debits generated in a model year, maintained and reported separately for passenger automobiles and light trucks, shall be the sum of the credits or debits calculated in paragraph (k)(4) of this section and any of the following credits, if applicable, minus any N_2O and/or CH_4 CO_2-equivalent debits calculated according to the provisions of § 86.1818–12(f)(4):

* * * * *

(iv) Full size pickup truck credits earned according to the provisions of § 86.1866–12(e).

(6) The expiration date of unused CO_2 credits is based on the model year in which the credits are earned, as follows:

(i) Unused CO_2 credits from the 2009 model year shall retain their full value through the 2014 model year. Credits remaining at the end of the 2014 model year shall expire.

(ii) Unused CO_2 credits from the 2010 through 2015 model years shall retain their full value through the 2021 model year. Credits remaining at the end of the 2021 model year shall expire.

(iii) Unused CO_2 credits from the 2016 and later model years shall retain their full value through the five subsequent model years after the model year in which they were generated. Credits remaining at the end of the fifth model year after the model year in which they were generated shall expire.

(7) * * *

(i) Credits generated and calculated according to the method in paragraphs (k)(4) and (5) of this section may not be used to offset deficits other than those deficits accrued with respect to the standard in § 86.1818. Credits may be banked and used in a future model year in which a manufacturer's average CO_2 level exceeds the applicable standard. Credits may be transferred between the passenger automobile and light truck fleets of a given manufacturer. Credits may also be traded to another manufacturer according to the provisions in paragraph (k)(8) of this section. Before trading or carrying over credits to the next model year, a manufacturer must apply available credits to offset any deficit, where the deadline to offset that credit deficit has not yet passed.

* * * * *

(8) * * *

(iv) * * *

(A) If a manufacturer ceases production of passenger automobiles and light trucks, the manufacturer continues to be responsible for offsetting any debits outstanding within the required time period. Any failure to offset the debits will be considered a violation of paragraph (k)(8)(i) of this section and may subject the manufacturer to an enforcement action for sale of vehicles not covered by a certificate, pursuant to paragraphs (k)(8)(ii) and (iii) of this section.

* * * * *

(l) * * *

(1) * * *

(ii) Manufacturers producing any passenger automobiles or light trucks subject to the provisions in this subpart must establish, maintain, and retain all the following information in adequately organized records for each passenger automobile or light truck subject to this subpart:

* * * * *

(F) Carbon-related exhaust emission standard, N_2O emission standard, and CH_4 emission standard to which the passenger automobile or light truck is certified.

* * * * *

16. Section 86.1866–12 is amended as follows:

a. By revising the heading,

b. By revising paragraphs (a) and (b).

c. By revising paragraph (c) introductory text.

d. By revising paragraphs (c)(1) through (3).

e. By revising paragraph (c)(5) introductory text.

f. By revising paragraph (c)(5)(i).

g. By revising paragraph (c)(5)(iii) introductory text.

h. By redesignating paragraph (c)(5)(iv) and paragraph (c)(5)(v).

i. By adding new paragraph (c)(5)(iv).

j. By redesignating paragraph (c)(6) as (c)(8).

k. By adding paragraphs (c)(6) and (7).

l. By revising paragraph (d).

m. By adding paragraph (e).

The revisions and additions read as follows:

§ 86.1866–12 CO_2 fleet average credit and incentive programs.

(a) *Advanced technology vehicles.* (1) Electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles, as those terms are defined in § 86.1803–01, that are certified and produced and delivered for sale in the United States in the 2012 through 2025 model years may use a value of zero (0) grams/mile of CO_2 to represent the proportion of electric operation of a vehicle that is derived from electricity that is generated from sources that are not onboard the vehicle.

(i) Model years 2012 through 2016: The use of zero (0) grams/mile CO_2 is limited to the first 200,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2012 through 2016 model years, except that a manufacturer that produces and delivers for sale 25,000 or more such vehicles in the 2012 model year shall be subject to a limitation on the use of zero (0) grams/mile CO_2 to the first 300,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2012 through 2016 model years.

(ii) Model years 2017 through 2021: For electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale in the 2017 through 2021 model years, such use of zero (0) grams/mile CO_2 is unrestricted.

(iii) Model years 2022 through 2025: The use of zero (0) grams/mile CO_2 is limited to the first 200,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2022 through 2025 model years, except that a manufacturer that produces and delivers for sale 300,000 or more such vehicles in the 2019 through 2021 model years shall be subject to a limitation on the use of zero (0) grams/mile CO_2 to the first 600,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2022 through 2025 model years.

(2) For electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles, as those terms are defined in § 86.1803–01, that are certified and produced and delivered for sale in the United States in the 2017 through 2021 model years and that meet the additional specifications in this section, the manufacturer may use the production multipliers in this paragraph (a)(2) when determining the manufacturer's fleet average carbon-related exhaust emissions under § 600.512 of this chapter. Full size pickup trucks eligible for and using a production multiplier are not eligible for the performance-based credits described in paragraph (e)(3) of this section.

(i) The production multipliers, by model year, for electric vehicles and fuel cell vehicles, are as follows:

Model year	Production multiplier
2017	2.0
2018	2.0
2019	2.0
2020	1.75
2021	1.5

(ii) (A) The production multipliers, by model year, for plug-in hybrid electric vehicles, are as follows:

Model year	Production multiplier
2017	1.6
2018	1.6
2019	1.6
2020	1.45
2021	1.3

(B) The minimum all-electric driving range that a plug-in hybrid electric vehicle must have in order to qualify for use of a production multiplier is 10.2 miles on its nominal storage capacity of electricity when operated on the highway fuel economy test cycle. Alternatively, a plug-in hybrid electric vehicle may qualify for use of a production multiplier by having an equivalent all-electric driving range greater than or equal to 10.2 miles during its actual charge-depleting range as measured on the highway fuel economy test cycle and tested according to the requirements of SAE J1711, Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles (incorporated by reference, see § 86.1). The equivalent all-electric range of a PHEV is determined from the following formula:

$$EAER = R_{CDA} \times \frac{(CO2_{CS} - CO2_{CD})}{CO2_{CS}}$$

Where:

EAER = the equivalent all-electric range attributed to charge-depleting operation of a plug-in hybrid electric vehicle on the highway fuel economy test cycle.

R_{CDA} = The actual charge-depleting range determined according to SAE J1711, Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles (incorporated by reference, see § 86.1).

$CO2_{CS}$ = The charge-sustaining CO_2 emissions in grams per mile on the highway fuel economy test determined according to SAE J1711, Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles (incorporated by reference, see § 86.1).

$CO2_{CD}$ = The charge-depleting CO_2 emissions in grams per mile on the highway fuel economy test determined according to SAE J1711, Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-In Hybrid Vehicles (incorporated by reference, see § 86.1).

(iii) The actual production of qualifying vehicles may be multiplied by the applicable value according to the model year, and the result, rounded to the nearest whole number, may be used to represent the production of qualifying vehicles when calculating average carbon-related exhaust emissions under § 600.512 of this chapter.

(b) *Credits for reduction of air conditioning refrigerant leakage.* Manufacturers may generate credits applicable to the CO_2 fleet average program described in § 86.1865–12 by implementing specific air conditioning system technologies designed to reduce air conditioning refrigerant leakage over the useful life of their passenger automobiles and/or light trucks. Credits shall be calculated according to this paragraph (b) for each air conditioning system that the manufacturer is using to generate CO_2 credits. Manufacturers may also generate early air conditioning refrigerant leakage credits under this paragraph (b) for the 2009 through 2011 model years according to the provisions of § 86.1867–12(b).

(1) The manufacturer shall calculate an annual rate of refrigerant leakage from an air conditioning system in grams per year according to the provisions of § 86.166–12.

(2) The CO_2-equivalent gram per mile leakage reduction to be used to calculate the total leakage credits generated by the air conditioning system shall be determined according to the following formulae, rounded to the nearest tenth of a gram per mile:

(i) Passenger automobiles:

$$Leakage\ Credit = MaxCredit \times \left[1 - \left(\frac{LeakScore}{16.6}\right)\right] \times \left(\frac{GWP_{REF}}{GWP_{HFC134a}}\right) - HiLeakDis$$

Where:

HiLeakDis means the high leak disincentive, which is zero for model years 2012 through 2016, and for 2017 and later model years is determined using the following equation, except that if GWP_{REF} is greater than 150 or if the result is less than zero HiLeakDis shall be set equal to zero and if the result is greater than 1.8 g/mi HiLeakDis shall be set to 1.8 g/mi:

$$HiLeakDis = 1.8 \times [((LeakScore - MinScore)/((16.6 - MinScore))]$$

MaxCredit is 12.6 (grams CO_2-equivalent/mile) for air conditioning systems using HFC–134a, and 13.8 (grams CO_2-equivalent/mile) for air conditioning systems using a refrigerant with a lower global warming potential.

LeakScore means the annual refrigerant leakage rate determined according to the provisions of § 86.166–12(a), except if the calculated rate is less than 8.3 grams/year (4.1 grams/year for systems using only electric compressors), the rate for the purpose of this formula shall be 8.3 grams/year (4.1 grams/year for systems using only electric compressors).

The constant 16.6 is the average passenger automobile impact of air conditioning leakage in units of grams/year;

GWP_{REF} means the global warming potential of the refrigerant as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator;

$GWP_{HFC134a}$ means the global warming potential of HFC–134a as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator.

MinScore is 8.3 grams/year, except that for systems using only electric compressors it is 4.1 grams/year.

(ii) Light trucks:

$$Leakage\ Credit = MaxCredit \times \left[1 - \left(\frac{LeakScore}{20.7}\right)\right] \times \left(\frac{GWP_{REF}}{GWP_{HFC134a}}\right) - HiLeakDis$$

Where:

HiLeakDis means the high leak disincentive, which is zero for model years 2012 through 2016, and for 2017 and later model years is determined using the following equation, except that if GWP_{REF} is greater than 150 or if the result is less than zero HiLeakDis shall be set equal to zero and if the result is greater than 2.1 g/mi HiLeakDis shall be set to 2.1g/mi:

$$HiLeakDis = 2.1 \times [((LeakScore - MinScore)/((20.7 - MinScore))]$$

MaxCredit is 15.6 (grams CO_2-equivalent/mile) for air conditioning systems using HFC–134a, and 17.2 (grams CO_2-equivalent/mile) for air conditioning systems using a refrigerant with a lower global warming potential.

Leakage means the annual refrigerant leakage rate determined according to the provisions of § 86.166–12(a), except if the calculated rate is less than 10.4 grams/year (5.2 grams/year for systems using only electric compressors), the rate for the purpose of this formula shall be 10.4 grams/year (5.2 grams/year for systems using only electric compressors).

The constant 20.7 is the average light truck impact of air conditioning leakage in units of grams/year.

GWP_{REF} means the global warming potential of the refrigerant as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator.

GWP_{R134a} means the global warming potential of HFC–134a as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator.

MinScore is 10.4 grams/year, except that for systems using only electric compressors it is 5.2 grams/year.

(3) The total leakage reduction credits generated by the air conditioning system shall be calculated separately for passenger automobiles and light trucks according to the following formula:

Total Credits (megagrams) = (Leakage × Production × VLM) 1,000,000

Where:

Leakage = the CO_2-equivalent leakage credit value in grams per mile determined in paragraph (b)(2) of this section.

Production = The total number of passenger automobiles or light trucks, whichever is applicable, produced with the air conditioning system to which to the leakage credit value from paragraph (b)(2) of this section applies.

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865.

(4) The results of paragraph (b)(3) of this section, rounded to the nearest whole number, shall be included in the manufacturer's credit/debit totals calculated in § 86.1865–12(k)(5).

(5) The following values for refrigerant global warming potential (GWP_{REF}), or alternative values as determined by the Administrator, shall be used in the calculations of this paragraph (b). The Administrator will determine values for refrigerants not included in this paragraph (b)(5) upon request by a manufacturer.

(i) For HFC–134a, GWP_{REF} = 1430;

(ii) For HFC–152a, GWP_{REF} = 124;

(iii) For HFO–1234yf, GWP_{REF} = 4;

(iv) For CO_2, GWP_{REF} = 1.

(c) *Credits for improving air conditioning system efficiency.* Manufacturers may generate credits applicable to the CO_2 fleet average program described in § 86.1865–12 by implementing specific air conditioning system technologies designed to reduce air conditioning-related CO_2 emissions over the useful life of their passenger automobiles and/or light trucks. Credits shall be calculated according to this paragraph (c) for each air conditioning system that the manufacturer is using to generate CO_2 credits. Manufacturers may also generate early air conditioning efficiency credits under this paragraph (c) for the 2009 through 2011 model years according to the provisions of § 86.1867–12(b). For model years 2012 and 2013 the manufacturer may determine air conditioning efficiency credits using the requirements in paragraphs (c)(1) through (4) of this section. For model years 2014 and later the eligibility requirements specified in either paragraph (c)(5) or (6) of this section must be met before an air conditioning system is allowed to generate credits.

(1)(i) 2012 through 2016 model year air conditioning efficiency credits are available for the following technologies in the gram per mile amounts indicated in the following table:

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Air Conditioning Technology	Credit Value (g/mi)
Reduced reheat, with externally-controlled, variable-displacement compressor (*e.g.* a compressor that controls displacement based on temperature setpoint and/or cooling demand of the air conditioning system control settings inside the passenger compartment).	1.7
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor (*e.g.* a compressor that controls displacement based on conditions within, or internal to, the air conditioning system, such as head pressure, suction pressure, or evaporator outlet temperature).	1.1
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 °F or higher: Air conditioning systems that operated with closed-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.	1.7
Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature is 75 °F or higher. Air conditioning systems that operate with open-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.	1.1

Blower motor controls which limit wasted electrical energy (*e.g.* pulse width modulated power controller).	0.9
Internal heat exchanger (*e.g.* a device that transfers heat from the high-pressure, liquid-phase refrigerant entering the evaporator to the low-pressure, gas-phase refrigerant exiting the evaporator).	1.1
Improved condensers and/or evaporators with system analysis on the component(s) indicating a coefficient of performance improvement for the system of greater than 10% when compared to previous industry standard designs).	1.1
Oil separator. The manufacturer must submit an engineering analysis demonstrating the increased improvement of the system relative to the baseline design, where the baseline component for comparison is the version which a manufacturer most recently had in production on the same vehicle design or in a similar or related vehicle model. The characteristics of the baseline component shall be compared to the new component to demonstrate the improvement.	0.6

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(i) 2017 and later model year air conditioning efficiency credits are available for the following technologies in the gram per mile amounts indicated for each vehicle category in the following table:

BILLING CODE 4910–59–P

Air Conditioning Technology	Passenger Automobiles (g/mi)	Light Trucks (g/mi)
Reduced reheat, with externally-controlled, variable-displacement compressor (*e.g.* a compressor that controls displacement based on temperature setpoint and/or cooling demand of the air conditioning system control settings inside the passenger compartment).	1.5	2.2
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor (*e.g.* a compressor that controls displacement based on conditions within, or internal to, the air conditioning system, such as head pressure, suction pressure, or evaporator outlet temperature).	1.0	1.4
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 °F or higher: Air conditioning systems that operated with closed-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.	1.5	2.2

Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature is 75 °F or higher. Air conditioning systems that operate with open-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.	1.0	1.4
Blower motor controls which limit wasted electrical energy (*e.g.* pulse width modulated power controller).	0.8	1.1
Internal heat exchanger (*e.g.* a device that transfers heat from the high-pressure, liquid-phase refrigerant entering the evaporator to the low-pressure, gas-phase refrigerant exiting the evaporator).	1.0	1.4
Improved condensers and/or evaporators with system analysis on the component(s) indicating a coefficient of performance improvement for the system of greater than 10% when compared to previous industry standard designs).	1.0	1.4

Oil separator. The manufacturer must submit an engineering analysis demonstrating the increased improvement of the system relative to the baseline design, where the baseline component for comparison is the version which a manufacturer most recently had in production on the same vehicle design or in a similar or related vehicle model. The characteristics of the baseline component shall be compared to the new component to demonstrate the improvement.	0.5	0.7

BILLING CODE 4910–59–C

(2) Air conditioning efficiency credits are determined on an air conditioning system basis. For each air conditioning system that is eligible for a credit based on the use of one or more of the items listed in paragraph (c)(1) of this section, the total credit value is the sum of the gram per mile values listed in paragraph (c)(1) of this section for each item that applies to the air conditioning system.

(i) In the 2012 through 2016 model years the total credit value for an air conditioning system may not be greater than 5.7 grams per mile.

(ii) In the 2017 and later model years the total credit value for an air conditioning system may not be greater than 5.0 grams per mile for any passenger automobile or 7.2 grams per mile for any light truck.

(3) The total efficiency credits generated by an air conditioning system shall be calculated separately for passenger automobiles and light trucks according to the following formula:

Total Credits (Megagrams) = (Credit × Production × VLM) 1,000,000

Where:

Credit = the CO_2 efficiency credit value in grams per mile determined in paragraph (c)(2) or (c)(5) of this section, whichever is applicable.

Production = The total number of passenger automobiles or light trucks, whichever is applicable, produced with the air conditioning system to which to the efficiency credit value from paragraph (c)(2) of this section applies.

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865.

* * * * *

(5) For the 2014 through 2016 model years, manufacturers must validate air conditioning credits by using the Air Conditioning Idle Test Procedure according to the provisions of this paragraph (c)(5). In lieu of using the Air Conditioning Idle Test Procedure to determine eligibility to generate air conditioning efficiency credits in the 2014 through 2016 model years, the manufacturer may choose the AC17 reporting option specified in paragraph (c)(7) of this section.

(i) After the 2013 model year, for each air conditioning system selected by the manufacturer to generate air conditioning efficiency credits, the manufacturer shall perform the Air Conditioning Idle Test Procedure specified in § 86.165–12 of this part.

* * * * *

(iii) For an air conditioning system to be eligible to generate credits in the 2014 through 2016 model years the increased CO_2 emissions as a result of the operation of that air conditioning system determined according to the Idle Test Procedure in § 86.165–14 must be less than 21.3 grams per minute. In lieu of using 21.3 grams per minute, manufacturers may optionally use the procedures in paragraph (c)(5)(iv) of this section to determine an alternative limit value.

* * * * *

(iv) Optional Air Conditioning Idle Test limit value for 2014 through 2016 model years. For an air conditioning system to be eligible to generate credits in the 2014 through 2016 model years, the increased CO_2 emissions as a result of the operation of that air conditioning system determined according to the Idle Test Procedure in § 86.165–12 must be less than the value calculated by the following equation and rounded to the nearest tenth of gram per minute:

$$Idle\ Test\ Threshold = 20.5 - (1.58 \times Displacment)$$

(A) If the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–12 is less than or equal to the Idle Test Threshold, the total credit value for use in paragraph (c)(3) of this section shall be as determined in paragraph (c)(2) of this section.

(B) If the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–12 is greater than the Idle Test Threshold and less than the Idle Test Threshold plus 6.4, the total credit value for use in paragraph (c)(3) of this section shall be as determined according to the following formula:

$$TCV = TCV_1 \times \left[1 - \left(\frac{ITP - ITT}{6.4}\right)\right]$$

Where:

TCV = The total credit value for use in paragraph (c)(3) of this section;

TCV_1 = The total credit value determined according to paragraph (c)(2) of this section; and

ITP = the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–14.

ITT = the Idle Test Threshold from paragraph (c)(5)(iii) or (c)(5)(iv) of this section, whichever is applicable.

(6) For the 2017 and later model years, manufacturers must validate air conditioning credits by using the AC17 Test Procedure according to the provisions of this paragraph (c)(6).

(i) For each air conditioning system selected by the manufacturer to generate air conditioning efficiency credits, the manufacturer shall perform the AC17 Air Conditioning Efficiency Test Procedure specified in § 86.167–14 of this part, according to the requirements of this paragraph (c)(6).

(ii) Each air conditioning system shall be tested as follows:

(A) Perform the AC17 test on a vehicle that incorporates the air conditioning system with the credit-generating technologies.

(B) Perform the AC17 test on a vehicle which does not incorporate the credit-generating technologies. The tested vehicle must be similar to the vehicle tested under paragraph (c)(6)(ii)(A) of this section.

(C) Subtract the CO_2 emissions determined from testing under paragraph (c)(6)(ii)(A) of this section from the CO_2 emissions determined from testing under paragraph (c)(6)(ii)(B) of this section and round to the nearest 0.1 grams/mile. If the result is less than or equal to zero, the air conditioning system is not eligible to generate credits. If the result is greater than or equal to the total of the gram per mile credits determined in paragraph (c)(2) of this section, then the air conditioning system is eligible to generate the maximum allowable value determined in paragraph (c)(2) of this section. If the result is greater than zero but less than the total of the gram per mile credits determined in paragraph (c)(2) of this section, then the air conditioning system is eligible to generate credits in the amount determined by subtracting the CO_2 emissions determined from testing under paragraph (c)(6)(ii)(A) of this section from the CO_2 emissions determined from testing under paragraph (c)(6)(ii)(B) of this section and rounding to the nearest 0.1 grams/mile.

(iii) For the first model year for which an air conditioning system is expected to generate credits, the manufacturer must select for testing the highest-selling subconfiguration within each vehicle platform that uses the air conditioning system. Credits may continue to be generated by the air conditioning system installed in a vehicle platform provided that:

(A) The air conditioning system components and/or control strategies do not change in any way that could be expected to cause a change in its efficiency;

(B) The vehicle platform does not change in design such that the changes could be expected to cause a change in the efficiency of the air conditioning system; and

(C) The manufacturer continues to test at least one sub-configuration within each platform using the air conditioning system, in each model year, until all sub-configurations within each platform have been tested.

(iv) Each air conditioning system must be tested and must meet the testing criteria in order to be allowed to generate credits. Using good engineering judgment, in the first model year for which an air conditioning system is expected to generate credits, the manufacturer must select for testing the highest-selling subconfiguration within each vehicle platform using the air conditioning system. Credits may continue to be generated by an air conditioning system in subsequent model years if the manufacturer continues to test at least one sub-configuration within each platform on an annual basis, as long as the air conditioning system and vehicle platform do not change substantially.

(7) AC17 reporting requirements for model years 2014 through 2016. As an alternative to the use of the Air Conditioning Idle Test to demonstrate eligibility to generate air conditioning efficiency credits, manufacturers may use the provisions of this paragraph (c)(7).

(i) The manufacturer shall perform the AC17 test specified in § 86.167–14 of this part on each vehicle platform for which the manufacturer intends to accrue air conditioning efficiency credits and report the results separately for all four phases of the test to the Environmental Protection Agency.

(ii) The manufacturer shall also report the following information for each vehicle tested: The vehicle class, model type, curb weight, engine displacement, transmission class and configuration, interior volume, climate control system type and characteristics, refrigerant used, compressor type, and evaporator/condenser characteristics.

(d) *Off-cycle credits.* Manufacturers may generate credits for CO_2-reducing technologies where the CO_2 reduction benefit of the technology is not adequately captured on the Federal Test Procedure and/or the Highway Fuel Economy Test. These technologies must have a measurable, demonstrable, and verifiable real-world CO_2 reduction that occurs outside the conditions of the Federal Test Procedure and the Highway Fuel Economy Test. These optional credits are referred to as ''off-cycle'' credits. Off-cycle technologies used to generate emission credits are considered emission-related components subject to applicable requirements, and must be demonstrated to be effective for the full useful life of the vehicle. Unless the manufacturer demonstrates that the technology is not subject to in-use deterioration, the manufacturer must account for the deterioration in their analysis. The manufacturer must use one of the three options specified in this paragraph (d) to determine the CO_2 gram per mile credit applicable to an off-cycle technology. Note that the option provided in paragraph (d)(1) of this section applies only to the 2017 and later model years. The manufacturer should notify EPA in their pre-model year report of their intention to generate any credits under this paragraph (d).

(1) *Credit available for certain off-cycle technologies.* The provisions of this paragraph (d)(1) are applicable only to 2017 and later model year vehicles.

(i) The manufacturer may generate a CO_2 gram/mile credit for certain technologies as specified in the following table, provided that each technology is applied to the minimum percentage of the manufacturer's total U.S. production of passenger automobiles and light trucks specified in the table in each model year for which credit is claimed. Technology definitions are in paragraph (d)(1)(iv) of this section.

Off-Cycle Technology	Passenger Automobiles (g/mi)	Light Trucks (g/mi)	Minimum percent of U.S. production
Active aerodynamics	0.6	1.0	10
High efficiency exterior lighting	1.1	1.1	10
Engine heat recovery	0.7 per 100W of capacity	0.7 per 100W of capacity	n/a
Engine start-stop (idle-off)	2.9	4.5	10
Active transmission warm-up	1.8	1.8	10
Active engine warm-up	1.8	1.8	10
Electric heater circulation pump	1.0	1.5	n/a
Solar roof panels	3.0	3.0	n/a
Thermal control	3.0	4.3	n/a

(A) Credits may also be accrued for thermal control technologies as defined in paragraph (d)(1)(iv) of this section in the amounts shown in the following table:

Thermal Control Technology	Credit value: Passenger Automobiles (g/mi)	Credit Value: Light Trucks (g/mi)
Glass or glazing	≤2.9	≤3.9
Active seat ventilation	1.0	1.3
Solar reflective paint	0.4	0.5
Passive cabin ventilation	1.7	2.3
Active cabin ventilation	2.1	2.8

(B) The maximum credit allowed for thermal control technologies is limited to 3.0 g/mi for passenger automobiles and to 4.3 g/mi for light trucks. The maximum credit allowed for glass or glazing is limited to 3.0 g/mi for passenger automobiles and to 4.3 g/mi for light trucks.

(C) Glass or glazing credits are calculated using the following equation:

$$\text{Credit} = \left[Z \times \sum_{i=1}^{n} \frac{T_i \times G_i}{G} \right]$$

Where:

Credit = the total glass or glazing credits, in grams per mile, for a vehicle, which may not exceed 3.0 g/mi for passenger automobiles or 4.3 g/mi for light trucks;

Z = 0.3 for passenger automobiles and 0.4 for light trucks;

G_i = the measured glass area of window *i*, in square meters and rounded to the nearest tenth;

G = the total glass area of the vehicle, in square meters and rounded to the nearest tenth;

T_i = the estimated temperature reduction for the glass area of window *i*, determined using the following formula:

$$T_i = 0.3987 \times (Tts_{base} - Tts_{new})$$

Where:

Tts_{new} = the total solar transmittance of the glass, measured according to ISO 13837, "Safety glazing materials—Method for determination of solar transmittance" (incorporated by reference; see § 86.1).

Tts_{base} = 62 for the windshield, side-front, side-rear, rear-quarter, and backlite locations, and 40 for rooflite locations.

(ii) The maximum allowable decrease in the manufacturer's combined passenger automobile and light truck fleet average CO_2 emissions attributable to use of the default credit values in paragraph (d)(1)(i) of this section is 10 grams per mile. If the total of the CO_2 g/mi credit values from the table in paragraph (d)(1)(i) of this section does not exceed 10 g/mi for any passenger automobile or light truck in a manufacturer's fleet, then the total off-cycle credits may be calculated according to paragraph (d)(5) of this section. If the total of the CO_2 g/mi credit values from the table in paragraph (d)(1)(i) of this section exceeds 10 g/mi for any passenger automobile or light truck in a manufacturer's fleet, then the gram per mile decrease for the combined passenger automobile and light truck fleet must be determined according to paragraph (d)(1)(ii)(A) of this section to determine whether the 10 g/mi limitation has been exceeded.

(A) Determine the gram per mile decrease for the combined passenger automobile and light truck fleet using the following formula:

$$\text{Decrease} = \frac{Credits \times 1{,}000{,}000}{[(\text{Prod}_C \times 195{,}264) + (\text{Prod}_T \times 225{,}865)]}$$

Where:

Credits = The total of passenger automobile and light truck credits, in Megagrams, determined according to paragraph (d)(5) of this section and limited to those credits accrued by using the default gram per mile values in paragraph (d)(1)(i) of this section.

Prod_C = The number of passenger automobiles produced by the manufacturer and delivered for sale in the U.S.

Prod_T = The number of light trucks produced by the manufacturer and delivered for sale in the U.S.

(B) If the value determined in paragraph (d)(1)(ii)(A) of this section is greater than 10 grams per mile, the total credits, in Megagrams, that may be accrued by a manufacturer using the default gram per mile values in paragraph (d)(1)(i) of this section shall be determined using the following formula:

$$\text{Credit (Megagrams)} = \frac{[10 \times ((\mathbf{Prod_C} \times 195{,}264) + (\mathbf{Prod_T} \times 225{,}865))]}{1}{,}000{,}000$$

Where:

$Prod_C$ = The number of passenger automobiles produced by the manufacturer and delivered for sale in the U.S.

$Prod_T$ = The number of light trucks produced by the manufacturer and delivered for sale in the U.S.

(C) If the value determined in paragraph (d)(1)(ii)(A) of this section is not greater than 10 grams per mile, then the credits that may be accrued by a manufacturer using the default gram per mile values in paragraph (d)(1)(i) of this section do not exceed the allowable limit, and total credits may be determined for each category of vehicles according to paragraph (d)(5) of this section.

(D) If the value determined in paragraph (d)(1)(ii)(A) of this section is greater than 10 grams per mile, then the combined passenger automobile and light truck credits, in Megagrams, that may be accrued using the calculations in paragraph (d)(5) of this section must not exceed the value determined in paragraph (d)(1)(ii)(B) of this section. This limitation should generally be done by reducing the amount of credits attributable to the vehicle category that caused the limit to be exceeded such that the total value does not exceed the value determined in paragraph (d)(1)(ii)(B) of this section.

(iii) In lieu of using the default gram per mile values specified in paragraph (d)(1)(i) of this section for specific technologies, a manufacturer may determine an alternative value for any of the specified technologies. An alternative value must be determined using one of the methods specified in paragraph (d)(2) or (3) of this section.

(iv) Definitions for the purposes of this paragraph (d)(1) are as follows:

(A) *Active aerodynamic improvements* means technologies that are activated only at certain speeds to improve aerodynamic efficiency by a minimum of three percent, while preserving other vehicle attributes or functions.

(B) *Electric heater circulation pump* means a pump system installed in a stop-start equipped vehicle or in a hybrid electric vehicle or plug-in hybrid electric vehicle that continues to circulate hot coolant through the heater core when the engine is stopped during a stop-start event. This system must be calibrated to keep the engine off for 1 minute or more when the external ambient temperature is 30 deg F.

(C) *High efficiency exterior lighting* means a lighting technology that, when installed on the vehicle, is expected to reduce the total electrical demand of the exterior lighting system by a minimum of 60 watts when compared to conventional lighting systems. To be eligible for this credit the high efficiency lighting must be installed in the following components: Parking/position, front and rear turn signals, front and rear side markers, stop/brake lights (including the center-mounted location), taillights, backup/reverse lights, and license plate lighting.

(D) *Engine start-stop* means a technology which enables a vehicle to automatically turn off the engine when the vehicle comes to a rest and restart the engine when the driver applies pressure to the accelerator or releases the brake. Off-cycle engine start-stop credits will only be allowed if the Administrator has made a determination under the testing and calculation provisions in 40 CFR part 600 that engine start-stop is the predominant operating mode.

(E) *Solar roof panels* means the installation of solar panels on an electric vehicle or a plug-in hybrid electric vehicle such that the solar energy is used to provide energy to the electric drive system of the vehicle by charging the battery or directly providing power to the electric motor with the equivalent of at least 50 Watts of rated electricity output.

(F) *Active transmission warmup* means a system that uses waste heat from the exhaust system to warm the transmission fluid to an operating temperature range quickly using a heat exchanger in the exhaust system, increasing the overall transmission efficiency by reducing parasitic losses associated with the transmission fluid, such as losses related to friction and fluid viscosity.

(G) *Active engine warmup* means a system using waste heat from the exhaust system to warm up targeted parts of the engine so that it reduces engine friction losses and enables the closed-loop fuel control more quickly. It would allow a faster transition from cold operation to warm operation, decreasing CO_2 emissions, and increasing fuel economy.

(H) *Engine heat recovery* means a system that captures heat that would otherwise be lost through the exhaust system or through the radiator and converting that heat to electrical energy that is used to meet the electrical requirements of the vehicle. Such a system must have a capacity of at least 100W to achieve 0.7 g/mi of credit. Every additional 100W of capacity will result in an additional 0.7 g/mi of credit.

(I) *Active seat ventilation* means a device which draws air from the seating surface which is in contact with the occupant and exhausts it to a location away from the seat.

(J) *Solar reflective paint* means a vehicle paint or surface coating which reflects at least 65 percent of the impinging infrared solar energy, as determined using ASTM standards E903, E1918–06, or C1549–09. These ASTM standards are incorporated by reference; see § 86.1.

(K) *Passive cabin ventilation* means ducts or devices which utilize convective airflow to move heated air from the cabin interior to the exterior of the vehicle.

(L) *Active cabin ventilation* means devices which mechanically move heated air from the cabin interior to the exterior of the vehicle.

(2) *Technology demonstration using EPA 5-cycle methodology.* To demonstrate an off-cycle technology and to determine a CO_2 credit using the EPA 5-cycle methodology, the manufacturer shall determine the off-cycle city/highway combined carbon-related exhaust emissions benefit by using the EPA 5-cycle methodology described in 40 CFR Part 600. Testing shall be performed on a representative vehicle, selected using good engineering judgment, for each model type for which the credit is being demonstrated. The emission benefit of a technology is determined by testing both with and without the off-cycle technology operating. Multiple off-cycle technologies may be demonstrated on a test vehicle. The manufacturer shall conduct the following steps and submit all test data to the EPA.

(i) Testing without the off-cycle technology installed and/or operating. Determine carbon-related exhaust emissions over the FTP, the HFET, the US06, the SC03, and the cold temperature FTP test procedures according to the test procedure provisions specified in 40 CFR part 600 subpart B and using the calculation procedures specified in § 600.113–08 of this chapter. Run each of these tests a minimum of three times without the off-cycle technology installed and operating and average the per phase (bag) results for each test procedure. Calculate the 5-cycle weighted city/highway combined carbon-related exhaust emissions from the averaged per phase results, where the 5-cycle city value is weighted 55% and the 5-cycle highway value is weighted 45%. The resulting combined city/highway value is the baseline 5-cycle carbon-related exhaust emission value for the vehicle.

(ii) Testing with the off-cycle technology installed and/or operating. Determine carbon-related exhaust emissions over the US06, the SC03, and the cold temperature FTP test procedures according to the test procedure provisions specified in 40 CFR part 600 subpart B and using the calculation procedures specified in § 600.113–08 of this chapter. Run each of these tests a minimum of three times with the off-cycle technology installed and operating and average the per phase (bag) results for each test procedure. Calculate the 5-cycle weighted city/highway combined carbon-related exhaust emissions from the averaged per phase results, where the 5-cycle city value is weighted 55% and the 5-cycle highway value is weighted 45%. Use the averaged per phase results for the FTP and HFET determined in paragraph (d)(2)(i) of this section for operation without the off-cycle technology in this calculation. The resulting combined city/highway value is the 5-cycle carbon-related exhaust emission value showing the off-cycle benefit of the technology but excluding any benefit of the technology on the FTP and HFET.

(iii) Subtract the combined city/highway value determined in paragraph (d)(2)(i) of this section from the value determined in paragraph (d)(2)(ii) of this section. The result is the off-cycle benefit of the technology or technologies being evaluated. If this benefit is greater than or equal to three percent of the value determined in paragraph (d)(2)(i) of this section then the manufacturer may use this value, rounded to the nearest tenth of a gram per mile, to determine credits under paragraph (d)(4) of this section.

(iv) If the value calculated in paragraph (d)(2)(iii) of this section is less than three percent of the value determined in paragraph (d)(2)(i) of this section, then the manufacturer must repeat the testing required under paragraphs (d)(2)(i) and (ii) of this section, except instead of running each test three times they shall run each test two additional times. The off-cycle benefit of the technology or technologies being evaluated shall be calculated as in paragraph (d)(2)(iii) of this section using all the tests conducted under paragraph (d) of this section. If the value calculated in paragraph (d)(2)(iii) of this section is less than three percent of the value determined in paragraph (d)(2)(i) of this section, then the manufacturer must verify the emission reduction potential of the off-cycle technology or technologies using the EPA Vehicle Simulation Tool (incorporated by reference; see § 86.1), and if the results support a credit value that is less than three percent of the value determined in paragraph (d)(2)(i) of this section then the manufacturer may use the off-cycle benefit of the technology or technologies calculated as in paragraph (d)(2)(iii) of this section using all the tests conducted under paragraph (d) of this section, rounded to the nearest tenth of a gram per mile, to determine credits under paragraph (d)(4) of this section.

(3) *Technology demonstration using alternative EPA-approved methodology.* (i) This option may be used only with EPA approval, and the manufacturer must be able to justify to the Administrator why the 5-cycle option described in paragraph (d)(2) of this section insufficiently characterizes the effectiveness of the off-cycle technology. In cases where the EPA 5-cycle methodology described in paragraph (d)(2) of this section cannot adequately measure the emission reduction attributable to an innovative off-cycle technology, the manufacturer may develop an alternative approach. Prior to a model year in which a manufacturer intends to seek these credits, the manufacturer must submit a detailed analytical plan to EPA. The manufacturer may seek EPA input on the proposed methodology prior to conducting testing or analytical work, and EPA will provide input on the manufacturer's analytical plan. The alternative demonstration program must be approved in advance by the Administrator and should:

(A) Use modeling, on-road testing, on-road data collection, or other approved analytical or engineering methods;

(B) Be robust, verifiable, and capable of demonstrating the real-world emissions benefit with strong statistical significance;

(C) Result in a demonstration of baseline and controlled emissions over a wide range of driving conditions and number of vehicles such that issues of data uncertainty are minimized;

(D) Result in data on a model type basis unless the manufacturer demonstrates that another basis is appropriate and adequate.

(ii) *Notice and opportunity for public comment.* The Administrator will publish a notice of availability in the **Federal Register** notifying the public of a manufacturer's proposed alternative off-cycle credit calculation methodology. The notice will include details regarding the proposed methodology, but will not include any Confidential Business Information. The notice will include instructions on how to comment on the methodology. The Administrator will take public comments into consideration in the final determination, and will notify the public of the final determination. Credits may not be accrued using an approved methodology until the first model year for which the Administrator has issued a final approval.

(4) *Review and approval process for off-cycle credits.* (i) *Initial steps required.* (A) A manufacturer requesting off-cycle credits under the provisions of paragraph (d)(2) of this section must conduct the testing and/or simulation described in that paragraph.

(B) A manufacturer requesting off-cycle credits under the provisions of paragraph (d)(3) of this section must develop a methodology for demonstrating and determining the benefit of the off-cycle technology, and carry out any necessary testing and analysis required to support that methodology.

(C) A manufacturer requesting off-cycle credits under paragraph (d) of this section must conduct testing and/or prepare engineering analyses that demonstrate the in-use durability of the technology for the full useful life of the vehicle.

(ii) *Data and information requirements.* The manufacturer seeking off-cycle credits must submit an application for off-cycle credits determined under paragraphs (d)(2) and (d)(3) of this section. The application must contain the following:

(A) A detailed description of the off-cycle technology and how it functions to reduce CO_2 emissions under conditions not represented on the FTP and HFET.

(B) A list of the vehicle model(s) which will be equipped with the technology.

(C) A detailed description of the test vehicles selected and an engineering analysis that supports the selection of those vehicles for testing.

(D) All testing and/or simulation data required under paragraph (d)(2) or (d)(3) of this section, as applicable, plus any other data the manufacturer has considered in the analysis.

(E) For credits under paragraph (d)(3) of this section, a complete description of the methodology used to estimate the off-cycle benefit of the technology and all supporting data, including vehicle testing and in-use activity data.

(F) An estimate of the off-cycle benefit by vehicle model and the fleetwide benefit based on projected sales of vehicle models equipped with the technology.

(G) An engineering analysis and/or component durability testing data or whole vehicle testing data demonstrating the in-use durability of the off-cycle technology components.

(iii) *EPA review of the off-cycle credit application.* Upon receipt of an application from a manufacturer, EPA will do the following:

(A) Review the application for completeness and notify the manufacturer within 30 days if additional information is required.

(B) Review the data and information provided in the application to determine if the application supports the level of credits estimated by the manufacturer.

(C) For credits under paragraph (d)(3) of this section, EPA will make the application available to the public for comment, as described in paragraph (d)(3)(ii) of this section, within 60 days of receiving a complete application. The public review period will be specified as 30 days, during which time the public may submit comments. Manufacturers may submit a written rebuttal of comments for EPA consideration or may revise their application in response to comments. A revised application should be submitted after the end of the public review period, and EPA will review the application as if it was a new application submitted under this paragraph (d)(4)(iii).

(iv) *EPA decision.* (A) For credits under paragraph (d)(2) of this section, EPA will notify the manufacturer of its decision within 60 days of receiving a complete application.

(B) For credits under paragraph (d)(3) of this section, EPA will notify the manufacturer of its decision after reviewing and evaluating the public comments. EPA will make the decision and rationale available to the public.

(C) EPA will notify the manufacturer in writing of its decision to approve or deny the application, and will provide the reasons for the decision. EPA will make the decision and rationale available to the public.

(5) *Calculation of total off-cycle credits.* Total off-cycle credits in Megagrams of CO_2 (rounded to the nearest whole number) shall be calculated separately for passenger automobiles and light trucks according to the following formula:

Total Credits (Megagrams) = (Credit × Production × VLM) 1,000,000

Where:

Credit = the credit value in grams per mile determined in paragraph (d)(1), (d)(2) or (d)(3) of this section.

Production = The total number of passenger automobiles or light trucks, whichever is applicable, produced with the off-cycle technology to which to the credit value determined in paragraph (d)(1), (d)(2), or (d)(3) of this section applies.

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865.

(e) *Credits for certain full-size pickup trucks.* Full-size pickup trucks may be eligible for additional credits based on the implementation of hybrid technologies or on exhaust emission performance, as described in this paragraph (e). Credits may be generated under either paragraph (e)(2) or (e)(3) of this section for a qualifying pickup truck, but not both.

(1) The following definitions apply for the purposes of this paragraph (e).

(i) *Full size pickup truck* means a light truck which has a passenger compartment and an open cargo box and which meets the following specifications:

(A) A minimum cargo bed width between the wheelhouses of 48 inches, measured as the minimum lateral distance between the limiting interferences (pass-through) of the wheelhouses. The measurement shall exclude the transitional arc, local protrusions, and depressions or pockets, if present. An open cargo box means a vehicle where the cargo box does not have a permanent roof. Vehicles sold with detachable covers are considered ''open'' for the purposes of these criteria.

(B) A minimum open cargo box length of 60 inches, where the length is defined by the lesser of the pickup bed length at the top of the body and the pickup bed length at the floor, where the length at the top of the body is defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate as measured at the cargo floor surface along vehicle centerline, and the length at the floor is defined as the longitudinal distance from the inside front of the pickup bed to the inside of the closed endgate as measured at the cargo floor surface along vehicle centerline.

(C) A minimum towing capability of 5,000 pounds, where minimum towing capability is determined by subtracting the gross vehicle weight rating from the gross combined weight rating, or a minimum payload capability of 1,700 pounds, where minimum payload capability is determined by subtracting the curb weight from the gross vehicle weight rating.

(ii) *Mild hybrid gasoline-electric vehicle* means a vehicle that has start/stop capability and regenerative braking capability, where the recaptured braking energy over the Federal Test Procedure is at least 15 percent but less than 75 percent of the total braking energy, where the percent of recaptured braking energy is measured and calculated according to § 600.116–12(c).

(iii) *Strong hybrid gasoline-electric vehicle* means a vehicle that has start/stop capability and regenerative braking capability, where the recaptured braking energy over the Federal Test Procedure is at least 75 percent of the total braking energy, where the percent of recaptured braking energy is measured and calculated according to § 600.116–12(c).

(2) *Credits for implementation of gasoline-electric hybrid technology.* Full size pickup trucks that implement hybrid gasoline-electric technologies may be eligible for an additional credit under this paragraph (e)(2). Pickup trucks using the credits under this paragraph (e)(2) may not use the credits described in paragraph (e)(3) of this section.

(i) Full size pickup trucks that are mild hybrid gasoline-electric vehicles and that are produced in the 2017 through 2021 model years are eligible for a credit of 10 grams/mile. To receive this credit, the manufacturer must produce a quantity of mild hybrid full size pickup trucks such that the proportion of production of such vehicles, when compared to the manufacturer's total production of full size pickup trucks, is not less than the amount specified in the table below for each model year.

Model year	Required minimum percent of full size pickup trucks
2017	30%
2018	40%
2019	55%
2020	70%
2021	80%

(ii) Full size pickup trucks that are strong hybrid gasoline-electric vehicles and that are produced in the 2017 through 2025 model years are eligible for a credit of 20 grams/mile. To receive this credit, the manufacturer must produce a quantity of strong hybrid full size pickup trucks such that the proportion of production of such vehicles, when compared to the manufacturer's total production of full size pickup trucks, is not less than 10 percent for each model year.

(3) *Credits for emission reduction performance.* Full size pickup trucks that achieve carbon-related exhaust emission values below the applicable target value determined in 86.1818–12(c)(3) may be eligible for an additional credit. For the purposes of this paragraph (e)(3), carbon-related exhaust emission values may include any applicable air conditioning leakage and/or efficiency credits as determined in paragraphs (b) and (c) of this section. Pickup trucks using the credits under this paragraph (e)(3) may not use the credits described in paragraph (e)(2) of this section or the production multipliers described in paragraph (a)(2) of this section.

(i) Full size pickup trucks that achieve carbon-related exhaust emissions less than or equal to the applicable target value determined in 86.1818–12(c)(3) multiplied by 0.85 (rounded to the nearest gram/mile) and greater than the applicable target value determined in 86.1818–12(c)(3) multiplied by 0.80 (rounded to the nearest gram/mile) in a model year are eligible for a credit of 10 grams/mile. A pickup truck that qualifies for this credit in a model year may claim this credit for subsequent model years through the 2021 model year if the carbon-related exhaust emissions of that pickup truck do not increase relative to the emissions in the model year in which the pickup truck qualified for the credit. To qualify for this credit in each model year, the manufacturer must produce a quantity of full size pickup trucks that meet the initial emission eligibility requirements of this paragraph (e)(3)(i) such that the proportion of production of such vehicles, when compared to the manufacturer's total production of full size pickup trucks, is not less than the amount specified in the table below for each model year.

Model year	Required minimum percent of full size pickup trucks
2017	15%
2018	20%
2019	28%
2020	35%
2021	40%

(ii) Full size pickup trucks that achieve carbon-related exhaust emissions less than or equal to the applicable target value determined in 86.1818–12(c)(3) multiplied by 0.80 (rounded to the nearest gram/mile) in a model year are eligible for a credit of 20 grams/mile. A pickup truck that qualifies for this credit in a model year may claim this credit for a maximum of five subsequent model years if the carbon-related exhaust emissions of that pickup truck do not increase relative to the emissions in the model year in which the pickup truck first qualified for the credit. This credit may not be claimed in any model year after 2025. To qualify for this credit, the manufacturer must produce a quantity of full size pickup trucks that meet the emission requirements of this paragraph (e)(3)(i) such that the proportion of production of such vehicles, when compared to the manufacturer's total production of full size pickup trucks, is not less than 10 percent in each model year. A pickup truck that qualifies for this credit in a model year and is subject to a major redesign in a subsequent model year such that it qualifies for the credit in the model year of the redesign may be allowed to qualify for an additional five years (not to go beyond the 2025 model year) with the approval of the Administrator.

(4) *Calculation of total full size pickup truck credits.* Total credits in Megagrams of CO_2 (rounded to the nearest whole number) shall be calculated for qualifying full size pickup trucks according to the following formula:

$$\text{Total Credits (Megagrams)} = ([(10 \times \text{Production}_{10}) + (20 \times \text{Production}_{20})] \times 225{,}865) \quad 1{,}000{,}000$$

Where:

Production_{10} = The total number of full size pickup trucks produced with a credit value of 10 grams per mile from paragraphs (e)(2) and (e)(3).

Production_{20} = The total number of full size pickup trucks produced with a credit value of 20 grams per mile from paragraphs (e)(2) and (e)(3).

17. Section 86.1867–12 is amended by revising paragraph (a)(2)(i) to read as follows:

§ 86.1867–12 Optional early CO_2 credit programs.

* * * * *

(a) * * *

(2) * * *

(i) Credits under this pathway shall be calculated according to the provisions of paragraph (a)(1) of this section, except credits may only be generated by vehicles sold in a model year in California and in states with a section 177 program in effect in that model year. For the purposes of this section, ''section 177 program'' means State regulations or other laws that apply to vehicle emissions from any of the following categories of motor vehicles: Passenger automobiles, light-duty trucks up through 6,000 pounds GVWR, and medium-duty vehicles from 6,001 to 14,000 pounds GVWR, as these categories of motor vehicles are defined in the California Code of Regulations, Title 13, Division 3, Chapter 1, Article 1, Section 1900.

* * * * *

PART 600—FUEL ECONOMY AND GREENHOUSE GAS EXHAUST EMISSIONS OF MOTOR VEHICLES

18. The authority citation for part 600 continues to read as follows:

Authority: 49 U.S.C. 32901—23919q, Pub. L. 109–58.

Subpart B—[Amended]

19. Section 600.002 is amended by revising the definitions of ''combined fuel economy'' and ''fuel economy'' to read as follows:

§ 600.002 Definitions.

* * * * *

Combined fuel economy means:

(1) The fuel economy value determined for a vehicle (or vehicles) by harmonically averaging the city and highway fuel economy values, weighted 0.55 and 0.45, respectively.

(2) For electric vehicles, for the purpose of calculating average fuel economy pursuant to the provisions of part 600, subpart F, the term means the equivalent petroleum-based fuel economy value as determined by the calculation procedure promulgated by the Secretary of Energy. For the purpose of labeling pursuant to the provisions of part 600, subpart D, the term means the fuel economy value as determined by the procedures specified in § 600.116–12.

* * * * *

Fuel economy means:

(1) The average number of miles traveled by an automobile or group of automobiles per volume of fuel consumed as calculated in this part; or

(2) For the purpose of calculating average fuel economy pursuant to the

provisions of part 600, subpart F, fuel economy for electrically powered automobiles means the equivalent petroleum-based fuel economy as determined by the Secretary of Energy in accordance with the provisions of 10 CFR part 474. For the purpose of labeling pursuant to the provisions of part 600, subpart D, the term means the fuel economy value as determined by the procedures specified in § 600.116–12.

* * * * *

20. Section 600.111–08 is amended by revising the introductory text to read as follows:

§ 600.111–08 Test procedures.

This section provides test procedures for the FTP, highway, US06, SC03, and the cold temperature FTP tests. Testing shall be performed according to test procedures and other requirements contained in this part 600 and in part 86 of this chapter, including the provisions of part 86, subparts B, C, and S. Test hybrid electric vehicles using the procedures of SAE J1711 (incorporated by reference in § 600.011). For FTP testing, this generally involves emission sampling over four phases (bags) of the UDDS (cold-start, transient, warm-start, transient); however, these four phases may be combined into two phases (phases 1 + 2 and phases 3 + 4). Test plug-in hybrid electric vehicles using the procedures of SAE J1711 (incorporated by reference in § 600.011) as described in § 600.116–12. Test electric vehicles using the procedures of SAE J1634 (incorporated by reference in § 600.011) as described in § 600.116–12.

* * * * *

21. Section 600.113–12 is amended by revising paragraphs (g)(2)(iv)(C) and (j) through (m) to read as follows:

§ 600.113–12 Fuel economy, CO_2 emissions, and carbon-related exhaust emission calculations for FTP, HFET, US06, SC03 and cold temperature FTP tests.

* * * * *

(g) * * *

(2) * * *

(iv) * * *

(C) For the 2012 through 2016 model years only, manufacturers may use an assigned value of 0.010 g/mi for N_2O FTP and HFET test values. This value is not required to be adjusted by a deterioration factor.

* * * * *

(j)(1) For methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol, the fuel economy in miles per gallon of methanol is to be calculated using the following equation:

$$mpg = (CWF \times SG \times 3781.8)/((CWF_{exHC} \times HC) + (0.429 \times CO) + (0.273 \times CO_2) + (0.375 \times CH_3OH) + (0.400 \times HCHO))$$

Where

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(2)(i) of this section and rounded according to paragraph (g)(3) of this section.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section (for M100 fuel, CWF_{exHC} = 0.866).

HC = Grams/mile HC as obtained in paragraph (g)(1) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(1) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(1) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(1) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(1) of this section.

(2)(i) For 2012 and later model year methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol, the carbon-related exhaust emissions in grams per mile while operating on methanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (CWF_{exHC}/0.273 \times HC) + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section (for M100 fuel, CWF_{exHC} = 0.866).

HC = Grams/mile HC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(2) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(2) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818 of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol while operating on methanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = [(CWF_{exHC}/0.273) \times NMHC] + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section (for M100 fuel, CWF_{exHC} = 0.866).

NMHC = Grams/mile HC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(2) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(2) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g)(2) of this section.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g)(2) of this section.

(k)(1) For automobiles fueled with natural gas and automobiles designed to operate on gasoline and natural gas, the fuel economy in miles per gallon of natural gas is to be calculated using the following equation:

$$mpg_e = \frac{CWF_{HC/NG} \times D_{NG} \times 121.5}{(0.749 \times CH_4) + (CWF_{NMHC} \times NMHC) + (0.429 \times CO) + (0.273 \times (CO_2 - CO_{2NG}))}$$

Where:

mpg_e = miles per gasoline gallon equivalent of natural gas.

$CWF_{HC/NG}$ = carbon weight fraction based on the hydrocarbon constituents in the natural gas fuel as obtained in paragraph (f)(3) of this section and rounded according to paragraph (g)(3) of this section.

D_{NG} = density of the natural gas fuel [grams/ft³ at 68 F (20 C) and 760 mm Hg (101.3

kPa)] pressure as obtained in paragraph (g)(3) of this section.

CH_4, NMHC, CO, and CO_2 = weighted mass exhaust emissions [grams/mile] for methane, non-methane HC, carbon monoxide, and carbon dioxide as obtained in paragraph (g)(2) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section and rounded according to paragraph (g)(3) of this section.

CO_{2NG} = grams of carbon dioxide in the natural gas fuel consumed per mile of travel.

$$CO_{2NG} = FC_{NG} \times D_{NG} \times WF_{CO2}$$

Where:

$$FC_{NG} = \frac{(0.749 \times CH_4) + (CWF_{NMHC} \times NMHC) + (0.429 \times CO) + (0.273 \times CO_2)}{CWF_{NG} \times D_{NG}}$$

= cubic feet of natural gas fuel consumed per mile

Where:

CWF_{NG} = the carbon weight fraction of the natural gas fuel as calculated in paragraph (f)(3) of this section.

WF_{CO2} = weight fraction carbon dioxide of the natural gas fuel calculated using the mole fractions and molecular weights of the natural gas fuel constituents per ASTM D 1945 (incorporated by reference in § 600.011).

(2)(i) For automobiles fueled with natural gas and automobiles designed to operate on gasoline and natural gas, the carbon-related exhaust emissions in grams per mile while operating on natural gas is to be calculated for 2012 and later model year vehicles using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = 2.743 \times CH_4 + CWF_{NMHC}/0.273 \times NMHC + 1.571 \times CO + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g)(2) of this section.

NMHC = Grams/mile NMHC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section and rounded according to paragraph (f)(3) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818 of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year automobiles fueled with natural gas and automobiles designed to operate on gasoline and natural gas while operating on natural gas is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (25 \times CH_4) + [(CWF_{NMHC}/0.273) \times NMHC] + (1.571 \times CO) + CO_2 + (298 \times N_2O)$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CH_4 = Grams/mile CH_4as obtained in paragraph (g)(2) of this section.

NMHC = Grams/mile NMHC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section and rounded according to paragraph (f)(3) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g)(2) of this section.

(l)(1) For ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol, the fuel economy in miles per gallon of ethanol is to be calculated using the following equation:

$$mpg = (CWF \times SG \times 3781.8)/((CWF_{exHC} \times HC) + (0.429 \times CO) + (0.273 \times CO_2) + (0.375 \times CH_3OH) + (0.400 \times HCHO) + (0.521 \times C_2H_5OH) + (0.545 \times C_2H_4O))$$

Where:

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

HC = Grams/mile HC as obtained in paragraph (g)(1) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(1) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(1) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(1) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(1) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (g)(1) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (g)(1) of this section.

(2)(i) For 2012 and later model year ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol, the carbon-related exhaust emissions in grams per mile while operating on ethanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (CWF_{exHC}/0.273 \times HC) + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + (1.911 \times C_2H_5OH) + (1.998 \times C_2H_4O) + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

HC = Grams/mile HC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(2) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(2) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (g)(2) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (g)(2) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818 of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol while operating on ethanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = [(CWF_{exHC}/0.273) \times NMHC] + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + (1.911 \times C_2H_5OH)$$

$+ (1.998 \times C_2H_4O) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

NMHC = Grams/mile HC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g)(2) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (g)(2) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(2) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (g)(2) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (g)(2) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g)(2) of this section.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g)(2) of this section.

(m) Manufacturers shall determine CO_2 emissions and carbon-related exhaust emissions for electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles according to the provisions of this paragraph (m). Subject to the limitations on the number of vehicles produced and delivered for sale as described in § 86.1866 of this chapter, the manufacturer may be allowed to use a value of 0 grams/mile to represent the emissions of fuel cell vehicles and the proportion of electric operation of a electric vehicles and plug-in hybrid electric vehicles that is derived from electricity that is generated from sources that are not onboard the vehicle, as described in paragraphs (m)(1) through (3) of this section. For purposes of labeling under this part, the CO_2 emissions for electric vehicles shall be 0 grams per mile. Similarly, for purposes of labeling under this part, the CO_2 emissions for plug-in hybrid electric vehicles shall be 0 grams per mile for the proportion of electric operation that is derived from electricity that is generated from sources that are not onboard the vehicle. For manufacturers no longer eligible to use 0 grams per mile to represent electric operation, the provisions of this paragraph (m) shall be used to determine the non-zero value for CREE for purposes of meeting the greenhouse gas emission standards described in § 86.1818 of this chapter.

(1) For electric vehicles, but not including fuel cell vehicles, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest one gram per mile:

$CREE = CREE_{UP} - CREE_{GAS}$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002, which may be set equal to zero for eligible 2012 through 2025 model year electric vehicles for a certain number of vehicles produced and delivered for sale as described in § 86.1866–12(a) of this chapter.

$$CREE_{UP} = \frac{EC}{GRIDLOSS} \times AVGUSUP, \text{ and}$$

$$CREE_{GAS} = 0.2485 \times TargetCO_2,$$

Where:

EC = The vehicle energy consumption in watt-hours per mile, determined according to procedures established by the Administrator under § 600.116–12.

GRIDLOSS = 0.93 (to account for grid transmission losses).

AVGUSUP = 0.642 for the 2012 through 2016 model years, and 0.574 for 2017 and later model years (the nationwide average electricity greenhouse gas emission rate at the powerplant, in grams per watt-hour).

$TargetCO_2$ = The CO_2Target Value determined according to § 86.1818 of this chapter for passenger automobiles and light trucks, respectively.

(2) For plug-in hybrid electric vehicles the carbon-related exhaust emissions in grams per mile is to be calculated according to the provisions of § 600.116, except that the CREE for charge-depleting operation shall be the sum of the CREE associated with gasoline consumption and the net upstream CREE determined according to paragraph (m)(1)(i) of this section, rounded to the nearest one gram per mile.

(3) For 2012 and later model year fuel cell vehicles, the carbon-related exhaust emissions in grams per mile shall be calculated using the method specified in paragraph (m)(1) of this section, except that $CREE_{UP}$ shall be determined according to procedures established by the Administrator under § 600.111–08(f). As described in § 86.1866 of this chapter the value of CREE may be set equal to zero for a certain number of 2012 through 2025 model year fuel cell vehicles.

* * * * *

22. Section 600.116–12 is amended as follows:

a. By revising the heading.

b. By revising paragraph (a) introductory text.

c. By adding paragraph (c).

The revisions and additions read as follows:

§ 600.116–12 Special procedures related to electric vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles.

(a) Determine fuel economy values for electric vehicles as specified in §§ 600.210 and 600.311 using the procedures of SAE J1634 (incorporated by reference in § 600.011), with the follo wing clarifications and modifications:

* * * * *

(c) *Determining the proportion of recovered braking energy for hybrid electric vehicles.* Hybrid electric vehicles tested under this part may determine the proportion of braking energy recovered over the FTP relative to the total available braking energy required over the FTP. This determination is required for pickup trucks accruing credits for implementation of hybrid technology under § 86. 1866–12(e)(2), and requires the measurement of electrical current (in amps) flowing into the hybrid system battery for the duration of the test.

(1) Calculate the theoretical maximum amount of energy that could be recovered by a hybrid electric vehicle over the FTP test cycle, where the test cycle time and velocity points are expressed at 10 Hz, and the velocity (miles/hour) is expressed to the nearest 0.01 miles/hour, as follows:

(i) For each time point in the 10 Hz test cycle (*i.e.,* at each 0.1 seconds):

(A) Determine the road load power in kilowatts using the following equation:

$$P_{roadload} = \frac{V_{mph} \times 0.44704(\times 4.448 \times (A + (B \times V_{mph}) + (C \times V_{mph}^2))}{1000}$$

Where:

A, B, and C are the vehicle-specific dynamometer road load coefficients in lb-force, lb-force/mph, and lb-force/mph^2, respectively; and

V_{mph} = velocity in miles/hour, expressed to the nearest 0.01 miles/hour.

(B) Determine the applied deceleration power in kilowatts using the following equation. Positive values indicate acceleration and negative values indicate deceleration.

$$P_{accel} = \frac{ETW \times (V \times 0.44704) \times (0.44704 \times (V_{t+1} - V))}{220.5}$$

Where:

ETW = the vehicle Emission Test Weight (lbs);

V = velocity in miles/hour, rounded to the nearest 0.01 miles/hour;

V_{t+1} = the velocity in miles/hour at the next time point in the 10 Hz speed vs. time table, rounded to the nearest 0.01 miles/hour.

(C) Determine braking power in kilowatts using the following equation.

$$P_{brake} = P_{accel} - P_{roadload}$$

Where:

P_{accel} = the value determined in paragraph (c)(1)(i)(B) of this section;

$P_{roadload}$ = the value determined in paragraph (c)(1)(i)(A) of this section; and

P_{brake} = 0 if P_{accel} is greater than or equal to $P_{roadload}$.

(ii) [Reserved]

(2) The total maximum braking energy (E_{brake}) that could theoretically be recovered is equal to the absolute value of the sum of all the values of P_{brake} determined in paragraph c)(1)(i)(C) of this section, divided by 36,000 and rounded to the nearest 0.01 kilowatt hours.

(3) Calculate the actual amount of energy recovered by a hybrid electric vehicle when tested on the FTP according to the provisions of this part.

(i) Measure the state of charge, in Amp-hours, of the hybrid battery system at each second of the FTP.

(ii) Calculate the change in the state of charge (current in Watt hours) at each second of the test using the following equation:

$$dSOC = (AH_t - AH_{t-1}) \times V$$

Where:

dSOC = the change in the state of charge of the hybrid battery system, in Watt hours;

AH_t = the state of charge of the battery system, in Amp hours, at time t in the test;

AH_{t-1} = the state of charge of the battery system, in Amp hours, at time t-1 in the test; and

V = the nominal voltage of the hybrid battery system.

(iii) Depending on the equipment and methodology used by a manufacturer, batter charging during the test may be represented by either a negative current or by a positive current. Determine the total energy recovered by the hybrid battery system as follows:

(A) If battery charging is represented by positive current, then the total energy recovered by the hybrid battery system, in kilowatt hours, is the sum of the positive current values for each second of the test determined in paragraph (c)(3)(ii) of this section, divided by 1,000 and rounded to the nearest 0.01 kilowatt hours.

(B) If battery charging is represented by negative current, then the total energy recovered by the hybrid battery system, in kilowatt hours, is the absolute value of the sum of the negative current values for each second of the test determined in paragraph (c)(3)(ii) of this section, divided by 1,000 and rounded to the nearest 0.01 kilowatt hours.

(4) The percent of braking energy recovered by a hybrid system relative to the total available energy is determined by the following equation, rounded to the nearest one percent:

$$Energy\ Recovered\ \% = \frac{E_{rec}}{E_{max}} \times 100$$

Where:

E_{rec} = The actual total energy recovered, in kilowatt hours, as determined in paragraph (c)(2)(iii) of this section; and

E_{max} = The theoretical maximum amount of energy, in kilowatt hours, that could be recovered by a hybrid electric vehicle over the FTP test cycle, as determined in paragraph (c)(2) of this section.

23. Section 600.303–12 is amended as follows:

a. By revising the introductory text.

b. By revising paragraph (b) introductory text.

c. By revising paragraph (b)(6).

d. By revising paragraph (c).

The revisions read as follows:

§ 600.303–12 Fuel economy label—special requirements for flexible-fuel vehicles.

Fuel economy labels for flexible-fuel vehicles must meet the specifications described in § 600.302, with the modifications described in this section. This section describes how to label flexible-fuel vehicles equipped with gasoline engines. If the vehicle has a diesel engine, all the references to ''gas'' or ''gasoline'' in this section are understood to refer to ''diesel'' or ''diesel fuel'', respectively. All values described in this section are based on gasoline operation, unless otherwise specifically noted.

* * * * *

(b) Include the following elements instead of the information identified in § 600.302–12(c)(1):

* * * * *

(6) Add the following statement after the statements described in § 600.302–12(c)(2): ''Values are based on gasoline and do not reflect performance and ratings based on E85.'' Adjust this statement as appropriate for vehicles designed to operate on different fuels.

(c) You may include the sub-heading ''Driving Range'' below the combined fuel economy value, with range bars below this sub-heading as follows:

(1) Insert a horizontal range bar nominally 80 mm long to show how far the vehicle can drive from a full tank of gasoline. Include a vehicle logo at the right end of the range bar. Include the following left-justified expression inside the range bar: ''Gasoline: × miles''. Complete the expression by identifying the appropriate value for total driving range from § 600.311.

(2) Insert a second horizontal range bar as described in paragraph (*c*)(*1*) of this section that shows how far the vehicle can drive from a full tank with the second fuel. Establish the length of the line based on the proportion of driving ranges for the different fuels. Identify the appropriate fuel in the range bar.

24. Section 600.311–12 is amended as follows:

a. By revising paragraph (c)(1).

b. By revising paragraph (e)(3)(vii).

c. By adding paragraph (e)(4).

The revisions and addition read as follows:

§ 600.311–12 Determination of values for fuel economy labels.

* * * * *

(c) * * *

(1) For vehicles with engines that are not plug-in hybrid electric vehicles, calculate the fuel consumption rate in gallons per 100 miles (or gasoline gallon equivalent per 100 miles for fuels other than gasoline or diesel fuel) with the following formula, rounded to the first decimal place:

Fuel Consumption Rate = 100/MPG

Where:

MPG = The value for combined fuel economy from § 600.210–12(c), rounded to the nearest whole mpg.

* * * * *

(e) * * *

(3) * * *

(vii) Calculate the annual fuel cost based on the combined values for city and highway driving using the following equation:

Annual fuel cost = ($/milecity × 0.55 + $/milehwy × 0.45) × Average Annual Miles

(4) Round the annual fuel cost to the nearest $50 by dividing the unrounded annual fuel cost by 50, then rounding the result to the nearest whole number, then multiplying this rounded result by 50 to determine the annual fuel cost to be used for purposes of labeling.

* * * * *

25. Section 600.510–12 is amended as follows:

a. By removing and reserving paragraph (b)(3)(iii).

b. By adding paragraph (b)(4).

c. By revising paragraph (c).

d. By revising paragraph (g)(1) introductory text.

e. By revising paragraph (g)(3).

f. By revising paragraph (h) introductory text.

g. By revising paragraph (j)(2)(vii).

h. By revising paragraph (k).

The addition and revisions read as follows:

§ 600.510–12 Calculation of average fuel economy and average carbon-related exhaust emissions.

* * * * *

(b) * * *

(4) Emergency vehicles may be excluded from the fleet average carbon-related exhaust emission calculations described in paragraph (j) of this section. The manufacturer should notify the Administrator that they are making such an election in the model year reports required under § 600.512 of this chapter. Such vehicles should be excluded from both the calculation of the fleet average standard for a manufacturer under 40 CFR 86.1818–12(c)(4) and from the calculation of the fleet average carbon-related exhaust emissions in paragraph (j) of this section.

(c)(1) Average fuel economy shall be calculated as follows:

(i) Except as allowed in paragraph (d) of this section, the average fuel economy for the model years before 2017 will be calculated individually for each category identified in paragraph (a)(1) of this according to the provisions of paragraph (c)(2) of this section.

(ii) Except as permitted in paragraph (d) of this section, the average fuel economy for the 2017 and later model years will be calculated individually for each category identified in paragraph (a)(1) of this section using the following equation:

$$\text{Average MPG} = \frac{1}{\left[\frac{1}{MPG} - (AC + OC + PU)\right]}$$

Where:

Average MPG = the fleet average fuel economy for a category of vehicles;

MPG = the average fuel economy for a category of vehicles determined according to paragraph (c)(2) of this section;

AC = Air conditioning fuel economy credits for a category of vehicles, in gallons per mile, determined according to paragraph (c)(3)(i) of this section;

OC = Off-cycle technology fuel economy credits for a category of vehicles, in gallons per mile, determined according to paragraph (c)(3)(ii) of this section; and

PU = Pickup truck fuel economy credits for the light truck category, in gallons per mile, determined according to paragraph (c)(3)(iii) of this section.

(2) Divide the total production volume of that category of automobiles by a sum of terms, each of which corresponds to a model type within that category of automobiles and is a fraction determined by dividing the number of automobiles of that model type produced by the manufacturer in the model year by:

(i) For gasoline-fueled and diesel-fueled model types, the fuel economy calculated for that model type in accordance with paragraph (b)(2) of this section; or

(ii) For alcohol-fueled model types, the fuel economy value calculated for that model type in accordance with paragraph (b)(2) of this section divided by 0.15 and rounded to the nearest 0.1 mpg; or

(iii) For natural gas-fueled model types, the fuel economy value calculated for that model type in accordance with paragraph (b)(2) of this section divided by 0.15 and rounded to the nearest 0.1 mpg; or

(iv) For alcohol dual fuel model types, for model years 1993 through 2019, the harmonic average of the following two terms; the result rounded to the nearest 0.1 mpg:

(A) The combined model type fuel economy value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type fuel economy value for operation on alcohol fuel as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of paragraph (g) of this section are met; or

(v) For alcohol dual fuel model types, for model years after 2019, the combined model type fuel economy determined according to the following equation and rounded to the nearest 0.1 mpg:

$$MPG = \left(\frac{F}{MPG_A} + \frac{(1-F)}{MPG_G}\right)^{-1}$$

Where:

F = 0.00 unless otherwise approved by the Administrator according to the provisions of paragraph (k) of this section;

MPG_A = The combined model type fuel economy for operation on alcohol fuel as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of paragraph (g) of this section are met; and

MPG_G = The combined model type fuel economy for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i).

(vi) For natural gas dual fuel model types, for model years 1993 through 2019, the harmonic average of the following two terms; the result rounded to the nearest 0.1 mpg:

(A) The combined model type fuel economy value for operation on gasoline or diesel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type fuel economy value for operation on natural gas as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of paragraph (g) of this section are met; or

(vii) For natural gas dual fuel model types, for model years after 2019, the combined model type fuel economy determined according to the following formula and rounded to the nearest 0.1 mpg:

$$MPG = \left(\frac{UF}{MPG_{CNG}} + \frac{(1-UF)}{MPG_G}\right)^{-1}$$

Where:

MPG_{CNG} = The combined model type fuel economy for operation on natural gas as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of paragraph (g) of this section are met; and

MPG_G = The combined model type fuel economy for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i).

UF = A Utility Factor (UF) value selected from the following table based on the driving range of the vehicle while operating on natural gas. Determine the vehicle's driving range in miles by multiplying the combined fuel economy as determined in § 600.208–12(b)(5)(ii) by the vehicle's usable fuel storage capacity (as defined at § 600.002 and expressed in gasoline gallon equivalents), and rounding to the nearest 10 miles.

Driving Range (miles)	UF
10	0.228
20	0.397
30	0.523
40	0.617
50	0.689
60	0.743
70	0.785
80	0.818
90	0.844
100	0.865
110	0.882
120	0.896
130	0.907
140	0.917
150	0.925
160	0.932
170	0.939
180	0.944
190	0.949
200	0.954

210	0.958
220	0.962
230	0.965
240	0.968
250	0.971
260	0.973
270	0.976
280	0.978
290	0.980
300	0.981

(3) *Fuel consumption improvement.* Calculate the separate air conditioning, off-cycle, and pickup truck fuel consumption improvement as follows:

(i) Air conditioning fuel consumption improvements are calculated separately for each category identified in paragraph (a)(1) of this section using the following equation:

$$\text{AC Credit (gal/mi)} = \frac{(ACCredit \times 1{,}000{,}000)}{(VLM \times Production \times 8887)}$$

Where:

FE Credit = the fleet production-weighted total value of air conditioning efficiency credits for all air conditioning systems in the applicable fleet, expressed in gallons per mile;

ACCredit = the total of all air conditioning efficiency credits for the vehicle category, in megagrams, from 40 CFR 86.1866–12(c)(3);

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865; and

Production = the total production volume for the category of vehicles (either passenger automobiles or light trucks).

(ii) Off-cycle technology fuel consumption improvements are calculated separately for each category identified in paragraph (a)(1) of this section using the following equation:

$$\text{Off-Cycle Credit (gal/mi)} = \frac{(OCCredit \times 1{,}000{,}000)}{(VLM \times Production \times 8887)}$$

Where:

FE Credit = the fleet production-weighted total value of off-cycle technology credits for all off-cycle technologies in the applicable fleet, expressed in gallons per mile;

OCCredit = the total of all off-cycle technology credits for the vehicle category, in megagrams, from 40 CFR 86.1866–12(d)(5);

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865; and

Production = the total production volume for the category of vehicles (either passenger automobiles or light trucks).

(iii) Full size pickup truck fuel consumption improvements are calculated for the light truck category identified in paragraph (a)(1) of this section using the following equation:

$$\text{Pickup Truck Credit (gal/mi)} = \frac{(PUCredit \times 1{,}000{,}000)}{(VLM \times Production \times 8887)}$$

Where:

FE Credit = the fleet production-weighted total value of full size pickup truck credits for the light truck fleet, expressed in gallons per mile;

PUCredit = the total of all full size pickup truck credits, in megagrams, from 40 CFR 86.1866–12(e)(4); and

Production = the total production volume for the light truck category.

* * * * *

(g)(1) Dual fuel automobiles must provide equal or greater energy efficiency while operating on the alternative fuel as while operating on gasoline or diesel fuel to obtain the CAFE credit determined in paragraphs (c)(2)(iv) and (v) of this section or to obtain the carbon-related exhaust emissions credit determined in paragraphs (j)(2)(ii) and (iii) of this section. The following equation must hold true:

$$E_{alt}/E_{pet} \geq 1$$

Where:

$E_{alt} = [FE_{alt}/(NHV_{alt} \times D_{alt})] \times 10^6$ = energy efficiency while operating on alternative fuel rounded to the nearest 0.01 miles/million BTU.

$E_{pet} = [FE_{pet}/(NHV_{pet} \times D_{pet})] \times 10^6$ = energy efficiency while operating on gasoline or diesel (petroleum) fuel rounded to the nearest 0.01 miles/million BTU.

FE_{alt} is the fuel economy [miles/gallon for liquid fuels or miles/100 standard cubic feet for gaseous fuels] while operated on the alternative fuel as determined in § 600.113–12(a) and (b).

FE_{pet} is the fuel economy [miles/gallon] while operated on petroleum fuel (gasoline or diesel) as determined in § 600.113–12(a) and (b).

NHV_{alt} is the net (lower) heating value [BTU/lb] of the alternative fuel.

NHV_{pet} is the net (lower) heating value [BTU/lb] of the petroleum fuel.

D_{alt} is the density [lb/gallon for liquid fuels or lb/100 standard cubic feet for gaseous fuels] of the alternative fuel.

D_{pet} is the density [lb/gallon] of the petroleum fuel.

* * * * *

(3) Dual fuel passenger automobiles manufactured during model years 1993 through 2019 must meet the minimum driving range requirements established by the Secretary of Transportation (49 CFR part 538) to obtain the CAFE credit determined in paragraphs (c)(2)(iv) and (v) of this section.

(h) For model years 1993 and later, and for each category of automobile identified in paragraph (a)(1) of this section, the maximum increase in average fuel economy determined in paragraph (c) of this section attributable to dual fuel automobiles, except where the alternative fuel is electricity, shall be as follows:

Model year	Maximum increase (mpg)
1993–2014	1.2
2015	1.0
2016	0.8
2017	0.6
2018	0.4
2019	0.2
2020 and later	0.0

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* * * * *

(j) * * *

(2) * * *

(vii) For natural gas dual fuel model types, for model years 2016 and later, the combined model type carbon-related exhaust emissions value determined according to the following formula and rounded to the nearest gram per mile:

$$CREE = [CREE_{CNG} \times UF] + [CREE_{GAS} \times (1 - UF)]$$

Where:

$CREE_{CNG}$ = The combined model type carbon-related exhaust emissions value for operation on natural gas as determined in § 600.208–12(b)(5)(ii); and

$CREE_{GAS}$ = The combined model type carbon-related exhaust emissions value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i).

UF = A Utility Factor (UF) value selected from the following table based on the driving range of the vehicle while operating on natural gas. Determine the vehicle's driving range in miles by multiplying the combined fuel economy as determined in § 600.208–12(b)(5)(ii) by the vehicle's usable fuel storage capacity (as defined at § 600.002 and expressed in gasoline gallon equivalents), and rounding to the nearest 10 miles.

Driving Range (miles)	**UF**
10	0.228
20	0.397
30	0.523
40	0.617
50	0.689
60	0.743
70	0.785
80	0.818
90	0.844
100	0.865
110	0.882
120	0.896
130	0.907
140	0.917
150	0.925
160	0.932
170	0.939
180	0.944
190	0.949
200	0.954

210	0.958
220	0.962
230	0.965
240	0.968
250	0.971
260	0.973
270	0.976
280	0.978
290	0.980
300	0.981

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(k) *Alternative in-use weighting factors for dual fuel model types.* Using one of the methods in either paragraph (k)(1) or (2) of this section, manufacturers may request the use of alternative values for the weighting factor F in the equations in paragraphs (c)(2)(v) and (j)(2)(vi) of this section. Unless otherwise approved by the Administrator, the manufacturer must use the value of F that is in effect in paragraphs (c)(2)(v) and (j)(2)(vi) of this section.

(1) Upon written request from a manufacturer, the Administrator will determine and publish by written guidance an appropriate value of F for each requested alternative fuel based on the Administrator's assessment of real-world use of the alternative fuel. Such published values would be available for any manufacturer to use. The Administrator will periodically update these values upon written request from a manufacturer.

(2) The manufacturer may optionally submit to the Administrator its own demonstration regarding the real-world use of the alternative fuel in their vehicles and its own estimate of the appropriate value of F in the equations in paragraphs (c)(2)(v) and (j)(2)(vi) of this section. Depending on the nature of the analytical approach, the manufacturer could provide estimates of F that are model type specific or that are generally applicable to the manufacturer's dual fuel fleet. The manufacturer's analysis could include use of data gathered from on-board sensors and computers, from dual fuel vehicles in fleets that are centrally fueled, or from other sources. The analysis must be based on sound statistical methodology and must account for analytical uncertainty. Any approval by the Administrator will pertain to the use of values of F for the model types specified by the manufacturer.

26. Section 600.514–12 is amended by revising paragraphs (b)(1)(v) and (vii) and adding paragraphs (b)(1)(viii) and (ix) to read as follows:

§ 600.514–12 Reports to the Environmental Protection Agency.

* * * * *

(b) * * *

(1) * * *

(v) A description of the various credit, transfer and trading options that will be used to comply with each applicable standard category, including the amount of credit the manufacturer intends to generate for air conditioning leakage, air conditioning efficiency, off-cycle technology, advanced technology vehicles, hybrid or low emission full-size pickup trucks, and various early credit programs;

* * * * *

(vii) A summary by model year (beginning with the 2009 model year) of the number of electric vehicles, fuel cell vehicles and plug-in hybrid vehicles using (or projected to use) the advanced technology vehicle credit and incentives program;

(viii) The methodology which will be used to comply with N_2O and CH_4 emission standards;

(ix) Notification of the manufacturer's intent to exclude emergency vehicles from the calculation of fleet average standards and the end-of-year fleet average, including a description of the excluded emergency vehicles and the quantity of such vehicles excluded.

* * * * *

Title 49

National Highway Traffic Safety Administration

In consideration of the foregoing, under the authority of 49 U.S.C. 32901, 32902, and 32903, and delegation of authority at 49 CFR 1.50, NHTSA proposes to amend 49 CFR Chapter V as follows:

PART 523—VEHICLE CLASSIFICATION

27. The authority citation for part 523 continues to read as follows:

Authority: 49 U.S.C. 32901, delegation of authority at 49 CFR 1.50.

28. Revise § 523.2 to read as follows:

§ 523.2 Definitions.

Approach angle means the smallest angle, in a plane side view of an automobile, formed by the level surface on which the automobile is standing and a line tangent to the front tire static loaded radius arc and touching the underside of the automobile forward of the front tire.

Axle clearance means the vertical distance from the level surface on which an automobile is standing to the lowest point on the axle differential of the automobile.

Base tire (for passenger automobiles, light trucks, and medium duty passenger vehicles) means the tire that has the highest production sales volume that is installed by the vehicle manufacturer on each vehicle configuration of a model type.

Basic vehicle frontal area is used as defined in 40 CFR 86.1803.

Breakover angle means the supplement of the largest angle, in a plan side view of an automobile, that can be formed by two lines tangent to the front and rear static loaded radii arcs and intersecting at a point on the underside of the automobile.

Cab-complete vehicle means a vehicle that is first sold as an incomplete vehicle that substantially includes the vehicle cab section as defined in 40 CFR 1037.801. For example, vehicles known commercially as chassis-cabs, cab-chassis, box-deletes, bed-deletes, and cut-away vans are considered cab-complete vehicles. A cab includes a steering column and a passenger compartment. Note that a vehicle lacking some components of the cab is a cab-complete vehicle if it substantially includes the cab.

Cargo-carrying volume means the luggage capacity or cargo volume index, as appropriate, and as those terms are defined in 40 CFR 600.315–08, in the case of automobiles to which either of these terms apply. With respect to automobiles to which neither of these terms apply, ''cargo-carrying volume'' means the total volume in cubic feet, rounded to the nearest 0.1 cubic feet, of either an automobile's enclosed non-seating space that is intended primarily for carrying cargo and is not accessible from the passenger compartment, or the space intended primarily for carrying cargo bounded in the front by a vertical plane that is perpendicular to the longitudinal centerline of the automobile and passes through the rearmost point on the rearmost seat and elsewhere by the automobile's interior surfaces.

Class 2b vehicles are vehicles with a gross vehicle weight rating (GVWR) ranging from 8,501 to 10,000 pounds (lbs).

Class 3 through Class 8 vehicles are vehicles with a GVWR of 10,001 lbs or more, as defined in 49 CFR 565.15.

Commercial medium- and heavy-duty on-highway vehicle means an on-highway vehicle with a GVWR of 10,000 lbs or more, as defined in 49 U.S.C. 32901(a)(7).

Complete vehicle means a vehicle that requires no further manufacturing operations to perform its intended function and is a functioning vehicle that has the primary load-carrying device or container (or equivalent equipment) attached or is designed to pull a trailer. Examples of equivalent equipment include fifth wheel trailer hitches, firefighting equipment, and utility booms.

Curb weight is defined the same as *vehicle curb weight* in 40 CFR 86.1803–01.

Departure angle means the smallest angle, in a plane side view of an automobile, formed by the level surface on which the automobile is standing and a line tangent to the rear tire static loaded radius arc and touching the underside of the automobile rearward of the rear tire.

Final stage manufacturer has the meaning given in 49 CFR 567.3.

Footprint is defined as the product of track width (measured in inches, calculated as the average of front and rear track widths, and rounded to the nearest tenth of an inch) times wheelbase (measured in inches and rounded to the nearest tenth of an inch), divided by 144 and then rounded to the nearest tenth of a square foot. For purposes of this definition, ''track width'' is the lateral distance between the centerlines of the base tires at ground, including the camber angle. For purposes of this definition, ''wheelbase'' is the longitudinal distance between front and rear wheel centerlines.

Full-size pickup truck means a light truck or medium duty passenger vehicle that meets the requirements specified in 40 CFR 86.1866–12(e).

Gross combination weight rating (GCWR) means the value specified by the manufacturer as the maximum allowable loaded weight of a combination vehicle (*e.g.,* tractor plus trailer).

Gross vehicle weight rating (GVWR) means the value specified by the manufacturer as the maximum design loaded weight of a single vehicle (*e.g.,* vocational vehicle).

Heavy-duty engine means any engine used for (or which the engine manufacturer could reasonably expect to be used for) motive power in a heavy-duty vehicle. For purposes of this definition in this part, the term ''engine'' includes internal combustion engines and other devices that convert chemical fuel into motive power. For example, a fuel cell and motor used in a heavy-duty vehicle is a heavy-duty engine.

Heavy-duty off-road vehicle means a heavy-duty vocational vehicle or vocational tractor that is intended for off-road use meeting either of the following criteria:

(1) Vehicles with tires installed having a maximum speed rating at or below 55 mph.

(2) Vehicles primarily designed to perform work off-road (such as in oil fields, forests, or construction sites), and meeting at least one of the criteria of paragraph (2)(i) of this definition and at least one of the criteria of paragraph (2)(ii) of this definition.

(i) Vehicles must have affixed components designed to work in an off-road environment (for example, hazardous material equipment or drilling equipment) or be designed to operate at low speeds making them unsuitable for normal highway operation.

(ii) Vehicles must:

(A) Have an axle that has a gross axle weight rating (GAWR), as defined in 49 CFR 571.3, of 29,000 pounds or more;

(B) Have a speed attainable in 2 miles of not more than 33 mph; or

(C) Have a speed attainable in 2 miles of not more than 45 mph, an unloaded vehicle weight that is not less than 95 percent of its GVWR, and no capacity to carry occupants other than the driver and operating crew.

Heavy-duty vehicle means a vehicle as defined in § 523.6.

Incomplete vehicle means a vehicle which does not have the primary load carrying device or container attached when it is first sold as a vehicle or any vehicle that does not meet the definition of a complete vehicle. This may include vehicles sold to secondary vehicle manufacturers. Incomplete vehicles include cab-complete vehicles.

Innovative technology means technology certified as such under 40 CFR 1037.610.

Light truck means a non-passenger automobile as defined in § 523.5.

Medium duty passenger vehicle means a vehicle which would satisfy the criteria in § 523.5 (relating to light trucks) but for its gross vehicle weight rating or its curb weight, which is rated at more than 8,500 lbs GVWR or has a vehicle curb weight of more than 6,000 lbs or has a basic vehicle frontal area in excess of 45 square feet, and which is designed primarily to transport passengers, but does not include a vehicle that:

(1) Is an ''incomplete vehicle''' as defined in this subpart; or

(2) Has a seating capacity of more than 12 persons; or

(3) Is designed for more than 9 persons in seating rearward of the driver's seat; or

(4) Is equipped with an open cargo area (for example, a pick-up truck box or bed) of 72.0 inches in interior length or more. A covered box not readily accessible from the passenger compartment will be considered an open cargo area for purposes of this definition.

Mild hybrid gasoline-electric vehicle means a vehicle as defined by EPA in 40 CFR 86.1866–12(e).

Motor home has the meaning given in 49 CFR 571.3.

Motor vehicle has the meaning given in 40 CFR 85.1703.

Passenger-carrying volume means the sum of the front seat volume and, if any, rear seat volume, as defined in 40 CFR 600.315–08, in the case of automobiles to which that term applies. With respect to automobiles to which that term does not apply, ''passenger-carrying volume'' means the sum in cubic feet, rounded to the nearest 0.1 cubic feet, of the volume of a vehicle's front seat and seats to the rear of the front seat, as applicable, calculated as follows with the head room, shoulder room, and leg room dimensions determined in accordance with the procedures outlined in Society of Automotive Engineers Recommended Practice J1100a, Motor Vehicle Dimensions (Report of Human Factors Engineering Committee, Society of Automotive Engineers, approved September 1973 and last revised September 1975).

(1) For front seat volume, divide 1,728 into the product of the following SAE dimensions, measured in inches to the nearest 0.1 inches, and round the quotient to the nearest 0.001 cubic feet.

(i) H61–Effective head room—front.

(ii) W3—Shoulder room—front.

(iii) L34—Maximum effective leg room-accelerator.

(2) For the volume of seats to the rear of the front seat, divide 1,728 into the product of the following SAE dimensions, measured in inches to the nearest 0.1 inches, and rounded the quotient to the nearest 0.001 cubic feet.

(i) H63—Effective head room—second.

(ii) W4—Shoulder room—second.

(iii) L51—Minimum effective leg room—second.

Pickup truck means a non-passenger automobile which has a passenger compartment and an open cargo area (bed).

Recreational vehicle or RV means a motor vehicle equipped with living space and amenities found in a motor home.

Running clearance means the distance from the surface on which an automobile is standing to the lowest point on the automobile, excluding unsprung weight.

Static loaded radius arc means a portion of a circle whose center is the center of a standard tire-rim combination of an automobile and whose radius is the distance from that center to the level surface on which the automobile is standing, measured with the automobile at curb weight, the wheel parallel to the vehicle's longitudinal centerline, and the tire inflated to the manufacturer's recommended pressure.

Strong hybrid gasoline-electric vehicle means a vehicle as defined by EPA in 40 CFR 86.1866–12(e).

Temporary living quarters means a space in the interior of an automobile in which people may temporarily live and which includes sleeping surfaces, such as beds, and household conveniences, such as a sink, stove, refrigerator, or toilet.

Van means a vehicle with a body that fully encloses the driver and a cargo carrying or work performing compartment. The distance from the leading edge of the windshield to the foremost body section of vans is typically shorter than that of pickup trucks and sport utility vehicles.

Vocational tractor means a tractor that is classified as a vocational vehicle according to 40 CFR 1037.630.

Vocational vehicle means a vehicle that is equipped for a particular industry, trade or occupation such as construction, heavy hauling, mining, logging, oil fields, refuse and includes vehicles such as school buses, motorcoaches and RVs.

Work truck means a vehicle that is rated at more than 8,500 pounds and less than or equal to 10,000 pounds gross vehicle weight, and is not a medium-duty passenger vehicle as defined in 40 CFR 86.1803 effective as of December 20, 2007.

PART 531—PASSENGER AUTOMOBILE AVERAGE FUEL ECONOMY STANDARDS

29. The authority citation for part 531 continues to read as follows:

Authority: 49 U.S.C. 32902; delegation of authority at 49 CFR 1.50.

30. Amend § 531.5 by revising paragraph (a) Introductory text, revising paragraphs (b), (c), and (d), redesignating paragraph (e) as paragraph (f), and adding a new paragraph (e) to read as follows:

§ 531.5 Fuel economy standards.

(a) Except as provided in paragraph (e) of this section, each manufacturer of passenger automobiles shall comply with the fleet average fuel economy standards in Table I, expressed in miles per gallon, in the model year specified as applicable:

* * * * *

(b) For model year 2011, a manufacturer's passenger automobile fleet shall comply with the fleet average fuel economy level calculated for that model year according to Figure 1 and the appropriate values in Table II.

Figure 1:

$$Required\_Fuel\_Economy\_Level = \frac{N}{\sum_i \frac{N_i}{T_i}}$$

Where:

N is the total number (sum) of passenger automobiles produced by a manufacturer;

N_i is the number (sum) of the *ith* passenger automobile model produced by the manufacturer; and

T_i is the fuel economy target of the *ith* model passenger automobile, which is determined according to the following formula, rounded to the nearest hundredth:

$$T = \frac{1}{\frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\frac{e^{(x-c)d}}{1 + e^{(x-c)d}}}$$

Where:

Parameters *a, b, c,* and *d* are defined in Table II;

e = 2.718; and

x = footprint (in square feet, rounded to the nearest tenth) of the vehicle model.

TABLE II – PARAMETERS FOR THE PASSENGER AUTOMOBILE FUEL ECONOMY TARGETS

Model year	Parameters			
	a (mpg)	*b* (mpg)	*c* (gal/mi/ft²)	*d* (gal/mi)
2011	31.20	24.00	51.41	1.91

(c) For model years 2012–2025, a manufacturer's passenger automobile fleet shall comply with the fleet average fuel economy level calculated for that model year according to Figure 2 and the appropriate values in Table III.

Figure 2:

$$CAFE_{required} = \frac{\sum_i PRODUCTION_i}{\sum_i \frac{PRODUCTION_i}{TARGET_i}}$$

Where:

$CAFE_{required}$ is the fleet average fuel economy standard for a given fleet (domestic passenger automobiles or import passenger automobiles);

Subscript *i* is a designation of multiple groups of automobiles, where each group's designation, *i.e., i* = 1, 2, 3, etc., represents automobiles that share a unique model type and footprint within the applicable fleet, either domestic passenger automobiles or import passenger automobiles;

$Production_i$ is the number of passenger automobiles produced for sale in the United States within each *ith* designation, *i.e.,* which share the same model type and footprint;

$TARGET_i$ is the fuel economy target in miles per gallon (mpg) applicable to the footprint of passenger automobiles within each *ith* designation, *i.e.,* which share the same model type and footprint, calculated according to Figure 3 and rounded to the nearest hundredth of a mpg, *i.e.,* 35.455 = 35.46 mpg, and the summations in the numerator and denominator are both performed over all models in the fleet in question.

Figure 3:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Where:

TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet);

Parameters *a, b, c,* and *d* are defined in Table III; and

The *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values.

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TABLE III – PARAMETERS FOR THE PASSENGER AUTOMOBILE FUEL ECONOMY TARGETS, MYS 2012-2025

Model year	**Parameters**			
	a (mpg)	*b* (mpg)	*c* (gal/mi/ft^2)	*d* (gal/mi)
2012	35.95	27.95	0.0005308	0.006057
2013	36.80	28.46	0.0005308	0.005410
2014	37.75	29.03	0.0005308	0.004725
2015	39.24	29.90	0.0005308	0.003719
2016	41.09	30.96	0.0005308	0.002573
2017	43.61	32.65	0.0005131	0.001896
2018	45.21	33.84	0.0004954	0.001811
2019	46.87	35.07	0.0004783	0.001729
2020	48.74	36.47	0.0004603	0.001643
2021	50.83	38.02	0.0004419	0.001555
2022	53.21	39.79	0.0004227	0.001463
2023	55.71	41.64	0.0004043	0.001375
2024	58.32	43.58	0.0003867	0.001290
2025	61.07	45.61	0.0003699	0.001210

(d) In addition to the requirements of paragraphs (b) and (c) of this section, each manufacturer shall also meet the minimum fleet standard for domestically manufactured passenger automobiles expressed in Table IV:

TABLE IV – MINIMUM FUEL ECONOMY STANDARDS FOR DOMESTICALLY MANUFACTURED PASSENGER AUTOMOBILES, MYS 2011-2021

Model year	Minimum standard
2011	27.8
2012	30.7
2013	31.4
2014	32.1
2015	33.3
2016	34.7
2017	36.8
2018	38.1
2019	39.6
2020	41.1
2021	42.9
2022	44.9
2023	47.0
2024	49.2
2025	51.5

(e) For model years 2022–2025, each manufacturer shall comply with the standards set forth in paragraphs (c) and (d) in this section, if NHTSA determines in a rulemaking, initiated after January 1, 2017, and conducted in accordance with 49 U.S.C. 32902, that the standards in paragraphs (c) and (d) are the maximum feasible standards for model years 2022–2025. If, for any of those model years, NHTSA determines that the maximum feasible standard for passenger cars and the corresponding minimum standard for domestically manufactured passenger cars should be set at a different level, manufacturers shall comply with those different standards in lieu of the standards set forth for those model years in paragraphs (c) and (d), and NHTSA will revise this section to reflect the different standards.

* * * * *

31. Amend § 531.6 by revising paragraph (a) to read as follows:

§ 531.6 Measurement and calculation procedures.

(a) The fleet average fuel economy performance of all passenger automobiles that are manufactured by a manufacturer in a model year shall be determined in accordance with procedures established by the Administrator of the Environmental Protection Agency under 49 U.S.C. 32904 and set forth in 40 CFR part 600. For model years 2017 to 2025, a manufacturer is eligible to increase the fuel economy performance of passenger cars in accordance with procedures established by EPA set forth in 40 CFR part 600, including any adjustments to fuel economy EPA allows, such as for fuel consumption improvements related to air conditioning efficiency and off-cycle technologies.

* * * * *

32. Revise Appendix A to part 531 to read as follows:

Appendix to Part 531—Example of Calculating Compliance Under § 531.5(c)

Assume a hypothetical manufacturer (Manufacturer X) produces a fleet of domestic passenger automobiles in MY 2012 as follows:

APPENDIX TABLE I

Model type				Description	Actual measured fuel economy (mpg)	Volume
Group	Carline name	Basic engine (L)	Transmission class			
1	PC A FWD	1.8	A5	2-door sedan	34.0	1,500
2	PC A FWD	1.8	M6	2-door sedan	34.6	2,000
3	PC A FWD	2.5	A6	4-door wagon	33.8	2,000
4	PC A AWD	1.8	A6	4-door wagon	34.4	1,000
5	PC A AWD	2.5	M6	2-door hatchback	32.9	3,000
6	PC B RWD	2.5	A6	4-door wagon	32.2	8,000
7	PC B RWD	2.5	A7	4-door sedan	33.1	2,000
8	PC C AWD	3.2	A7	4-door sedan	30.6	5,000
9	PC C FWD	3.2	M6	2-door coupe	28.5	3,000
Total						27,500

NOTE TO APPENDIX TABLE I: Manufacturer X's required fleet average fuel economy standard level would first be calculated by determining the fuel economy targets applicable to each unique model type and footprint combination for model type groups 1-9 as illustrated in Appendix Table II:

APPENDIX TABLE II

Manufacturer X calculates a fuel economy target standard for each unique model type and footprint combination.

Model type				Description	Base tire size	Wheelbase (inches)	Track width F&R average (inches)	Foot print (ft^2)	Volume	Fuel economy target standard (mpg)
Group	Carline name	Basic engine (L)	Transmission class							
1	PC A	1.8	A5	2-door sedan	205/75R	99.8	61.2	42.4	1,500	35.01

	FWD				14					
2	PC A FWD	1.8	M6	2-door sedan	215/70R 15	99.8	60.9	42.2	2,000	35.14
3	PC A FWD	2.5	A6	4-door wagon	215/70R 15	100.0	60.9	42.3	2,000	35.08
4	PC A AWD	1.8	A6	4-door wagon	235/60R 15	100.0	61.2	42.5	1,000	35.95
5	PC A AWD	2.5	M6	2-door hatchback	225/65R 16	99.6	59.5	41.2	3,000	35.81
6	PC B RWD	2.5	A6	4-door wagon	265/55R 18	109.2	66.8	50.7	8,000	30.33
7	PC B RWD	2.5	A7	4-door sedan	235/65R 17	109.2	67.8	51.4	2,000	29.99
8	PC C AWD	3.2	A7	4-door sedan	265/55R 18	111.3	67.8	52.4	5,000	29.52
9	PC C FWD	3.2	M6	2-door coupe	225/65R 16	111.3	67.2	51.9	3,000	29.76
Total...									27,500	

NOTE TO APPENDIX TABLE II: With the appropriate fuel economy targets determined for each unique model type and footprint combination, Manufacturer X's required fleet average fuel economy standard would be calculated as illustrated in Appendix Figure 1:

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Appendix Figure 1 – Calculation of Manufacturer X's fleet average fuel economy standard using Table II:

Fleet average fuel economy standard =

$$= \frac{(Manufacturer's\ Domestic\ Passenger\ Automobile\ Production\ for\ Applicable\ Model\ Year)}{\sum_i \left(\frac{Group_1\ Production}{Group_1 Target\ Standard} + \frac{Group_2\ Production}{Group_2 Target\ Standard} + \cdots \frac{Group_9\ Production}{Group_9 Target\ Standard}\right)}$$

$$= \frac{(27{,}500)}{\left(\frac{1500}{35.01} + \frac{2000}{35.14} + \frac{2000}{35.08} + \frac{1000}{35.95} + \frac{3000}{35.81} + \frac{8000}{30.33} + \frac{2000}{29.99} + \frac{5000}{29.52} + \frac{3000}{29.79}\right)}$$

= 31.6 mpg

Appendix Figure 2 – Calculation of Manufacturer X's actual fleet average fuel economy performance level using Table I:

Fleet average fuel economy performance =

$$= \frac{(Manufacturer's\ Domestic\ Passenger\ Automobile\ Production\ for\ Applicable\ Model\ Year)}{\sum_i \left(\frac{Group_1\ Production}{Group_1 Performance} + \frac{Group_2\ Production}{Group_2 Performance} + \cdots \frac{Group_9\ Production}{Group_9 Performance}\right)}$$

$$= \frac{(27{,}500)}{\left(\frac{1500}{34.0} + \frac{2000}{34.6} + \frac{2000}{33.8} + \frac{1000}{34.4} + \frac{3000}{32.9} + \frac{8000}{32.2} + \frac{2000}{33.1} + \frac{5000}{30.6} + \frac{3000}{28.5}\right)}$$

= 32.0 mpg

NOTE TO APPENDIX FIGURE 2: Since the actual fleet average fuel economy performance of Manufacturer X's fleet is 32.0 mpg, as compared to its required fleet fuel economy standard of 31.6 mpg, Manufacturer X complied with the CAFE standard for MY 2012 as set forth in § 531.5(c).

PART 533—LIGHT TRUCK FUEL ECONOMY STANDARDS

33. The authority citation for part 531 continues to read as follows:

Authority: 49 U.S.C. 32902; delegation of authority at 49 CFR 1.50.

34. Amend § 533.5 by revising paragraphs (a), (f), (g), (h), (i) and adding paragraphs (j) and (k) to read as follows:

§ 533.5 Requirements.

(a) Each manufacturer of light trucks shall comply with the following fleet average fuel economy standards, expressed in miles per gallon, in the model year specified as applicable:

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TABLE I

Model year	2-wheel drive light trucks		4-wheel drive light trucks		Limited product line light trucks
	Captive imports	Other	Captive imports	Other	
1979……..	…………	17.2	…………..	15.8	………………
1980……..	16.0	16.0	14.0	14.0	14.0
1981……..	16.7	16.7	15.0	15.0	14.5

TABLE II

Model year	Combined standard		2-wheel drive light trucks		4-wheel drive light trucks	
	Captive imports	Others	Captive imports	Others	Captive imports	Others
1982………	17.5	17.5	18.0	18.0	16.0	16.0
1983………	19.0	19.0	19.5	19.5	17.5	17.5
1984………	20.0	20.0	20.3	20.3	18.5	18.5
1985………	19.5	19.5	19.7	19.7	18.9	18.9
1986………	20.0	20.0	20.5	20.5	19.5	19.5
1987………	20.5	20.5	21.0	21.0	19.5	19.5
1988………	20.5	20.5	21.0	21.0	19.5	19.5
1989………	20.5	20.5	21.5	21.5	19.0	19.0
1990………	20.0	20.0	20.5	20.5	19.0	19.0
1991………	20.2	20.2	20.7	20.7	19.1	19.1

TABLE III

Model Year	Combined standard	
	Captive imports	Other
1992	20.2	20.2
1993	20.4	20.4
1994	20.5	20.5
1995	20.6	20.6

TABLE IV

Model year	Standard
2001	20.7
2002	20.7
2003	20.7
2004	20.7
2005	21.0
2006	21.6
2007	22.2
2008	22.5
2009	23.1
2010	23.5

Figure 1:

$$Required\_Fuel\_Economy\_Level = \frac{N}{\sum_i \frac{N_i}{T_i}}$$

Where:

N is the total number (sum) of light trucks produced by a manufacturer;

N_i is the number (sum) of the *ith* light truck model type produced by a manufacturer; and

T_i is the fuel economy target of the *ith* light truck model type, which is determined according to the following formula, rounded to the nearest hundredth:

$$T = \frac{1}{\frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\frac{e^{(x-c)d}}{1 + e^{(x-c)d}}}$$

Where:

Parameters *a, b, c,* and *d* are defined in Table V;

e = 2.718; and

x = footprint (in square feet, rounded to the nearest tenth) of the model type.

TABLE V – PARAMETERS FOR THE LIGHT TRUCK FUEL ECONOMY TARGETS FOR MYS 2008-2011

Model year	Parameters			
	a (mpg)	*b* (mpg)	*c* (gal/mi/ft^2)	*d* (gal/mi)
2008	28.56	19.99	49.30	5.58
2009	30.07	20.87	48.00	5.81
2010	29.96	21.20	48.49	5.50
2011	27.10	21.10	56.41	4.28

Figure 2:

$$CAFE_{required} = \frac{\sum_i PRODUCTION_i}{\sum_i \frac{PRODUCTION_i}{TARGET_i}}$$

Where:

$CAFE_{required}$ is the fleet average fuel economy standard for a given light truck fleet;

Subscript i is a designation of multiple groups of light trucks, where each group's designation, *i.e.,* i = 1, 2, 3, etc., represents light trucks that share a unique model type and footprint within the applicable fleet.

$Production_i$ is the number of light trucks produced for sale in the United States within each *ith* designation, *i.e.,* which share the same model type and footprint;

$TARGET_i$ is the fuel economy target in miles per gallon (mpg) applicable to the footprint of light trucks within each *ith* designation, *i.e.,* which share the same model type and footprint, calculated according to either Figure 3 or Figure 4, as appropriate, and rounded to the nearest hundredth of a mpg, *i.e.,* 35.455 = 35.46 mpg, and the summations in the numerator and denominator are both performed over all models in the fleet in question.

Figure 3

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Where:

TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet);

Parameters *a, b, c,* and *d* are defined in Table VI; and

The *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values.

TABLE VI – PARAMETERS FOR THE LIGHT TRUCK FUEL ECONOMY TARGETS FOR MYs 2012-2016

Model year	Parameters			
	a (mpg)	*b* (mpg)	*c* (gal/mi/ft^2)	*d* (gal/mi)
2012	29.82	22.27	0.0004546	0.014900
2013	30.67	22.74	0.0004546	0.013968
2014	31.38	23.13	0.0004546	0.013225
2015	32.72	23.85	0.0004546	0.011920
2016	34.42	24.74	0.0004546	0.010413

Figure 4:

$$TARGET = MAX\left(\frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}, \frac{1}{MIN\left[MAX\left(g \times FOOTPRINT + h \frac{1}{e}\right), \frac{1}{f}\right]}\right)$$

TABLE VII – PARAMETERS FOR THE LIGHT TRUCK FUEL ECONOMY TARGETS FOR MYS 2017-2025

Model year	Parameters							
	a (mpg)	*b* (mpg)	*c* (gal/mi/ft^2)	*d* (gal/mi)	*e* (mpg)	*f* (mpg)	*g* (gal/mi/ft^2)	*h* (gal/mi)
2017	36.26	25.09	0.0005484	0.005097	35.10	25.09	0.0004546	0.009851
2018	37.36	25.20	0.0005358	0.004797	35.31	25.20	0.0004546	0.009682
2019	38.16	25.25	0.0005265	0.004623	35.41	25.25	0.0004546	0.009603
2020	39.11	25.25	0.0005140	0.004494	35.41	25.25	0.0004546	0.009603
2021	41.80	25.25	0.0004820	0.004164	35.41	25.25	0.0004546	0.009603
2022	43.79	26.29	0.0004607	0.003944	35.41	25.25	0.0004546	0.009603
2023	45.89	27.53	0.0004404	0.003735	35.41	25.25	0.0004546	0.009603
2024	48.09	28.83	0.0004210	0.003534	35.41	25.25	0.0004546	0.009603
2025	50.39	30.19	0.0004025	0.003343	35.41	25.25	0.0004546	0.009603

* * * * *

(f) For each model year 1996 and thereafter, each manufacturer shall combine its captive imports with its other light trucks and comply with the fleet average fuel economy standard in paragraph (a) of this section.

(g) For model years 2008–2010, at a manufacturer's option, a manufacturer's light truck fleet may comply with the fuel economy standard calculated for each model year according to Figure 1 and the appropriate values in Table V, with said option being irrevocably chosen for that model year and reported as specified in § 537.8.

(h) For model year 2011, a manufacturer's light truck fleet shall comply with the fleet average fuel economy standard calculated for that model year according to Figure 1 and the appropriate values in Table V.

(i) For model years 2012–2016, a manufacturer's light truck fleet shall comply with the fleet average fuel economy standard calculated for that model year according to Figures 2 and 3 and the appropriate values in Table VI.

(j) For model years 2017–2025, a manufacturer's light truck fleet shall comply with the fleet average fuel economy standard calculated for that model year according to Figures 2 and 4 and the appropriate values in Table VII.

(k) For model years 2022–2025, each manufacturer shall comply with the standards set forth in paragraph (j) of this section, if NHTSA determines in a rulemaking, initiated after January 1, 2017, and conducted in accordance with 49 U.S.C. 32902, that the standards in paragraph (j) are the maximum feasible standards for model years 2022–2025. If, for any of those model years, NHTSA determines that the maximum feasible standard for light trucks should be set at a different level, manufacturers shall comply with those different standards in lieu of the standards set forth for those model years in paragraph (j), and NHTSA will revise this section to reflect the different standards.

* * * * *

35. Amend § 533.6 by revising paragraph (b) to read as follows:

§ 533.6 Measurement and calculation procedures.

* * * * *

(b) The fleet average fuel economy performance of all vehicles subject to part 533 that are manufactured by a manufacturer in a model year shall be determined in accordance with procedures established by the Administrator of the Environmental Protection Agency under 49 U.S.C. 32904 and set forth in 40 CFR part 600. For model years 2017 to 2025, a manufacturer is eligible to increase the fuel economy performance of light trucks in accordance with procedures established by EPA and set forth in 40 CFR part 600, including any adjustments to fuel economy EPA allows, such as for fuel consumption improvements related to air conditioning efficiency, off-cycle technologies, and hybridization and other over-compliance for full-size pickup trucks.

36. Redesignate Appendix A to part 533 as Appendix to part 533 and revise it to read as follows:

Appendix to Part 533—Example of Calculating Compliance Under § 533.5(i)

Assume a hypothetical manufacturer (Manufacturer X) produces a fleet of light trucks in MY 2012 as follows:

APPENDIX TABLE I

Model type				Description	Actual measured fuel economy (mpg)	Volume
Group	Carline name	Basic engine (L)	Transmission class			
1	Pickup A 2WD	4	A5	Reg cab, MB	27.1	800
2	Pickup B 2WD	4	M5	Reg cab, MB	27.6	200
3	Pickup C 2WD	4.5	A5	Reg cab, LB	23.9	300
4	Pickup C 2WD	4	M5	Ext cab, MB	23.7	400
5	Pickup C 4WD	4.5	A5	Crew cab, SB	23.5	400
6	Pickup D 2WD	4.5	A6	Crew cab, SB	23.6	400
7	Pickup E 2WD	5	A6	Ext cab, LB	22.7	500
8	Pickup E 2WD	5	A6	Crew cab, MB	22.5	500
9	Pickup F 2WD	4.5	A5	Reg cab, LB	22.5	1,600
10	Pickup F 4WD	4.5	A5	Ext cab, MB	22.3	800
11	Pickup F 4WD	4.5	A5	Crew cab, SB	22.2	800
Total						6,700

4	Pickup C 2WD	4	M5	Ext cab, MB	23.7	400
5	Pickup C 4WD	4.5	A5	Crew cab, SB	23.5	400
6	Pickup D 2WD	4.5	A6	Crew cab, SB	23.6	400
7	Pickup E 2WD	5	A6	Ext cab, LB	22.7	500
8	Pickup E 2WD	5	A6	Crew cab, MB	22.5	500
9	Pickup F 2WD	4.5	A5	Reg cab, LB	22.5	1,600
10	Pickup F 4WD	4.5	A5	Ext cab, MB	22.3	800
11	Pickup F 4WD	4.5	A5	Crew cab, SB	22.2	800
Total						6,700

NOTE TO APPENDIX TABLE I: Manufacturer X's required fleet average fuel economy standard level would first be calculated by determining the fuel economy targets applicable to each unique model type and footprint combination for model type groups 1-11 as illustrated in Appendix Table II:

APPENDIX TABLE II

Manufacturer X calculates a fuel economy target standard for each unique model type and footprint combination.

Model type				Description	Base tire size	Wheelbase (inches)	Track width F&R average (inches)	Footprint (ft^2)	Volume	Fuel economy target standard (mpg)
Group	Carline name	Basic engine (L)	Transmission class							
1	Pickup A 2WD	4	A5	Reg cab, MB	235/75R 15	100.0	68.8	47.8	800	27.30
2	Pickup B 2WD	4	M5	Reg cab, MB	235/75R 15	100.0	68.2	47.4	200	27.44
3	Pickup C 2WD	4.5	A5	Reg cab, LB	255/70R 17	125.0	68.8	59.7	300	23.79
4	Pickup C 2WD	4	M5	Ext cab, MB	255/70R 17	125.0	68.8	59.7	400	23.79
5	Pickup C 4WD	4.5	A5	Crew cab, SB	275/70R 17	150.0	69.0	71.9	400	22.27
6	Pickup D 2WD	4.5	A6	Crew cab, SB	255/70R 17	125.0	68.8	59.7	400	23.79
7	Pickup E 2WD	5	A6	Ext cab, LB	255/70R 17	125.0	68.8	59.7	500	23.79
8	Pickup E	5	A6	Crew cab, MB	285/70R	125.0	69.2	60.1	500	23.68

	2WD			MB	17					
9	Pickup F 2WD	4.5	A5	Reg cab, LB	255/70R 17	125.0	68.9	59.8	1,600	23.76
10	Pickup F 4WD	4.5	A5	Ext cab, MB	275/70R 17	150.0	69.0	71.9	800	22.27
11	Pickup F 4WD	4.5	A5	Crew cab, SB	285/70R 17	150.0	69.2	72.1	800	22.27
Total............									6,700	

NOTE TO APPENDIX TABLE II: With the appropriate fuel economy targets determined for each unique model type and footprint combination, Manufacturer X's required fleet average fuel economy standard would be calculated as illustrated in Appendix Figure 1:

Appendix Figure 1 – Calculation of Manufacturer X's fleet average fuel economy standard using Table II:

Fleet average fuel economy standard =

$$= \frac{(Manufacturer's\ Lig\square t\ Truck\ Production\ for\ Applicable\ Model\ Year)}{\sum_i\left(\frac{Group_1\ Production}{Group_1 Target\ Standard} + \frac{Group_{2a}\ Production}{Group_2 Target\ Standard} + \cdots \frac{Group_{11}\ Production}{Group_{11} Target\ Standard}\right)}$$

$$= \frac{(6{,}700)}{\left(\frac{800}{27.30} + \frac{200}{27.44} + \frac{300}{23.79} + \frac{400}{23.79} + \frac{400}{22.27} + \frac{400}{23.79} + \frac{500}{23.79} + \frac{500}{23.68} + \frac{1600}{23.76} + \frac{800}{22.27} + \frac{800}{22.27}\right)}$$

= 23.7 mpg

Appendix Figure 2 – Calculation of Manufacturer X's actual fleet average fuel economy performance level using Table I:

Fleet average fuel economy performance =

$$= \frac{(Manufacturer's\ Lig\square t\ Truck\ Production\ for\ Applicable\ Model\ Year)}{\sum_i \left(\frac{Group_1\ Production}{Group_1 Performance} + \frac{Group_2\ Production}{Group_2 Performance} + \cdots \frac{Group_{11}\ Production}{Group_{11} Performance}\right)}$$

$$= \frac{(27{,}500)}{\left(\frac{1500}{34.0} + \frac{2000}{34.6} + \frac{2000}{33.8} + \frac{1000}{34.4} + \frac{3000}{32.9} + \frac{8000}{32.2} + \frac{2000}{33.1} + \frac{5000}{30.6} + \frac{3000}{28.5}\right)}$$

= 23.3 mpg

NOTE TO APPENDIX FIGURE 2: Since the actual fleet average fuel economy performance of Manufacturer X's fleet is 23.3 mpg, as compared to its required fleet fuel economy standard of 23.7 mpg, Manufacturer X did not comply with the CAFE standard for MY 2012 as set forth in § 533.5(i).

Where:

TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet);

Parameters *a, b, c, d, e, f, g,* and *h* are defined in Table VII; and

The *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values.

PART 536—TRANSFER AND TRADING OF FUEL ECONOMY CREDITS

37. Revise the authority citation for part 536 to read as follows:

Authority: 49 U.S.C. 32903; delegation of authority at 49 CFR 1.50.

38. Amend § 536.4 by revising paragraph (c) to read as follows:

§ 536.4 Credits.

* * * * *

(c) *Adjustment factor.* When traded or transferred and used, fuel economy credits are adjusted to ensure fuel oil savings is preserved. For traded credits, the user (or buyer) must multiply the calculated adjustment factor by the number of its shortfall credits it plans to offset in order to determine the number of equivalent credits to acquire from the earner (or seller). For transferred credits, the user of credits must multiply the calculated adjustment factor by the number of its shortfall credits it plans to offset in order to determine the number of equivalent credits to transfer from the compliance category holding the available credits. The adjustment factor is calculated according to the following formula:

$$A = \frac{VMT_u * MPG_{ae} * MPG_{se}}{VMT_e * MPG_{au} * MPG_{su}}$$

Where:

A = Adjustment factor applied to traded and transferred credits;

VMT_e = Lifetime vehicle miles traveled as provided in the following table for the model year and compliance category in which the credit was earned;

VMT_u = Lifetime vehicle miles traveled as provided in the following table for the model year and compliance category in which the credit is used for compliance;

Model year	Lifetime Vehicle Miles Traveled (VMT)						
	2011	2012	2013	2014	2015	2016	2017-2025
Passenger Cars	152,922	177,238	177,366	178,652	180,497	182,134	195,264
Light Trucks	172,552	208,471	208,537	209,974	212,040	213,954	225,865

MPG_{se} = Required fuel economy standard for the originating (earning) manufacturer, compliance category, and model year in which the credit was earned;

MPG_{ae} = Actual fuel economy for the originating manufacturer, compliance category, and model year in which the credit was earned;

MPG_{su} = Required fuel economy standard for the user (buying) manufacturer, compliance category, and model year in which the credit is used for compliance; and

MPG_{au} = Actual fuel economy for the user manufacturer, compliance category, and model year in which the credit is used for compliance.

39. Amend § 536.9 by revising paragraph (c) to read as follows:

§ 536.9 Use of credits with regard to the domestically manufactured passenger automobile minimum standard.

* * * * *

(c) Transferred or traded credits may not be used, pursuant to 49 U.S.C. 32903(g)(4) and (f)(2), to meet the domestically manufactured passenger automobile minimum standard specified in 49 U.S.C. 32902(b)(4) and in 49 CFR 531.5(d).

* * * * *

40. Amend § 536.10 by revising the section heading and paragraphs (b) and (c) and adding paragraph (d) to read as follows:

§ 536.10 Treatment of dual-fuel and alternative-fuel vehicles.

* * * * *

(b) If a manufacturer's calculated fuel economy for a particular compliance category, including any statutorily-required calculations for alternative fuel and dual fuel vehicles, is higher or lower than the applicable fuel economy standard, manufacturers will earn credits or must apply credits or pay civil penalties equal to the difference between the calculated fuel economy level in that compliance category and the applicable standard. Credits earned are the same as any other credits, and may be held, transferred, or traded by the manufacturer subject to the limitations of the statute and this regulation.

(c) For model years up to and including MY 2019, if a manufacturer builds enough dual fuel vehicles (except plug-in electric vehicles) to improve the calculated fuel economy in a particular compliance category by more than the limits set forth in 49 U.S.C. 32906(a), the improvement in fuel economy for compliance purposes is restricted to the statutory limit. Manufacturers may not earn credits nor reduce the application of credits or fines for calculated improvements in fuel economy based on dual fuel vehicles beyond the statutory limit.

(d) For model years 2020 and beyond, a manufacturer must calculate the fuel economy of dual fueled vehicles in accordance with 40 CFR 600.510–12(c)(2)(v) and (vii).

PART 537—AUTOMOTIVE FUEL ECONOMY REPORTS

41. The authority citation for part 537 continues to read as follows:

Authority: 49 U.S.C. 32907, delegation of authority at 49 CFR 1.50.

42. Amend § 537.5 by revising paragraph (c)(4) to read as follows:

* * * * *

(c) * * *

(4) Be submitted on CD or by email with the contents in a pdf or MS Word format except the information required in 537.7 must be provided in a MS Excel format. Submit 2 copies of the CD to: Administrator, National Highway Traffic Administration, 1200 New Jersey Avenue SW., Washington, DC 20590, or submit reports electronically to the following secure email address: *cafe@dot.gov*;

* * * * *

43. Amend § 537.7 by revising paragraphs (b)(3), (c)(4), and (c)(5) to read as follows:

§ 537.7 Pre-model year and mid-model year reports.

* * * * *

(b) * * *

(3) State the projected required fuel economy for the manufacturer's passenger automobiles and light trucks

determined in accordance with 49 CFR 531.5(c) and 49 CFR 533.5 and based upon the projected sales figures provided under paragraph (c)(2) of this section. For each unique model type and footprint combination of the manufacturer's automobiles, provide the information specified in paragraph (b)(3)(i) and (ii) of this section in tabular form. List the model types in order of increasing average inertia weight from top to bottom down the left side of the table and list the information categories in the order specified in paragraphs (i) and (ii) of this section from left to right across the top of the table. Other formats, such as those accepted by EPA, which contain all of the information in a readily identifiable format are also acceptable.

(i) In the case of passenger automobiles:

(A) Beginning model year 2013, base tire as defined in 49 CFR 523.2,

(B) Beginning model year 2013, front axle, rear axle and average track width as defined in 49 CFR 523.2,

(C) Beginning model year 2013, wheelbase as defined in 49 CFR 523.2, and

(D) Beginning model year 2013, footprint as defined in 49 CFR 523.2.

(ii) In the case of light trucks:

(A) Beginning model year 2013, base tire as defined in 49 CFR 523.2,

(B) Beginning model year 2013, front axle, rear axle and average track width as defined in 49 CFR 523.2,

(C) Beginning model year 2013, wheelbase as defined in 49 CFR 523.2, and

(D) Beginning model year 2013, footprint as defined in 49 CFR 523.2.

* * * * *

(c) * * *

(4) (i) Loaded vehicle weight;

(ii) Equivalent test weight;

(iii) Engine displacement, liters;

(iv) SAE net rated power, kilowatts;

(v) SAE net horsepower;

(vi) Engine code;

(vii) Fuel system (number of carburetor barrels or, if fuel injection is used, so indicate);

(viii) Emission control system;

(ix) Transmission class;

(x) Number of forward speeds;

(xi) Existence of overdrive (indicate yes or no);

(xii) Total drive ratio (N/V);

(xiii) Axle ratio;

(xiv) Combined fuel economy;

(xv) Projected sales for the current model year;

(xvi) Air conditioning efficiency improvement technologies used to acquire the incentive in 40 CFR 86.1866 and the amount of the incentive;

(xvii) Full-size pickup truck technologies used to acquire the incentive in 40 CFR 86.1866 and the amount of the incentive;

(xviii) Off-cycle technologies used to acquire the incentive in 40 CFR 86.1866 and the amount of the incentive;

(xix) (A) In the case of passenger automobiles:

(*1*) Interior volume index, determined in accordance with subpart D of 40 CFR part 600;

(*2*) Body style;

(B) In the case of light trucks:

(*1*) Passenger-carrying volume;

(*2*) Cargo-carrying volume;

(xx) Frontal area;

(xxi) Road load power at 50 miles per hour, if determined by the manufacturer for purposes other than compliance with this part to differ from the road load setting prescribed in 40 CFR 86.177–11(d);

(xxii) Optional equipment that the manufacturer is required under 40 CFR parts 86 and 600 to have actually installed on the vehicle configuration, or the weight of which must be included in the curb weight computation for the vehicle configuration, for fuel economy testing purposes.

(5) For each model type of automobile which is classified as a non-passenger vehicle (light truck) under part 523 of this chapter, provide the following data:

(i) For an automobile designed to perform at least one of the following functions in accordance with 523.5 (a) indicate (by "yes" or "no") whether the vehicle can:

(A) Transport more than 10 persons (if yes, provide actual designated seating positions);

(B) Provide temporary living quarters (if yes, provide applicable conveniences as defined in 523.2);

(C) Transport property on an open bed (if yes, provide bed size width and length);

(D) Provide, as sold to the first retail purchaser, greater cargo-carrying than passenger-carrying volume, such as in a cargo van and quantify the value; if a vehicle is sold with a second-row seat, its cargo-carrying volume is determined with that seat installed, regardless of whether the manufacturer has described that seat as optional; or

(E) Permit expanded use of the automobile for cargo-carrying purposes or other non passenger-carrying purposes through:

(*1*) For non-passenger automobiles manufactured prior to model year 2012, the removal of seats by means installed for that purpose by the automobile's manufacturer or with simple tools, such as screwdrivers and wrenches, so as to create a flat, floor level, surface extending from the forward-most point of installation of those seats to the rear of the automobile's interior; or

(*2*) For non-passenger automobiles manufactured in model year 2008 and beyond, for vehicles equipped with at least 3 rows of designated seating positions as standard equipment, permit expanded use of the automobile for cargo-carrying purposes or other nonpassenger-carrying purposes through the removal or stowing of foldable or pivoting seats so as to create a flat, leveled cargo surface extending from the forward-most point of installation of those seats to the rear of the automobile's interior.

(ii) For an automobile capable of off-highway operation, identify which of the features below qualify the vehicle as off-road in accordance with 523.5 (b) and quantify the values of each feature:

(A) 4-wheel drive; or

(B) A rating of more than 6,000 pounds gross vehicle weight; and

(C) Has at least four of the following characteristics calculated when the automobile is at curb weight, on a level surface, with the front wheels parallel to the automobile's longitudinal centerline, and the tires inflated to the manufacturer's recommended pressure. The exact value of each feature should be quantified:

(*1*) Approach angle of not less than 28 degrees.

(*2*) Breakover angle of not less than 14 degrees.

(*3*) Departure angle of not less than 20 degrees.

(*4*) Running clearance of not less than 20 centimeters.

(*5*) Front and rear axle clearances of not less than 18 centimeters each.

* * * * *

44. Amend § 537.8 by revising paragraph (a)(3) to read as follows:

§ 537.8 Supplementary reports.

(a) * * *

(3) Each manufacturer whose pre-model year report omits any of the information specified in § 537.7 (b), (c)(1) and (2), or (c)(4) shall file a supplementary report containing the information specified in paragraph (b)(3) of this section.

* * * * *

Dated: November 16, 2011.

Ray LaHood,

Secretary, Department of Transportation.

Dated: November 16, 2011.

Lisa P. Jackson,

Administrator, Environmental Protection Agency.

[FR Doc. 2011–30358 Filed 11–30–11; 8:45 am]

BILLING CODE 4910–59–P

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 85, 86, and 600

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Parts 531, 533, 536, 537 and 538

[EPA–HQ–OAR–2009–0472; FRL–9134–6; NHTSA–2009–0059]

RIN 2060–AP58; RIN 2127–AK50

Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule

AGENCY: Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA).

ACTION: Final rule.

SUMMARY: EPA and NHTSA are issuing this joint Final Rule to establish a National Program consisting of new standards for light-duty vehicles that will reduce greenhouse gas emissions and improve fuel economy. This joint Final Rule is consistent with the National Fuel Efficiency Policy announced by President Obama on May 19, 2009, responding to the country's critical need to address global climate change and to reduce oil consumption. EPA is finalizing greenhouse gas emissions standards under the Clean Air Act, and NHTSA is finalizing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act, as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years 2012 through 2016, and represent a harmonized and consistent National Program. Under the National Program, automobile manufacturers will be able to build a single light-duty national fleet that satisfies all requirements under both programs while ensuring that consumers still have a full range of vehicle choices. NHTSA's final rule also constitutes the agency's Record of Decision for purposes of its National Environmental Policy Act (NEPA) analysis.

DATES: This final rule is effective on July 6, 2010, *sixty days after date of publication in the* **Federal Register.** The incorporation by reference of certain publications listed in this regulation is approved by the Director of the Federal Register as of July 6, 2010.

ADDRESSES: EPA and NHTSA have established dockets for this action under Docket ID No. EPA–HQ–OAR–2009–0472 and NHTSA–2009–0059, respectively. All documents in the docket are listed on the *http://www.regulations.gov* Web site. Although listed in the index, some information is not publicly available, *e.g.,* CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the Internet and will be publicly available only in hard copy form. Publicly available docket materials are available either electronically through *http://www.regulations.gov* or in hard copy at the following locations: *EPA:* EPA Docket Center, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744. *NHTSA:* Docket Management Facility, M–30, U.S. Department of Transportation, West Building, Ground Floor, Rm. W12–140, 1200 New Jersey Avenue, SE., Washington, DC 20590. The Docket Management Facility is open between 9 a.m. and 5 p.m. Eastern Time, Monday through Friday, except Federal holidays.

FOR FURTHER INFORMATION CONTACT:

EPA: Tad Wysor, Office of Transportation and Air Quality, Assessment and Standards Division, Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor MI 48105; telephone number: 734–214–4332; fax number: 734–214–4816; e-mail address: *wysor.tad@epa.gov,* or Assessment and Standards Division Hotline; telephone number (734) 214–4636; e-mail address *asdinfo@epa.gov. NHTSA:* Rebecca Yoon, Office of Chief Counsel, National Highway Traffic Safety Administration, 1200 New Jersey Avenue, SE., Washington, DC 20590. Telephone: (202) 366–2992.

SUPPLEMENTARY INFORMATION:

Does this action apply to me?

This action affects companies that manufacture or sell new light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles, as defined under EPA's CAA regulations,[1] and passenger automobiles (passenger cars) and non-passenger automobiles (light trucks) as defined under NHTSA's CAFE regulations.[2] Regulated categories and entities include:

Category	NAICS codes [A]	Examples of potentially regulated entities
Industry	336111, 336112	Motor vehicle manufacturers.
Industry	811112, 811198, 541514	Commercial Importers of Vehicles and Vehicle Components.

[A]North American Industry Classification System (NAICS).

This list is not intended to be exhaustive, but rather provides a guide regarding entities likely to be regulated by this action. To determine whether particular activities may be regulated by this action, you should carefully examine the regulations. You may direct questions regarding the applicability of this action to the person listed in **FOR FURTHER INFORMATION CONTACT.**

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[1] "Light-duty vehicle," "light-duty truck," and "medium-duty passenger vehicle" are defined in 40 CFR 86.1803–01. Generally, the term "light-duty vehicle" means a passenger car, the term "light-duty truck" means a pick-up truck, sport-utility vehicle, or minivan of up to 8,500 lbs gross vehicle weight rating, and "medium-duty passenger vehicle" means a sport-utility vehicle or passenger van from 8,500 to 10,000 lbs gross vehicle weight rating. Medium-duty passenger vehicles do not include pick-up trucks.

[2] "Passenger car" and "light truck" are defined in 49 CFR part 523.

I. Overview of Joint EPA/NHTSA National Program

A. Introduction

The National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) are each announcing final rules whose benefits will address the urgent and closely intertwined challenges of energy independence and security and global warming. These rules will implement a strong and coordinated Federal greenhouse gas (GHG) and fuel economy program for passenger cars, light-duty-trucks, and medium-duty passenger vehicles (hereafter light-duty vehicles), referred to as the National Program. The rules will achieve substantial reductions of GHG emissions and improvements in fuel economy from the light-duty vehicle part of the transportation sector, based on technology that is already being commercially applied in most cases and that can be incorporated at a reasonable cost. NHTSA's final rule also constitutes the agency's Record of Decision for purposes of its NEPA analysis.

This joint rulemaking is consistent with the President's announcement on May 19, 2009 of a National Fuel Efficiency Policy of establishing consistent, harmonized, and streamlined requirements that would reduce GHG emissions and improve fuel economy for all new cars and light-duty trucks sold in the United States.[3] The National Program will deliver additional environmental and energy benefits, cost savings, and administrative efficiencies on a nationwide basis that would likely not be available under a less coordinated approach. The National Program also represents regulatory convergence by making it possible for the standards of two different Federal agencies and the standards of California and other states to act in a unified fashion in providing these benefits. The National Program will allow automakers to produce and sell a single fleet nationally, mitigating the additional costs that manufacturers would otherwise face in having to comply with multiple sets of Federal and State standards. This joint notice is also consistent with the Notice of Upcoming Joint Rulemaking issued by DOT and EPA on May 19, 2009[4] and responds to the President's January 26, 2009 memorandum on CAFE standards for model years 2011 and beyond,[5] the details of which can be found in Section IV of this joint notice.

Climate change is widely viewed as a significant long-term threat to the global environment. As summarized in the Technical Support Document for EPA's Endangerment and Cause or Contribute Findings under Section 202(a) of the Clean Air Act, anthropogenic emissions of GHGs are very likely (90 to 99 percent probability) the cause of most of the observed global warming over the last 50 years.[6] The primary GHGs of concern are carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Mobile sources emitted 31 percent of all U.S. GHGs in 2007 (transportation sources, which do not include certain off-highway sources, account for 28 percent) and have been the fastest-growing source of U.S. GHGs since 1990.[7] Mobile sources addressed in the recent endangerment and contribution findings under CAA section 202(a)—light-duty vehicles, heavy-duty trucks, buses, and motorcycles—accounted for 23 percent of all U.S. GHG in 2007.[8] Light-duty vehicles emit CO_2, methane, nitrous oxide, and hydrofluorocarbons and are responsible for nearly 60 percent of all mobile source GHGs and over 70 percent of Section 202(a) mobile source GHGs. For light-duty vehicles in 2007, CO_2 emissions represent about 94 percent of all greenhouse emissions (including HFCs), and the CO_2 emissions measured over the EPA tests used for fuel economy compliance represent about 90 percent of total light-duty vehicle GHG emissions.[9 10]

Improving energy security by reducing our dependence on foreign oil has been a national objective since the first oil price shocks in the 1970s. Net petroleum imports now account for approximately 60 percent of U.S.

[3] President Obama Announces National Fuel Efficiency Policy, The White House, May 19, 2009. Available at: *http://www.whitehouse.gov/the_press_office/President-Obama-Announces-National-Fuel-Efficiency-Policy/*. Remarks by the President on National Fuel Efficiency Standards, The White House, May 19, 2009. Available at: *http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-on-national-fuel-efficiency-standards/*.

[4] 74 FR 24007 (May 22, 2009).

[5] Available at: *http://www.whitehouse.gov/the_press_office/Presidential_Memorandum_Fuel_Economy/*.

[6] "Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act" Docket: EPA–HQ–OAR–2009–0472–11292, *http://epa.gov/climatechange/endangerment.html*.

[7] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007. EPA 430–R–09–004. Available at *http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf*.

[8] U.S. EPA. 2009 Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC. pp. 180–194. Available at *http://epa.gov/climatechange/endangerment/downloads/Endangerment%20TSD.pdf*.

[9] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007. EPA 430–R–09–004. Available at *http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf*.

[10] U.S. Environmental Protection Agency. RIA, Chapter 2.

petroleum consumption. World crude oil production is highly concentrated, exacerbating the risks of supply disruptions and price shocks. Tight global oil markets led to prices over $100 per barrel in 2008, with gasoline reaching as high as $4 per gallon in many parts of the U.S., causing financial hardship for many families. The export of U.S. assets for oil imports continues to be an important component of the historically unprecedented U.S. trade deficits. Transportation accounts for about two-thirds of U.S. petroleum consumption. Light-duty vehicles account for about 60 percent of transportation oil use, which means that they alone account for about 40 percent of all U.S. oil consumption.

1. Building Blocks of the National Program

The National Program is both needed and possible because the relationship between improving fuel economy and reducing CO_2 tailpipe emissions is a very direct and close one. The amount of those CO_2 emissions is essentially constant per gallon combusted of a given type of fuel. Thus, the more fuel efficient a vehicle is, the less fuel it burns to travel a given distance. The less fuel it burns, the less CO_2 it emits in traveling that distance.[11] While there are emission control technologies that reduce the pollutants (*e.g.,* carbon monoxide) produced by imperfect combustion of fuel by capturing or converting them to other compounds, there is no such technology for CO_2. Further, while some of those pollutants can also be reduced by achieving a more complete combustion of fuel, doing so only increases the tailpipe emissions of CO_2. Thus, there is a single pool of technologies for addressing these twin problems, *i.e.,* those that reduce fuel consumption and thereby reduce CO_2 emissions as well.

a. DOT's CAFE Program

In 1975, Congress enacted the Energy Policy and Conservation Act (EPCA), mandating that NHTSA establish and implement a regulatory program for motor vehicle fuel economy to meet the various facets of the need to conserve energy, including ones having energy independence and security, environmental and foreign policy implications. Fuel economy gains since 1975, due both to the standards and market factors, have resulted in saving billions of barrels of oil and avoiding billions of metric tons of CO_2 emissions. In December 2007, Congress enacted the Energy Independence and Securities Act (EISA), amending EPCA to require substantial, continuing increases in fuel economy standards.

The CAFE standards address most, but not all, of the real world CO_2 emissions because a provision in EPCA as originally enacted in 1975 requires the use of the 1975 passenger car test procedures under which vehicle air conditioners are not turned on during fuel economy testing.[12] Fuel economy is determined by measuring the amount of CO_2 and other carbon compounds emitted from the tailpipe, not by attempting to measure directly the amount of fuel consumed during a vehicle test, a difficult task to accomplish with precision. The carbon content of the test fuel [13] is then used to calculate the amount of fuel that had to be consumed per mile in order to produce that amount of CO_2. Finally, that fuel consumption figure is converted into a miles-per-gallon figure. CAFE standards also do not address the 5–8 percent of GHG emissions that are not CO_2, *i.e.,* nitrous oxide (N_2O), and methane (CH_4) as well as emissions of CO_2 and hydrofluorocarbons (HFCs) related to operation of the air conditioning system.

b. EPA's GHG Standards for Light-duty Vehicles

Under the Clean Air Act EPA is responsible for addressing air pollutants from motor vehicles. On April 2, 2007, the U.S. Supreme Court issued its opinion in *Massachusetts* v. *EPA,*[14] a case involving EPA's a 2003 denial of a petition for rulemaking to regulate GHG emissions from motor vehicles under section 202(a) of the Clean Air Act (CAA).[15] The Court held that GHGs fit within the definition of air pollutant in the Clean Air Act and further held that the Administrator must determine whether or not emissions from new motor vehicles cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, or whether the science is too uncertain to make a reasoned decision. The Court further ruled that, in making these decisions, the EPA Administrator is required to follow the language of section 202(a) of the CAA. The Court rejected the argument that EPA cannot regulate CO_2 from motor vehicles because to do so would *de facto* tighten fuel economy standards, authority over which has been assigned by Congress to DOT. The Court stated that "[b]ut that DOT sets mileage standards in no way licenses EPA to shirk its environmental responsibilities. EPA has been charged with protecting the public's 'health' and 'welfare', a statutory obligation wholly independent of DOT's mandate to promote energy efficiency." The Court concluded that "[t]he two obligations may overlap, but there is no reason to think the two agencies cannot both administer their obligations and yet avoid inconsistency." [16] The case was remanded back to the Agency for reconsideration in light of the Court's decision.[17]

On December 15, 2009, EPA published two findings (74 FR 66496): That emissions of GHGs from new motor vehicles and motor vehicle engines contribute to air pollution, and that the air pollution may reasonably be anticipated to endanger public health and welfare.

c. California Air Resources Board Greenhouse Gas Program

In 2004, the California Air Resources Board approved standards for new light-duty vehicles, which regulate the emission of not only CO_2, but also other GHGs. Since then, thirteen states and the District of Columbia, comprising approximately 40 percent of the light-duty vehicle market, have adopted California's standards. These standards apply to model years 2009 through 2016 and require CO_2 emissions for passenger cars and the smallest light trucks of 323 g/mi in 2009 and 205 g/mi in 2016, and for the remaining light trucks of 439 g/mi in 2009 and 332 g/mi in 2016. On June 30, 2009, EPA granted California's request for a waiver of preemption under the CAA.[18] The granting of the waiver permits California and the other states to proceed with implementing the California emission standards.

In addition, to promote the National Program, in May 2009, California announced its commitment to take several actions in support of the National Program, including revising its

[11] Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, "Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base," National Academies Press, 1992. p. 287.

[12] Although EPCA does not require the use of 1975 test procedures for light trucks, those procedures are used for light truck CAFE standard testing purposes.

[13] This is the method that EPA uses to determine compliance with NHTSA's CAFE standards.

[14] 549 U.S. 497 (2007).

[15] 68 FR 52922 (Sept. 8, 2003).

[16] 549 U.S. at 531–32.

[17] For further information on *Massachusetts* v. *EPA* see the July 30, 2008 Advance Notice of Proposed Rulemaking, "Regulating Greenhouse Gas Emissions under the Clean Air Act", 73 FR 44354 at 44397. There is a comprehensive discussion of the litigation's history, the Supreme Court's findings, and subsequent actions undertaken by the Bush Administration and the EPA from 2007–2008 in response to the Supreme Court remand. Also see 74 FR 18886, at 1888–90 (April 24, 2009).

[18] 74 FR 32744 (July 8, 2009).

program for MYs 2009–2011 to facilitate compliance by the automakers, and revising its program for MYs 2012–2016 such that compliance with the Federal GHG standards will be deemed to be compliance with California's GHG standards. This will allow the single national fleet produced by automakers to meet the two Federal requirements and to meet California requirements as well. California is proceeding with a rulemaking intended to revise its 2004 regulations to meet its commitments. Several automakers and their trade associations also announced their commitment to take several actions in support of the National Program, including not contesting the final GHG and CAFE standards for MYs 2012–2016, not contesting any grant of a waiver of preemption under the CAA for California's GHG standards for certain model years, and to stay and then dismiss all pending litigation challenging California's regulation of GHG emissions, including litigation concerning preemption under EPCA of California's and other states' GHG standards.

2. Public Participation

The agencies proposed their respective rules on September 28, 2009 (74 FR 49454), and received a large number of comments representing many perspectives on the proposed rule. The agencies received oral testimony at three public hearings in different parts of the country, and received written comments from more than 130 organizations, including auto manufacturers and suppliers, States, environmental and other non-governmental organizations (NGOs), and over 129,000 comments from private citizens.

The vast majority of commenters supported the central tenets of the proposed CAFE and GHG programs. That is, there was broad support from most organizations for a National Program that achieves a level of 250 gram/mile fleet average CO_2, which would be 35.5 miles per gallon if the automakers were to meet this CO_2 level solely through fuel economy improvements. The standards will be phased in over model years 2012 through 2016 which will allow manufacturers to build a common fleet of vehicles for the domestic market. In general, commenters from the automobile industry supported the proposed standards as well as the credit opportunities and other compliance provisions providing flexibility, while also making some recommendations for changes. Environmental and public interest non-governmental organizations (NGOs), as well as most States that commented, were also generally supportive of the National Program standards. Many of these organizations also expressed concern about the possible impact on program benefits, depending on how the credit provisions and flexibilities are designed. The agencies also received specific comments on many aspects of the proposal.

Throughout this notice, the agencies discuss many of the key issues arising from the public comments and the agencies' responses. In addition, the agencies have addressed all of the public comments in the Response to Comments document associated with this final rule.

B. Summary of the Joint Final Rule and Differences From the Proposal

In this joint rulemaking, EPA is establishing GHG emissions standards under the Clean Air Act (CAA), and NHTSA is establishing Corporate Average Fuel Economy (CAFE) standards under the Energy Policy and Conservation Action of 1975 (EPCA), as amended by the Energy Independence and Security Act of 2007 (EISA). The intention of this joint rulemaking is to set forth a carefully coordinated and harmonized approach to implementing these two statutes, in accordance with all substantive and procedural requirements imposed by law.

NHTSA and EPA have coordinated closely and worked jointly in developing their respective final rules. This is reflected in many aspects of this joint rule. For example, the agencies have developed a comprehensive Joint Technical Support Document (TSD) that provides a solid technical underpinning for each agency's modeling and analysis used to support their standards. Also, to the extent allowed by law, the agencies have harmonized many elements of program design, such as the form of the standard (the footprint-based attribute curves), and the definitions used for cars and trucks. They have developed the same or similar compliance flexibilities, to the extent allowed and appropriate under their respective statutes, such as averaging, banking, and trading of credits, and have harmonized the compliance testing and test protocols used for purposes of the fleet average standards each agency is finalizing. Finally, under their respective statutes, each agency is called upon to exercise its judgment and determine standards that are an appropriate balance of various relevant statutory factors. Given the common technical issues before each agency, the similarity of the factors each agency is to consider and balance, and the authority of each agency to take into consideration the standards of the other agency, both EPA and NHTSA are establishing standards that result in a harmonized National Program.

This joint final rule covers passenger cars, light-duty trucks, and medium-duty passenger vehicles built in model years 2012 through 2016. These vehicle categories are responsible for almost 60 percent of all U.S. transportation-related GHG emissions. EPA and NHTSA expect that automobile manufacturers will meet these standards by utilizing technologies that will reduce vehicle GHG emissions and improve fuel economy. Although many of these technologies are available today, the emissions reductions and fuel economy improvements finalized in this notice will involve more widespread use of these technologies across the light-duty vehicle fleet. These include improvements to engines, transmissions, and tires, increased use of start-stop technology, improvements in air conditioning systems, increased use of hybrid and other advanced technologies, and the initial commercialization of electric vehicles and plug-in hybrids. NHTSA's and EPA's assessments of likely vehicle technologies that manufacturers will employ to meet the standards are discussed in detail below and in the Joint TSD.

The National Program is estimated to result in approximately 960 million metric tons of total carbon dioxide equivalent emissions reductions and approximately 1.8 billion barrels of oil savings over the lifetime of vehicles sold in model years (MYs) 2012 through 2016. In total, the combined EPA and NHTSA 2012–2016 standards will reduce GHG emissions from the U.S. light-duty fleet by approximately 21 percent by 2030 over the level that would occur in the absence of the National Program. These actions also will provide important energy security benefits, as light-duty vehicles are about 95 percent dependent on oil-based fuels. The agencies project that the total benefits of the National Program will be more than $240 billion at a 3% discount rate, or more than $190 billion at a 7% discount rate. In the discussion that follows in Sections III and IV, each agency explains the related benefits for their individual standards.

Together, EPA and NHTSA estimate that the average cost increase for a model year 2016 vehicle due to the National Program will be less than $1,000. The average U.S. consumer who purchases a vehicle outright is estimated to save enough in lower fuel costs over the first three years to offset these higher vehicle costs. However, most U.S. consumers purchase a new vehicle using credit rather than paying cash and the typical car loan today is a five year, 60 month loan. These consumers will see immediate savings due to their vehicle's lower fuel consumption in the form of a net reduction in annual costs of $130–$180 throughout the duration of the loan (that is, the fuel savings will outweigh the increase in loan payments by $130–$180 per year). Whether a consumer takes out a loan or purchases a new vehicle outright, over the lifetime of a model year 2016 vehicle, the consumer's net savings could be more than $3,000. The average 2016 MY vehicle will emit 16 fewer metric tons of CO_2-equivalent emissions (that is, CO_2 emissions plus HFC air conditioning leakage emissions) during its lifetime. Assumptions that underlie these conclusions are discussed in greater detail in the agencies' respective regulatory impact analyses and in Section III.H.5 and Section IV.

This joint rule also results in important regulatory convergence and certainty to automobile companies. Absent this rule, there would be three separate Federal and State regimes independently regulating light-duty vehicles to reduce fuel consumption and GHG emissions: NHTSA's CAFE standards, EPA's GHG standards, and the GHG standards applicable in California and other States adopting the California standards. This joint rule will allow automakers to meet both the NHTSA and EPA requirements with a single national fleet, greatly simplifying the industry's technology, investment and compliance strategies. In addition, to promote the National Program, California announced its commitment to take several actions, including revising its program for MYs 2012–2016 such that compliance with the Federal GHG standards will be deemed to be compliance with California's GHG standards. This will allow the single national fleet used by automakers to meet the two Federal requirements and to meet California requirements as well. California is proceeding with a rulemaking intended to revise its 2004 regulations to meet its commitments. EPA and NHTSA are confident that these GHG and CAFE standards will successfully harmonize both the Federal and State programs for MYs 2012–2016 and will allow our country to achieve the increased benefits of a single, nationwide program to reduce light-duty vehicle GHG emissions and reduce the country's dependence on fossil fuels by improving these vehicles' fuel economy.

A successful and sustainable automotive industry depends upon, among other things, continuous technology innovation in general, and low GHG emissions and high fuel economy vehicles in particular. In this respect, this action will help spark the investment in technology innovation necessary for automakers to successfully compete in both domestic and export markets, and thereby continue to support a strong economy.

While this action covers MYs 2012–2016, many stakeholders encouraged EPA and NHTSA to also begin working toward standards for MY 2017 and beyond that would maintain a single nationwide program. The agencies recognize the importance of and are committed to a strong, coordinated national program for light-duty vehicles for model years beyond 2016.

Key elements of the National Program finalized today are the level and form of the GHG and CAFE standards, the available compliance mechanisms, and general implementation elements. These elements are summarized in the following section, with more detailed discussions about EPA's GHG program following in Section III, and about NHTSA's CAFE program in Section IV. This joint final rule responds to the wide array of comments that the agencies received on the proposed rule. This section summarizes many of the major comments on the primary elements of the proposal and describes whether and how the final rule has changed, based on the comments and additional analyses. Major comments and the agencies' responses to them are also discussed in more detail in later sections of this preamble. For a full summary of public comments and EPA's and NHTSA's responses to them, please see the Response to Comments document associated with this final rule.

1. Joint Analytical Approach

NHTSA and EPA have worked closely together on nearly every aspect of this joint final rule. The extent and results of this collaboration are reflected in the elements of the respective NHTSA and EPA rules, as well as the analytical work contained in the Joint Technical Support Document (Joint TSD). The Joint TSD, in particular, describes important details of the analytical work that are shared, as well as any differences in approach. These include the build up of the baseline and reference fleets, the derivation of the shape of the curves that define the standards, a detailed description of the costs and effectiveness of the technology choices that are available to vehicle manufacturers, a summary of the computer models used to estimate how technologies might be added to vehicles, and finally the economic inputs used to calculate the impacts and benefits of the rules, where practicable.

EPA and NHTSA have jointly developed attribute curve shapes that each agency is using for its final standards. Further details of these functions can be found in Sections III and IV of this preamble as well as Chapter 2 of the Joint TSD. A critical technical underpinning of each agency's analysis is the cost and effectiveness of the various control technologies. These are used to analyze the feasibility and cost of potential GHG and CAFE standards. A detailed description of all of the technology information considered can be found in Chapter 3 of the Joint TSD (and for A/C, Chapter 2 of the EPA RIA). This detailed technology data forms the inputs to computer models that each agency uses to project how vehicle manufacturers may add those technologies in order to comply with the new standards. These are the OMEGA and Volpe models for EPA and NHTSA, respectively. The models and their inputs can also be found in the docket. Further description of the model and outputs can be found in Sections III and IV of this preamble, and Chapter 3 of the Joint TSD. This comprehensive joint analytical approach has provided a sound and consistent technical basis for each agency in developing its final standards, which are summarized in the sections below.

The vast majority of public comments expressed strong support for the joint analytical work performed for the proposal. Commenters generally agreed with the analytical work and its results, and supported the transparency of the analysis and its underlying data. Where commenters raised specific points, the agencies have considered them and made changes where appropriate. The agencies' further evaluation of various technical issues also led to a limited number of changes. A detailed discussion of these issues can be found in Section II of this preamble, and the Joint TSD.

2. Level of the Standards

In this notice, EPA and NHTSA are establishing two separate sets of standards, each under its respective statutory authorities. EPA is setting national CO_2 emissions standards for light-duty vehicles under section 202(a) of the Clean Air Act. These standards will require these vehicles to meet an estimated combined average emissions level of 250 grams/mile of CO_2 in model year 2016. NHTSA is setting CAFE standards for passenger cars and light trucks under 49 U.S.C. 32902. These standards will require manufacturers of those vehicles to meet an estimated combined average fuel economy level of 34.1 mpg in model year 2016. The standards for both agencies begin with the 2012 model year, with standards increasing in stringency through model year 2016. They represent a harmonized approach that will allow industry to build a single national fleet that will satisfy both the GHG requirements under the CAA and CAFE requirements under EPCA/EISA.

Given differences in their respective statutory authorities, however, the agencies' standards include some important differences. Under the CO_2 fleet average standards adopted under CAA section 202(a), EPA expects manufacturers to take advantage of the option to generate CO_2-equivalent credits by reducing emissions of hydrofluorocarbons (HFCs) and CO_2 through improvements in their air conditioner systems. EPA accounted for these reductions in developing its final CO_2 standards. NHTSA did not do so because EPCA does not allow vehicle manufacturers to use air conditioning credits in complying with CAFE standards for passenger cars.[19] CO_2 emissions due to air conditioning operation are not measured by the test procedure mandated by statute for use in establishing and enforcing CAFE standards for passenger cars. As a result, improvement in the efficiency of passenger car air conditioners is not considered as a possible control technology for purposes of CAFE.

These differences regarding the treatment of air conditioning improvements (related to CO_2 and HFC reductions) affect the relative stringency of the EPA standard and NHTSA standard for MY 2016. The 250 grams per mile of CO_2 equivalent emissions limit is equivalent to 35.5 mpg[20] if the automotive industry were to meet this CO_2 level all through fuel economy improvements. As a consequence of the prohibition against NHTSA's allowing credits for air conditioning improvements for purposes of passenger car CAFE compliance, NHTSA is setting fuel economy standards that are estimated to require a combined (passenger car and light truck) average fuel economy level of 34.1 mpg by MY 2016.

The vast majority of public comments expressed strong support for the National Program standards, including the stringency of the agencies' respective standards and the phase-in from model year 2012 through 2016. There were a number of comments supporting standards more stringent than proposed, and a few others supporting less stringent standards, in particular for the 2012–2015 model years. The agencies' consideration of comments and their updated technical analyses led to only very limited changes in the footprint curves and did not change the agencies' projections that the nationwide fleet will achieve a level of 250 grams/mile by 2016 (equivalent to 35.5 mpg). The responses to these comments are discussed in more detail in Sections III and IV, respectively, and in the Response to Comments document.

As proposed, NHTSA and EPA's final standards, like the standards NHTSA promulgated in March 2009 for MY 2011, are expressed as mathematical functions depending on vehicle footprint. Footprint is one measure of vehicle size, and is determined by multiplying the vehicle's wheelbase by the vehicle's average track width.[21] The standards that must be met by each manufacturer's fleet will be determined by computing the sales-weighted average (harmonic average for CAFE) of the targets applicable to each of the manufacturer's passenger cars and light trucks. Under these footprint-based standards, the levels required of individual manufacturers will depend, as noted above, on the mix of vehicles sold. NHTSA's and EPA's respective standards are shown in the tables below. It is important to note that the standards are the attribute-based curves established by each agency. The values in the tables below reflect the agencies' projection of the corresponding fleet levels that will result from these attribute-based curves.

As a result of public comments and updated economic and future fleet projections, EPA and NHTSA have updated the attribute based curves for this final rule, as discussed in detail in Section II.B of this preamble and Chapter 2 of the Joint TSD. This update in turn affects costs, benefits, and other impacts of the final standards. Thus, the agencies have updated their overall projections of the impacts of the final rule standards, and these results are only slightly different from those presented in the proposed rule.

As shown in Table I.B.2–1, NHTSA's fleet-wide CAFE-required levels for passenger cars under the final standards are projected to increase from 33.3 to 37.8 mpg between MY 2012 and MY 2016. Similarly, fleet-wide CAFE levels for light trucks are projected to increase from 25.4 to 28.8 mpg. NHTSA has also estimated the average fleet-wide required levels for the combined car and truck fleets. As shown, the overall fleet average CAFE level is expected to be 34.1 mpg in MY 2016. These numbers do not include the effects of other flexibilities and credits in the program. These standards represent a 4.3 percent average annual rate of increase relative to the MY 2011 standards.[22]

TABLE I.B.2–1—AVERAGE REQUIRED FUEL ECONOMY (mpg) UNDER FINAL CAFE STANDARDS

	2011-base	2012	2013	2014	2015	2016
Passenger Cars	30.4	33.3	34.2	34.9	36.2	37.8
Light Trucks	24.4	25.4	26.0	26.6	27.5	28.8
Combined Cars & Trucks	27.6	29.7	30.5	31.3	32.6	34.1

[19] There is no such statutory limitation with respect to light trucks.

[20] The agencies are using a common conversion factor between fuel economy in units of miles per gallon and CO_2 emissions in units of grams per mile. This conversion factor is 8,887 grams CO_2 per gallon gasoline fuel. Diesel fuel has a conversion factor of 10,180 grams CO_2 per gallon diesel fuel though for the purposes of this calculation, we are assuming 100% gasoline fuel.

[21] See 49 CFR 523.2 for the exact definition of "footprint."

[22] Because required CAFE levels depend on the mix of vehicles sold by manufacturers in a model year, NHTSA's estimate of future required CAFE levels depends on its estimate of the mix of vehicles that will be sold in that model year. NHTSA currently estimates that the MY 2011 standards will require average fuel economy levels of 30.4 mpg for passenger cars, 24.4 mpg for light trucks, and 27.6 mpg for the combined fleet.

Accounting for the expectation that some manufacturers could continue to pay civil penalties rather than achieving required CAFE levels, and the ability to use FFV credits,[23] NHTSA estimates that the CAFE standards will lead to the following average achieved fuel economy levels, based on the projections of what each manufacturer's fleet will comprise in each year of the program: [24]

TABLE I.B.2–2—PROJECTED FLEET-WIDE ACHIEVED CAFE LEVELS UNDER THE FINAL FOOTPRINT-BASED CAFE STANDARDS (mpg)

	2012	2013	2014	2015	2016
Passenger Cars	32.3	33.5	34.2	35.0	36.2
Light Trucks	24.5	25.1	25.9	26.7	27.5
Combined Cars & Trucks	28.7	29.7	30.6	31.5	32.7

NHTSA is also required by EISA to set a minimum fuel economy standard for domestically manufactured passenger cars in addition to the attribute-based passenger car standard. The minimum standard "shall be the greater of (A) 27.5 miles per gallon; or (B) 92 percent of the average fuel economy projected by the Secretary for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year.* * * "[25]

Based on NHTSA's current market forecast, the agency's estimates of these minimum standards under the MY 2012–2016 CAFE standards (and, for comparison, the final MY 2011 standard) are summarized below in Table I.B.2–3.[26] For eventual compliance calculations, the final calculated minimum standards will be updated to reflect the average fuel economy level required under the final standards.

TABLE I.B.2–3—ESTIMATED MINIMUM STANDARD FOR DOMESTICALLY MANUFACTURED PASSENGER CARS UNDER MY 2011 AND MY 2012–2016 CAFE STANDARDS FOR PASSENGER CARS (mpg)

2011	2012	2013	2014	2015	2016
27.8	30.7	31.4	32.1	33.3	34.7

EPA is establishing GHG emissions standards, and Table I.B.2–4 provides EPA's estimates of their projected overall fleet-wide CO_2 equivalent emission levels.[27] The g/mi values are CO_2 equivalent values because they include the projected use of air conditioning (A/C) credits by manufacturers, which include both HFC and CO_2 reductions.

TABLE I.B.2–4—PROJECTED FLEET-WIDE EMISSIONS COMPLIANCE LEVELS UNDER THE FOOTPRINT-BASED CO_2 STANDARDS (g/mi)

	2012	2013	2014	2015	2016
Passenger Cars	263	256	247	236	225
Light Trucks	346	337	326	312	298
Combined Cars & Trucks	295	286	276	263	250

As shown in Table I.B.2–4, fleet-wide CO_2 emission level requirements for cars are projected to increase in stringency from 263 to 225 g/mi between MY 2012 and MY 2016. Similarly, fleet-wide CO_2 equivalent emission level requirements for trucks are projected to increase in stringency from 346 to 298 g/mi. As shown, the overall fleet average CO_2 level requirements are projected to increase in stringency from 295 g/mi in MY 2012 to 250 g/mi in MY 2016.

EPA anticipates that manufacturers will take advantage of program flexibilities such as flexible fueled vehicle credits and car/truck credit trading. Due to the credit trading between cars and trucks, the estimated improvements in CO_2 emissions are distributed differently than shown in Table I.B.2–4, where full manufacturer compliance without credit trading is assumed. Table I.B.2–5 shows EPA's projection of the achieved emission levels of the fleet for MY 2012 through 2016, which does consider the impact of car/truck credit transfer and the increase in emissions due to certain program flexibilities including flex fueled vehicle credits and the temporary lead time allowance alternative standards. The use of optional air conditioning credits is considered both in this analysis of achieved levels and of the

[23] The penalties are similar in function to essentially unlimited, fixed-price allowances.

[24] NHTSA's estimates account for availability of CAFE credits for the sale of flexible-fuel vehicles (FFVs), and for the potential that some manufacturers will pay civil penalties rather than comply with the CAFE standards. This yields NHTSA's estimates of the real-world fuel economy that will likely be achieved under the final CAFE standards. NHTSA has not included any potential impact of car-truck credit transfer in its estimate of the achieved CAFE levels.

[25] 49 U.S.C. 32902(b)(4).

[26] In the March 2009 final rule establishing MY 2011 standards for passenger cars and light trucks, NHTSA estimated that the minimum required CAFE standard for domestically manufactured passenger cars would be 27.8 mpg under the MY 2011 passenger car standard.

[27] These levels do not include the effect of flexible fuel credits, transfer of credits between cars and trucks, temporary lead time allowance, or any other credits with the exception of air conditioning.

compliance levels described above. As can be seen in Table I.B.2–5, the projected achieved levels are slightly higher for model years 2012–2015 due to EPA's assumptions about manufacturers' use of the regulatory flexibilities, but by model year 2016 the achieved level is projected to be 250 g/mi for the fleet.

TABLE I.B.2–5—PROJECTED FLEET-WIDE ACHIEVED EMISSION LEVELS UNDER THE FOOTPRINT-BASED CO_2 STANDARDS (g/mi)

	2012	2013	2014	2015	2016
Passenger Cars	267	256	245	234	223
Light Trucks	365	353	340	324	303
Combined Cars & Trucks	305	293	280	266	250

Several auto manufacturers stated that the increasingly stringent requirements for fuel economy and GHG emissions in the early years of the program should follow a more linear phase-in. The agencies' consideration of comments and of their updated technical analyses did not lead to changes to the phase-in of the standards discussed above. This issue is discussed in more detail in Sections II.D, and in Sections III and IV.

NHTSA's and EPA's technology assessment indicates there is a wide range of technologies available for manufacturers to consider in upgrading vehicles to reduce GHG emissions and improve fuel economy. Commenters were in general agreement with this assessment.[28] As noted, these include improvements to the engines such as use of gasoline direct injection and downsized engines that use turbochargers to provide performance similar to that of larger engines, the use of advanced transmissions, increased use of start-stop technology, improvements in tire rolling resistance, reductions in vehicle weight, increased use of hybrid and other advanced technologies, and the initial commercialization of electric vehicles and plug-in hybrids. EPA is also projecting improvements in vehicle air conditioners including more efficient as well as low leak systems. All of these technologies are already available today, and EPA's and NHTSA's assessments are that manufacturers will be able to meet the standards through more widespread use of these technologies across the fleet.

With respect to the practicability of the standards in terms of lead time, during MYs 2012–2016 manufacturers are expected to go through the normal automotive business cycle of redesigning and upgrading their light-duty vehicle products, and in some cases introducing entirely new vehicles not on the market today. This rule allows manufacturers the time needed to incorporate technology to achieve GHG reductions and improve fuel economy during the vehicle redesign process. This is an important aspect of the rule, as it avoids the much higher costs that would occur if manufacturers needed to add or change technology at times other than their scheduled redesigns. This time period also provides manufacturers the opportunity to plan for compliance using a multi-year time frame, again consistent with normal business practice. Over these five model years, there will be an opportunity for manufacturers to evaluate almost every one of their vehicle model platforms and add technology in a cost effective way to control GHG emissions and improve fuel economy. This includes redesign of the air conditioner systems in ways that will further reduce GHG emissions. Various commenters stated that the proposed phase-in of the standards should be introduced more aggressively, less aggressively, or in a more linear manner. However, our consideration of these comments about the phase-in, as well as our revised analyses, leads us to conclude that the general rate of introduction of the standards as proposed remains appropriate. This conclusion is also not affected by the slight difference from the proposal in the final footprint-based curves. These issues are addressed further in Sections III and IV.

Both agencies considered other standards as part of the rulemaking analyses, both more and less stringent than those proposed. EPA's and NHTSA's analyses of alternative standards are contained in Sections III and IV of this preamble, respectively, as well as the agencies' respective RIAs.

The CAFE and GHG standards described above are based on determining emissions and fuel economy using the city and highway test procedures that are currently used in the CAFE program. Some environmental and other organizations commented that the test procedures should be improved to reflect more real-world driving conditions; auto manufacturers in general do not support such changes to the test procedures at this time. Both agencies recognize that these test procedures are not fully representative of real-world driving conditions. For example, EPA has adopted more representative test procedures that are used in determining compliance with emissions standards for pollutants other than GHGs. These test procedures are also used in EPA's fuel economy labeling program. However, as discussed in Section III, the current information on effectiveness of the individual emissions control technologies is based on performance over the CAFE test procedures. For that reason, EPA is using the current CAFE test procedures for the CO_2 standards and is not changing those test procedures in this rulemaking. NHTSA, as discussed above, is limited by statute in what test procedures can be used for purposes of passenger car testing, although there is no such statutory limitation with respect to test procedures for trucks. However, the same reasons for not changing the truck test procedures apply for CAFE as well.

Both EPA and NHTSA are interested in developing programs that employ test procedures that are more representative of real-world driving conditions, to the extent authorized under their respective statutes. This is an important issue, and the agencies intend to continue to evaluate it in the context of a future rulemaking to address standards for model year 2017 and thereafter. This could include consideration of a range of test procedure changes to better represent real-world driving conditions in terms of speed, acceleration, deceleration, ambient temperatures, use of air conditioners, and the like. With respect to air conditioner operation, EPA discusses the public comments on these issues and the final procedures for determining emissions credits for controls on air conditioners in Section III.

[28] The close relationship between emissions of CO_2—the most prevalent greenhouse gas emitted by motor vehicles—and fuel consumption, means that the technologies to control CO_2 emissions and to improve fuel economy overlap to a great degree.

Finally, based on the information EPA developed in its recent rulemaking that updated its fuel economy labeling program to better reflect average real-world fuel economy, the calculation of fuel savings and CO_2 emissions reductions that will be achieved by the CAFE and GHG standards includes adjustments to account for the difference between the fuel economy level measured in the CAFE test procedure and the fuel economy actually achieved on average under real-world driving conditions. These adjustments are industry averages for the vehicles' performance as a whole, however, and are not a substitute for the information on effectiveness of individual control technologies that will be explored for purposes of a future GHG and CAFE rulemaking.

3. Form of the Standards

NHTSA and EPA proposed attribute-based standards for passenger cars and light trucks. NHTSA adopted an attribute approach based on vehicle footprint in its Reformed CAFE program for light trucks for model years 2008–2011,[29] and recently extended this approach to passenger cars in the CAFE rule for MY 2011 as required by EISA.[30] The agencies also proposed using vehicle footprint as the attribute for the GHG and CAFE standards. Footprint is defined as a vehicle's wheelbase multiplied by its track width—in other words, the area enclosed by the points at which the wheels meet the ground. Most commenters that expressed a view on this topic supported basing the standards on an attribute, and almost all of these supported the proposed choice of vehicle footprint as an appropriate attribute. The agencies continue to believe that the standards are best expressed in terms of an attribute, and that the footprint attribute is the most appropriate attribute on which to base the standards. These issues are further discussed later in this notice and in Chapter 2 of the Joint TSD.

Under the footprint-based standards, each manufacturer will have a GHG and CAFE target unique to its fleet, depending on the footprints of the vehicle models produced by that manufacturer. A manufacturer will have separate footprint-based standards for cars and for trucks. Generally, larger vehicles (*i.e.,* vehicles with larger footprints) will be subject to less stringent standards (*i.e.,* higher CO_2 grams/mile standards and lower CAFE standards) than smaller vehicles. This is because, generally speaking, smaller vehicles are more capable of achieving lower levels of CO_2 and higher levels of fuel economy than larger vehicles. While a manufacturer's fleet average standard could be estimated throughout the model year based on projected production volume of its vehicle fleet, the standard to which the manufacturer must comply will be based on its final model year production figures. A manufacturer's calculation of fleet average emissions at the end of the model year will thus be based on the production-weighted average emissions of each model in its fleet.

The final footprint-based standards are very similar in shape to those proposed. NHTSA and EPA include more discussion of the development of the final curves in Section II below, with a full discussion in the Joint TSD. In addition, a full discussion of the equations and coefficients that define the curves is included in Section III for the CO_2 curves and Section IV for the mpg curves. The following figures illustrate the standards. First, Figure I.B.3–1 shows the fuel economy (mpg) car standard curve.

Under an attribute-based standard, every vehicle model has a performance target (fuel economy for the CAFE standards, and CO_2 g/mile for the GHG emissions standards), the level of which depends on the vehicle's attribute (for this rule, footprint). The manufacturers' fleet average performance is determined by the production-weighted [31] average (for CAFE, harmonic average) of those targets. NHTSA and EPA are setting CAFE and CO_2 emissions standards defined by constrained linear functions and, equivalently, piecewise linear functions.[32] As a possible option for future rulemakings, the constrained linear form was introduced by NHTSA in the 2007 NPRM proposing CAFE standards for MY 2011–2015.

NHTSA is establishing the attribute curves below for assigning a fuel economy level to an individual vehicle's footprint value, for model years 2012 through 2016. These mpg values will be production weighted to determine each manufacturer's fleet average standard for cars and trucks. Although the general model of the equation is the same for each vehicle category and each year, the parameters of the equation differ for cars and trucks. Each parameter also changes on an annual basis, resulting in the yearly increases in stringency. Figure I.B.3–1 below illustrates the passenger car CAFE standard curves for model years 2012 through 2016 while Figure I.B.3–2 below illustrates the light truck standard curves for model years 2012–2016. The MY 2011 final standards for cars and trucks, which are specified by a constrained logistic function rather than a constrained linear function, are shown for comparison.

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[29] 71 FR 17566 (Apr. 6, 2006).

[30] 74 FR 14196 (Mar. 30, 2009).

[31] Based on vehicles produced for sale in the United States.

[32] The equations are equivalent but are specified differently due to differences in the agencies' respective models.

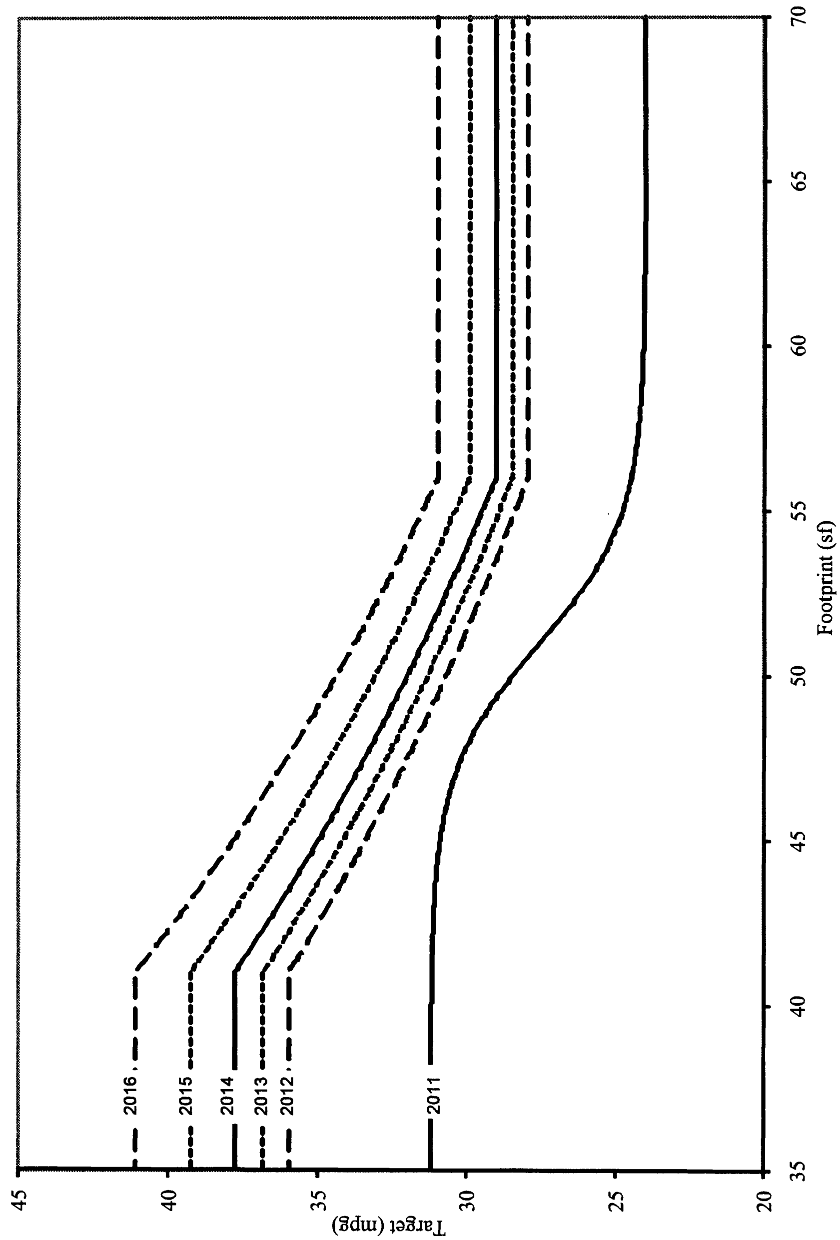

Figure I.B.3-1. MY 2011 and MY 2012-2016 Passenger Car Fuel Economy Targets

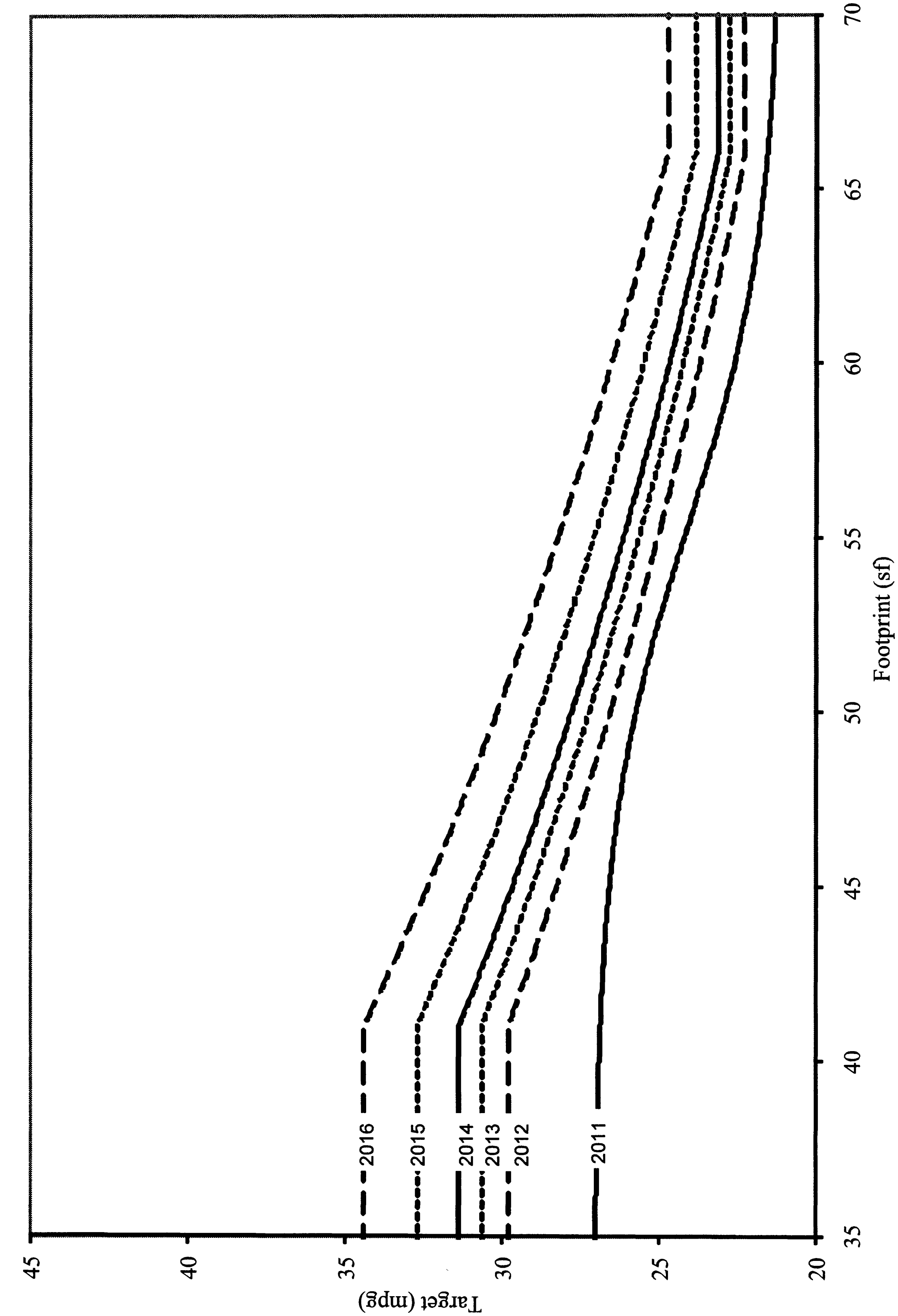

Figure I.B.3-2. MY 2011 and MY 2012-2016 Light Truck Fuel Economy Targets

EPA is establishing the attribute curves below for assigning a CO_2 level to an individual vehicle's footprint value, for model years 2012 through 2016. These CO_2 values will be production weighted to determine each manufacturer's fleet average standard for cars and trucks. As with the CAFE curves above, the general form of the equation is the same for each vehicle category and each year, but the parameters of the equation differ for cars and trucks. Again, each parameter also changes on an annual basis, resulting in the yearly increases in stringency. Figure I.B.3–3 below illustrates the CO_2 car standard curves for model years 2012 through 2016 while Figure I.B.3–4 shows the CO_2 truck standard curves for model years 2012–2016.

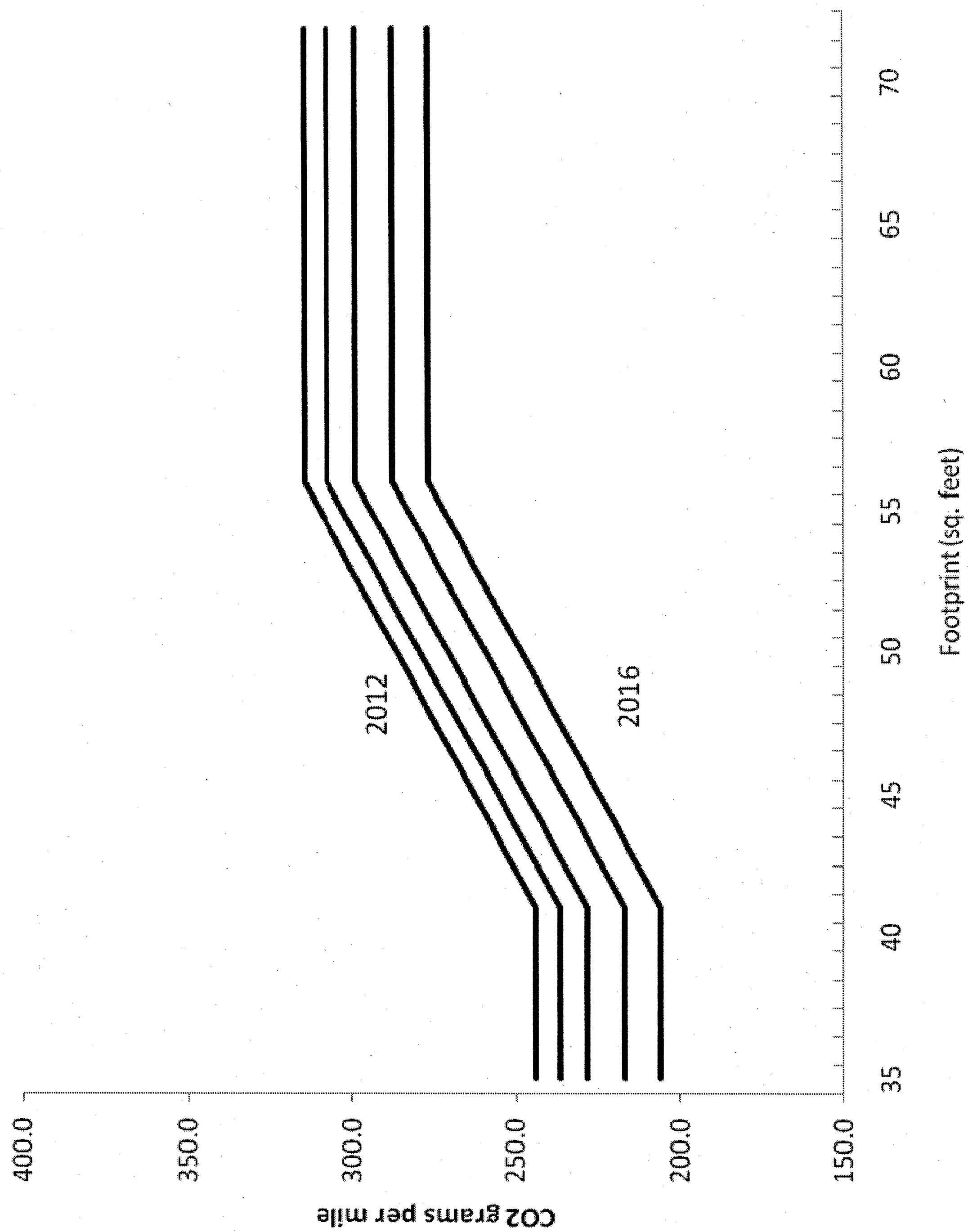

Figure I.B.3-3 CO_2 (g/mi) Car Standard Curves

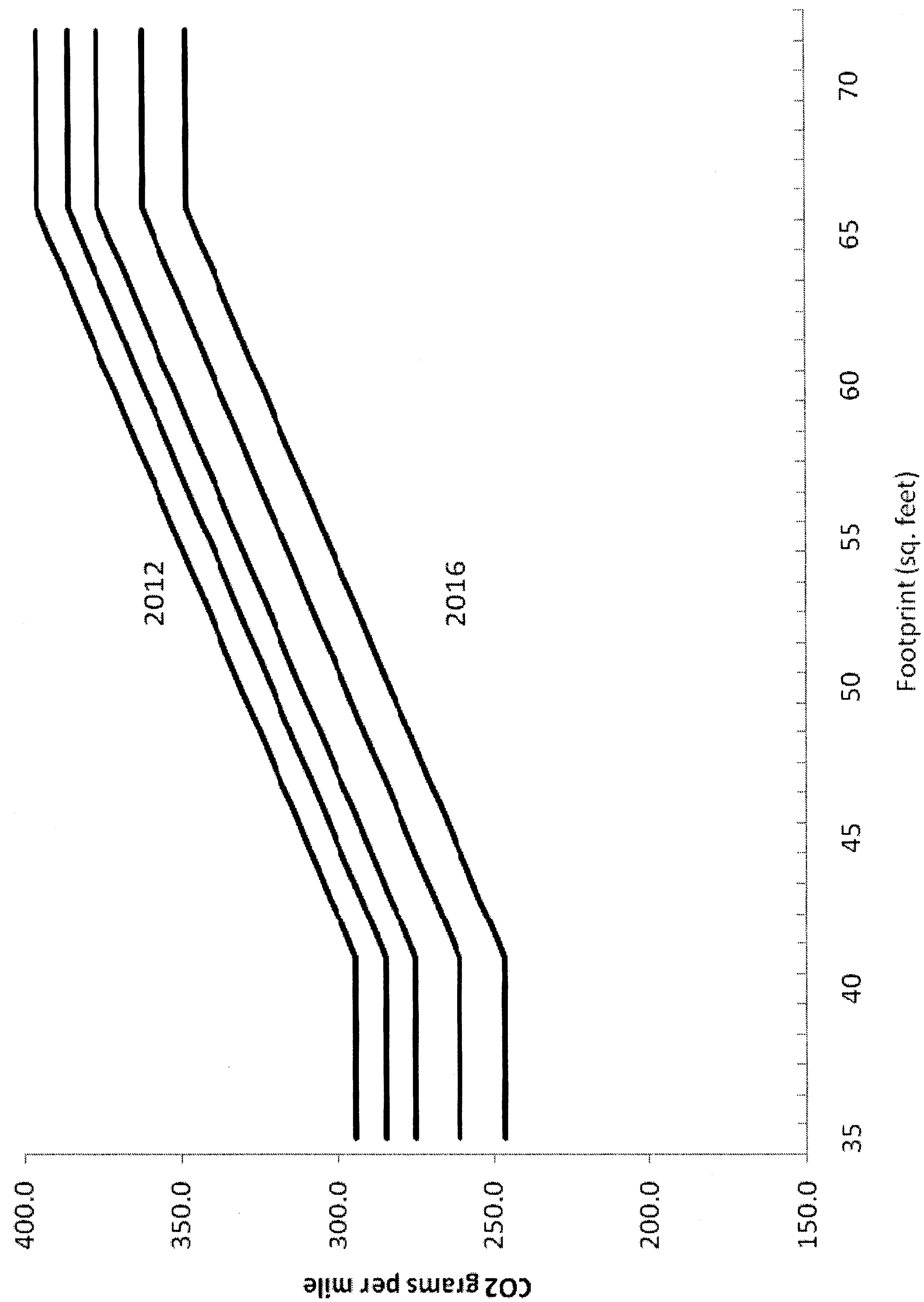

Figure I.B.3-4 CO_2 (g/mi) Truck Standard Curves

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NHTSA and EPA received a number of comments about the shape of the car and truck curves. We address these comments further in Section II.C below as well as in Sections III and IV.

As proposed, NHTSA and EPA will use the same vehicle category definitions for determining which vehicles are subject to the car curve standards versus the truck curve standards. In other words, a vehicle classified as a car under the NHTSA CAFE program will also be classified as a car under the EPA GHG program, and likewise for trucks. Auto industry commenters generally agreed with this approach and believe it is an important aspect of harmonization across the two agencies' programs. Some other commenters expressed concern about potential consequences, especially in how cars and trucks are distinguished. However, EPA and NHTSA are employing the same car and truck definitions for the MY 2012–2016 CAFE and GHG standards as those used in the CAFE program for the 2011 model year standards.[33] This issue is further discussed for the EPA standards in Section III, and for the NHTSA standards in Section IV. This approach of using CAFE definitions allows EPA's CO_2 standards and the CAFE standards to be harmonized across all vehicles for this program. However, EPA is not changing the car/truck definition for the purposes of any other previous rules.

Generally speaking, a smaller footprint vehicle will have higher fuel economy and lower CO_2 emissions relative to a larger footprint vehicle when both have the same degree of fuel efficiency improvement technology. In this final rule, the standards apply to a manufacturers overall fleet, not an individual vehicle, thus a manufacturers fleet which is dominated by small footprint vehicles will have a higher fuel economy requirement (lower CO_2 requirement) than a manufacturer whose fleet is dominated by large footprint vehicles. A footprint-based CO_2 or CAFE standard can be relatively neutral with respect to vehicle size and consumer choice. All vehicles, whether smaller or larger, must make improvements to reduce CO_2 emissions or improve fuel economy, and therefore all vehicles will be relatively more expensive. With the footprint-based standard approach, EPA and NHTSA believe there should be no significant effect on the relative distribution of different vehicle sizes in the fleet, which means that consumers will still be able to purchase the size of vehicle that meets their needs. While targets are manufacturer specific, rather than vehicle specific, Table I.B.3–1 illustrates the fact that different vehicle sizes will have varying CO_2 emissions and fuel economy targets under the final standards.

TABLE I.B.3—1 MODEL YEAR 2016 CO_2 AND FUEL ECONOMY TARGETS FOR VARIOUS MY 2008 VEHICLE TYPES

Vehicle type	Example models	Example model footprint (sq. ft.)	CO_2 emissions target (g/mi)	Fuel economy target (mpg)
Example Passenger Cars				
Compact car	Honda Fit	40	206	41.1
Midsize car	Ford Fusion	46	230	37.1
Fullsize car	Chrysler 300	53	263	32.6
Example Light-duty Trucks				
Small SUV	4WD Ford Escape	44	259	32.9
Midsize crossover	Nissan Murano	49	279	30.6
Minivan	Toyota Sienna	55	303	28.2
Large pickup truck	Chevy Silverado	67	348	24.7

4. Program Flexibilities

EPA's and NHTSA's programs as established in this rule provide compliance flexibility to manufacturers, especially in the early years of the National Program. This flexibility is expected to provide sufficient lead time for manufacturers to make necessary technological improvements and reduce the overall cost of the program, without compromising overall environmental and fuel economy objectives. The broad goal of harmonizing the two agencies' standards includes preserving manufacturers' flexibilities in meeting the standards, to the extent appropriate and required by law. The following section provides an overview of this final rule's flexibility provisions. Many auto manufacturers commented in support of these provisions as critical to meeting the standards in the lead time provided. Environmental groups, some States, and others raised concerns about the possibility for windfall credits and loss of program benefits. The provisions in the final rule are in most cases the same as those proposed. However consideration of the issues raised by commenters has led to modifications in certain provisions. These comments and the agencies' response are discussed in Sections III and IV below and in the Response to Comments document.

a. CO_2/CAFE Credits Generated Based on Fleet Average Performance

Under this NHTSA and EPA final rule, the fleet average standards that apply to a manufacturer's car and truck fleets are based on the applicable footprint-based curves. At the end of each model year, when production of the model year is complete, a production-weighted fleet average will be calculated for each averaging set (cars and trucks). Under this approach, a manufacturer's car and/or truck fleet that achieves a fleet average CO_2/CAFE level better than the standard can generate credits. Conversely, if the fleet average CO_2/CAFE level does not meet the standard, the fleet would incur debits (also referred to as a shortfall).

Under the final program, a manufacturer whose fleet generates credits in a given model year would have several options for using those credits, including credit carry-back, credit carry-forward, credit transfers, and credit trading. These provisions exist in the MY 2011 CAFE program under EPCA and EISA, and similar provisions are part of EPA's Tier 2 program for light-duty vehicle criteria pollutant emissions, as well as many

[33] 49 CFR 523.

other mobile source standards issued by EPA under the CAA. The manufacturer will be able to carry back credits to offset a deficit that had accrued in a prior model year and was subsequently carried over to the current model year. EPCA also provides for this. EPCA restricts the carry-back of CAFE credits to three years, and as proposed EPA is establishing the same limitation, in keeping with the goal of harmonizing both sets of standards.

After satisfying any need to offset pre-existing deficits, remaining credits can be saved (banked) for use in future years. Under the CAFE program, EISA allows manufacturers to apply credits earned in a model year to compliance in any of the five subsequent model years.[34] As proposed, under the GHG program, EPA is also allowing manufacturers to use these banked credits in the five years after the year in which they were generated (*i.e.,* five years carry-forward).

EISA required NHTSA to establish by regulation a CAFE credits transferring program, which NHTSA established in a March 2009 final rule codified at 49 CFR Part 536, to allow a manufacturer to transfer credits between its vehicle fleets to achieve compliance with the standards. For example, credits earned by over-compliance with a manufacturer's car fleet average standard could be used to offset debits incurred due to that manufacturer's not meeting the truck fleet average standard in a given year. EPA's Tier 2 program also provides for this type of credit transfer. As proposed for purposes of this rule, EPA allows unlimited credit transfers across a manufacturer's car-truck fleet to meet the GHG standard. This is based on the expectation that this flexibility will facilitate manufacturers' ability to comply with the GHG standards in the lead time provided, and will allow the required GHG emissions reductions to be achieved in the most cost effective way. Under the CAA, unlike under EISA, there is no statutory limitation on car-truck credit transfers. Therefore, EPA is not constraining car-truck credit transfers, as doing so would reduce the flexibility for lead time, and would increase costs with no corresponding environmental benefit. For the CAFE program, however, EISA limits the amount of credits that may be transferred, which has the effects of limiting the extent to which a manufacturer can rely upon credits in lieu of making fuel economy improvements to a particular portion of its vehicle fleet, but also of potentially increasing the costs of improving the manufacturer's overall fleet. EISA also prohibits the use of transferred credits to meet the statutory minimum level for the domestic car fleet standard.[35] These and other statutory limits will continue to apply to the determination of compliance with the CAFE standards.

EISA also allowed NHTSA to establish by regulation a CAFE credit trading program, which NHTSA established in the March 2009 final rule at 40 CFR part 536, to allow credits to be traded (sold) to other vehicle manufacturers. As proposed, EPA allows credit trading in the GHG program. These sorts of exchanges are typically allowed under EPA's current mobile source emission credit programs, although manufacturers have seldom made such exchanges. Under the NHTSA CAFE program, EPCA also allows these types of credit trades, although, as with transferred credits, traded credits may not be used to meet the minimum domestic car standards specified by statute.[36] Comments discussing these provisions supported the proposed approach. These final provisions are the same as proposed.

As further discussed in Section IV of this preamble, NHTSA sought to find a way to provide credits for improving the efficiency of light truck air conditioners (A/Cs) and solicited public comments to that end. The agency did so because the power necessary to operate an A/C compressor places a significant additional load on the engine, thus reducing fuel economy and increasing CO_2 tailpipe emissions. *See* Section III.C.1 below. The agency would have made a similar effort regarding cars, but a 1975 statutory provision made it unfruitful even to explore the possibility of administratively proving such credits for cars. The agency did not identify a workable way of providing such credits for light trucks in the context of this rulemaking.

b. Air Conditioning Credits Under the EPA Final Rule

Air conditioning (A/C) systems contribute to GHG emissions in two ways. Hydrofluorocarbon (HFC) refrigerants, which are powerful GHGs, can leak from the A/C system (direct A/C emissions). As just noted, operation of the A/C system also places an additional load on the engine, which results in additional CO_2 tailpipe emissions (indirect A/C related emissions). EPA is allowing manufacturers to generate credits by reducing either or both types of GHG emissions related to A/C systems. Specifically, EPA is establishing a method to calculate CO_2 equivalent reductions for the vehicle's full useful life on a grams/mile basis that can be used as credits in meeting the fleet average CO_2 standards. EPA's analysis indicates that this approach provides manufacturers with a highly cost-effective way to achieve a portion of GHG emissions reductions under the EPA program. EPA is estimating that manufacturers will on average generate 11 g/mi GHG credit toward meeting the 250 g/mi by 2016 (though some companies may generate more). EPA will also allow manufacturers to earn early A/C credits starting in MY 2009 through 2011, as discussed further in a later section. There were many comments on the proposed A/C provisions. Nearly every one of these was supportive of EPA including A/C control as part of this rule, though there was some disagreement on some of the details of the program. The HFC crediting scheme was widely supported. The comments mainly were concentrated on indirect A/C related credits. The auto manufacturers and suppliers had some technical comments on A/C technologies, and there were many concerns with the proposed idle test. EPA has made some minor adjustments in both of these areas that we believe are responsive to these concerns. EPA addresses A/C issues in greater detail in Section III of this preamble and in Chapter 2 of EPA's RIA.

c. Flexible-Fuel and Alternative Fuel Vehicle Credits

EPCA authorizes a compliance flexibility incentive under the CAFE program for production of dual-fueled or flexible-fuel vehicles (FFV) and dedicated alternative fuel vehicles. FFVs are vehicles that can run both on an alternative fuel and conventional fuel. Most FFVs are E85 capable vehicles, which can run on either gasoline or a mixture of up to 85 percent ethanol and 15 percent gasoline (E85). Dedicated alternative fuel vehicles are vehicles that run exclusively on an alternative fuel. EPCA was amended by EISA to extend the period of availability of the FFV incentive, but to begin phasing it out by annually reducing the amount of FFV incentive that can be used toward compliance with the CAFE standards.[37] Although NHTSA

[34] 49 U.S.C. 32903(a)(2).

[35] 49 U.S.C. 32903(g)(4).

[36] 49 U.S.C. 32903(f)(2).

[37] EPCA provides a statutory incentive for production of FFVs by specifying that their fuel economy is determined using a special calculation procedure that results in those vehicles being assigned a higher fuel economy level than would

Continued

expressed concern about the non-use of alternative fuel by FFVs in a 2002 report to Congress (Effects of the Alternative Motor Fuels Act CAFE Incentives Policy), EISA does not premise the availability of the FFV credits on actual use of alternative fuel by an FFV vehicle. Under NHTSA's CAFE program, pursuant to EISA, no FFV credits will be available for CAFE compliance after MY 2019.[38] For dedicated alternative fuel vehicles, there are no limits or phase-out of the credits. As required by the statute, NHTSA will continue to allow the use of FFV credits for purposes of compliance with the CAFE standards until the end of the EISA phase-out period.

For the GHG program, as proposed, EPA will allow FFV credits in line with EISA limits, but only during the period from MYs 2012 to 2015. After MY 2015, EPA will only allow FFV credits based on a manufacturer's demonstration that the alternative fuel is actually being used in the vehicles and based on the vehicle's actual performance. EPA discusses this in more detail in Section III.C of the preamble, including a summary of key comments. These provisions are being finalized as proposed, with further discussion in Section III.C of how manufacturers can demonstrate that the alternative fuel is being used.

d. Temporary Lead-Time Allowance Alternative Standards Under the EPA Final Rule

Manufacturers with limited product lines may be especially challenged in the early years of the National Program, and need additional lead time. Manufacturers with narrow product offerings may not be able to take full advantage of averaging or other program flexibilities due to the limited scope of the types of vehicles they sell. For example, some smaller volume manufacturer fleets consist entirely of vehicles with very high baseline CO_2 emissions. Their vehicles are above the CO_2 emissions target for that vehicle footprint, but do not have other types of vehicles in their production mix with which to average. Often, these manufacturers pay fines under the CAFE program rather than meet the applicable CAFE standard. EPA believes that these technological circumstances call for more lead time in the form of a more gradual phase-in of standards.

EPA is finalizing a temporary lead-time allowance for manufacturers that sell vehicles in the U.S. in MY 2009 and for which U.S. vehicle sales in that model year are below 400,000 vehicles. This allowance will be available only during the MY 2012–2015 phase-in years of the program. A manufacturer that satisfies the threshold criteria will be able to treat a limited number of vehicles as a separate averaging fleet, which will be subject to a less stringent GHG standard.[39] Specifically, a standard of 25 percent above the vehicle's otherwise applicable foot-print target level will apply to up to 100,000 vehicles total, spread over the four year period of MY 2012 through 2015. Thus, the number of vehicles to which the flexibility could apply is limited. EPA also is setting appropriate restrictions on credit use for these vehicles, as discussed further in Section III. By MY 2016, these allowance vehicles must be averaged into the manufacturer's full fleet (*i.e.,* they will no longer be eligible for a different standard). EPA discusses this in more detail in Section III.B of the preamble.

EPA received comments from several smaller manufacturers that the TLAAS program was insufficient to allow manufacturers with very limited product lines to comply. These manufacturers commented that they need additional lead time to meet the standards, because their CO_2 baselines are significantly higher and their vehicle product lines are even more limited, reducing their ability to average across their fleets compared even to other TLAAS manufacturers. EPA fully summarizes the public comments on the TLAAS program, including comments not supporting the program, in Section III.B. In summary, in response to the lead time issues raised by manufacturers, EPA is modifying the TLAAS program that applies to manufacturers with between 5,000 and 50,000 U.S. vehicle sales in MY 2009. EPA believes these provisions are necessary given that, compared with other TLAAS manufacturers, these manufacturers have even more limited product offerings across which to average and higher baseline CO_2 emissions, and thus need additional lead-time to meet the standards. These manufacturers would have an increased allotment of vehicles, a total of 250,000, compared to 100,000 vehicles (for other TLAAS-eligible manufacturers). In addition, the TLAAS program for these manufacturers would be extended by one year, through MY 2016 for these vehicles, for a total of five years of eligibility. The other provisions of the TLAAS program would continue to apply, such as the restrictions on credit trading and the level of the standard. Additional restrictions would also apply to these vehicles, as discussed in Section III. In addition, for the smallest volume manufacturers, those with below 5,000 U.S. vehicle sales, EPA is not setting standards at this time but is instead deferring standards until a future rulemaking. This is essentially the same approach we are using for small businesses, which are exempted from this rule. The unique issues involved with these manufacturers will be addressed in that future rulemaking. Further discussion of the public comment on these issues and details on these changes from the proposed program are included in Section III.

e. Additional Credit Opportunities Under the Clean Air Act (CAA)

EPA is establishing additional opportunities for early credits in MYs 2009–2011 through over-compliance with a baseline standard. The baseline standard is set to be equivalent, on a national level, to the California standards. Credits can be generated by over-compliance with this baseline in one of two ways—over-compliance by the fleet of vehicles sold in California and the CAA section 177 States (*i.e.,* those States adopting the California program), or over-compliance with the fleet of vehicles sold in the 50 States. EPA is also providing for early credits based on over-compliance with CAFE, but only for vehicles sold in States outside of California and the CAA section 177 states. Under the early credit provisions, no early FFV credits would be allowed, except those achieved by over-compliance with the California program based on California's provisions that manufacturers demonstrate actual use of the alternative fuel. EPA's early credits provisions are designed to ensure that there would be no double counting of early credits. NHTSA notes, however, that credits for overcompliance with CAFE standards during MYs 2009–2011 will still be available for manufacturers to use toward compliance in future model years, just as before.

EPA received comments from some environmental organizations and States expressing concern that these early credits were inappropriate windfall credits because they provided credits for actions that were not surplus, that is above what would otherwise be required for compliance with either State or Federal motor vehicle standards. This focused on the credits

otherwise occur. This is typically referred to as an FFV credit.

[38] *Id.*

[39] EPCA does not permit such an allowance. Consequently, manufacturers who may be able to take advantage of a lead-time allowance under the GHG standards would be required to comply with the applicable CAFE standard or be subject to penalties for non-compliance.

for over-compliance with the California standards generated during model years 2009 and perhaps 2010, where according to commenters the CAFE requirements were in effect more stringent than the California standards. EPA believes that early credits provide a valuable incentive for manufacturers that have implemented fuel efficient technologies in excess of their CAFE compliance obligations prior to MY 2012. With appropriate restrictions, these credits, reflecting over-compliance over a three model year time frame (MY 2009–2011) and not just over one or two model years, will be surplus reductions and not otherwise required by law. Therefore, EPA is finalizing these provisions largely as proposed, but in response to comments, with an additional restriction on the trading of MY 2009 credits. The overall structure of this early credit program addresses concerns about the potential for windfall credits in the first one or two model years. This issue is fully discussed in Section III.C.

EPA is providing an additional temporary incentive to encourage the commercialization of advanced GHG/fuel economy control technologies—including electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs)—for model years 2012–2016. EPA's proposal included an emissions compliance value of zero grams/mile for EVs and FCVs, and the electric portion of PHEVs, and a multiplier in the range of 1.2 to 2.0, so that each advanced technology vehicle would count as greater than one vehicle in a manufacturer's fleetwide compliance calculation. EPA received many comments on the proposed incentives. Many State and environmental organization commenters believed that the combination of these incentives could undermine the GHG benefits of the rule, and believed the emissions compliance values should take into account the net upstream GHG emissions associated with electrified vehicles compared to vehicles powered by petroleum based fuel. Auto manufacturers generally supported the incentives, some believing the incentives to be a critical part of the National Program. Most auto makers supported both the zero grams/mile emissions compliance value and the higher multipliers.

Upon considering the public comments on this issue, EPA is finalizing an advanced technology vehicle incentive program that includes a zero gram/mile emissions compliance value for EVs and FCVs, and the electric portion of PHEVs, for up to the first 200,000 EV/PHEV/FCV vehicles produced by a given manufacturer during MY 2012–2016 (for a manufacturer that produces less than 25,000 EVs, PHEVs, and FCVs in MY 2012), or for up to the first 300,000 EV/PHEV/FCV vehicles produced during MY 2012–2016 (for a manufacturer that produces 25,000 or more EVs, PHEVs, and FCVs in MY 2012). For any production greater than this amount, the compliance value for the vehicle will be greater than zero gram/mile, set at a level that reflects the vehicle's net increase in upstream GHG emissions in comparison to the gasoline vehicle it replaces. In addition, EPA is not finalizing a multiplier. EPA will also allow this early advanced technology incentive program beginning in MYs 2009–2011. The purpose of these provisions is to provide a temporary incentive to promote technologies which have the potential to produce very large GHG reductions in the future. The tailpipe GHG emissions from EVs, FCVs, and PHEVs operated on grid electricity are zero, and traditionally the emissions of the vehicle itself are all that EPA takes into account for purposes of compliance with standards set under section 202(a). This has not raised any issues for criteria pollutants, as upstream emissions associated with production and distribution of the fuel are addressed by comprehensive regulatory programs focused on the upstream sources of those emissions. At this time, however, there is no such comprehensive program addressing upstream emissions of GHGs, and the upstream GHG emissions associated with production and distribution of electricity are higher than the corresponding upstream GHG emissions of gasoline or other petroleum based fuels. In the future, vehicle fleet electrification combined with advances in low-carbon technology in the electricity sector have the potential to transform the transportation sector's contribution to the country's GHG emissions. EPA will reassess the issue of how to address EVs, PHEVs, and FCVs in rulemakings for model years 2017 and beyond, based on the status of advanced vehicle technology commercialization, the status of upstream GHG control programs, and other relevant factors. Further discussion of the temporary advanced technology vehicle incentives, including more detail on the public comments and EPA's response, is found in Section III.C.

EPA is also providing an option for manufacturers to generate credits for employing new and innovative technologies that achieve GHG reductions that are not reflected on current test procedures, as proposed. Examples of such "off-cycle" technologies might include solar panels on hybrids, adaptive cruise control, and active aerodynamics, among other technologies. These three credit provisions are discussed in more detail in Section III.

5. Coordinated Compliance

Previous NHTSA and EPA regulations and statutory provisions establish ample examples on which to develop an effective compliance program that achieves the energy and environmental benefits from CAFE and motor vehicle GHG standards. NHTSA and EPA have developed a program that recognizes, and replicates as closely as possible, the compliance protocols associated with the existing CAA Tier 2 vehicle emission standards, and with CAFE standards. The certification, testing, reporting, and associated compliance activities closely track current practices and are thus familiar to manufacturers. EPA already oversees testing, collects and processes test data, and performs calculations to determine compliance with both CAFE and CAA standards. Under this coordinated approach, the compliance mechanisms for both programs are consistent and non-duplicative. EPA will also apply the CAA authorities applicable to its separate in-use requirements in this program.

The compliance approach allows manufacturers to satisfy the new program requirements in the same general way they comply with existing applicable CAA and CAFE requirements. Manufacturers would demonstrate compliance on a fleet-average basis at the end of each model year, allowing model-level testing to continue throughout the year as is the current practice for CAFE determinations. The compliance program design establishes a single set of manufacturer reporting requirements and relies on a single set of underlying data. This approach still allows each agency to assess compliance with its respective program under its respective statutory authority.

NHTSA and EPA do not anticipate any significant noncompliance under the National Program. However, failure to meet the fleet average standards (after credit opportunities are exhausted) would ultimately result in the potential for penalties under both EPCA and the CAA. The CAA allows EPA considerable discretion in assessment of penalties. Penalties under the CAA are typically determined on a vehicle-specific basis by determining the number of a manufacturer's highest emitting vehicles that caused the fleet average standard violation. This is the same mechanism used for EPA's National Low Emission Vehicle and Tier 2 corporate average standards, and to date there have been no instances of noncompliance. CAFE penalties are specified by EPCA and would be assessed for the entire noncomplying fleet at a rate of $5.50 times the number of vehicles in the fleet, times the number of tenths of mpg by which the fleet average falls below the standard. In the event of a compliance action arising out of the same facts and circumstances, EPA could consider CAFE penalties when determining appropriate remedies for the EPA case.

Several stakeholders commented on the proposed coordinated compliance approach. The comments indicated broad support for the overall approach EPA proposed. In particular, both regulated industry and the public interest community appreciated the attempt to streamline compliance by adopting current practice where possible and by coordinating EPA and NHTSA compliance requirements. Thus the final compliance program design is largely unchanged from the proposal. Some commenters requested additional detail or clarification in certain areas and others suggested some relatively narrow technical changes, and EPA has responded to these suggestions. EPA and NHTSA summarize these comments and the agencies' responses in Sections III and IV, respectively, below. The Response to Comments document associated with this document includes all of the comments and responses received during the comment period.

C. Summary of Costs and Benefits of the National Program

This section summarizes the projected costs and benefits of the CAFE and GHG emissions standards. These projections helped inform the agencies' choices among the alternatives considered and provide further confirmation that the final standards are an appropriate choice within the spectrum of choices allowable under their respective statutory criteria. The costs and benefits projected by NHTSA to result from these CAFE standards are presented first, followed by those from EPA's analysis of the GHG emissions standards.

For several reasons, the estimates for costs and benefits presented by NHTSA and EPA, while consistent, are not directly comparable, and thus should not be expected to be identical. Most important, NHTSA and EPA's standards would require slightly different fuel efficiency improvements. EPA's GHG standard is more stringent in part due to its assumptions about manufacturers' use of air conditioning credits, which result from reductions in air conditioning-related emissions of HFCs and CO_2. NHTSA was unable to make assumptions about manufacturers' improving the efficiency of air conditioners due to statutory limitations. In addition, the CAFE and GHG standards offer different program flexibilities, and the agencies' analyses differ in their accounting for these flexibilities (for example, FFVs), primarily because NHTSA is statutorily prohibited from considering some flexibilities when establishing CAFE standards, while EPA is not. These differences contribute to differences in the agencies' respective estimates of costs and benefits resulting from the new standards.

NHTSA performed two analyses: a primary analysis that shows the estimates of costs, fuel savings, and related benefits that the agency considered for purposes of establishing new CAFE standards, and a supplemental analysis that reflects the agency's best estimate of the potential real-world effects of the CAFE standards, including manufacturers' potential use of FFV credits in accordance with the provisions of EISA concerning their availability. Because EPCA prohibits NHTSA from considering the ability of manufacturers to use of FFV credits to increase their fleet average fuel economy when *establishing* CAFE standards, the agency's primary analysis does not include them. However, EPCA does not prohibit NHTSA from considering the fact that manufacturers may pay civil penalties rather than complying with CAFE standards, and NHTSA's primary analysis accounts for some manufacturers' tendency to do so. In addition, NHTSA's supplemental analysis of the effect of FFV credits on benefits and costs from its CAFE standards, demonstrates the real-world impacts of FFVs, and the summary estimates presented in Section IV include these effects. Including the use of FFV credits reduces estimated per-vehicle compliance costs of the program. However, as shown below, including FFV credits does not significantly change the projected fuel savings and CO_2 reductions, because FFV credits reduce the fuel economy levels that manufacturers achieve not only under the standards, but also under the baseline MY 2011 CAFE standards.

Also, EPCA, as amended by EISA, allows manufacturers to transfer credits between their passenger car and light truck fleets. However, EPCA also prohibits NHTSA from considering manufacturers' ability to increase their average fuel economy through the use of CAFE credits when determining the stringency of the CAFE standards. Because of this prohibition, NHTSA's primary analysis does not account for the extent to which credit transfers might actually occur. For purposes of its supplemental analysis, NHTSA considered accounting for the possibility that some manufacturers might utilize the opportunity under EPCA to transfer some CAFE credits between the passenger car and light truck fleets, but determined that in NHTSA's year-by-year analysis, manufacturers' credit transfers cannot be reasonably estimated at this time.[40]

EPA made explicit assumptions about manufacturers' use of FFV credits under both the baseline and control alternatives, and its estimates of costs and benefits from the GHG standards reflect these assumptions. However, under the GHG standards, FFV credits would be available through MY 2015; starting in MY 2016, EPA will only allow FFV credits based on a manufacturer's demonstration that the alternative fuel is actually being used in the vehicles and the actual GHG performance for the vehicle run on that alternative fuel.

EPA's analysis also assumes that manufacturers would transfer credits between their car and truck fleets in the MY 2011 baseline subject to the maximum value allowed by EPCA, and that unlimited car-truck credit transfers would occur under the GHG standards. Including these assumptions in EPA's analysis increases the resulting estimates of fuel savings and reductions in GHG emissions, while reducing EPA's estimates of program compliance costs.

Finally, under the EPA GHG program, there is no ability for a manufacturer to intentionally pay fines in lieu of meeting the standard. Under EPCA, however, vehicle manufacturers are allowed to pay fines as an alternative to compliance with applicable CAFE standards. NHTSA's analysis explicitly estimates the level of voluntary fine payment by individual manufacturers, which reduces NHTSA's estimates of

[40] NHTSA's analysis estimates multi-year planning effects within a context in which each model year is represented explicitly, and technologies applied in one model year carry forward to future model years. NHTSA does not currently have a reasonable basis to estimate how a manufacturer might, for example, weigh the transfer of credits from the passenger car to the light truck fleet in MY 2013 against the potential to carry light truck technologies forward from MY 2013 through MY 2016.

both the costs and benefits of its CAFE standards. In contrast, the CAA does not allow for fine payment (civil penalties) in lieu of compliance with emission standards, and EPA's analysis of benefits from its standard thus assumes full compliance. This assumption results in higher estimates of fuel savings, of reductions in GHG emissions, and of manufacturers' compliance costs to sell fleets that comply with both NHTSA's CAFE program and EPA's GHG program.

In summary, the projected costs and benefits presented by NHTSA and EPA are not directly comparable, because the GHG emission levels established by EPA include air conditioning-related improvements in equivalent fuel efficiency and HFC reductions, because of the assumptions incorporated in EPA's analysis regarding car-truck credit transfers, and because of EPA's projection of complete compliance with the GHG standards. It should also be expected that overall, EPA's estimates of GHG reductions and fuel savings achieved by the GHG standards will be slightly higher than those projected by NHTSA only for the CAFE standards because of the reasons described above. For the same reasons, EPA's estimates of manufacturers' costs for complying with the passenger car and light trucks GHG standards are slightly higher than NHTSA's estimates for complying with the CAFE standards.

A number of stakeholders commented on NHTSA's and EPA's analytical assumptions in estimating costs and benefits of the program. These comments and any changes from the proposed values are summarized in Section II.F, and further in Sections III (for EPA) and IV (for NHTSA); the Response to Comments document presents the detailed responses to each of the comments.

1. Summary of Costs and Benefits of NHTSA's CAFE Standards

NHTSA has analyzed in detail the costs and benefits of the final CAFE standards. Table I.C.1–1 presents the total costs, benefits, and net benefits for NHTSA's final CAFE standards. The values in Table I.C.1–1 display the total costs for all MY 2012–2016 vehicles and the benefits and net benefits represent the impacts of the standards over the full lifetime of the vehicles projected to be sold during model years 2012–2016. It is important to note that there is significant overlap in costs and benefits for NHTSA's CAFE program and EPA's GHG program and therefore combined program costs and benefits, which together comprise the National Program, are not a sum of the two individual programs.

TABLE I.C.1–1—NHTSA'S ESTIMATED 2012–2016 MODEL YEAR COSTS, BENEFITS, AND NET BENEFITS UNDER THE CAFE STANDARDS BEFORE FFV CREDITS

[2007 dollars]

3% Discount Rate:	$billions
Costs	51.8
Benefits	182.5
Net Benefits	130.7
7% Discount Rate:	
Costs	51.8
Benefits	146.3
Net Benefits	94.5

NHTSA estimates that these new CAFE standards will lead to fuel savings totaling 61 billion gallons throughout the useful lives of vehicles sold in MYs 2012–2016. At a 3% discount rate, the present value of the economic benefits resulting from those fuel savings is $143 billion. At a 7% discount rate, the present value of the economic benefits resulting from those fuel savings is $112 billion.[41]

The agency further estimates that these new CAFE standards will lead to corresponding reductions in CO_2 emissions totaling 655 million metric tons (mmt) during the useful lives of vehicles sold in MYs 2012–2016. The present value of the economic benefits from avoiding those emissions is $14.5 billion, based on a global social cost of carbon value of approximately $21 per metric ton (in 2010, and growing thereafter).[42] It is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to increases in average fuel economy and CO_2 emissions reductions. The two agencies' standards together comprise the National Program, and this discussion of costs and benefits of NHTSA's CAFE standards does not change the fact that both the CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program.

TABLE I.C.1–2—NHTSA FUEL SAVED (BILLION GALLONS) AND CO_2 EMISSIONS AVOIDED (mmt) UNDER CAFE STANDARDS (WITHOUT FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Fuel (b. gal.)	4.2	8.9	12.5	16.0	19.5	61.0
CO_2 (mmt)	44	94	134	172	210	655

Considering manufacturers' ability to earn credit toward compliance by selling FFVs, NHTSA estimates very little change in incremental fuel savings and avoided CO_2 emissions, assuming FFV credits would be used toward both the baseline and final standards:

TABLE I.C.1–3—NHTSA FUEL SAVED (BILLION GALLONS) AND CO_2 EMISSIONS AVOIDED (MILLION METRIC TONS, MMT) UNDER CAFE STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Fuel (b. gal.)	4.9	8.2	11.3	15.0	19.1	58.6

[41] These figures do not account for the compliance flexibilities that NHTSA is prohibited from considering when determining the level of new CAFE standards, because manufacturers' decisions to use those flexibilities are voluntary.

[42] NHTSA also estimated the benefits associated with three more estimates of a one ton GHG reduction in 2010 ($5, $35, and $65), which will likewise grow thereafter. *See* Section II for a more detailed discussion of the social cost of carbon.

TABLE I.C.1–3—NHTSA FUEL SAVED (BILLION GALLONS) AND CO_2 EMISSIONS AVOIDED (MILLION METRIC TONS, MMT) UNDER CAFE STANDARDS (WITH FFV CREDITS)—Continued

	2012	2013	2014	2015	2016	Total
CO_2 (mmt)	53	89	123	163	208	636

NHTSA estimates that these fuel economy increases would produce other benefits both to drivers (*e.g.,* reduced time spent refueling) and to the U.S. (*e.g.,* reductions in the costs of petroleum imports *beyond* the direct savings from reduced oil purchases, as well as some disbenefits (*e.g.,* increase traffic congestion) caused by drivers' tendency to travel more when the cost of driving declines (as it does when fuel economy increases). NHTSA has estimated the total monetary value to society of these benefits and disbenefits, and estimates that the standards will produce significant net benefits to society. Using a 3% discount rate, NHTSA estimates that the present value of these benefits would total more than $180 billion over the useful lives of vehicles sold during MYs 2012–2016. More discussion regarding monetized benefits can be found in Section IV of this notice and in NHTSA's Regulatory Impact Analysis. Note that the benefit calculation in Tables I.C.1–4 through 1–7 includes the benefits of reducing CO_2 emissions,[43] but not the benefits of reducing other GHG emissions.

TABLE I.C.1–4—NHTSA DISCOUNTED BENEFITS ($BILLION) UNDER THE CAFE STANDARDS (BEFORE FFV CREDITS, USING 3 PERCENT DISCOUNT RATE)

	2012	2013	2014	2015	2016	Total
Passenger Cars	6.8	15.2	21.6	28.7	35.2	107.5
Light Trucks	5.1	10.7	15.5	19.4	24.3	75.0
Combined	11.9	25.8	37.1	48.0	59.5	182.5

Using a 7% discount rate, NHTSA estimates that the present value of these benefits would total more than $145 billion over the same time period.

TABLE I.C.1–5—NHTSA DISCOUNTED BENEFITS ($BILLION) UNDER THE CAFE STANDARDS (BEFORE FFV CREDITS, USING 7 PERCENT DISCOUNT RATE)

	2012	2013	2014	2015	2016	Total
Passenger Cars	5.5	12.3	17.5	23.2	28.6	87.0
Light Trucks	4.0	8.4	12.2	15.3	19.2	59.2
Combined	9.5	20.7	29.7	38.5	47.8	146.2

NHTSA estimates that FFV credits could reduce achieved benefits by about 3.8%:

TABLE I.C.1–6A—NHTSA DISCOUNTED BENEFITS ($BILLION) UNDER THE CAFE STANDARDS (WITH FFV CREDITS, USING A 3 PERCENT DISCOUNT RATE)

	2012	2013	2014	2015	2016	Total
Passenger Cars	7.6	13.7	19.1	25.6	34.0	100.0
Light Trucks	6.4	10.4	14.6	19.8	24.4	75.6
Combined	14.0	24.1	33.7	45.4	58.4	175.6

TABLE I.C.1–6B—NHTSA DISCOUNTED BENEFITS ($BILLION) UNDER THE CAFE STANDARDS (WITH FFV CREDITS, USING A 7 PERCENT DISCOUNT RATE)

	2012	2013	2014	2015	2016	Total
Passenger Cars	6.1	11.1	15.5	20.7	27.6	80.9
Light Trucks	5.0	8.2	11.5	15.6	19.3	59.7

[43] CO_2 benefits for purposes of these tables are calculated using the $21/ton SCC values. Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency.

TABLE I.C.1–6B—NHTSA DISCOUNTED BENEFITS ($BILLION) UNDER THE CAFE STANDARDS (WITH FFV CREDITS, USING A 7 PERCENT DISCOUNT RATE)—Continued

	2012	2013	2014	2015	2016	Total
Combined	11.2	19.3	27.0	36.4	46.9	140.7

NHTSA attributes most of these benefits—about $143 billion (at a 3% discount rate and excluding consideration of FFV credits), as noted above—to reductions in fuel consumption, valuing fuel (for societal purposes) at the future pre-tax prices projected in the Energy Information Administration's (AEO's) reference case forecast from the Annual Energy Outlook (AEO) 2010 Early Release. NHTSA's Final Regulatory Impact Analysis (FRIA) accompanying this rule presents a detailed analysis of specific benefits of the rule.

TABLE I.C.1–7—SUMMARY OF BENEFITS FUEL SAVINGS AND CO_2 EMISSIONS REDUCTION DUE TO THE RULE (BEFORE FFV CREDITS)

	Amount	Monetized value (discounted)	
		3% discount rate	7% discount rate
Fuel savings	61.0 billion gallons	$143.0 billion	$112.0 billion.
CO_2 emissions reductions	655 mmt	$14.5 billion	$14.5 billion.

NHTSA estimates that the increases in technology application necessary to achieve the projected improvements in fuel economy will entail considerable monetary outlays. The agency estimates that incremental costs for achieving its standards—that is, outlays by vehicle manufacturers over and above those required to comply with the MY 2011 CAFE standards—will total about $52 billion (*i.e.,* during MYs 2012–2016).

TABLE I.C.1–8—NHTSA INCREMENTAL TECHNOLOGY OUTLAYS ($BILLION) UNDER THE CAFE STANDARDS (BEFORE FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Passenger Cars	4.1	5.4	6.9	8.2	9.5	34.2
Light Trucks	1.8	2.5	3.7	4.3	5.4	17.6
Combined	5.9	7.9	10.5	12.5	14.9	51.7

NHTSA estimates that use of FFV credits could significantly reduce these outlays:

TABLE I.C.1–9—NHTSA INCREMENTAL TECHNOLOGY OUTLAYS ($BILLION) UNDER CAFE STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Passenger Cars	2.6	3.6	4.8	6.1	7.5	24.6
Light Trucks	1.1	1.5	2.5	3.4	4.4	12.9
Combined	3.7	5.1	7.3	9.5	11.9	37.5

The agency projects that manufacturers will recover most or all of these additional costs through higher selling prices for new cars and light trucks. To allow manufacturers to recover these increased outlays (and, to a much lesser extent, the civil penalties that some companies are expected to pay for noncompliance), the agency estimates that the standards would lead to increases in average new vehicle prices ranging from $457 per vehicle in MY 2012 to $985 per vehicle in MY 2016:

TABLE I.C.1–10—NHTSA INCREMENTAL INCREASES IN AVERAGE NEW VEHICLE COSTS ($) UNDER CAFE STANDARDS (BEFORE FFV CREDITS)

	2012	2013	2014	2015	2016
Passenger Cars	505	573	690	799	907
Light Trucks	322	416	621	752	961

TABLE I.C.1–10—NHTSA INCREMENTAL INCREASES IN AVERAGE NEW VEHICLE COSTS ($) UNDER CAFE STANDARDS (BEFORE FFV CREDITS)—Continued

	2012	2013	2014	2015	2016
Combined	434	513	665	782	926

NHTSA estimates that use of FFV credits could significantly reduce these costs, especially in earlier model years:

TABLE I.C.1–11—NHTSA INCREMENTAL INCREASES IN AVERAGE NEW VEHICLE COSTS ($) UNDER CAFE STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016
Passenger Cars	303	378	481	593	713
Light Trucks	194	260	419	581	784
Combined	261	333	458	589	737

NHTSA estimates, therefore, that the total benefits of these CAFE standards will be more than three times the magnitude of the corresponding costs. As a consequence, its standards would produce net benefits of $130.7 billion at a 3 percent discount rate (with FFV credits, $138.2 billion) or $94.5 billion at a 7 percent discount rate over the useful lives of vehicles sold during MYs 2012–2016.

2. Summary of Costs and Benefits of EPA's GHG Standards

EPA has analyzed in detail the costs and benefits of the final GHG standards. Table I.C.2–1 shows EPA's estimated lifetime discounted cost, benefits and net benefits for all vehicles projected to be sold in model years 2012–2016. It is important to note that there is significant overlap in costs and benefits for NHTSA's CAFE program and EPA's GHG program and therefore combined program costs and benefits are not a sum of the individual programs.

TABLE I.C.2–1—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME DISCOUNTED COSTS, BENEFITS, AND NET BENEFITS ASSUMING THE $21/TON SCC VALUE [a b c d]

[2007 dollars]

3% Discount rate	$Billions
Costs	51.5
Benefits	240
Net Benefits	189
7% Discount rate	
Costs	51.5
Benefits	192
Net Benefits	140

[a] Although EPA estimated the benefits associated with four different values of a one ton GHG reduction ($5, $21, $35, $65), for the purposes of this overview presentation of estimated costs and benefits EPA is showing the benefits associated with the marginal value deemed to be central by the interagency working group on this topic: $21 per ton of CO2e, in 2007 dollars and 2010 emissions. The $21/ton value applies to 2010 CO_2 emissions and grows over time.

[b] As noted in Section III.H, SCC increases over time. The $21/ton value applies to 2010 CO_2 emissions and grows larger over time.

[c] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

[d] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

Table I.C.2–2 shows EPA's estimated lifetime fuel savings and CO_2 equivalent emission reductions for all vehicles sold in the model years 2012–2016. The values in Table I.C.2–2 are projected lifetime totals for each model year and are not discounted. As documented in EPA's Final RIA, the potential credit transfer between cars and trucks may change the distribution of the fuel savings and GHG emission impacts between cars and trucks. As discussed above with respect to NHTSA's CAFE standards, it is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to increases in average fuel economy and reductions in CO_2 emissions. The two agencies' standards together comprise the National Program, and this discussion of costs and benefits of EPA's GHG standards does not change the fact that both the CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program.

TABLE I.C.2–2—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME FUEL SAVED AND GHG EMISSIONS AVOIDED

		2012	2013	2014	2015	2016	Total
Cars	Fuel (billion gallons)	4.0	5.5	7.3	10.5	14.3	41.6
	Fuel (billion barrels)	0.10	0.13	0.17	0.25	0.34	0.99
	CO_2 EQ (mmt)	49.3	68.5	92.7	134	177	521

TABLE I.C.2–2—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME FUEL SAVED AND GHG EMISSIONS AVOIDED—Continued

		2012	2013	2014	2015	2016	Total
Light Trucks	Fuel (billion gallons)	3.3	5.0	6.6	9.0	12.2	36.1
	Fuel (billion barrels)	0.08	0.12	0.16	0.21	0.29	0.86
	CO_2 EQ (mmt)	39.6	61.7	81.6	111	147	441
Combined	Fuel (billion gallons)	7.3	10.5	13.9	19.5	26.5	77.7
	Fuel (billion barrels)	0.17	0.25	0.33	0.46	0.63	1.85
	CO_2 EQ (mmt)	88.8	130	174	244	325	962

Table I.C.2–3 shows EPA's estimated lifetime discounted benefits for all vehicles sold in model years 2012–2016. Although EPA estimated the benefits associated with four different values of a one ton GHG reduction ($5, $21, $35, $65), for the purposes of this overview presentation of estimated benefits EPA is showing the benefits associated with one of these marginal values, $21 per ton of CO_2, in 2007 dollars and 2010 emissions. Table I.C.2–3 presents benefits based on the $21 value. Section III.H presents the four marginal values used to estimate monetized benefits of GHG reductions and Section III.H presents the program benefits using each of the four marginal values, which represent only a partial accounting of total benefits due to omitted climate change impacts and other factors that are not readily monetized. The values in the table are discounted values for each model year of vehicles throughout their projected lifetimes. The benefits include all benefits considered by EPA such as fuel savings, GHG reductions, PM benefits, energy security and other externalities such as reduced refueling and accidents, congestion and noise. The lifetime discounted benefits are shown for one of four different social cost of carbon (SCC) values considered by EPA. The values in Table I.C.2–3 do not include costs associated with new technology required to meet the GHG standard.

TABLE I.C.2–3—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME DISCOUNTED BENEFITS ASSUMING THE $21/TON SCC VALUE [a b c]

[Billions of 2007 dollars]

Discount rate	Model year					
	2012	2013	2014	2015	2016	Total
3%	$21.8	$32.0	$42.8	$60.8	$83.3	$240
7%	17.4	25.7	34.2	48.6	66.4	192

[a] The benefits include all benefits considered by EPA such as the economic value of reduced fuel consumption and accompanying savings in refueling time, climate-related economic benefits from reducing emissions of CO_2 (but not other GHGs), economic benefits from reducing emissions of PM and other air pollutants that contribute to its formation, and reductions in energy security externalities caused by U.S. petroleum consumption and imports. The analysis also includes disbenefits stemming from additional vehicle use, such as the economic damages caused by accidents, congestion and noise.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses. Also, as noted in Section III.H, SCC increases over time. The $21/ton value applies to 2010 emissions and grows larger over time.

Table I.C.2–4 shows EPA's estimated lifetime fuel savings, lifetime CO_2 emission reductions, and the monetized net present values of those fuel savings and CO_2 emission reductions. The gallons of fuel and CO_2 emission reductions are projected lifetime values for all vehicles sold in the model years 2012–2016. The estimated fuel savings in billions of barrels and the GHG reductions in million metric tons of CO_2 shown in Table I.C.2–4 are totals for the five model years throughout their projected lifetime and are not discounted. The monetized values shown in Table I.C.2–4 are the summed values of the discounted monetized-fuel savings and monetized-CO_2 reductions for the five model years 2012–2016 throughout their lifetimes. The monetized values in Table I.C.2–4 reflect both a 3 percent and a 7 percent discount rate as noted.

TABLE I.C.2–4—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME FUEL SAVINGS, CO_2 EMISSION REDUCTIONS, AND DISCOUNTED MONETIZED BENEFITS AT A 3% DISCOUNT RATE

[Monetized values in 2007 dollars]

	Amount	$ value (billions)
Fuel savings	1.8 billion barrels	$182, 3% discount rate. $142, 7% discount rate.

TABLE I.C.2–4—EPA'S ESTIMATED 2012–2016 MODEL YEAR LIFETIME FUEL SAVINGS, CO_2 EMISSION REDUCTIONS, AND DISCOUNTED MONETIZED BENEFITS AT A 3% DISCOUNT RATE—Continued

[Monetized values in 2007 dollars]

	Amount	$ value (billions)
CO_{2e} emission reductions (CO_2 portion valued assuming $21/ton CO_2 in 2010).	962 MMT CO_{2e}	$17 [a b].

[a] $17 billion for 858 MMT of reduced CO_2 emissions. As noted in Section III.H, the $21/ton value applies to 2010 emissions and grows larger over time. Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[b] Note that net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.

Table I.C.2–5 shows EPA's estimated incremental and total technology outlays for cars and trucks for each of the model years 2012–2016. The technology outlays shown in Table I.C.2–5 are for the industry as a whole and do not account for fuel savings associated with the program.

TABLE I.C.2–5—EPA'S ESTIMATED INCREMENTAL TECHNOLOGY OUTLAYS

[Billions of 2007 dollars]

	2012	2013	2014	2015	2016	Total
Cars	$3.1	$5.0	$6.5	$8.0	$9.4	$31.9
Trucks	1.8	3.0	3.9	4.8	6.2	19.7
Combined	4.9	8.0	10.3	12.7	15.6	51.5

Table I.C.2–6 shows EPA's estimated incremental cost increase of the average new vehicle for each model year 2012–2016. The values shown are incremental to a baseline vehicle and are not cumulative. In other words, the estimated increase for 2012 model year cars is $342 relative to a 2012 model year car absent the National Program. The estimated increase for a 2013 model year car is $507 relative to a 2013 model year car absent the National Program (not $342 plus $507).

TABLE I.C.2–6—EPA'S ESTIMATED INCREMENTAL INCREASE IN AVERAGE NEW VEHICLE COST

[2007 dollars per unit]

	2012	2013	2014	2015	2016
Cars	$342	$507	$631	$749	$869
Trucks	314	496	652	820	1,098
Combined	331	503	639	774	948

D. Background and Comparison of NHTSA and EPA Statutory Authority

Section I.C of the proposal contained a detailed overview discussion of the NHTSA and EPA statutory authorities. In addition to the discussion in the proposal, each agency discusses comments pertaining to its statutory authority and the agency's responses in Sections III and IV of this notice, respectively.

II. Joint Technical Work Completed for This Final Rule

A. Introduction

In this section NHTSA and EPA discuss several aspects of the joint technical analyses on which the two agencies collaborated. These analyses are common to the development of each agency's final standards. Specifically we discuss: the development of the vehicle market forecast used by each agency for assessing costs, benefits, and effects, the development of the attribute-based standard curve shapes, the determination of the relative stringency between the car and truck fleet standards, the technologies the agencies evaluated and their costs and effectiveness, and the economic assumptions the agencies included in their analyses. The Joint Technical Support Document (TSD) discusses the agencies' joint technical work in more detail.

B. Developing the Future Fleet for Assessing Costs, Benefits, and Effects

1. Why did the agencies establish a baseline and reference vehicle fleet?

In order to calculate the impacts of the EPA and NHTSA regulations, it is necessary to estimate the composition of the future vehicle fleet absent these regulations, to provide a reference point relative to which costs, benefits, and effects of the regulations are assessed. As in the proposal, EPA and NHTSA have developed this comparison fleet in two parts. The first step was to develop a baseline fleet based on model year 2008 data. The second step was to project that fleet into model years 2011–2016. This is called the reference fleet.

The third step was to modify that MY 2011–2016 reference fleet such that it had sufficient technology to meet the MY 2011 CAFE standards. This final version of the reference fleet is the light-duty fleet estimated to exist in MY 2012–2016 in the absence of today's standards, based on the assumption that manufacturers would continue to meet the MY 2011 CAFE standards (or pay civil penalties allowed under EPCA [44]) in the absence of further increases in the stringency of CAFE standards. Each agency used this approach to develop a final reference fleet to use in its modeling. All of the agencies' estimates of emission reductions, fuel economy improvements, costs, and societal impacts are developed in relation to the respective reference fleets.

EPA and NHTSA proposed a transparent approach to developing the baseline and reference fleets, largely working from publicly available data. This proposed approach differed from previous CAFE rules, which relied on confidential manufacturers' product plan information to develop the baseline. Most of the public comments to the NPRM addressing this issue supported this methodology for developing the inputs to the rule's analysis. Because the input sheets can be made public, stakeholders can verify and check EPA's and NHTSA's modeling, and perform their own analyses with these datasets. In this final rulemaking, EPA and NHTSA are using an approach very similar to that proposed, continuing to rely on publicly available data as the basis for the baseline and reference fleets.

2. How did the agencies develop the baseline vehicle fleet?

At proposal, EPA and NHTSA developed a baseline fleet comprised of model year 2008 data gathered from EPA's emission certification and fuel economy database. MY 2008 was used as the basis for the baseline vehicle fleet because it was the most recent model year for which a complete set of data is publicly available. This remains the case. Manufacturers are not required to submit final sales and mpg figures for MY 2009 until April 2010,[45] after the CAFE standard's mandated promulgation date. Consequently, in this final rule, EPA and NHTSA made no changes to the method or the results of the MY 2008 baseline fleet used at proposal, except for some specific corrections to engineering inputs for some vehicle models reflected in the market forecast input to NHTSA's CAFE model. More details about how the agencies constructed this baseline fleet can be found in Chapter 1.2 of the Joint TSD. Corrections to engineering inputs for some vehicle models in the market forecast input to NHTSA's CAFE model are discussed in Chapter 2 of the Joint TSD.

3. How did the agencies develop the projected MY 2011–2016 vehicle fleet?

EPA and NHTSA have based the projection of total car and total light truck sales for MYs 2011–2016 on projections made by the Department of Energy's Energy Information Administration (EIA). EIA publishes a mid-term projection of national energy use called the Annual Energy Outlook (AEO). This projection utilizes a number of technical and econometric models which are designed to reflect both economic and regulatory conditions expected to exist in the future. In support of its projection of fuel use by light-duty vehicles, EIA projects sales of new cars and light trucks. In the proposal, the agencies used the three reports published by EIA as part of the AEO 2009. We also stated that updated versions of these reports could be used in the final rules should AEO timely issue a new version. EIA published an early version of its AEO 2010 in December 2009, and the agencies are making use of it in this final rulemaking. The differences in projected sales in the 2009 report (used in the NPRM) and the early 2010 report are very small, so NHTSA and EPA have decided to simply scale the NPRM volumes for cars and trucks (in the aggregate) to match those in the 2010 report. We thus employ the sales projections from the scaled updated 2009 Annual Energy Outlook, which is equivalent to AEO 2010 Early Release, for the final rule. The scaling factors for each model year are presented in Chapter 1 of the Joint TSD for this final rule.

The agencies recognize that AEO 2010 Early Release does include some impacts of future projected increases in CAFE stringency. We have closely examined the difference between AEO 2009 and AEO 2010 Early Release and we believe the differences in total sales and the car/truck split attributed to considerations of the standard in the final rule are small.[46]

In the AEO 2010 Early Release, EIA projects that total light-duty vehicle sales will gradually recover from their currently depressed levels by around 2013. In 2016, car sales are projected to be 9.4 million (57 percent) and truck sales are projected to be 7.1 million (43 percent). Although the total level of sales of 16.5 million units is similar to pre-2008 levels, the fraction of car sales is projected to be higher than that existing in the 2000–2007 timeframe. This projection reflects the impact of higher fuel prices, as well as EISA's requirement that the new vehicle fleet average at least 35 mpg by MY 2020. The agencies note that AEO does not represent the fleet at a level of detail sufficient to explicitly account for the reclassification—promulgated as part of NHTSA's final rule for MY 2011 CAFE standards—of a number of 2-wheel drive sport utility vehicles from the truck fleet to the car fleet for MYs 2011 and after. Sales projections of cars and trucks for future model years can be found in the Joint TSD for these final rules.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have been changing and are expected to continue to change. Manufacturers are introducing more crossover models which offer much of the utility of SUVs but use more car-like designs. The AEO 2010 report does not, however, distinguish such changes within the car and truck classes. In order to reflect these changes in fleet makeup, EPA and NHTSA considered several other available forecasts. EPA purchased and shared with NHTSA forecasts from two well-known industry analysts, CSM Worldwide (CSM), and J.D. Powers. NHTSA and EPA decided to use the forecast from CSM, modified as described below, for several reasons presented in the NPRM preamble [47] and draft Joint TSD. The changes between company market share and industry market segments were most significant from 2011–2014, while for 2014–2015 the changes were relatively small. Noting this, and lacking a credible forecast of company and segment shares after 2015, the agencies assumed 2016 market share and market segments to be the same as for 2015.

[44] That is, the manufacturers who have traditionally paid fines under EPCA instead of complying with the CAFE standards were "allowed," for purposes of the reference fleet, to reach only the CAFE level at which paying fines became more cost-effective than adding technology, even if that fell short of the MY 2011 standards.

[45] 40 CFR 600.512–08, Model Year Report.

[46] The agencies have also looked at the impact of the rule in EIA's projection, and concluded that the impact was small. EPA and NHTSA have evaluated the differences between the AEO 2010 (early draft) and AEO 2009 and found little difference in the fleet projections (or fuel prices). This analysis can be found in the memo to the docket: Kahan, A. and Pickrell, D. Memo to Docket EPA–HQ–OAR–2009–0472 and Docket NHTSA–2009–0059. "Energy Information Administration's Annual Energy Outlook 2009 and 2010." March 24, 2010.

[47] See, *e.g.,* 74 FR 49484.

CSM Worldwide provides quarterly sales forecasts for the automotive industry. In the NPRM, the agencies identified a concern with the 2nd quarter CSM forecast that was used as a basis for the projection. CSM projections at that time were based on an industry that was going through a significant financial transition, and as a result the market share forecasts for some companies were impacted in surprising ways. As the industry's situation has settled somewhat over the past year, the 4th quarter projection appears to address this issue—for example, it shows nearly a two-fold increase in sales for Chrysler compared to significant loss of market share shown for Chrysler in the 2nd quarter projection. Additionally, some commenters, such as GM, recognized that the fleet appeared to include an unusually high number of large pickup trucks.[48] In fact, the agencies discovered (independently of the comments) that CSM's standard forecast included all vehicles below 14,000 GVWR, including class 2b and 3 heavy duty vehicles, which are not regulated by this final rule.[49] The commenters were thus correct that light duty reference fleet projections at proposal had more full size trucks and vans due to the mistaken inclusion of the heavy duty versions of those vehicles. The agencies requested a separate data forecast from CSM that filtered their 4th quarter projection to exclude these heavy duty vehicles. The agencies then used this filtered 4th quarter forecast for the final rule. A detailed comparison of the market by manufacturer can be found in the final TSD. For the public's reference, copies of the 2nd, 3rd, and 4th quarter CSM forecasts have been placed in the docket for this rulemaking.[50]

We then projected the CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment onto the total sales estimates of AEO 2010. Tables II.B.3–1 and II.B.3–2 show the resulting projections for the reference 2016 model year and compare these to actual sales that occurred in baseline 2008 model year. Both tables show sales using the traditional definition of cars and light trucks.

TABLE II.B.3–1—ANNUAL SALES OF LIGHT-DUTY VEHICLES BY MANUFACTURER IN 2008 AND ESTIMATED FOR 2016

	Cars		Light trucks		Total	
	2008 MY	2016 MY	2008 MY	2016 MY	2008 MY	2016 MY
BMW	291,796	424,923	61,324	171,560	353,120	596,482
Chrysler	537,808	340,908	1,119,397	525,128	1,657,205	866,037
Daimler	208,052	272,252	79,135	126,880	287,187	399,133
Ford	709,583	1,118,727	1,158,805	1,363,256	1,868,388	2,481,983
General Motors	1,370,280	1,283,937	1,749,227	1,585,828	3,119,507	2,869,766
Honda	899,498	811,214	612,281	671,437	1,511,779	1,482,651
Hyundai	270,293	401,372	120,734	211,996	391,027	613,368
Kia	145,863	455,643	135,589	210,717	281,452	666,360
Mazda	191,326	350,055	111,220	144,992	302,546	495,047
Mitsubishi	76,701	49,914	24,028	88,754	100,729	138,668
Porsche	18,909	33,471	18,797	16,749	37,706	50,220
Nissan	653,121	876,677	370,294	457,114	1,023,415	1,333,790
Subaru	149,370	230,705	49,211	95,054	198,581	325,760
Suzuki	68,720	97,466	45,938	26,108	114,658	123,574
Tata	9,596	65,806	55,584	42,695	65,180	108,501
Toyota	1,143,696	2,069,283	1,067,804	1,249,719	2,211,500	3,319,002
Volkswagen	290,385	586,011	26,999	124,703	317,384	710,011
Total	7,034,997	9,468,365	6,806,367	7,112,689	13,841,364	16,580,353

TABLE II.B.3–2—ANNUAL SALES OF LIGHT-DUTY VEHICLES BY MARKET SEGMENT IN 2008 AND ESTIMATED FOR 2016

Cars			Light trucks		
	2008 MY	2016 MY		2008 MY	2016 MY
Full-Size Car	829,896	530,945	Full-Size Pickup	1,331,989	1,379,036
Luxury Car	1,048,341	1,548,242	Mid-Size Pickup	452,013	332,082
Mid-Size Car	2,166,849	2,550,561	Full-Size Van	33,384	65,650
Mini Car	617,902	1,565,373	Mid-Size Van	719,529	839,194
Small Car	1,912,736	2,503,566	Mid-Size MAV *	110,353	116,077
Specialty Car	459,273	769,679	Small MAV	231,265	62,514
			Full-Size SUV *	559,160	232,619
			Mid-Size SUV	436,080	162,502
			Small SUV	196,424	108,858
			Full-Size CUV *	264,717	260,662
			Mid-Size CUV	923,165	1,372,200
			Small CUV	1,548,288	2,181,296

[48] GM argued that the unusually large volume of large pickups led to higher overall requirements for those vehicles. As discussed below, the agencies' analysis for the final rule corrects the number of large pickups. With this correction and other updates to the agencies' market forecast and other analytical inputs, the target functions defining the final standards (and achieving the average required performance levels defining the national program) are very similar to those from the NPRM, especially for light trucks, as illustrated below in Figures II.C–7 and II.C–8.

[49] These include the Ford F–250 & F–350, Econoline E–250, & E–350; Chevy Express, Silverado 2500, & 3500; GMC Savana, Dodge 2500, & 3500; among others.

[50] The CSM Sales Forecast Excel file ("CSM North America Sales Forecasts 2Q09 3Q09 4Q09 for the Docket") is available in the docket (Docket EPA–HQ–OAR–2009–0472).

TABLE II.B.3–2—ANNUAL SALES OF LIGHT-DUTY VEHICLES BY MARKET SEGMENT IN 2008 AND ESTIMATED FOR 2016—Continued

Cars			Light trucks		
	2008 MY	2016 MY		2008 MY	2016 MY
Total Sales **	7,034,997	9,468,365		6,806,367	7,079,323

* MAV—Multi-Activity Vehicle, SUV—Sport Utility Vehicle, CUV—Crossover Utility Vehicle.
** Total Sales are based on the classic Car/Truck definition.

Determining which traditionally-defined trucks will be defined as cars for purposes of this final rule using the revised definition established by NHTSA for MYs 2011 and beyond requires more detailed information about each vehicle model. This is described in greater detail in Chapter 1 of the final TSD.

The forecasts obtained from CSM provided estimates of car and truck sales by segment and by manufacturer, but not by manufacturer for each market segment. Therefore, NHTSA and EPA needed other information on which to base these more detailed projected market splits. For this task, the agencies used as a starting point each manufacturer's sales by market segment from model year 2008, which is the baseline fleet. Because of the larger number of segments in the truck market, the agencies used slightly different methodologies for cars and trucks.

The first step for both cars and trucks was to break down each manufacturer's 2008 sales according to the market segment definitions used by CSM. For example, the agencies found that Ford's [51] cars sales in 2008 were broken down as shown in Table II.B.3–3:

TABLE II.B.3–3—BREAKDOWN OF FORD'S 2008 CAR SALES

Full-size cars	160,857 units.
Mid-size Cars	170,399 units.
Small/Compact Cars	180,249 units.
Subcompact/Mini Cars	None.
Luxury cars	87,272 units.
Specialty cars	110,805 units.

EPA and NHTSA then adjusted each manufacturer's sales of each of its car segments (and truck segments, separately) so that the manufacturer's total sales of cars (and trucks) matched the total estimated for each future model year based on AEO and CSM forecasts. For example, as indicated in Table II.B.3–1, Ford's total car sales in 2008 were 709,583 units, while the agencies project that they will increase to 1,113,333 units by 2016. This represents an increase of 56.9 percent. Thus, the agencies increased the 2008 sales of each Ford car segment by 56.9 percent. This produced estimates of future sales which matched total car and truck sales per AEO and the manufacturer breakdowns per CSM. However, the sales splits by market segment would not necessarily match those of CSM (shown for 2016 in Table II.B.3–2).

In order to adjust the market segment mix for cars, the agencies first adjusted sales of luxury, specialty and other cars. Since the total sales of cars for each manufacturer were already set, any changes in the sales of one car segment had to be compensated by the opposite change in another segment. For the luxury, specialty and other car segments, it is not clear how changes in sales would be compensated. For example, if luxury car sales decreased, would sales of full-size cars increase, mid-size cars, and so on? The agencies have assumed that any changes in the sales of cars within these three segments were compensated for by proportional changes in the sales of the other four car segments. For example, for 2016, the figures in Table II.B.3–2 indicate that luxury car sales in 2016 are 1,548,242 units. Luxury car sales are 1,048,341 units in 2008. However, after adjusting 2008 car sales by the change in total car sales for 2016 projected by EIA and a change in manufacturer market share per CSM, luxury car sales decreased to 1,523,171 units. Thus, overall for 2016, luxury car sales had to increase by 25,071 units or 6 percent. The agencies accordingly increased the luxury car sales by each manufacturer by this percentage. The absolute decrease in luxury car sales was spread across sales of full-size, mid-size, compact and subcompact cars in proportion to each manufacturer's sales in these segments in 2008. The same adjustment process was used for specialty cars and the "other cars" segment defined by CSM.

The agencies used a slightly different approach to adjust for changing sales of the remaining four car segments. Starting with full-size cars, the agencies again determined the overall percentage change that needed to occur in future year full-size car sales after 1) adjusting for total sales per AEO 2010, 2) adjusting for manufacturer sales mix per CSM and 3) adjusting the luxury, specialty and other car segments, in order to meet the segment sales mix per CSM. Sales of each manufacturer's large cars were adjusted by this percentage. However, instead of spreading this change over the remaining three segments, the agencies assigned the entire change to mid-size vehicles. The agencies did so because the CSM data followed the trend of increasing volumes of smaller cars while reducing volumes of larger cars. If a consumer had previously purchased a full-size car, we thought it unlikely that their next purchase would decrease by two size categories, down to a subcompact. It seemed more reasonable to project that they would drop one vehicle size category smaller. Thus, the change in each manufacturer's sales of full-size cars was matched by an opposite change (in absolute units sold) in mid-size cars.

The same process was then applied to mid-size cars, with the change in mid-size car sales being matched by an opposite change in compact car sales. This process was repeated one more time for compact car sales, with changes in sales in this segment being matched by the opposite change in the sales of subcompacts. The overall result was a projection of car sales for model years 2012–2016—the reference fleet—which matched the total sales projections of the AEO forecast and the manufacturer and segment splits of the CSM forecast. These sales splits can be found in Chapter 1 of the Joint TSD for this final rule.

As mentioned above, the agencies applied a slightly different process to truck sales, because the agencies could not confidently project how the change in sales from one segment preferentially went to or came from another particular segment. Some trend from larger vehicles to smaller vehicles would have been possible. However, the CSM forecasts indicated large changes in total sport utility vehicle, multi-activity vehicle and cross-over sales which could not be connected. Thus, the

[51] **Note**: In the NPRM, Ford's 2008 sales per segment, and the total number of cars was different than shown here. The change in values is due to a correction of vehicle segments for some of Ford's vehicles.

agencies applied an iterative, but straightforward process for adjusting 2008 truck sales to match the AEO and CSM forecasts.

The first three steps were exactly the same as for cars. EPA and NHTSA broke down each manufacturer's truck sales into the truck segments as defined by CSM. The agencies then adjusted all manufacturers' truck segment sales by the same factor so that total truck sales in each model year matched AEO projections for truck sales by model year. The agencies then adjusted each manufacturer's truck sales by segment proportionally so that each manufacturer's percentage of total truck sales matched that forecast by CSM. This again left the need to adjust truck sales by segment to match the CSM forecast for each model year.

In the fourth step, the agencies adjusted the sales of each truck segment by a common factor so that total sales for that segment matched the combination of the AEO and CSM forecasts. For example, projected sales of large pickups across all manufacturers were 1,286,184 units in 2016 after adjusting total sales to match AEO's forecast and adjusting each manufacturer's truck sales to match CSM's forecast for the breakdown of sales by manufacturer. Applying CSM's forecast of the large pickup segment of truck sales to AEO's total sales forecast indicated total large pickup sales of 1,379,036 units. Thus, we increased each manufacturer's sales of large pickups by 7 percent.[52] The agencies applied the same type of adjustment to all the other truck segments at the same time. The result was a set of sales projections which matched AEO's total truck sales projection and CSM's market segment forecast. However, after this step, sales by manufacturer no longer met CSM's forecast. Thus, we repeated step three and adjusted each manufacturer's truck sales so that they met CSM's forecast. The sales of each truck segment (by manufacturer) were adjusted by the same factor. The resulting sales projection matched AEO's total truck sales projection and CSM's manufacturer forecast, but sales by market segment no longer met CSM's forecast. However, the difference between the sales projections after this fifth step was closer to CSM's market segment forecast than it was after step three. In other words, the sales projection was converging to the desired result. The agencies repeated these adjustments, matching manufacturer sales mix in one step and then market segment in the next a total of 19 times. At this point, we were able to match the market segment splits exactly and the manufacturer splits were within 0.1 percent of our goal, which is well within the needs of this analysis.

The next step in developing the reference fleets was to characterize the vehicles within each manufacturer-segment combination. In large part, this was based on the characterization of the specific vehicle models sold in 2008—*i.e.,* the vehicles comprising the baseline fleet. EPA and NHTSA chose to base our estimates of detailed vehicle characteristics on 2008 sales for several reasons. One, these vehicle characteristics are not confidential and can thus be published here for careful review by interested parties. Two, because it is constructed beginning with actual sales data, this vehicle fleet is limited to vehicle models known to satisfy consumer demands in light of price, utility, performance, safety, and other vehicle attributes.

As noted above, the agencies gathered most of the information about the 2008 baseline vehicle fleet from EPA's emission certification and fuel economy database. The data obtained from this source included vehicle production volume, fuel economy, engine size, number of engine cylinders, transmission type, fuel type, etc. EPA's certification database does not include a detailed description of the types of fuel economy-improving/CO_2-reducing technologies considered in this final rule. Thus, the agencies augmented this description with publicly available data which includes more complete technology descriptions from Ward's Automotive Group.[53] In a few instances when required vehicle information (such as vehicle footprint) was not available from these two sources, the agencies obtained this information from publicly accessible Internet sites such as *Motortrend.com* and *Edmunds.com.*[54]

The projections of future car and truck sales described above apply to each manufacturer's sales by market segment. The EPA emissions certification sales data are available at a much finer level of detail, essentially vehicle configuration. As mentioned above, the agencies placed each vehicle in the EPA certification database into one of the CSM market segments. The agencies then totaled the sales by each manufacturer for each market segment. If the combination of AEO and CSM forecasts indicated an increase in a given manufacturer's sales of a particular market segment, then the sales of all the individual vehicle configurations were adjusted by the same factor. For example, if the Prius represented 30 percent of Toyota's sales of compact cars in 2008 and Toyota's sales of compact cars in 2016 was projected to double by 2016, then the sales of the Prius were doubled, and the Prius sales in 2016 remained 30 percent of Toyota's compact car sales.

The projection of average footprint for both cars and trucks remained virtually constant over the years covered by the final rulemaking. This occurrence is strictly a result of the CSM projections. There are a number of trends that occur in the CSM projections that caused the average footprint to remain constant. First, as the number of subcompacts increases, so do the number of 2-wheel drive crossover vehicles (that are regulated as cars). Second, truck volumes have many segment changes during the rulemaking time frame. There is no specific footprint related trend in any segment that can be linked to the unchanging footprint, but there is a trend that non-pickups' volumes will move from truck segments that are ladder frame to those that are unibody-type vehicles. A table of the footprint projections is available in the TSD as well as further discussion on this topic.

4. How was the development of the baseline and reference fleets for this Final Rule different from NHTSA's historical approach?

NHTSA has historically based its analysis of potential new CAFE standards on detailed product plans the agency has requested from manufacturers planning to produce light vehicles for sale in the United States. Although the agency has not attempted to compel manufacturers to submit such information, most major manufacturers and some smaller manufacturers have voluntarily provided it when requested.

The proposal discusses many of the advantages and disadvantages of the market forecast approach used by the agencies, including the agencies' interest in examining product plans as a check on the reference fleet developed by the agencies for this rulemaking. One of the primary reasons for the request for data in 2009 was to obtain permission from the manufacturers to make public their product plan information for model years 2010 and 2011. There are a number of reasons that this could be advantageous in the development of a reference fleet. First,

[52] **Note**: In the NPRM this example showed 29 percent instead of 7 percent. The significant decrease was due to using the filtered 4th quarter CSM forecast. Commenters, such as GM, had commented that we had too many full-size trucks and vans, and this change addresses their comment.

[53] Note that WardsAuto.com is a fee-based service, but all information is public to subscribers.

[54] Motortrend.com and Edmunds.com are free, no-fee Internet sites.

some known changes to the fleet may not be captured by the approach of solely using publicly available information. For example, the agencies' current market forecast includes some vehicles for which manufacturers have announced plans for elimination or drastic production cuts such as the Chevrolet Trailblazer, the Chrysler PT Cruiser, the Chrysler Pacifica, the Dodge Magnum, the Ford Crown Victoria, the Mercury Sable, the Pontiac Grand Prix, the Pontiac G5 and the Saturn Vue. These vehicle models appear explicitly in market inputs to NHTSA's analysis, and are among those vehicle models included in the aggregated vehicle types appearing in market inputs to EPA's analysis. However, although the agencies recognize that these specific vehicles will be discontinued, we continue to include them in the market forecast because they are useful as a surrogate for successor vehicles that may appear in the rulemaking time frame to replace the discontinued vehicles in that market segment.[55]

Second, the agencies' market forecast does not include some forthcoming vehicle models, such as the Chevrolet Volt, the Ford Fiesta and several publicly announced electric vehicles, including the announcements from Nissan regarding the Leaf. Nor does it include several MY 2009 or 2010 vehicles, such as the Honda Insight, the Hyundai Genesis and the Toyota Venza, as our starting point for defining specific vehicle models in the reference fleet was Model Year 2008. Additionally, the market forecast does not account for publicly announced technology introductions, such as Ford's EcoBoost system, whose product plans specify which vehicles and how many are planned to have this technology. Chrysler Group LLC has announced plans to offer small- and medium-sized cars using Fiat powertrains. Were the agencies to rely on manufacturers' product plans (that were submitted), the market forecast would account for not only these specific examples, but also for similar examples that have not yet been announced publicly.

Some commenters, such as CBD and NESCAUM, suggested that the agencies' omission of known future vehicles and technologies in the reference fleet causes inaccuracies, which CBD further suggested could lead the agencies to set lower standards. On the other hand, CARB commented that "the likely impact of this omission is minor." Because the agencies' analysis examines the costs and benefits of progressively adding technology to manufacturers' fleets, the omission of future vehicles and technologies primarily affects how much additional technology (and, therefore, how much incremental cost and benefit) is available relative to the point at which the agencies' examination of potential new standards begins. Thus, in fact, the omission only reflects the reference fleet, rather than the agencies' conclusions regarding how stringent the standards should be. This is discussed further below. The agencies believe the above-mentioned comments by CBD, NESCAUM, and others are based on a misunderstanding of the agencies' approach to analyzing potential increases in regulatory stringency. The agencies also note that manufacturers do not always use technology solely to increase fuel economy, and that use of technology to increase vehicles' acceleration performance or utility would probably make that technology unavailable toward more stringent standards. Considering the incremental nature of the agencies' analysis, and the counterbalancing aspects of potentially omitted technology in the reference fleet, the agencies believe their determination of the stringency of new standards has not been impacted by any such omissions.

Moreover, EPA and NHTSA believe that not including such vehicles after MY 2008 does not significantly impact our estimates of the technology required to comply with the standards. If included, these vehicles could increase the extent to which manufacturers are, in the reference case, expected to over-comply with the MY 2011 CAFE standards, and could thereby make the new standards appear to cost less and yield less benefit relative to the reference case. However, in the agencies' judgment, production of the most advanced technology vehicles, such as the Chevy Volt or the Nissan Leaf (for example), will most likely be too limited during MY 2011 through MY 2016 to significantly impact manufacturers' compliance positions. While we are projecting the characteristics of the future fleet by extrapolating from the MY 2008 fleet, the primary difference between the future fleet and the 2008 fleet in the same vehicle segment is the use of additional CO_2-reducing and fuel-saving technologies. Both the NHTSA and EPA models add such technologies to evaluate means of complying with the standards, and the costs of doing so. Thus, our future projections of the vehicle fleet generally shift vehicle designs towards those more likely to be typical of newer vehicles. Compared to using product plans that show continued fuel economy increases planned based on expectations that CAFE standards will continue to increase, this approach helps to clarify the costs and benefits of the new standards, as the costs and benefits of all fuel economy improvements beyond those required by the MY 2011 CAFE standards are being assigned to the final rules. In some cases, the "actual" (vs. projected or "modeled") new vehicles being introduced into the market by manufacturers are done so in anticipation of this rulemaking. On the other hand, manufacturers may plan to continue using technologies to improve vehicle performance and/or utility, not just fuel economy. Our approach prevents some of these actual technological improvements and their associated cost and fuel economy improvements from being assumed in the reference fleet. Thus, the added technology will not be considered to be free (or having no benefits) for the purposes of this rule.

In this regard, the agencies further note that manufacturer announcements regarding forward models (or future vehicle models) need not be accepted automatically. Manufacturers tend to limit accurate production intent information in these releases for reasons such as: (a) Competitors will closely examine their information for data in their product planning decisions; (b) the press coverage of forward model announcements is not uniform, meaning highly anticipated models have more coverage and materials than models that may be less exciting to the public and consistency and uniformity cannot be ensured with the usage of press information; and (c) these market projections are subject to change (sometimes significant), and manufacturers may not want to give the appearance of being indecisive, or under/over-confident to their shareholders and the public with premature release of information.

NHTSA has evaluated the use of public manufacturer forward model press information to update the vehicle fleet inputs to the baseline and reference fleet. The challenges in this approach are evidenced by the continuous stream of manufacturer press releases throughout a defined rulemaking period. Manufacturers' press releases suffer from the same types of inaccuracies that many commenters believe can affect product plans.

[55] An example of this is in the GM Pontiac line, which is in the process of being phased out during the course of this rulemaking. GM has similar vehicles within their other brands (like Chevy) that will "presumably" pick up the loss in Pontiac share. We model this simply by leaving the Pontiac brand in.

Manufacturers can often be overly optimistic in their press releases, both on projected date of release of new models and on sales volumes.

More generally and more critically, as discussed in the proposal and as endorsed by many of the public comments, there are several advantages to the approach used by the agencies in this final rule. Most importantly, today's market forecast is much more transparent. The information sources used to develop today's market forecast are all either in the public domain or available commercially. Another significant advantage of today's market forecast is the agencies' ability to assess more fully the incremental costs and benefits of the proposed standards. In addition, by developing baseline and reference fleets from common sources, the agencies have been able to avoid some errors—perhaps related to interpretation of requests—that have been observed in past responses to NHTSA's requests. An additional advantage of the approach used for this rule is a consistent projection of the change in fuel economy and CO_2 emissions across the various vehicles from the application of new technology. With the approach used for this final rule, the baseline market data comes from actual vehicles (on the road today) which have actual fuel economy test data (in contrast to manufacturer estimates of future product fuel economy)—so there is no question what is the basis for the fuel economy or CO_2 performance of the baseline market data as it is.

5. How does manufacturer product plan data factor into the baseline used in this Final Rule?

In the spring and fall of 2009, many manufacturers submitted product plans in response to NHTSA's recent requests that they do so. NHTSA and EPA both have access to these plans, and both agencies have reviewed them in detail. A small amount of product plan data was used in the development of the baseline. The specific pieces of data are:

Wheelbase.
Track Width Front.
Track Width Rear.
EPS (Electric Power Steering).
ROLL (Reduced Rolling Resistance).
LUB (Advance Lubrication *i.e.* low weight oil).
IACC (Improved Electrical Accessories).
Curb Weight.
GVWR (Gross Vehicle Weight Rating).

The track widths, wheelbase, curb weight, and GVWR for vehicles could have been looked up on the Internet (159 were), but were taken from the product plans when available for convenience. To ensure accuracy, a sample from each product plan was used as a check against the numbers available from *Motortrend.com.* These numbers will be published in the baseline file since they can be easily looked up on the internet. On the other hand, EPS, ROLL, LUB, and IACC are difficult to determine without using manufacturer's product plans. These items will not be published in the baseline file, but the data has been aggregated into the agencies' baseline in the technology effectiveness and cost effectiveness for each vehicle in a way that allows the baseline for the model to be published without revealing the manufacturer's data.

Also, some technical information that manufacturers have provided in product plans regarding specific vehicle models is, at least insofar as NHTSA and EPA have been able to determine, not available from public or commercial sources. While such gaps do not bear significantly on the agencies' analysis, the diversity of pickup configurations necessitated utilizing a sales-weighted average footprint value [56] for many manufacturers' pickups. Since our modeling only utilizes footprint in order to estimate each manufacturer's CO_2 or fuel economy standard and all the other vehicle characteristics are available for each pickup configuration, this approximation has no practical impact on the projected technology or cost associated with compliance with the various standards evaluated. The only impact which could arise would be if the relative sales of the various pickup configurations changed, or if the agencies were to explore standards with a different shape. This would necessitate recalculating the average footprint value in order to maintain accuracy.

Additionally, as discussed in the NPRM, in an effort to update the 2008 baseline to account for the expected changes in the fleet in the near-term model years 2009–2011 described above, NHTSA requested permission from the manufacturers to make this limited product plan information public. Unfortunately, virtually no manufacturers agreed to allow the use of their data after 2009 model year. A few manufacturers, such as GM and Ford, stated we could use their 2009 product plan data after the end of production (December 31), but this would not have afforded us sufficient time to do the analysis for the final rule. Since the agencies were unable to obtain consistent updates, the baseline and reference fleets were not updated beyond 2008 model year for the final rule. The 2008 baseline fleet and projections were instead updated using the latest AEO and CSM data as discussed earlier.

NHTSA and EPA recognize that the approach applied for the current rule gives transparency and openness of the vehicle market forecast high priority, and accommodates minor inaccuracies that may be introduced by not accounting for future product mix changes anticipated in manufacturers' confidential product plans. For any future fleet analysis that the agencies are required to perform, NHTSA and EPA plan to request that manufacturers submit product plans and allow some public release of information. In performing this analysis, the agencies plan to reexamine potential tradeoffs between transparency and technical reasonableness, and to explain resultant choices.

C. Development of Attribute-Based Curve Shapes

In the NPRM, NHTSA and EPA proposed to set attribute-based CAFE and CO_2 standards that are defined by a mathematical function for MYs 2012–2016 passenger cars and light trucks. EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy, and be expressed in the form of a mathematical function.[57] The CAA has no such requirement, though in past rules, EPA has relied on both universal and attribute-based standards (*e.g.,* for nonroad engines, EPA uses the attribute of horsepower). However, given the advantages of using attribute-based standards and given the

[56] A full-size pickup might be offered with various combinations of cab style (*e.g.,* regular, extended, crew) and box length (*e.g.,* 5½′, 6½′, 8′) and, therefore, multiple footprint sizes. CAFE compliance data for MY 2008 data does not contain footprint information, and does not contain information that can be used to reliably identify which pickup entries correspond to footprint values estimable from public or commercial sources. Therefore, the agencies have used the known production levels of average values to represent all variants of a given pickup line (*e.g.,* all variants of the F–150 and the Sierra/Silverado) in order to calculate the sales-weighted average footprint value for each pickup family. Again, this has no impact on the results of our modeling effort, although it would require re-estimation if we were to examine light truck standards of a different shape. In the extreme, one single footprint value could be used for every vehicle sold by a single manufacturer as long as the fuel economy standard associated with this footprint value represented the sales-weighted, harmonic average of the fuel economy standards associated with each vehicle's footprint values.

[57] 49 U.S.C. 32902(a)(3)(A).

goal of coordinating and harmonizing CO_2 standards promulgated under the CAA and CAFE standards promulgated under EPCA, EPA also proposed to issue standards that are attribute-based and defined by mathematical functions. There was consensus in the public comments that EPA should develop attribute-based CO_2 standards.

Comments received in response to the agencies' decision to base standards on vehicle footprint were largely supportive. Several commenters (BMW, NADA, NESCAUM) expressed support for attribute-based (as opposed to flat or universal) standards generally, and agreed with EPA's decision to harmonize with NHTSA in this respect. Many commenters (Aluminum Association, BMW, ICCT, NESCAUM, NY DEC, Schade, Toyota) also supported the agencies' decision to continue setting CAFE standards, and begin setting GHG standards, on the basis of vehicle footprint, although one commenter (NJ DEP) opposed the use of footprint due to concern that it encourages manufacturers to upsize vehicles and undercut the gains of the standard. Of the commenters supporting the use of footprint, several focused on the benefits of harmonization—both between EPA and NHTSA, and between the U.S. and the rest of the world. BMW commented, for example, that many other countries use weight-based standards rather than footprint-based. While BMW did not object to NHTSA's and EPA's use of footprint-based standards, it emphasized the impact of this non-harmonization on manufacturers who sell vehicles globally, and asked the agencies to consider these effects. NADA supported the use of footprint, but cautioned that the agencies must be careful in setting the footprint curve for light trucks to ensure that manufacturers can continue to provide functionality like 4WD and towing/hauling capacity.

Some commenters requested that the agencies consider other or more attributes in addition to footprint, largely reiterating comments submitted to the MYs 2011–2015 CAFE NPRM. Cummins supported the agencies using a secondary attribute to account for towing and hauling capacity in large trucks, for example, while Ferrari asked the agencies to consider a multi-attribute approach incorporating curb weight, maximum engine power or torque, and/or engine displacement, as it had requested in the previous round of CAFE rulemaking. An individual, Mr. Kenneth Johnson, commented that weight-based standards would be preferable to footprint-based ones, because weight correlates better with fuel economy than footprint, because the use of footprint does not necessarily guarantee safety the way the agencies say it does, and because weight-based standards would be fairer to manufacturers.

In response, EPA and NHTSA continue to believe that the benefits of footprint-attribute-based standards outweigh any potential drawbacks raised by commenters, and that harmonization between the two agencies should be the overriding goal on this issue. As discussed by NHTSA in the MY 2011 CAFE final rule,[58] the agencies believe that the possibility of gaming is lowest with footprint-based standards, as opposed to weight-based or multi-attribute-based standards. Specifically, standards that incorporate weight, torque, power, towing capability, and/or off-road capability in addition to footprint would not only be significantly more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they would make it less certain that the future fleet would actually achieve the average fuel economy and CO_2 levels projected by the agencies. The agencies recognize that based on economic and consumer demand factors that are external to this rule, the distribution of footprints in the future may be different (either smaller or larger) than what is projected in this rule. However, the agencies continue to believe that there will not be significant shifts in this distribution as a direct consequence of this rule. The agencies are therefore finalizing MYs 2012–2016 CAFE and GHG standards based on footprint.

The agencies also recognize that there could be benefits for a number of manufacturers if there was greater international harmonization of fuel economy and GHG standards, but this is largely a question of how stringent standards are and how they are enforced. It is entirely possible that footprint-based and weight-based systems can coexist internationally and not present an undue burden for manufacturers if they are carefully crafted. Different countries or regions may find different attributes appropriate for basing standards, depending on the particular challenges they face—from fuel prices, to family size and land use, to safety concerns, to fleet composition and consumer preference, to other environmental challenges besides climate change. The agencies anticipate working more closely with other countries and regions in the future to consider how to mitigate these issues in a way that least burdens manufacturers while respecting each country's need to meet its own particular challenges.

Under an attribute-based standard, every vehicle model has a performance target (fuel economy and CO_2 emissions for CAFE and CO_2 emissions standards, respectively), the level of which depends on the vehicle's attribute (for the proposal, footprint). The manufacturers' fleet average performance is determined by the production-weighted[59] average (for CAFE, harmonic average) of those targets. NHTSA and EPA are promulgating CAFE and CO_2 emissions standards defined by constrained linear functions and, equivalently, piecewise linear functions.[60] As a possible option for future rulemakings, the constrained linear form was introduced by NHTSA in the 2007 NPRM proposing CAFE standards for MY 2011–2015. Described mathematically, the proposed constrained linear function was defined according to the following formula:[61]

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Where

TARGET = the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet),

a = the function's upper limit (in mpg),

b = the function's lower limit (in mpg),

[58] *See* 74 FR 14359 (Mar. 30, 2009).

[59] Production for sale in the United States.

[60] The equations are equivalent but are specified differently due to differences in the agencies' respective models.

[61] This function is linear in fuel consumption but not in fuel economy.

c = the slope (in gpm per square foot) of the sloped portion of the function,

d = the intercept (in gpm) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet, and the *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values; for example, *MIN*(1,2) = 1, *MAX*(1,2) = 2, and *MIN*[*MAX*(1,2),3)]=2.

Because the format is linear on a gallons-per-mile basis, not on a miles-per-gallon basis, it is plotted as fuel consumption below. Graphically, the constrained linear form appears as shown in Figure II.C–1.

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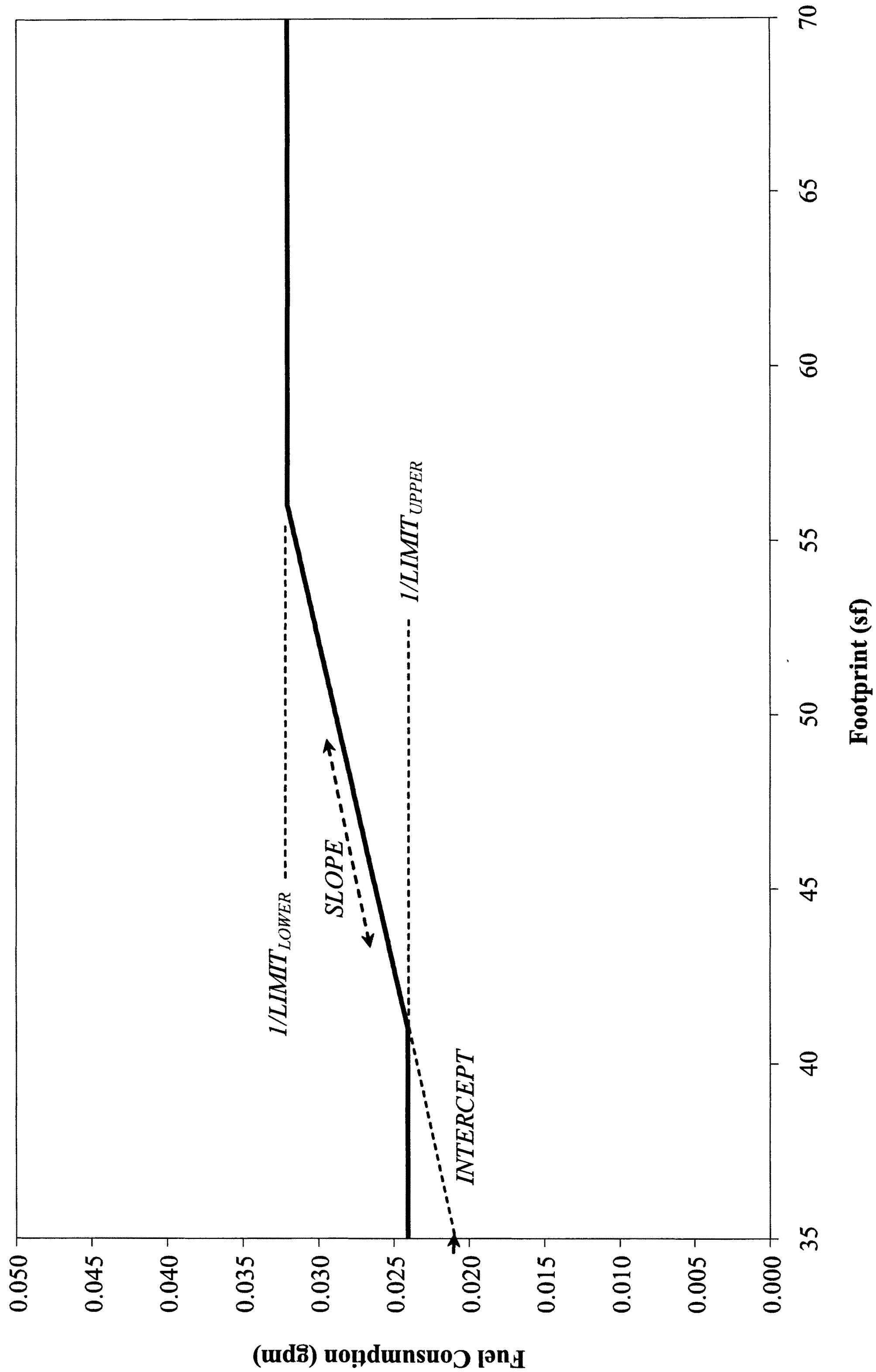

Figure II.C-1 The Shape of the Constrained Linear Form

The specific form and stringency for each fleet (passenger car and light trucks) and model year are defined through specific values for the four coefficients shown above.

EPA proposed the equivalent equation below for assigning CO_2 targets to an individual vehicle's footprint value. Although the general model of the equation is the same for each vehicle category and each year, the parameters of the equation differ for cars and trucks and for each model year. Described mathematically, EPA's proposed piecewise linear function was as follows:

Target = a, if $x \leq l$
Target = cx + d, if $l < x \leq h$
Target = b, if $x > h$

In the constrained linear form similar in form to the fuel economy equation above, this equation takes the simplified form:

Target = MIN [MAX (c * x + d, a), b]

Where

Target = the CO_2 target value for a given footprint (in g/mi)
a = the minimum target value (in g/mi CO_2)[62]
b = the maximum target value (in g/mi CO_2)
c = the slope of the linear function (in g/mi per sq ft CO_2)
d = is the intercept or zero-offset for the line (in g/mi CO_2)
x = footprint of the vehicle model (in square feet, rounded to the nearest tenth)
l & h are the lower and higher footprint limits or constraints or ("kinks") or the boundary between the flat regions and the intermediate sloped line (in sq ft)

Graphically, piecewise linear form, like the constrained linear form, appears as shown in Figure II.C–2.

[62] These a, b, d coefficients differ from the a, b, d coefficients in the constrained linear fuel economy equation primarily by a factor of 8887 (plus an additive factor for air conditioning).

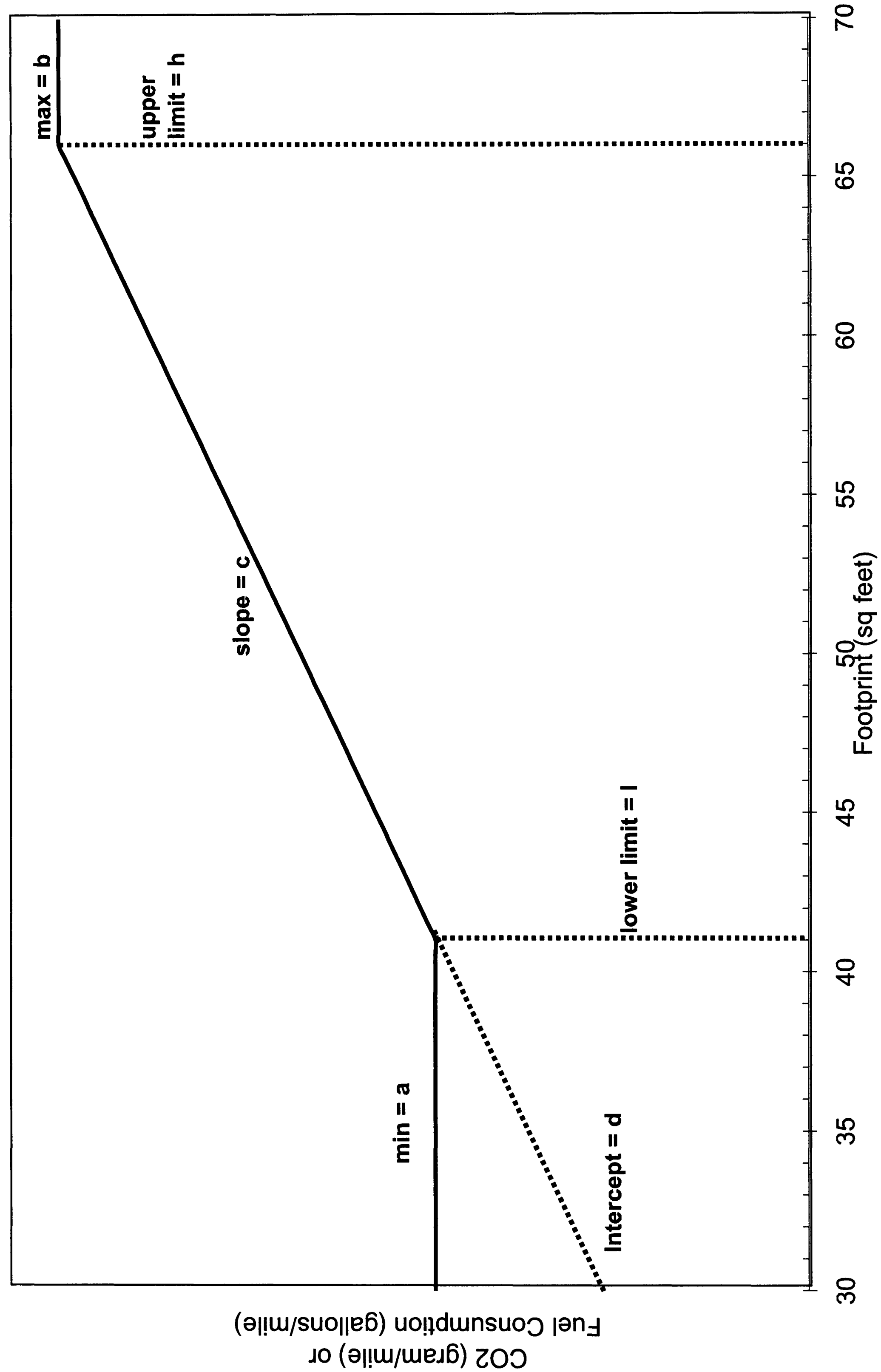

Figure II.C-2 The Shape of the Piecewise Linear Form

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As for the constrained linear form, the specific form and stringency of the piecewise linear function for each fleet (passenger car and light trucks) and model year are defined through specific values for the four coefficients shown above.

For purposes of the proposed rules, NHTSA and EPA developed the basic curve shapes using methods similar to those applied by NHTSA in fitting the curves defining the MY 2011 standards. The first step involved defining the relevant vehicle characteristics in the form used by NHTSA's CAFE model (*e.g.,* fuel economy, footprint, vehicle class, technology) described in Section II.B of this preamble and in Chapter 1 of the Joint TSD. However, because the baseline fleet utilizes a wide range of available fuel saving technologies, NHTSA used the CAFE model to develop a fleet to which all of the technologies discussed in Chapter 3 of the Joint TSD [63] were applied, except dieselization and strong hybridization. This was accomplished by taking the following steps: (1) Treating all manufacturers as unwilling to pay civil penalties rather than applying technology, (2) applying any technology at any time, irrespective of scheduled vehicle redesigns or freshening, and (3) ignoring "phase-in caps" that constrain the overall amount of technology that can be applied by the model to a given manufacturer's fleet. These steps helped to increase technological parity among vehicle models, thereby providing a better basis (than the baseline or reference fleets) for estimating the statistical relationship between vehicle size and fuel economy.

In fitting the curves, NHTSA and EPA also continued to fit the sloped portion of the function to vehicle models between the footprint values at which the agencies continued to apply constraints to limit the function's value for both the smallest and largest vehicles. Without a limit at the smallest footprints, the function—whether logistic or linear—can reach values that would be unfairly burdensome for a manufacturer that elects to focus on the market for small vehicles; depending on the underlying data, an unconstrained form, could result in stringency levels that are technologically infeasible and/or economically impracticable for those manufacturers that may elect to focus on the smallest vehicles. On the other side of the function, without a limit at the largest footprints, the function may provide no floor on required fuel economy. Also, the safety considerations that support the provision of a disincentive for downsizing as a compliance strategy apply weakly, if at all, to the very largest vehicles. Limiting the function's value for the largest vehicles leads to a function with an inherent absolute minimum level of performance, while remaining consistent with safety considerations.

Before fitting the sloped portion of the constrained linear form, NHTSA and EPA selected footprints above and below which to apply constraints (*i.e.,* minimum and maximum values) on the function. The agencies believe that the linear form performs well in describing the observed relationship between footprint and fuel consumption or CO_2 emissions for vehicle models within the footprint ranges covering most vehicle models, but that the single (as opposed to piecewise) linear form does not perform well in describing this relationship for the smallest and largest vehicle models. For passenger cars, the agency noted that several manufacturers offer small, sporty coupes below 41 square feet, such as the BMW Z4 and Mini, Honda S2000, Mazda MX–5 Miata, Porsche Carrera and 911, and Volkswagen New Beetle. Because such vehicles represent a small portion (less than 10 percent) of the passenger car market, yet often have performance, utility, and/or structural characteristics that could make it technologically infeasible and/or economically impracticable for manufacturers focusing on such vehicles to achieve the very challenging average requirements that could apply in the absence of a constraint, EPA and NHTSA proposed to "cut off" the linear portion of the passenger car function at 41 square feet. The agencies recognize that for manufacturers who make small vehicles in this size range, this cut off creates some incentive to downsize (*i.e.,* further reduce the size, and/or increase the production of models currently smaller than 41 square feet) to make it easier to meet the target. The cut off may also create the incentive for manufacturers who do not currently offer such models to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars smaller than 41 square feet—most consumers likely have some minimum expectation about interior volume, among other things. The agencies thus believe that the number of consumers who will want vehicles smaller than 41 square feet (regardless of how they are priced) is small, and that the incentive to downsize in response to this final rule, if present, will be minimal. For consistency, the agency proposed to "cut off" the light truck function at the same footprint, although no light trucks are currently offered below 41 square feet. The agencies further noted that above 56 square feet, the only passenger car model present in the MY 2008 fleet were four luxury vehicles with extremely low sales volumes—the Bentley Arnage and three versions of the Rolls Royce Phantom. NHTSA and EPA therefore also proposed to "cut off" the linear portion of the passenger car function at 56 square feet. Finally, the agencies noted that although public information is limited regarding the sales volumes of the many different configurations (cab designs and bed sizes) of pickup trucks, most of the largest pickups (*e.g.,* the Ford F–150, GM Sierra/Silverado, Nissan Titan, and Toyota Tundra) appear to fall just above 66 square feet in footprint. EPA and NHTSA therefore proposed to "cut off" the linear portion of the light truck function at 66 square feet.

Having developed a set of vehicle emissions and footprint data which represent the benefit of all non-diesel, non-hybrid technologies, we determined the initial values for parameters *c* and *d* were determined for cars and trucks separately. *c* and *d* were initially set at the values for which the average (equivalently, sum) of the absolute values of the differences was minimized between the "maximum technology" fleet fuel consumption (within the footprints between the upper and lower limits) and the straight line of the function defined above at the same corresponding vehicle footprints. That is, *c* and *d* were determined by minimizing the average absolute residual, commonly known as the MAD (Mean Absolute Deviation) approach, of the corresponding straight line.

Finally, NHTSA calculated the values of the upper and lower parameters (*a* and *b*) based on the corresponding footprints discussed above (41 and 56 square feet for passenger cars, and 41 and 66 square feet for light trucks).

The result of this methodology is shown below in Figures II.C–3 and II.C–4 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent.

[63] The agencies excluded diesel engines and strong hybrid vehicle technologies from this exercise (and only this exercise) because the agencies expect that manufacturers would not need to rely heavily on these technologies in order to comply with the proposed standards. NHTSA and EPA did include diesel engines and strong hybrid vehicle technologies in all other portions of their analyses.

For trucks, the corresponding MAD was 10 percent.

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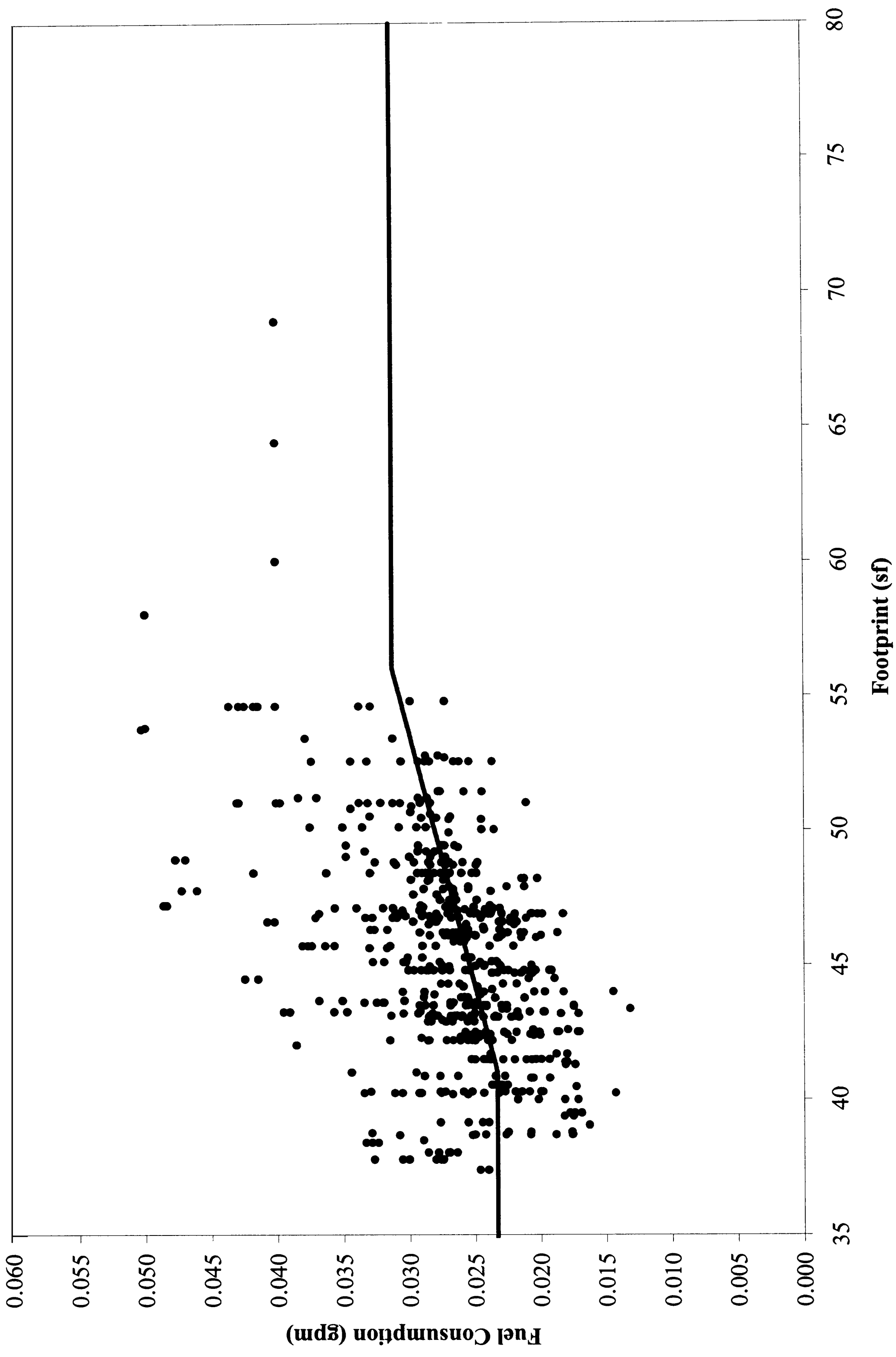

Figure II.C-3 "Maximum Technology" Passenger Fleet with Fitted Constrained Linear Function

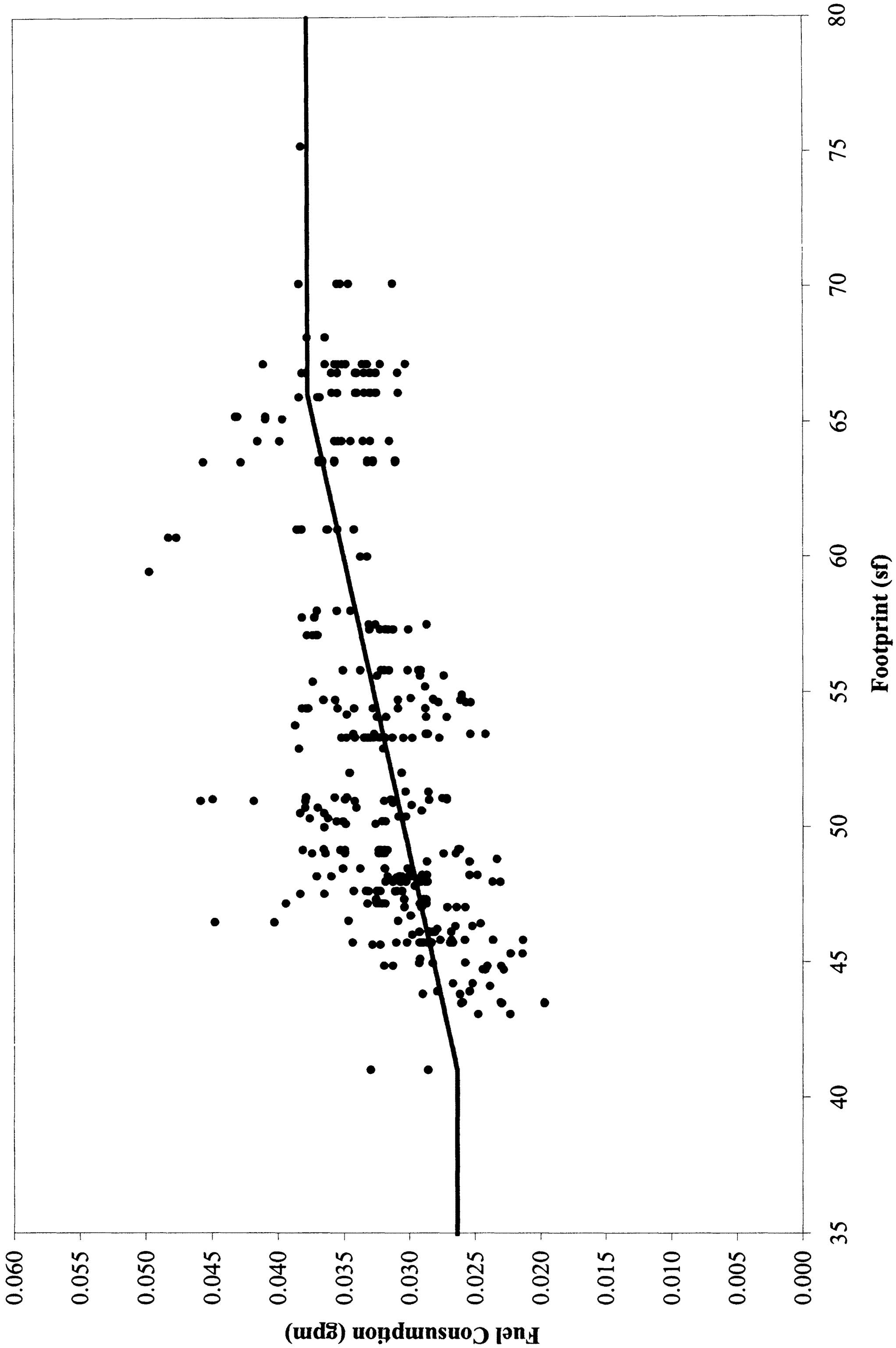

Figure II.C–4 "Maximum Technology" Light Truck with Fitted Constrained Linear Function

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The agencies used these functional forms as a starting point to develop mathematical functions defining the actual proposed standards as discussed above. The agencies then transposed these functions vertically (*i.e.,* on a gpm or CO_2 basis, uniformly downward) to produce the same fleetwide fuel economy (and CO_2 emission levels) for cars and light trucks described in the NPRM.

A number of public comments generally supported the agencies' choice of attribute-based mathematical functions, as well as the methods applied to fit the function. Ferrari indicated support for the use of a constrained linear form rather than a constrained logistic form, support for the application of limits on the functions' values, support for a generally less steep passenger car curve compared to MY 2011, and support for the inclusion of all manufacturers in the analysis used to fit the curves. ICCT also supported the use of a constrained linear form. Toyota expressed general support for the methods and outcome, including a less-steep passenger car curve, and the application of limits on fuel economy targets applicable to the smallest vehicles. The UAW commented that the shapes and levels of the curves are reasonable.

Other commenters suggested that changes to the agencies' methods and results would yield better outcomes. GM suggested that steeper curves would provide a greater incentive for limited-line manufacturers to apply technology to smaller vehicles. GM argued that steeper and, in their view, fairer curves could be obtained by using sales-weighted least-squares regression rather than minimization of the unweighted mean absolute deviation. Conversely, students from UC Santa Barbara commented that the passenger car and light truck curves should be flatter and should converge over time in order to encourage the market to turn, as the agencies' analysis assumes it will, away from light trucks and toward passenger cars.

NADA commented that there should be no "cut-off" points (*i.e.,* lower limits or floors), because these *de facto* "backstops" might limit consumer choice, especially for light trucks—a possibility also suggested by the Alliance. The Alliance and several individual manufacturers also commented that the cut-off point for light trucks should be shifted to 72 square feet (from the proposed 66 square feet), arguing that the preponderance of high-volume light truck models with footprints greater than 66 square feet is such that a 72 square foot cut-off point makes it unduly challenging for manufacturers serving the large pickup market and thereby constitutes a *de facto* backstop. Also, with respect to the smallest light truck models, Honda commented that the cut-off point should be set at the point defining the smallest 10 percent of the fleet, both for consistency with the passenger car cut-off point, and to provide a greater incentive for manufacturers to downsize the smallest light truck models (which provide greater functionality than passenger cars).

Other commenters focused on whether the agencies should have separate curves for different fleets or whether they should have a single curve that applied to both passenger cars and light trucks. This issue is related, to some extent, to commenters who discussed whether car and truck definitions should change. CARB, Ford, and Toyota supported separate curves for cars and trucks, generally stating that different fleets have different functional characteristics and these characteristics are appropriately addressed by separate curves. Likewise, AIAM, Chrysler, and NADA supported leaving the current definitions of car and truck the same. CBD, ICCT, and NESCAUM supported a single curve, based on concerns about manufacturers gaming the system and reclassifying passenger cars as light trucks in order to obtain the often-less stringent light truck standard, which could lead to lower benefits than anticipated by the agencies.

In addition, the students from UC Santa Barbara reported being unable to reproduce the agencies' analysis to fit curves to the passenger car and light truck fleets, even when using the model, inputs, and external analysis files posted to NHTSA's Web site when the NPRM was issued.

Having considered public comments, NHTSA and EPA have re-examined the development of curves underlying the standards proposed in the NPRM, and are promulgating standards based on the same underlying curves. The agencies have made this decision considering that, while EISA mandates that CAFE standards be defined by a mathematical function in terms of one or more attributes related to fuel economy, neither EISA nor the CAA require that the mathematical function be limited to the observed or theoretical dependence of fuel economy on the selected attribute or attributes. As a means by which CAFE and GHG standards are specified, the mathematical function can and does properly play a normative role. Therefore, NHTSA and EPA have concluded that, as supported by comments, the mathematical function can reasonably be based on a blend of analytical and policy considerations, as discussed below and in the Joint Technical Support Document.

With respect to GM's recommendation that NHTSA and EPA use weighted least-squares analysis, the agencies find that the market forecast used for analysis supporting both the NPRM and the final rule exhibits the two key characteristics that previously led NHTSA to use minimization of the unweighted Mean Absolute Deviation (MAD) rather than weighted least-squares analysis. First, projected model-specific sales volumes in the agencies' market forecast cover an extremely wide range, such that, as discussed in NHTSA's rulemaking for MY 2011, while unweighted regression gives low-selling vehicle models and high-selling vehicle models equal emphasis, sales-weighted regression would give some vehicle models considerably more emphasis than other vehicle models.[64] The agencies' intention is to fit a curve that describes a technical relationship between fuel economy and footprint, given comparable levels of technology, and this supports weighting discrete vehicle models equally. On the other hand, sales weighted regression would allow the difference between other vehicle attributes to be reflected in the analysis, and also would reflect consumer demand.

Second, even after NHTSA's "maximum technology" analysis to increase technological parity of vehicle models before fitting curves, the agencies' market forecast contains many significant outliers. As discussed in NHTSA's rulemaking for MY 2011, MAD is a statistical procedure that has been demonstrated to produce more efficient parameter estimates than least-squares analysis in the presence of significant outliers.[65] In addition, the

[64] For example, the agencies' market forecast shows MY 2016 sales of 187,000 units for Toyota's 2WD Sienna, and shows 27 model configurations with MY 2016 sales of fewer than 100 units. Similarly, the agencies' market forecast shows MY 2016 sales of 268,000 for the Toyota Prius, and shows 29 model configurations with MY 2016 sales of fewer than 100 units. Sales-weighted analysis would give the Toyota Sienna and Prius more than a thousand times the consideration of many vehicle model configurations. Sales-weighted analysis would, therefore, cause a large number of vehicle model configurations to be virtually ignored. *See* discussion in NHTSA's final rule for MY 2011 passenger car and light truck CAFE standards, 74 FR 14368 (Mar. 30, 2009), and in NHTSA's NPRM for that rulemaking, 73 FR 24423–24429 (May 2, 2008).

[65] *Id.* In the case of a dataset not drawn from a sample with a Gaussian, or normal, distribution, there is often a need to employ robust estimation methods rather than rely on least-squares approach to curve fitting. The least-squares approach has as an underlying assumption that the data are drawn

agencies remain concerned that the steeper curves resulting from weighted least-squares analysis would increase the risk that energy savings and environmental benefits would be lower than projected, because the steeper curves would provide a greater incentive to increase sales of larger vehicles with lower fuel economy levels. Based on these technical considerations and these concerns regarding potential outcomes, the agencies have decided not to re-fit curves using weighted least-squares analysis, but note that they may reconsider using least-squares regression in future analysis.

NHTSA and EPA have considered GM's comment that steeper curves would provide a greater incentive for limited-line manufacturers to apply technology to smaller vehicles. While the agencies agree that a steeper curve would, absent any changes in fleet mix, tend to shift average compliance burdens away from GM and toward companies that make smaller vehicles, the agencies are concerned, as stated above, that steeper curves would increase the risk that induced increases in vehicle size could erode projected energy and environmental benefits.

NHTSA and EPA have also considered the comments by the students from UC Santa Barbara indicating that the passenger car and light truck curves should be flatter and should converge over time. The agencies conclude that flatter curves would reduce the incentives intended in shifting from "flat" CAFE standards to attribute-based CAFE and GHG standards—those being the incentive to respond to attribute-based standards in ways that minimize compromises in vehicle safety, and the incentive for more manufacturers (than primarily those selling a wider range of vehicles) across the range of the attribute to have to increase the application of fuel-saving technologies. With regard to whether the agencies should set separate curves or a single one, NHTSA also notes that EPCA requires NHTSA to establish standards separately for passenger cars and light trucks, and thus concludes that the standards for each fleet should be based on the characteristics of vehicles in each fleet. In other words, the passenger car curve should be based on the characteristics of passenger cars, and the light truck curve should be based on the characteristics of light trucks—thus to the extent that those characteristics are different, an artificially-forced convergence would not accurately reflect those differences. However, such convergence could be appropriate depending on future trends in the light vehicle market, specifically further reduction in the differences between passenger car and light truck characteristics. While that trend was more apparent when car-like 2WD SUVs were classified as light trucks, it seems likely to diminish for the model year vehicles subject to these rules as the truck fleet will be more purely "truck-like" than has been the case in recent years.

NHTSA and EPA have also considered comments on the maxima and minima that the agencies have applied to "cut off" the linear function underlying the proposed curves for passenger cars and light trucks. Contrary to NADA's suggestion that there should be no such cut-off points, the agencies conclude that curves lacking maximum fuel economy targets (*i.e.,* minimum CO_2 targets) would result in average fuel economy and GHG requirements that would not be technologically feasible or economically practicable for manufacturers concentrating on those market segments. In addition, minimum fuel economy targets (*i.e.,* maximum CO_2 targets) are important to mitigate the risk to energy and environmental benefits of potential market shifts toward large vehicles. The agencies also disagree with comments by the Alliance and several individual manufacturers that the cut-off point for light trucks should be shifted to 72 square feet (from the proposed 66 square feet) to ease compliance burdens facing manufacturers serving the large pickup market. Such a shift would increase the risk that energy and environmental benefits of the standards would be compromised by induced increases in the sales of large pickups, in situations where the increased compliance burden is feasible and appropriate. Also, the agencies' market forecast suggests that most of the light trucks models with footprints larger than 66 square feet have curb weights near or above 5,000 pounds. This suggests, in turn, that in terms of highway safety, there is little or no need to discourage downsizing of light trucks with footprints larger than 66 square feet. Based on these energy, environmental, technological feasibility, economic practicability, and safety considerations, the agencies conclude that the light truck curve should be cut off at 66 square feet, as proposed, rather than at 72 square feet. The agencies also disagree with Honda's suggestion that the cut-off point for the smallest trucks be shifted to a larger footprint value, because doing so could potentially increase the incentive to reclassify vehicles in that size range as light trucks, and could thereby increase the possibility that energy and environmental benefits of the rule would be less than projected.

Finally, considering comments by the UC Santa Barbara students regarding difficulties reproducing NHTSA's analysis, NHTSA reexamined its analysis, and discovered some erroneous entries in model inputs underlying the analysis used to develop the curves proposed in the NPRM. These errors are discussed in NHTSA's final Regulatory Impact Analysis (FRIA) and have since been corrected. They include the following: Incorrect valvetrain phasing and lift inputs for many BMW engines, incorrect indexing for some Daimler models, incorrectly enabled valvetrain technologies for rotary engines and Atkinson cycle engines, omitted baseline applications of cylinder deactivation in some Honda and GM engines, incorrect valve phasing codes for some 4-cylinder Chrysler engines, omitted baseline applications of advanced transmissions in some VW models, incorrectly enabled advanced electrification technologies for several hybrid vehicle models, and incorrect DCT effectiveness estimates for subcompact passenger cars. These errors, while not significant enough to impact the overall analysis of stringency, did affect the fitted slope for the passenger car curve and would have prevented precise replication of NHTSA's NPRM analysis by outside parties.

After correcting these errors and repeating the curve development analysis presented in the NPRM, NHTSA obtained the curves shown below in Figures II.C–5 and II.C–6 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent. For trucks, the corresponding MAD was 10 percent.

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from a normal distribution, and hence fits a curve using a sum-of-squares method to minimize errors. This approach will, in a sample drawn from a non-normal distribution, give excessive weight to outliers by making their presence felt in proportion to the square of their distance from the fitted curve, and, hence, distort the resulting fit. With outliers in the sample, the typical solution is to use a robust method such as a minimum absolute deviation, rather than a squared term, to estimate the fit (*see, e.g.,* "AI Access: Your Access to Data Modeling," at *http://www.aiaccess.net/English/Glossaries/GlosMod/e_gm_O_Pa.htm#Outlier*). The effect on the estimation is to let the presence of each observation be felt more uniformly, resulting in a curve more representative of the data (*see, e.g.,* Peter Kennedy, *A Guide to Econometrics,* 3rd edition, 1992, MIT Press, Cambridge, MA).

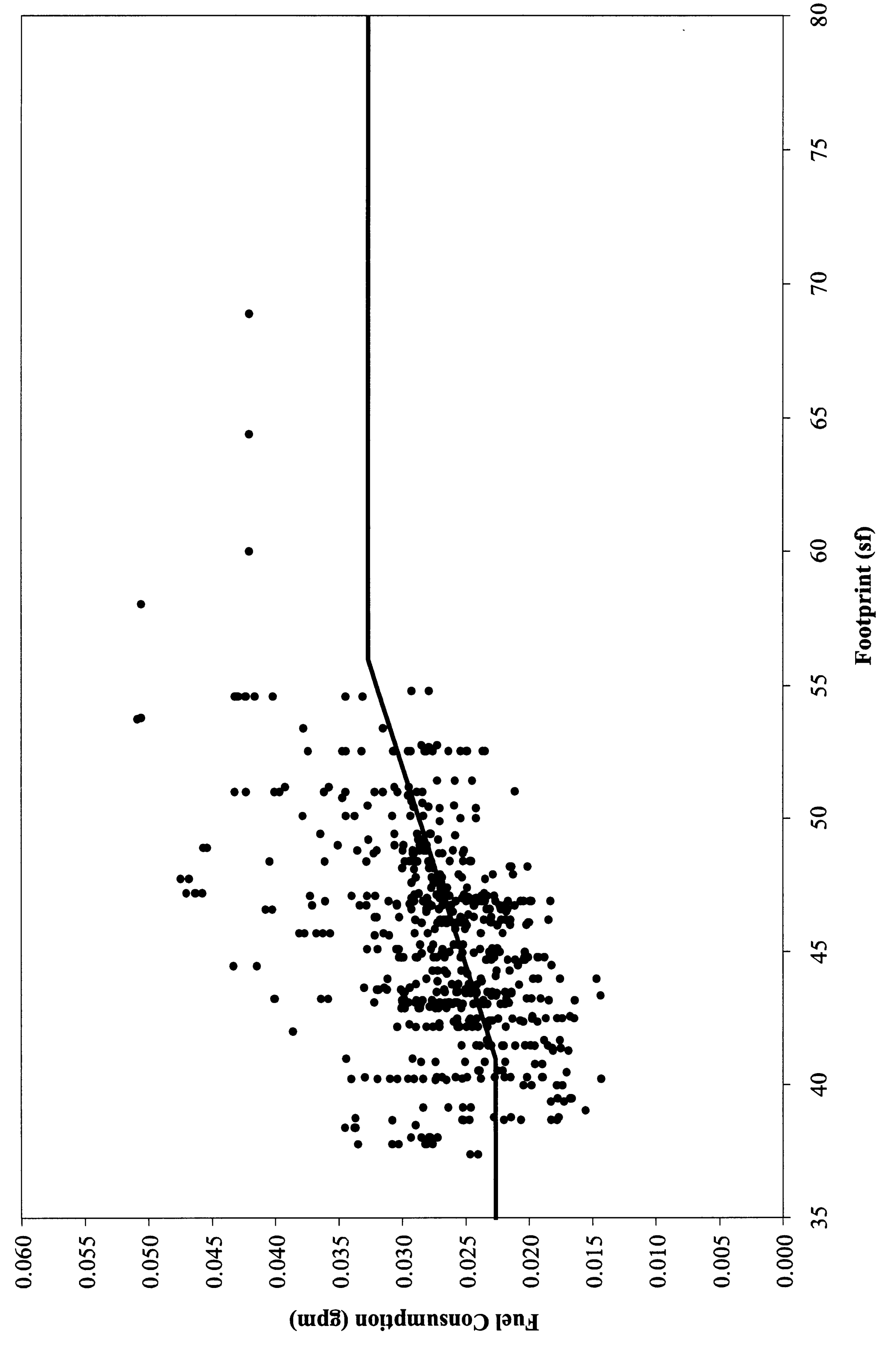

Figure II.C-5 Revised "Maximum Technology" Passenger Fleet with Fitted Constrained Linear Function

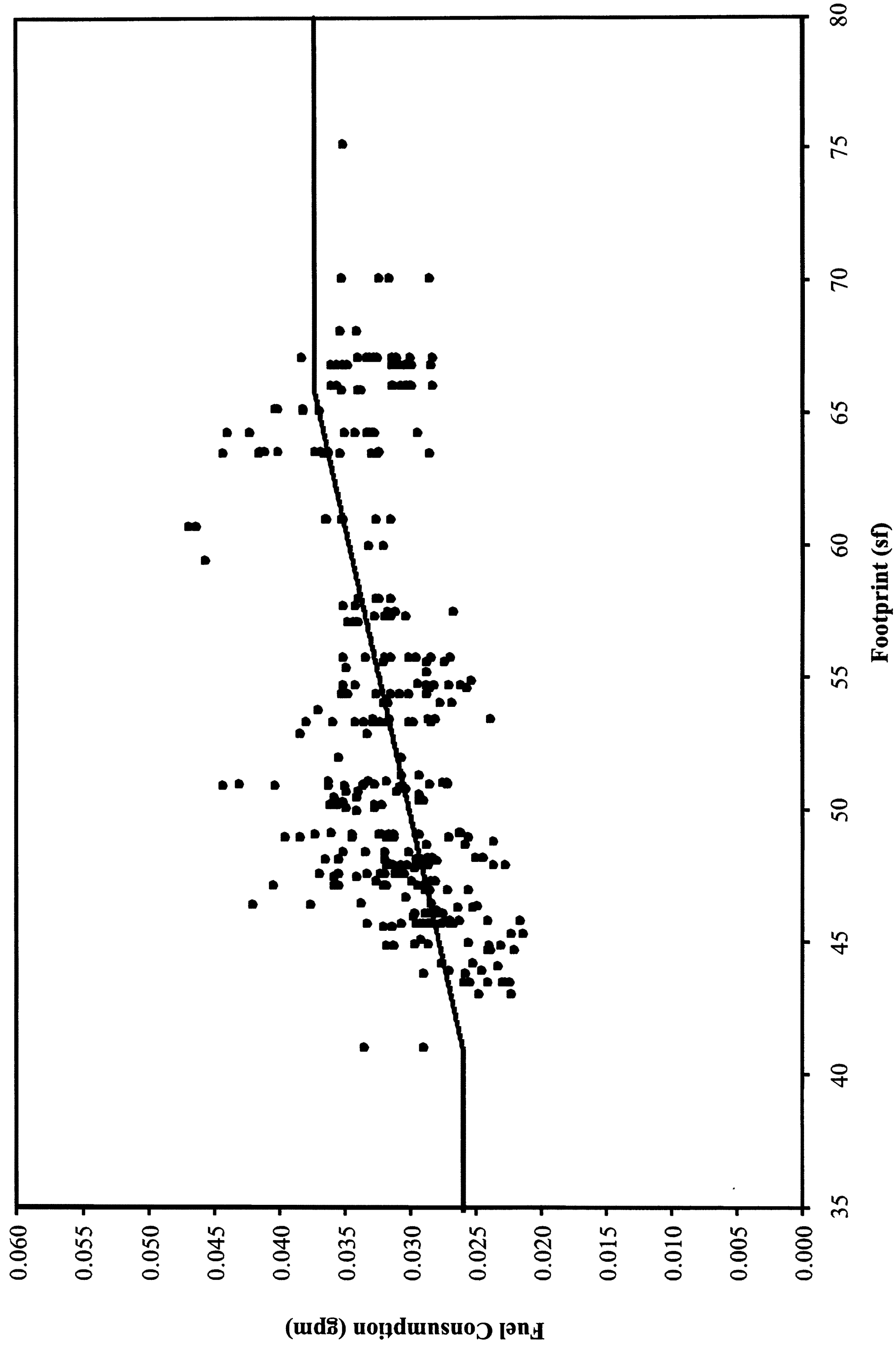

Figure II.C-6 Revised "Maximum Technology" Light Truck with Fitted Constrained Linear Function

This refitted passenger car curve is similar to that presented in the NPRM, and the refitted light truck curve is nearly identical to the corresponding curve in the NPRM. However, the slope of the refitted passenger car curve is about 27 percent steeper (on a gpm per sf basis) than the curve presented in the NPRM. For passenger cars and light trucks, respectively, Figures II.C–7 and II.C–8 show the results of adjustment—discussed in the next section—of the above curves to yield the average required fuel economy levels corresponding to the final standards.

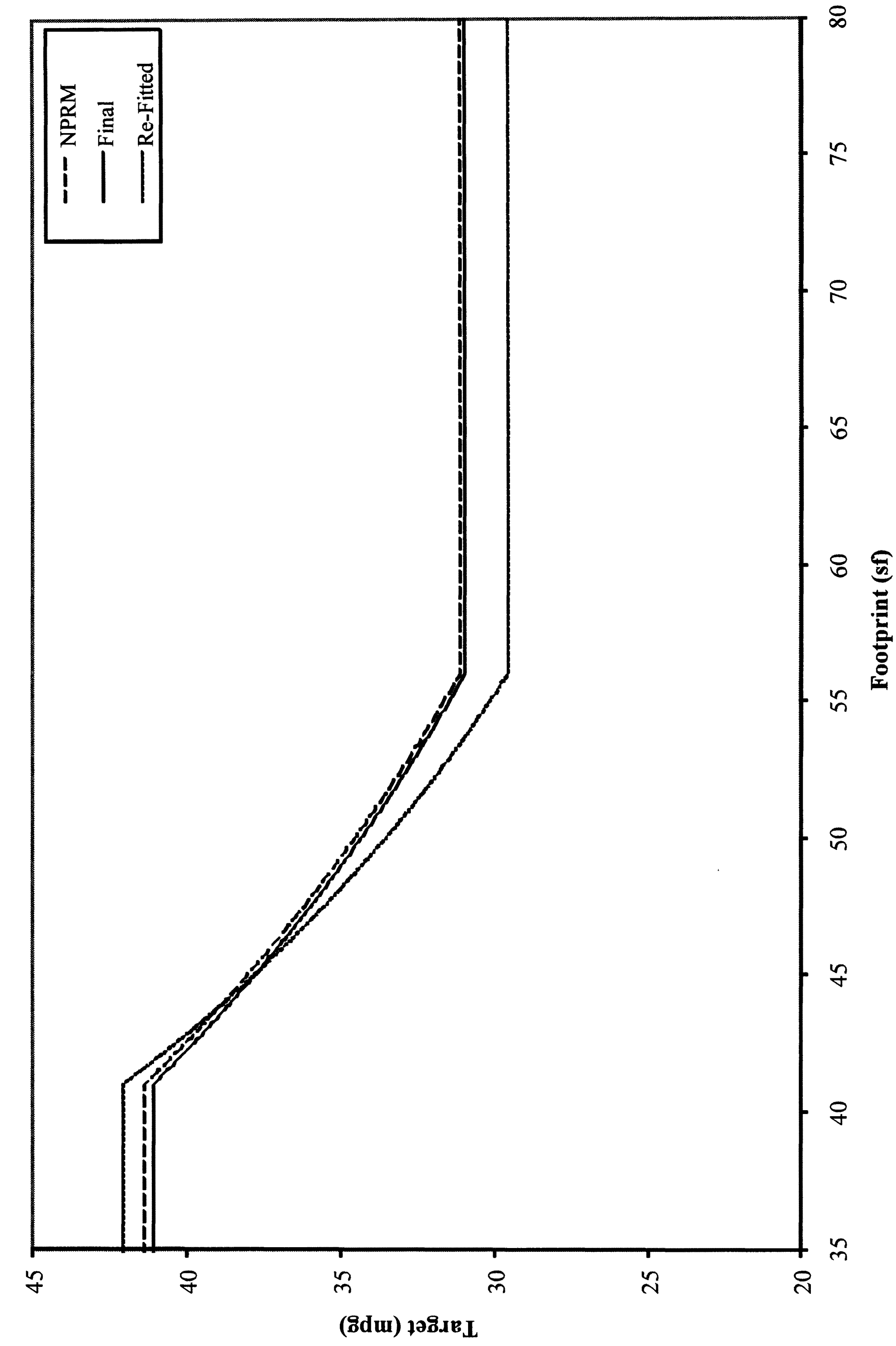

Figure II.C-7 MY 2016 Passenger Car Targets: NPRM, Final Rule, and if Using Re-Fitted Curve

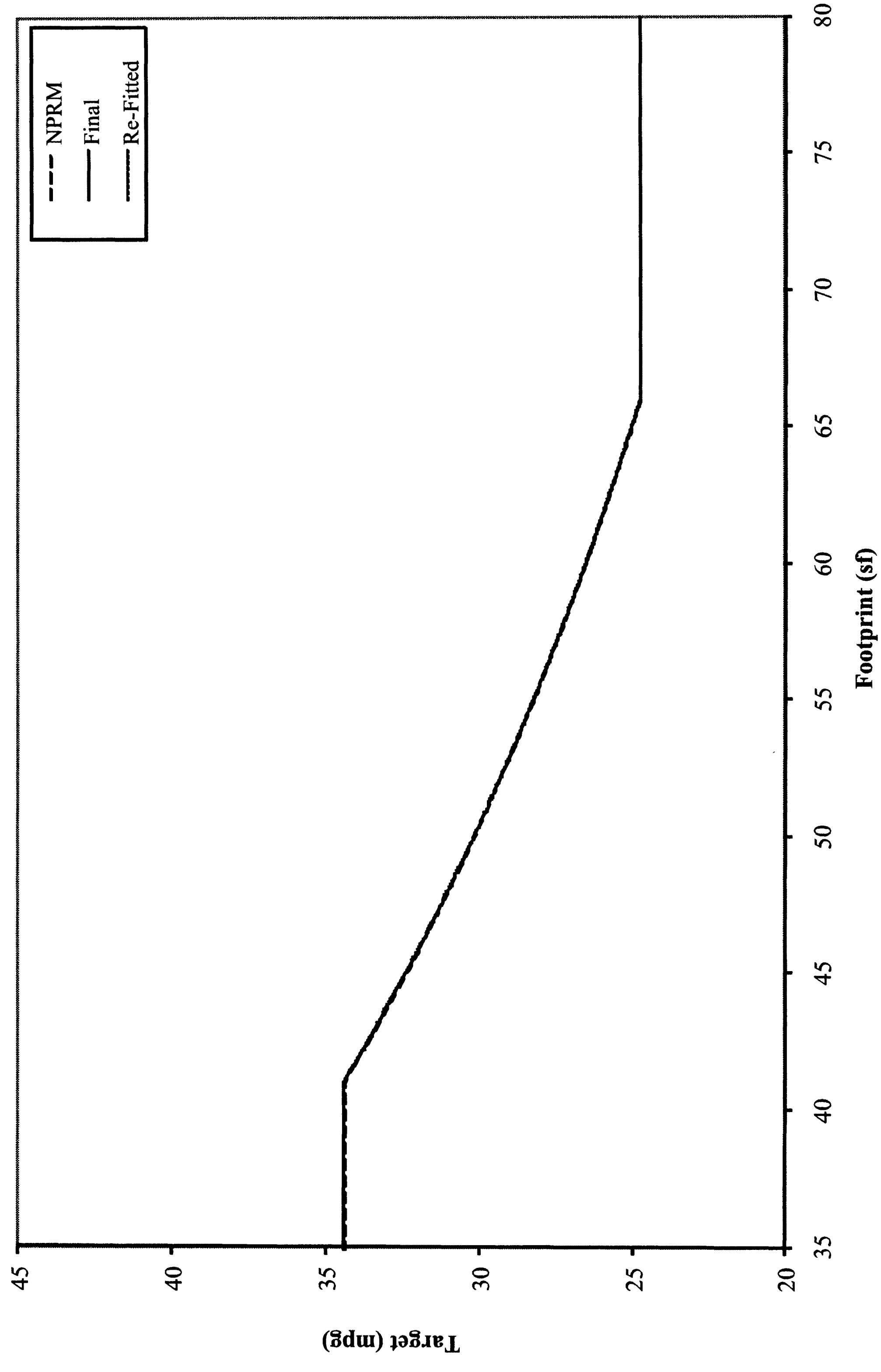

Figure II.C-8 MY 2016 Light Truck Targets: NPRM, Final Rule, and if Using Re-Fitted Curve

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While the resultant light truck curves are visually indistinguishable from one another, the refitted curve for passenger cars would increase stringency for the smallest cars, decrease stringency for the largest cars, and provide a greater incentive to increase vehicle size throughout the range of footprints within which NHTSA and EPA project most passenger car models will be sold through MY 2016. The agencies are concerned that these changes would make it unduly difficult for manufacturers to introduce new small passenger cars in the United States, and unduly risk losses in energy and environmental benefits by increasing incentives for the passenger car market to shift toward larger vehicles.

Also, the agencies note that the refitted passenger car curve produces only a slightly closer fit to the corrected fleet than would the curve estimated in the NPRM; with respect to the corrected fleet (between the "cut off" footprint values, and after the "maximum technology" analysis discussed above), the mean absolute deviation for the refitted curve is 13.887 percent, and that of a refitted curve held to the original slope is 13.933 percent. In other words, the data support the original slope very nearly as well as they support the refitted slope.

Considering NHTSA's and EPA's concerns regarding the change in incentives that would result from a refitted curve for passenger cars, and considering that the data support the original curves about as well as they would support refitted curves, the agencies are finalizing CAFE and GHG standards based on the curves presented in the NPRM.

Finally, regarding some commenters' inability to reproduce the agencies' NPRM analysis, NHTSA believes that its correction of the errors discussed above and its release (on NHTSA's Web site) of the updated Volpe model and all accompanying inputs and external analysis files should enable outside parties to independently reproduce the agencies' analysis. If outside parties continue to experience difficulty in doing so, we encourage them to contact NHTSA, and the agency will do its best to provide assistance.

Thus, in summary, the agencies' approach to developing the attribute-based mathematical functions for MY 2012–2016 CAFE and CO_2 standards represents the agencies' best technical judgment and consideration of potential outcomes at this time, and we are confident that the conclusions have resulted in appropriate and reasonable standards. The agencies recognize, however, that aspects of these decisions may merit updating or revision in future analysis to support CAFE and CO_2 standards or for other purposes. Consistent with best rulemaking practices, the agencies will take a fresh look at all assumptions and approaches to curve fitting, appropriate attributes, and mathematical functions in the context of future rulemakings.

The agencies also recognized in the NPRM the possibility that lower fuel prices could lead to lower fleetwide fuel economy (and higher CO_2 emissions) than projected in this rule. One way of addressing that concern is through the use of a universal standard—that is, an average standard set at a (single) absolute level. This is often described as a "backstop standard." The agencies explained that under the CAFE program, EISA requires such a minimum average fuel economy standard for domestic passenger cars, but is silent with regard to similar backstops for imported passenger cars and light trucks, while under the CAA, a backstop could be adopted under section 202(a) assuming it could be justified under the relevant statutory criteria. NHTSA and EPA also noted that the flattened portions of the curves at the largest footprints directionally address the issue of a backstop (*i.e.,* the mpg "floor" or gpm "ceiling" applied to the curves provides a universal and absolute value for that range of footprints). The agencies sought comment on whether backstop standards, or any other method within the agencies' statutory authority, should and can be implemented in order to guarantee a level of CO_2 emissions reductions and fuel savings under the attribute-based standards.

The agencies received a number of comments regarding the need for a backstop beyond NHTSA's alternative minimum standard. Comments were divided fairly evenly between support for and opposition to additional backstop standards. The following organizations supported the need for EPA and NHTSA to have explicit backstop standards: American Council for an Energy Efficient Economy (ACEEE), American Lung Association, California Air Resources Board (CARB), Environment America, Environment Defense Fund, Massachusetts Department of Environmental Protection, Natural Resources Defense Council (NRDC), Northeast States for Coordinated Air Use Management (NESCAUM), Public Citizen and Safe Climate Campaign, Sierra Club, State of Washington Department of Ecology, Union of Concerned Scientists, and a number of private citizens. Commenters in favor of additional backstop standards for all fleets for both NHTSA and EPA [66] generally stated that the emissions reductions and fuel savings expected to be achieved by MY 2016 depended on assumptions about fleet mix that might not come to pass, and that various kinds of backstop standards or "ratchet mechanisms" [67] were necessary to ensure that those reductions were achieved in fact. In addition, some commenters [68] stated that manufacturers might build larger vehicles or more trucks during MYs 2012–2016 than the agencies project, for example, because (1) any amount of slope in target curves encourages manufacturers to upsize, and (2) lower targets for light trucks than for passenger cars encourage manufacturers to find ways to reclassify vehicles as light trucks, such as by dropping 2WD versions of SUVs and offering only 4WD versions, perhaps spurred by NHTSA's reclassification of 2WD SUVs as passenger cars. Both of these mechanisms will be addressed further below. Some commenters also discussed EPA authority under the CAA to set backstops,[69] agreeing with EPA's analysis that section 202(a) allows such standards since EPA has wide discretion under that section to craft standards.

The following organizations opposed a backstop: Alliance of Automobile Manufacturers (AAM), Association of International Automobile Manufacturers (AIAM), Ford Motor Company, National Automobile Dealers Association (NADA), Toyota Motor Company, and the United Auto Workers Union. Commenters stating that additional backstops would not be necessary disagreed that upsizing was likely,[70] and emphasized the anti-backsliding characteristics of the target curves. Others argued that universal absolute standards as backstops could restrict consumer choice of vehicles. Commenters making legal arguments under EPCA/EISA[71] stated that Congress' silence regarding backstops for imported passenger cars and light trucks should be construed as a lack of authority for NHTSA to create further backstops. Commenters making legal arguments under the CAA[72] focused on the lack of clear authority under the CAA to create multiple GHG emissions standards for the same fleets of vehicles based on the same statutory criteria, and opposed EPA taking steps that would reduce harmonization with NHTSA in standard setting. Furthermore, AIAM indicated that EISA's requirement that the combined (car and truck) fuel economy level reach at least 35 mpg by

[66] ACEEE, American Lung Association, CARB, Christopher Lish, Environment America, EDF, MA DEP, NRDC, NESCAUM, Public Citizen, Sierra Club *et al.,* SCAQMD, UCS, WA DE.

[67] Commenters generally defined a "ratchet mechanism" as an automatic re-calculation of stringency to ensure cumulative goals are reached by 2016, even if emissions reductions and fuel savings fall short in the earlier years covered by the rulemaking.

[68] CBD, MA DEP, NJ DEP, Public Citizen, Sierra Club *et al.,* UCS.

[69] CARB, Public Citizen, Sierra Club *et al.*

[70] For example, the Alliance and Toyota said that upsizing would not be likely because (1) it would not necessarily make compliance with applicable standards easier, since larger vehicles tend to be heavier and heavier vehicles tend to achieve worse fuel economy/emissions levels; (2) it may require expensive platform changes; (3) target curves become increasingly more stringent from year to year, which reduces the benefits of upsizing; and (4) the mpg floor and gpm ceiling for the largest vehicles (the point at which the curve is "cut off") discourages manufacturers from continuing to upsize beyond a point because doing so makes it increasingly difficult to meet the flat standard at that part of the curve.

[71] AIAM, Alliance, Ford, NADA, Toyota.

[72] Alliance, Ford, NADA, UAW.

2020 itself constitutes a backstop.[73] One individual [74] commented that while additional backstop standards might be necessary given optimism of fleet mix assumptions, both agencies' authorities would probably need to be revised by Congress to clarify that backstop standards (whether for individual fleets or for the national fleet as a whole) were permissible.

In response, EPA and NHTSA remain confident that their projections of the future fleet mix are reliable, and that future changes in the fleet mix of footprints and sales are not likely to lead to more than modest changes in projected emissions reductions or fuel savings.[75] Both agencies thus remain confident in these fleet projections and the resulting emissions reductions and fuel savings from the standards. As explained in Section II.B above, the agencies' projections of the future fleet are based on the most transparent information currently available to the agencies. In addition, there are only a relatively few model years at issue. Moreover, market trends today are consistent with the agencies' estimates, showing shifts from light trucks to passenger cars and increased emphasis on fuel economy from all vehicles.

Finally, the shapes of the curves, including the "flattening" at the largest footprint values, tend to avoid or minimize regulatory incentives for manufacturers to upsize their fleet to change their compliance burden. Given the way the curves are fit to the data points (which represent vehicle models' fuel economy mapped against their footprint), the agencies believe that there is little real benefit to be gained by a manufacturer upsizing their vehicles. As discussed above, the agencies' analysis indicates that, for passenger car models with footprints falling between the two flattened portions of the corresponding curve, the actual slope of fuel economy with respect to footprint, if fit to that data by itself, is about 27 percent steeper than the curve the agencies are promulgating today. This difference suggests that manufacturers would, if anything, have more to gain by reducing vehicle footprint than by increasing vehicle footprint. For light trucks, the agencies' analysis indicates that, for models with footprints falling between the two flatted portions of the corresponding curve, the slope of fuel economy with respect to footprint is nearly identical to the curve the agencies are promulgating today. This suggests that, within this range, manufacturers would typically have little incentive to either incrementally increase or reduce vehicle footprint. The agencies recognize that based on economic and consumer demand factors that are external to this rule, the distribution of footprints in the future may be different (either smaller or larger) than what is projected in this rule. However, the agencies continue to believe that there will not be significant shifts in this distribution as a direct consequence of this rule.

At the same time, adding another backstop standard would have virtually no effect if the standard was weak, but a more stringent backstop could compromise the objectives served by attribute-based standards—that they distribute compliance burdens more equally among manufacturers, and at the same time encourage manufacturers to apply fuel-saving technologies rather than simply downsizing their vehicles, as they did in past decades under flat standards. This is why Congress mandated attribute-based CAFE standards in EISA. This compromise in objectives could occur for any manufacturer whose fleet average was above the backstop, irrespective of why they were above the backstop and irrespective of whether the industry as a whole was achieving the emissions and fuel economy benefits projected for the final standards, the problem the backstop is supposed to address. For example, the projected industry wide level of 250 gm/mile for MY 2016 is based on a mix of manufacturer levels, ranging from approximately 205 to 315 gram/mile [76] but resulting in an industry wide basis in a fleet average of 250 gm/mile. Unless the backstop was at a very weak level, above the high end of this range, then some percentage of manufacturers would be above the backstop even if the performance of the entire industry remains fully consistent with the emissions and fuel economy levels projected for the final standards. For these manufacturers and any other manufacturers who were above the backstop, the objectives of an attribute based standard would be compromised and unnecessary costs would be imposed. This could directionally impose increased costs for some manufacturers. It would be difficult if not impossible to establish the level of a backstop standard such that costs are likely to be imposed on manufacturers only when there is a failure to achieve the projected reductions across the industry as a whole. An example of this kind of industry wide situation could be when there is a significant shift to larger vehicles across the industry as a whole, or if there is a general market shift from cars to trucks. The problem the agencies are concerned about in those circumstances is not with respect to any single manufacturer, but rather is based on concerns over shifts across the fleet as a whole, as compared to shifts in one manufacturer's fleet that may be more than offset by shifts the other way in another manufacturer's fleet. However, in this respect, a traditional backstop acts as a manufacturer specific standard.

The concept of a ratchet mechanism recognizes this problem, and would impose the new more stringent standard only when the problem arises across the industry as a whole. While the new more stringent standards would enter into force automatically, any such standards would still need to provide adequate lead time for the manufacturers. Given the limited number of model years covered by this rulemaking and the short lead-time already before the 2012 model year, a ratchet mechanism in this rulemaking that would automatically tighten the standards at some point after model year 2012 is finished and apply the new more stringent standards for model

[73] NHTSA and EPA agree with AIAM that the EISA 35 mpg requirement in MY 2020 has a backstop-like function, in that it requires a certain level of achieved fleetwide fuel economy by a certain date, although it is not literally a backstop standard. Considering that NHTSA's MY 2011 CAFE standards increased projected average fuel economy requirements (relative to the MY 2010 standards) at a significantly faster rate than would be required to achieve the 35-in-2020 requirement, and considering that the standards being finalized today would increase projected average combined fuel economy requirements to 34.1 mpg in MY 2016, four years before MY 2020, the agencies believe that the U.S. vehicle market would have to shift in highly unexpected ways in order to put the 35-in-2020 requirement at risk, even despite the fact that due to the attribute-based standards, average fuel economy requirements will vary depending on the mix of vehicles produced for sale in the U.S. in each model year. The agencies further emphasize that both NHTSA and EPA plan to conduct and document retrospective analyses to evaluate how the market's evolution during the rulemaking timeframe compares with the agencies' forecasts employed for this rulemaking. Additionally, we emphasize that both agencies have the authority, given sufficient lead time, to revise their standards upwards if necessary to avoid missing the 35-in-2020 requirement.

[74] Schade.

[75] For reference, NHTSA's March 2009 final rule establishing MY 2011 CAFE standards was based on a forecast that passenger cars would represent 57.6 percent of the MY 2011 fleet, and that MY 2011 passenger cars and light trucks would average 45.6 square feet (sf) and 55.1 sf, respectively, such that average required CAFE levels would be 30.2 mpg, 24.1 mpg, and 27.3 mpg, respectively, for passenger cars, light trucks, and the overall light-duty fleet. Based on the agencies' current market forecast, even as soon as MY 2011, passenger cars will comprise a *larger* share (59.2 percent) of the light vehicle market; passenger cars and light trucks will, on average, be smaller by 0.5 sf and 1.3 sf, respectively; and average required CAFE levels will be higher by 0.2 mpg, 0.3 mpg, and 0.3 mpg, respectively, for passenger cars, light trucks, and the overall light-duty fleet.

[76] Based on estimated standards presented in Tables III.B.1–1 and III.B.1–2.

years 2016 or earlier, would fail to provide adequate lead time for any new, more stringent standards

Additionally, we do not believe that the risk of vehicle upsizing or changing vehicle offerings to "game" the passenger car and light truck definitions is as great as commenters imply for the model years in question.[77] The changes that commenters suggest manufacturers might make are neither so simple nor so likely to be accepted by consumers. For example, 4WD versions of vehicles tend to be more expensive and, other things being equal, have inherently lower fuel economy than their 2WD equivalent models. Therefore, although there is a market for 4WD vehicles, and some consumers might shift from 2WD vehicles to 4WD vehicles if 4WD becomes available at little or no extra cost, many consumers still may not desire to purchase 4WD vehicles because of concerns about cost premium and additional maintenance requirements; conversely, many manufacturers often require the 2WD option to satisfy demand for base vehicle models. Additionally, increasing the footprint of vehicles requires platform changes, which usually requires a product redesign phase (the agencies estimate that this occurs on average once every 5 years for most models). Alternatively, turning many 2WD SUVs into 2WD light trucks would require manufacturers to squeeze a third row of seats in or significantly increase their GVWR, which also requires a significant change in the vehicle.[78] The agencies are confident that the anticipated increases in average fuel economy and reductions in average CO_2 emission rates can be achieved without backstops under EISA or the CAA. As noted above, the agencies plan to conduct retrospective analysis to monitor progress. Both agencies have the authority to revise standards if warranted, as long as sufficient lead time is provided.

The agencies acknowledge that the MY 2016 fleet emissions and fuel economy goals of 250 g/mi and 34.1 mpg for EPA and NHTSA respectively are estimates and not standards (the MY 2012–2016 curves are the standards). Changes in fuel prices, consumer preferences, and/or vehicle survival and mileage accumulation rates could result in either smaller or larger oil and GHG savings. As explained above and elsewhere in the rule, the agencies believe that the possibility of not meeting (or, alternatively, exceeding) fuel economy and emissions goals exists, but is not likely. Given this, and given the potential complexities in designing an appropriate backstop, the agencies believe the balance here points to not adopting additional backstops at this time for the MYs 2012–2016 standards other than NHTSA's finalizing of the ones required by EPCA/EISA for domestic passenger cars. Nevertheless, the agencies recognize there are many factors that are inherently uncertain which can affect projections in the future, including fuel price and other factors which are unrelated to the standards contained in this final rule. Such factors can affect consumer preferences and are difficult to predict. At this time and based on the available information, the agencies have not included a backstop for model years 2012–2016. However, if circumstances change in the future in unanticipated ways, the agencies may revisit the issue of a backstop in the context of a future rulemaking either for model years 2012–2016 or as needed for standards for model years beyond 2016. This issue will be discussed further in Sections III and IV.

D. Relative Car-Truck Stringency

The agencies proposed fleetwide standards with the projected levels of stringency of 34.1 mpg or 250 g/mi in MY 2016 (as well as the corresponding intermediate year fleetwide standards) for NHTSA and EPA respectively. To determine the relative stringency of passenger car and light truck standards for those model years, the agencies were concerned that increasing the difference between the car and truck standards (either by raising the car standards or lowering the truck standards) could encourage manufacturers to build fewer cars and more trucks, likely to the detriment of fuel economy and CO_2 reductions.[79] In order to maintain consistent car/truck standards, the agencies applied a constant ratio between the estimated average required performance under the passenger car and light truck standards, in order to maintain a stable set of incentives regarding vehicle classification.

To calculate relative car-truck stringency for the proposal, the agencies explored a number of possible alternatives, and for the reasons described in the proposal used the Volpe model in order to estimate stringencies at which net benefits would be maximized. The agencies have followed the same approach in calculating the relative car-truck stringency for the final standards promulgated today. Further details of the development of this approach can be found in Section IV of this preamble as well as in NHTSA's RIA and EIS. NHTSA examined passenger car and light truck standards that would produce the proposed combined average fuel economy levels from Table I.B.2–2 above. NHTSA did so by shifting downward the curves that maximize net benefits, holding the relative stringency of passenger car and light truck standards constant at the level determined by maximizing net benefits, such that the average fuel economy required of passenger cars remained 31 percent higher than the average fuel economy required of light trucks. This methodology resulted in the average fuel economy levels for passenger cars and light trucks during MYs 2012–2016 as shown in Table I.B.1–1. The following chart illustrates this methodology of shifting the standards from the levels maximizing net benefits to the levels consistent with the combined fuel economy standards in this final rule.

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[77] We note that NHTSA's recent clarification of the light truck definitions has significantly reduced the potential for gaming, and resulted in the reclassification of over a million vehicles from the light truck to the passenger car fleet.

[78] Increasing the GVWR of a light truck (assuming this was the only goal) can be accomplished in a number of ways, and must include consideration of: (1) Redesign of wheel axles; (2) improving the vehicle suspension; (3) changes in tire specification (which will likely affect ride quality); (4) vehicle dynamics development (especially with vehicles equipped with electronic stability control); and (5) brake redesign. Depending on the vehicle, some of these changes may be easier or more difficult than others.

[79] For example, since many 2WD SUVs are classified as passenger cars, manufacturers have already warned that high car standards relative to truck standards could create an incentive for them to drop the 2WD version and sell only the 4WD version.

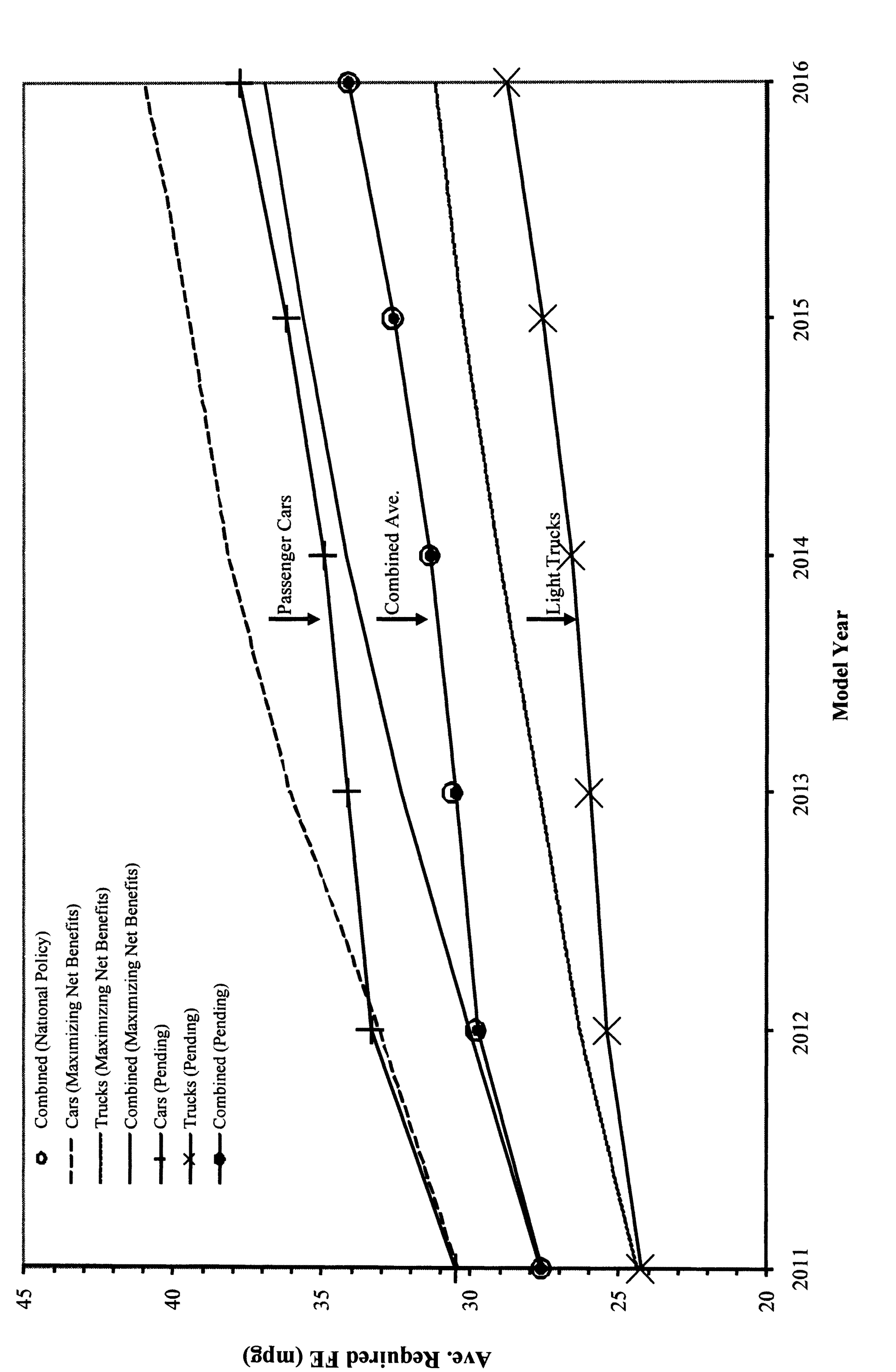

Figure II.D-1 Shifting the Standards from the Maximizing Net Benefit Levels to the Levels Consistent with the Combined Fuel Economy Standards in this Rule

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The final car and truck standards for EPA (Table I.B.1–4 above) were subsequently determined by first converting the average required fuel economy levels to average required CO_2 emission rates, and then applying the expected air conditioning credits for 2012–2016. These A/C credits are shown in the following table. Further details of the derivation of these factors can be found in Section III of this preamble or in the EPA RIA.

[80] We assume slightly higher A/C penetration in 2012 than was assumed in the proposal only to

Continued

TABLE II.D–1 EXPECTED FLEET A/C CREDITS (IN CO_2 EQUIVALENT g/mi) FROM 2012–2016

	Average technology penetration (%)	Average credit for cars	Average credit for trucks	Average credit for combined fleet
2012	[80] 28	3.4	3.8	3.5
2013	40	4.8	5.4	5.0
2014	60	7.2	8.1	7.5
2015	80	9.6	10.8	10.0
2016	85	10.2	11.5	10.6

The agencies sought comment on the use of this methodology for apportioning the fleet stringencies to relative car and truck standards for 2012–2016. General Motors commented that, compared to the passenger car standard, the light truck standard is too stringent because "the most fuel efficient cars and small trucks already meet the 2016 MY requirements" but "the most fuel efficient large trucks must increase fuel economy by 20 percent to meet the 2016 MY requirements." GM recommended that the agencies relax stringency specifically for large pickups, such as the Silverado.

The agencies disagree with the premise of the comment that the standard is too stringent under the applicable statutory provisions because some existing large trucks are not already meeting a later model year standard. Our analysis shows that the standards are not too stringent for manufacturers selling these vehicles. The agencies' analyses demonstrate a means by which manufacturers could apply cost-effective technologies in order to achieve the standards, and we have provided adequate lead time for the technology to be applied. More important, the agencies' analysis demonstrate that the fleetwide emission standards for MY 2016 are technically feasible, for example by implementing technologies such as engine downsizing, turbocharging, direct injection, improving accessories and tire rolling resistance, etc.

GM did not comment on the use of the methodology applied by the agencies to develop the gap between the passenger car and light truck standards—only on the outcome of the methodology. For the reasons discussed below, the agencies maintain that the methodology applied above provides an appropriate basis to determine the gap between the passenger car and light truck standards, and disagree with GM's arguments that the outcome is unfair.

First, GM's argument incorrectly suggests that every individual vehicle model must achieve its fuel economy and emissions targets. CAFE standards and new GHG emissions standards apply to fleetwide average performance, not model-specific performance, even though average required levels are based on average model-specific targets, and the agencies' analysis demonstrates that GM and other manufacturers of large trucks can cost-effectively comply with the new standards.

Second, GM implies that every manufacturer must be challenged equally with respect to fuel economy and emissions. Although NHTSA and EPA maintain that attribute-based CAFE and GHG emissions standards can more evenly balance compliance challenges, attribute-based standards are not intended to and cannot make these challenges equal, and while the agencies are mindful of the potential impacts of the standards on the relative competitiveness of different vehicle manufacturers, there is nothing in EPCA or the CAA [81] requiring that these challenges be equal.

We have also already addressed and rejected GM's suggestion of shifting the "cut off" point for light trucks from 66 square feet to 72 square feet, thereby "dropping the floor" of the target function for light trucks. As discussed in the preceding section, this is so as not to forego the rules' energy and environmental benefits, and because there is little or no safety basis to discourage downsizing of the largest light trucks.

Finally, NHTSA and EPA disagree with GM's claim that the outcome of the agencies' approach is unfairly burdensome for light trucks as compared to passenger cars. Based on the agencies' market forecast, NHTSA's analysis indicates that incremental technology outlays could, on average, be comparable for passenger cars and light trucks under the final CAFE standards, and further indicates that the ratio of total benefits to total costs could be greater under the final light truck standards than under the final passenger car standards.

E. Joint Vehicle Technology Assumptions

Vehicle technology assumptions, *i.e.,* assumptions about technologies' cost, effectiveness, and the rate at which they can be incorporated into new vehicles, are often controversial as they have a significant impact on the levels of the standards. The agencies must, therefore, take great care in developing and justifying these estimates. In developing technology inputs for the analysis of the MY 2012–2016 standards, the agencies reviewed the technology assumptions that NHTSA used in setting the MY 2011 standards, the comments that NHTSA received in response to its May 2008 Notice of Proposed Rulemaking (NPRM), and the comments received in response to the NPRM for this rule. This review is consistent with the request by President Obama in his January 26 memorandum to DOT. In addition, the agencies reviewed the technology input

correct for rounding that occurred in the curve setting process.

[81] As NHTSA explained in the NPRM, the Conference Report for EPCA, as enacted in 1975, makes clear, and the case law affirms, "a determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy." *CEI–I,* 793 F.2d 1322, 1352 (D.C. Cir. 1986). Instead, NHTSA is compelled "to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers." *Id.* The law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole. Similarly, EPA is afforded great discretion under section 202(a) of the CAA to balance issues of technical feasibility, cost, adequacy of lead time, and safety, and certainly is not required to do so in a manner that imposes regulatory obligations uniformly on each manufacturer. *See NRDC* v. *EPA,* 655 F. 2d 318, 322, 328 (D.C. Cir. 1981) (wide discretion afforded by the statutory factors, and EPA predictions of technical feasibility afforded considerable discretion subject to constraints of reasonableness EPA predictions of technical feasibility afforded considerable discretion subject to constraints of reasonableness); and cf. *International Harvester Co.* v. *Ruckelshaus,* 479 F. 2d 615, 640 (D.C. Cir. 1973) ("as long as feasible technology permits the demand for new passenger automobiles to be generally met, the basic requirements of the Act would be satisfied, even though this might occasion fewer models and a more limited choice of engine types").

estimates identified in EPA's July 2008 Advance Notice of Proposed Rulemaking. The review of these documents was supplemented with updated information from more current literature, new product plans from manufacturers, and from EPA certification testing.

As a general matter, EPA and NHTSA believe that the best way to derive technology cost estimates is to conduct real-world tear down studies. Most of the commenters on this issue agreed. The advantages not only lie in the rigor of the approach, but also in its transparency. These studies break down each technology into its respective components, evaluate the costs of each component, and build up the costs of the entire technology based on the contribution of each component and the processes required to integrate them. As such, tear down studies require a significant amount of time and are very costly. EPA has been conducting tear down studies to assess the costs of vehicle technologies under a contract with FEV. Further details for this methodology is described below and in the TSD.

Due to the complexity and time incurred in a tear down study, only a few technologies evaluated in this rulemaking have been costed in this manner thus far. The agencies prioritized the technologies to be costed first based on how prevalent the agencies believed they might be likely to be during the rulemaking time frame, and based on their anticipated cost-effectiveness. The agencies believe that the focus on these important technologies (listed below) is sufficient for the analysis in this rule, but EPA is continuing to analyze more technologies beyond this rule as part of studies both already underway and in the future. For most of the other technologies, because tear down studies were not yet available, the agencies decided to pursue, to the extent possible, the Bill of Materials (BOM) approach as outlined in NHTSA's MY 2011 final rule. A similar approach was used by EPA in the EPA 2008 Staff Technical Report. This approach was recommended to NHTSA by Ricardo, an international engineering consulting firm retained by NHTSA to aid in the analysis of public comments on its proposed standards for MYs 2011–2015 because of its expertise in the area of fuel economy technologies. A BOM approach is one element of the process used in tear down studies. The difference is that under a BOM approach, the build up of cost estimates is conducted based on a review of cost and effectiveness estimates for each component from available literature, while under a tear down study, the cost estimates which go into the BOM come from the tear down study itself. To the extent that the agencies departed from the MY 2011 CAFE final rule estimates, the agencies explained the reasons and provided supporting analyses in the Technical Support Document.

Similarly, the agencies followed a BOM approach for developing the technology effectiveness estimates, insofar as the BOM developed for the cost estimates helped to inform the appropriate effectiveness values derived from the literature review. The agencies supplemented the information with results from available simulation work and real world EPA certification testing.

The agencies would also like to note that per the Energy Independence and Security Act (EISA), the National Academies of Sciences has been conducting a study for NHTSA to update Chapter 3 of their 2002 NAS Report, which presents technology effectiveness estimates for light-duty vehicles. The update takes a fresh look at that list of technologies and their associated cost and effectiveness values. The updated NAS report was expected to be available on September 30, 2009, but has not been completed and released to the public. The results from this study thus are unavailable for this rulemaking. The agencies look forward to considering the results from this study as part of the next round of rulemaking for CAFE/GHG standards.

1. What technologies did the agencies consider?

The agencies considered over 35 vehicle technologies that manufacturers could use to improve the fuel economy and reduce CO_2 emissions of their vehicles during MYs 2012–2016. The majority of the technologies described in this section are readily available, well known, and could be incorporated into vehicles once production decisions are made. Other technologies considered may not currently be in production, but are beyond the research phase and under development, and are expected to be in production in the next few years. These are technologies which can, for the most part, be applied both to cars and trucks, and which are capable of achieving significant improvements in fuel economy and reductions in CO_2 emissions, at reasonable costs. The agencies did not consider technologies in the research stage because the lead time available for this rule is not sufficient to move most of these technologies from research to production.

The technologies considered in the agencies' analysis are briefly described below. They fall into five broad categories: Engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, and hybrid technologies. For a more detailed description of each technology and their costs and effectiveness, we refer the reader to Chapter 3 of the Joint TSD, Chapter III of NHTSA's FRIA, and Chapter 1 of EPA's final RIA. Technologies to reduce CO_2 and HFC emissions from air conditioning systems are discussed in Section III of this preamble and in EPA's final RIA.

Types of engine technologies that improve fuel economy and reduce CO_2 emissions include the following:

Low-friction lubricants—low viscosity and advanced low friction lubricants oils are now available with improved performance and better lubrication. If manufacturers choose to make use of these lubricants, they would need to make engine changes and possibly conduct durability testing to accommodate the low-friction lubricants.

Reduction of engine friction losses—can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve engine operation.

Conversion to dual overhead cam with dual cam phasing—as applied to overhead valves designed to increase the air flow with more than two valves per cylinder and reduce pumping losses.

Cylinder deactivation—deactivates the intake and exhaust valves and prevents fuel injection into some cylinders during light-load operation. The engine runs temporarily as though it were a smaller engine which substantially reduces pumping losses.

Variable valve timing—alters the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control residual gases.

Discrete variable valve lift—increases efficiency by optimizing air flow over a broader range of engine operation which reduces pumping losses. Accomplished by controlled switching between two or more cam profile lobe heights.

Continuous variable valve lift—is an electromechanically controlled system in which valve timing is changed as lift height is controlled. This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled.

Stoichiometric gasoline direct-injection technology—injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency.

Combustion restart—can be used in conjunction with gasoline direct-injection systems to enable idle-off or start-stop functionality. Similar to other start-stop technologies, additional enablers, such as electric power steering, accessory drive components, and auxiliary oil pump, might be required.

Turbocharging and downsizing—increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. This reduces pumping losses at lighter loads in comparison to a larger engine.

Exhaust-gas recirculation boost—increases the exhaust-gas recirculation used in the combustion process to increase thermal efficiency and reduce pumping losses.

Diesel engines—have several characteristics that give superior fuel efficiency, including reduced pumping losses due to lack of (or greatly reduced) throttling, and a combustion cycle that operates at a higher compression ratio, with a very lean air/fuel mixture, relative to an equivalent-performance gasoline engine. This technology requires additional enablers, such as NO_X trap catalyst after-treatment or selective catalytic reduction NO_X after-treatment. The cost and effectiveness estimates for the diesel engine and aftertreatment system utilized in this final rule have been revised from the NHTSA MY 2011 CAFE final rule. Additionally, the diesel technology option has been made available to small cars in the Volpe and OMEGA models. Though this is not expected to make a significant difference in the modeling results, the agencies agreed with the commenters that supported such a revision.

Types of transmission technologies considered include:

Improved automatic transmission controls— optimizes shift schedule to maximize fuel efficiency under wide ranging conditions, and minimizes losses associated with torque converter slip through lock-up or modulation.

Six-, seven-, and eight-speed automatic transmissions—the gear ratio spacing and transmission ratio are optimized to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions.

Dual clutch or automated shift manual transmissions—are similar to manual transmissions, but the vehicle controls shifting and launch functions. A dual-clutch automated shift manual transmission uses separate clutches for even-numbered and odd-numbered gears, so the next expected gear is pre-selected, which allows for faster and smoother shifting.

Continuously variable transmission—commonly uses V-shaped pulleys connected by a metal belt rather than gears to provide ratios for operation. Unlike manual and automatic transmissions with fixed transmission ratios, continuously variable transmissions can provide fully variable and an infinite number of transmission ratios that enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions.

Manual 6-speed transmission—offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission.

Types of vehicle technologies considered include:

Low-rolling-resistance tires—have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, thereby improving fuel economy and reducing CO_2 emissions.

Low-drag brakes—reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors.

Front or secondary axle disconnect for four-wheel drive systems—provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses.

Aerodynamic drag reduction—is achieved by changing vehicle shape or reducing frontal area, including skirts, air dams, underbody covers, and more aerodynamic side view mirrors.

Mass reduction and material substitution—Mass reduction encompasses a variety of techniques ranging from improved design and better component integration to application of lighter and higher-strength materials. Mass reduction is further compounded by reductions in engine power and ancillary systems (transmission, steering, brakes, suspension, etc.). The agencies recognize there is a range of diversity and complexity for mass reduction and material substitution technologies and there are many techniques that automotive suppliers and manufacturers are using to achieve the levels of this technology that the agencies have modeled in our analysis for the final standards.

Types of electrification/accessory and hybrid technologies considered include:

Electric power steering (EPS)—is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive.

Improved accessories (IACC)—may include high efficiency alternators, electrically driven (*i.e.,* on-demand) water pumps and cooling fans. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors. The latter is covered explicitly within the A/C credit program.

Air Conditioner Systems—These technologies include improved hoses, connectors and seals for leakage control. They also include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving tailpipe CO_2 emissions as a result of A/C use. These technologies are discussed later in this preamble and covered separately in the EPA RIA.

12-volt micro-hybrid (MHEV)—also known as idle-stop or start-stop and commonly implemented as a 12-volt belt-driven integrated starter-generator, this is the most basic hybrid system that facilitates idle-stop capability. Along with other enablers, this system replaces a common alternator with a belt-driven enhanced power starter-alternator, and a revised accessory drive system.

Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)—provides idle-stop capability and uses a higher voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator, that is belt driven and that can recover braking energy while the vehicle slows down (regenerative braking).

Integrated Motor Assist (IMA)/Crank integrated starter generator (CISG)—provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the wiring harness. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator that is crankshaft mounted and can recover braking energy while the vehicle slows down (regenerative braking).

2-mode hybrid (2MHEV)—is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO_2 emissions at highway speeds relative to other types of hybrid electric drive systems.

Power-split hybrid (PSHEV)—a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and a motor/generator. This motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. A second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels. The planetary gear splits engine power between the first motor/generator and the drive motor to either charge the battery or supply power to the wheels.

Plug-in hybrid electric vehicles (PHEV)—are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs with more energy storage and a greater capability to be discharged than other hybrids. They also use a control system that allows the battery pack to be substantially depleted under electric-only or blended mechanical/electric operation.

Electric vehicles (EV)—are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged primarily from grid electricity.

The cost estimates for the various hybrid systems have been revised from the estimates used in the MY 2011 CAFE final rule, in particular with respect to estimated battery costs.

2. How did the agencies determine the costs and effectiveness of each of these technologies?

As mentioned above, EPA and NHTSA believe that the best way to derive technology cost estimates is to conduct real-world tear down studies. To date, the costs of the following five technologies have been evaluated with respect to their baseline (or replaced) technologies. For these technologies noted below, the agencies relied on the tear down data available and scaling methodologies used in EPA's ongoing study with FEV. Only the cost estimate for the first technology on the list below was used in the NPRM. The others were completed subsequent to the publication of the NPRM.

1. Stoichiometric gasoline direct injection and turbo charging with engine downsizing (T–DS) for a large DOHC 4 cylinder engine to a small DOHC (dual overhead cam) 4 cylinder engine.
2. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a SOHC single overhead cam) 3 valve/cylinder V8 engine to a SOHC V6 engine.
3. Stoichiometric gasoline direct injection and turbo charging with engine downsizing for a DOHC V6 engine to a DOHC 4 cylinder engine.
4. 6-speed automatic transmission replacing a 5-speed automatic transmission.
5. 6-speed wet dual clutch transmission (DCT) replacing a 6-speed automatic transmission.

This costing methodology has been published and gone through a peer review.[82] Using this tear down costing methodology, FEV has developed costs for each of the above technologies. In addition, FEV and EPA extrapolated the engine downsizing costs for the following scenarios that were outside of the noted study cases:[83]

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
2. Downsizing a DOHC V8 to a DOHC V6.
3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
4. Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

The agencies relied on the findings of FEV in part for estimating the cost of these technologies in this rulemaking. However, for some of the technologies, NHTSA and EPA modified FEV's estimated costs. FEV made the assumption that these technologies would be mature when produced in large volumes (450,000 units or more). The agencies believe that there is some uncertainty regarding each manufacturer's near-term ability to employ the technology at the volumes assumed in the FEV analysis. There is also the potential for near term (earlier than 2016) supplier-level Engineering, Design and Testing (ED&T) costs to be in excess of those considered in the FEV analysis as existing equipment and facilities are converted to production of new technologies. The agencies have therefore decided to average the FEV results with the NPRM values in an effort to account for these near-term factors. This methodology was done for the following technologies:

1. Converting a port-fuel injected (PFI) DOHC I4 to a turbocharged-downsized-stoichiometric GDI DOHC I3.
2. Converting a PFI DOHC V6 engine to a T–DS-stoichiometric GDI DOHC I4.
3. Converting a PFI SOHC V6 engine to a T–DS-stoichiometric GDI DOHC I4.
4. Converting a PFI DOHC V8 engine to a T–DS-stoichiometric GDI DOHC V6.
5. Converting a PFI SOHC 3V V8 engine to a T–DS-stoichiometric GDI DOHC V6.
6. Converting a PFI SOHC 2V V8 engine to a T–DS-stoichiometric GDI DOHC V6.
7. Replacing a 4-speed automatic transmission with a 6-speed automatic transmission.
8. Replacing a 5-speed automatic transmission with a 6-speed automatic transmission.
9. Replacing a 6-speed automatic transmission with a 6-speed wet dual clutch transmission.

For the I4 to Turbo GDI I4 study applied in the NPRM, the agencies requested from FEV an adjusted cost estimate which accounted for these uncertainties as an adjustment to the base technology burden rate.[84] These new costs are used in the final rules. These details are also further described in the memo to the docket.[85] The confidential information provided by manufacturers as part of their product plan submissions to the agencies or discussed in meetings between the agencies and the manufacturers and

[82] EPA–420–R–09–020; EPA docket number EPA–HQ–OAR–2009–0472–11282 and 11285.

[83] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA–HQ–OAR–2009–0472, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

[84] Burden costs include the following fixed and variable costs: Rented and leased equipment; manufacturing equipment depreciation; plant office equipment depreciation; utilities expense; insurance (fire and general); municipal taxes; plant floor space (equipment and plant offices); maintenance of manufacturing equipment—non-labor; maintenance of manufacturing building—general, internal and external, parts, and labor; operating supplies; perishable and supplier-owned tooling; all other plant wages (excluding direct, indirect and MRO labor); returnable dunnage maintenance; and intra-company shipping costs (*see* EPA–HQ–OAR–2009–0472–0149).

[85] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA–HQ–OAR–2009–0472, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

suppliers served largely as a check on publicly-available data.

For the other technologies, considering all sources of information (including public comments) and using the BOM approach, the agencies worked together intensively to determine component costs for each of the technologies and build up the costs accordingly. Where estimates differ between sources, we have used our engineering judgment to arrive at what we believe to be the best available cost estimate, and explained the basis for that exercise of judgment in the TSD. Building on NHTSA's estimates developed for the MY 2011 CAFE final rule and EPA's Advance Notice of Proposed Rulemaking, which relied on the EPA 2008 Staff Technical Report,[86] the agencies took a fresh look at technology cost and effectiveness values for purposes of the joint rulemaking under the National Program. For costs, the agencies reconsidered both the direct or "piece" costs and indirect costs of individual components of technologies. For the direct costs, the agencies followed a bill of materials (BOM) approach employed in NHTSA's MY 2011 final rule based on recommendation from Ricardo, Inc., as described above. EPA used a similar approach in the EPA 2008 Staff Technical Report. A bill of materials, in a general sense, is a list of components or sub-systems that make up a system—in this case, an item of fuel economy-improving technology. In order to determine what a system costs, one of the first steps is to determine its components and what they cost.

NHTSA and EPA estimated these components and their costs based on a number of sources for cost-related information. The objective was to use those sources of information considered to be most credible for projecting the costs of individual vehicle technologies. For example, while NHTSA and Ricardo engineers had relied considerably in the MY 2011 final rule on the 2008 Martec Report for costing contents of some technologies, upon further joint review and for purposes of the MY 2012–2016 standards, the agencies decided that some of the costing information in that report was no longer accurate due to downward trends in commodity prices since the publication of that report. The agencies reviewed, then revalidated or updated cost estimates for individual components based on new information. Thus, while NHTSA and EPA found that much of the cost information used in NHTSA's MY 2011 final rule and EPA's staff report was consistent to a great extent, the agencies, in reconsidering information from many sources,[87] [88] [89] [90] [91] [92] [93] revised several component costs of several major technologies: turbocharging with engine downsizing (as described above), mild and strong hybrids, diesels, stoichiometric gasoline direct injection fuel systems, and valve train lift technologies. These are discussed at length in the Joint TSD and in NHTSA's final RIA.

Once costs were determined, they were adjusted to ensure that they were all expressed in 2007 dollars using a ratio of GDP values for the associated calendar years,[94] and indirect costs were accounted for using the ICM (indirect cost multiplier) approach explained in Chapter 3 of the Joint TSD, rather than using the traditional Retail Price Equivalent (RPE) multiplier approach. A report explaining how EPA developed the ICM approach can be found in the docket for this rule. The comments addressing the ICM approach were generally positive and encouraging. However, one commenter suggested that we had mischaracterized the complexity of a few of our technologies, which would result in higher or lower markups than presented in the NPRM. That commenter also suggested that we had used the ICMs as a means of placing a higher level of manufacturer learning on the cost estimates. The latter comment is not true and the methodology behind the ICM approach is explained in detail in the reports that are available in the docket for this rule.[95] The former is open to debate given the subjective nature of the engineering analysis behind it, but upon further thought both agencies believe that the complexities used in the NPRM were appropriate and have, therefore, carried those forward into the final rule. We discuss this in greater detail in the Response to Comments document.

Regarding estimates for technology effectiveness, NHTSA and EPA also reexamined the estimates from NHTSA's MY 2011 final rule and EPA's ANPRM and 2008 Staff Technical Report, which were largely consistent with NHTSA's 2008 NPRM estimates. The agencies also reconsidered other sources such as the 2002 NAS Report, the 2004 NESCCAF report, recent CAFE compliance data (by comparing similar vehicles with different technologies against each other in fuel economy testing, such as a Honda Civic Hybrid versus a directly comparable Honda Civic conventional drive), and confidential manufacturer estimates of technology effectiveness. NHTSA and EPA engineers reviewed effectiveness information from the multiple sources for each technology and ensured that such effectiveness estimates were based on technology hardware consistent with the BOM components used to estimate costs. The agencies also carefully examined the pertinent public comments. Together, they compared the multiple estimates and assessed their validity, taking care to ensure that common BOM definitions and other vehicle attributes such as performance, refinement, and drivability were taken into account. However, because the agencies' respective models employ different numbers of vehicle subclasses and use different modeling techniques to arrive at the standards, direct comparison of BOMs was somewhat more complicated. To address this and to confirm that the outputs from the different modeling techniques produced the same result, NHTSA and EPA developed mapping techniques, devising technology packages and mapping them to corresponding incremental technology estimates. This approach helped compare the outputs

[86] EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420–R–08–008, March 2008.

[87] National Research Council, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, Washington, DC (2002) (the "2002 NAS Report"), available at *http://www.nap.edu/openbook.php?isbn=0309076013* (last accessed August 7, 2009—update).

[88] Northeast States Center for a Clean Air Future (NESCCAF), "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," 2004 (the "2004 NESCCAF Report"), available at *http://www.nesccaf.org/documents/rpt040923ghglightduty.pdf* (last accessed August 7, 2009—update).

[89] "Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles," California Environmental Protection Agency, Air Resources Board, August 6, 2004.

[90] Energy and Environmental Analysis, Inc., "Technology to Improve the Fuel Economy of Light Duty Trucks to 2015," 2006 (the "2006 EEA Report"), Docket EPA–HQ–OAR–2009–0472.

[91] Martec, "Variable Costs of Fuel Economy Technologies," June 1, 2008, (the "2008 Martec Report") available at Docket No. NHTSA–2008–0089–0169.1.

[92] Vehicle fuel economy certification data.

[93] Confidential data submitted by manufacturers in response to the March 2009 and other requests for product plans.

[94] NHTSA examined the use of the CPI multiplier instead of GDP for adjusting these dollar values, but found the difference to be exceedingly small—only $0.14 over $100.

[95] Rogozhin, Alex, Michael Gallaher, and Walter McManus, "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA 420–R–09–003, Docket EPA Docket EPA–HQ–OAR–2009–0472–0142, February 2009, *http://epa.gov/otaq/ld-hwy/420r09003.pdf; A. Rogozhin et al., International Journal of Production Economics 124 (2010) 360–368, Volume 124, Issue 2, April 2010.*

from the incremental modeling technique to those produced by the technology packaging approach to ensure results that are consistent and could be translated into the respective models of the agencies.

In general, most effectiveness estimates used in both the MY 2011 final rule and the 2008 EPA staff report were determined to be accurate and were carried forward without significant change first into the NPRM, and now into these final rules. When NHTSA and EPA's estimates for effectiveness diverged slightly due to differences in how the agencies apply technologies to vehicles in their respective models, we report the ranges for the effectiveness values used in each model. There were only a few comments on the technology effectiveness estimates used in the NPRM. Most of the technologies that were mentioned in the comments were the more advanced technologies that are not assumed to have large penetrations in the market within the timeframe of this rule, notably hybrid technologies. Even if the effectiveness figures for hybrid vehicles were adjusted, it would have made little difference in the NHTSA and EPA analysis of the impacts and costs of the rule. The response to comments document has more specific responses to these comments.

The agencies note that the effectiveness values estimated for the technologies considered in the modeling analyses may represent average values, and do not reflect the enormous spectrum of possible values that could result from adding the technology to different vehicles. For example, while the agencies have estimated an effectiveness of 0.5 percent for low friction lubricants, each vehicle could have a unique effectiveness estimate depending on the baseline vehicle's oil viscosity rating. Similarly, the reduction in rolling resistance (and thus the improvement in fuel economy and the reduction in CO_2 emissions) due to the application of low rolling resistance tires depends not only on the unique characteristics of the tires originally on the vehicle, but on the unique characteristics of the tires being applied, characteristics which must be balanced between fuel efficiency, safety, and performance. Aerodynamic drag reduction is much the same—it can improve fuel economy and reduce CO_2 emissions, but it is also highly dependent on vehicle-specific functional objectives. For purposes of the final standards, NHTSA and EPA believe that employing average values for technology effectiveness estimates, as adjusted depending on vehicle subclass, is an appropriate way of recognizing the potential variation in the specific benefits that individual manufacturers (and individual vehicles) might obtain from adding a fuel-saving technology.

Chapter 3 of the Joint Technical Support Document contains a detailed description of our assessment of vehicle technology cost and effectiveness estimates. The agencies note that the technology costs included in this final rule take into account only those associated with the initial build of the vehicle. Although comments were received to the NPRM that suggested there could be additional maintenance required with some new technologies (*e.g.,* turbocharging, hybrids, etc.), and that additional maintenance costs could occur as a result, the agencies do not believe that the amount of additional cost will be significant in the timeframe of this rulemaking, based on the relatively low application rates for these technologies. The agencies will undertake a more detailed review of these potential costs in preparation for the next round of CAFE/GHG standards.

F. Joint Economic Assumptions

The agencies' final analysis of alternative CAFE and GHG standards for the model years covered by this final rulemaking rely on a range of forecast information, economic estimates, and input parameters. This section briefly describes the agencies' choices of specific parameter values. These economic values play a significant role in determining the benefits of both CAFE and GHG standards.

In reviewing these variables and the agency's estimates of their values for purposes of this final rule, NHTSA and EPA reconsidered previous comments that NHTSA had received, reviewed newly available literature, and reviewed comments received in response to the proposed rule. For this final rule, we made three major changes to the economic assumptions. First, we revised the technology costs to reflect more recently available data. Second, we updated fuel price and transportation demand assumptions to reflect the Annual Energy Outlook (AEO) 2010 Early Release. Third, we have updated our estimates of the social cost of carbon (SCC) based on a recent interagency process. The key economic assumptions are summarized below, and are discussed in greater detail in Section III (EPA) and Section IV (NHTSA), as well as in Chapter 4 of the Joint TSD, Chapter VIII of NHTSA's RIA and Chapter 8 of EPA's RIA.

Costs of fuel economy-improving technologies—These estimates are presented in summary form above and in more detail in the agencies' respective sections of this preamble, in Chapter 3 of the Joint TSD, and in the agencies' respective RIAs. The technology cost estimates used in this analysis are intended to represent manufacturers' direct costs for high-volume production of vehicles with these technologies and sufficient experience with their application so that all cost reductions due to "learning curve" effects have been fully realized. Costs are then modified by applying near-term indirect cost multipliers ranging from 1.11 to 1.64 to the estimates of vehicle manufacturers' direct costs for producing or acquiring each technology to improve fuel economy, depending on the complexity of the technology and the time frame over which costs are estimated. This accounts for both the direct and indirect costs associated with implementing new technologies in response to this final rule. The technology cost estimates for a select group of technologies have changed since the NPRM. These changes, as summarized in Section II.E and in Chapter 3 of the Joint TSD, were made in response to updated cost estimates available to the agencies shortly after publication of the NPRM, not in response to comments. In general, commenters were supportive of the cost estimates used in the NPRM and the transparency of the methodology used to generate them.

Potential opportunity costs of improved fuel economy—This estimate addresses the possibility that achieving the fuel economy improvements required by alternative CAFE or GHG standards would require manufacturers to compromise the performance, carrying capacity, safety, or comfort of their vehicle models. If it did so, the resulting sacrifice in the value of these attributes to consumers would represent an additional cost of achieving the required improvements, and thus of manufacturers' compliance with stricter standards. Currently the agencies assume that these vehicle attributes do not change, and include the cost of maintaining these attributes as part of the cost estimates for technologies. However, it is possible that the technology cost estimates do not include adequate allowance for the necessary efforts by manufacturers to maintain vehicle performance, carrying capacity, and utility while improving fuel economy and reducing GHG emissions. While, in principle, consumer vehicle demand models can measure these effects, these models do not appear to be robust across specifications, since authors derive a wide range of willingness-to-pay values for fuel economy from these models, and there is not clear guidance from the literature on whether one specification is clearly preferred over another. This issue is discussed in EPA's RIA, Section 8.1.2 and NHTSA's RIA Section VIII.H. The agencies requested comment on how to estimate explicitly the changes in vehicle buyers' welfare from the combination of higher prices for new vehicle models, increases in their fuel economy, and any accompanying changes in vehicle attributes such as performance, passenger- and cargo-carrying capacity, or other dimensions of utility. Commenters did not provide recommendations for how to evaluate the quality of different models or identify a model appropriate for the agencies' purposes. Some commenters expressed various concerns about the use of existing consumer vehicle choice models. While EPA and NHTSA are not using a consumer vehicle choice model to analyze the effects of this rule, we continue to investigate these models.

The on-road fuel economy "gap"—Actual fuel economy levels achieved by light-duty vehicles in on-road driving fall somewhat short of their levels measured under the laboratory-like test conditions used by NHTSA and EPA to establish compliance with the final CAFE and GHG standards. The agencies use an on-road fuel economy gap for light-duty vehicles of 20 percent lower than published fuel economy levels. For example, if the measured CAFE fuel economy value of a light truck is 20 mpg, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80).[96] NHTSA previously used this estimate in its MY 2011 final rule, and the agencies confirmed it based on independent analysis for use in this FRM. No substantive comments were received on this input.

Fuel prices and the value of saving fuel—Projected future fuel prices are a critical input into the preliminary economic analysis of alternative standards, because they determine the value of fuel savings both to new vehicle buyers and to society. For the proposed rule, the agencies had relied on the then most recent fuel price projections from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2009 (Revised Updated). However, for this final rule, the agencies have updated the analyses based on AEO 2010 (December 2009 Early Release) Reference Case forecasts of inflation-adjusted (constant-dollar) retail gasoline and diesel fuel prices, which represent the EIA's most up-to-date estimate of the most likely course of future prices for petroleum products.[97] AEO 2010 includes slightly lower petroleum prices compared to AEO 2009.

The forecasts of fuel prices reported in EIA's AEO 2010 Early Release Reference Case extends through 2035, compared to the AEO 2009 which only went through 2030. As in the proposal, fuel prices beyond the time frame of AEO's forecast were estimated using an average growth rate.

While EIA revised AEO 2010, the vehicle MPG standards are similar to those that were published in AEO 2009. No substantive comments were received on the use of AEO as a source of fuel prices.[98]

Consumer valuation of fuel economy and payback period—In estimating the impacts on vehicle sales, the agencies assume that potential buyers value the resulting fuel savings improvements that would result from alternative CAFE and GHG standards over only part of the expected lifetime of the vehicles they purchase. Specifically, we assume that buyers value fuel savings over the first five years of a new vehicle's lifetime, and that buyers discount the value of these future fuel savings using rates of 3% and 7%. The five-year figure represents the current average term of consumer loans to finance the purchase of new vehicles. One commenter argued that higher-fuel-economy vehicles should have higher resale prices than vehicles with lower fuel economy, but did not provide supporting data. This revision, if made, would increase the net benefits of the rule. Another commenter supported the use of a five-year payback period for this analysis. In the absence of data to support changes, EPA and NHTSA have kept the same assumptions. In the analysis of net benefits, EPA and NHTSA assume that vehicle buyers benefit from the full fuel savings over the vehicle's lifetime, discounted for present value calculations at 3 and 7 percent.

Vehicle sales assumptions—The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number of vehicles expected to be produced and sold.[99] The agencies relied on the AEO 2010 Early Release for forecasts of total vehicle sales, while the baseline market forecast developed by the agencies (*see* Section II.B) divided total projected sales into sales of cars and light trucks.

Vehicle survival assumptions—We then applied updated values of age-specific survival rates for cars and light trucks to these adjusted forecasts of passenger car and light truck sales to determine the number of these vehicles remaining in use during each year of their expected lifetimes. No substantive comments were received on vehicle survival assumptions.

Total vehicle use—We then calculated the total number of miles that cars and light trucks produced in each model year will be driven during each year of their lifetimes using estimates of annual vehicle use by age tabulated from the Federal Highway Administration's 2001 National Household Transportation Survey (NHTS),[100] adjusted to account for the effect on vehicle use of subsequent increases in fuel prices. Due to the lower fuel prices projected in AEO 2010, the average vehicle is estimated to be used slightly more (~3 percent) over its lifetime than assumed in the proposal. In order to insure that the resulting mileage schedules imply reasonable estimates of future growth in *total* car and light truck use, we calculated the rate of growth in annual car and light truck mileage at each age that is necessary for total car and light truck travel to increase at the rates forecast in the AEO 2010 Early Release Reference Case. The growth rate in average annual car and light truck use produced by this calculation is

[96] U.S. Environmental Protection Agency, Final Technical Support Document, Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates, EPA420–R–06–017, December 2006.

[97] Energy Information Administration, Annual Energy Outlook 2010, Early Release Reference Case (December 2009), Table 12. Available at *http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html* (last accessed February 02, 2010).

[98] Kahan, A. and Pickrell, D. Memo to Docket EPA–HQ–OAR–2009–0472 and Docket NHTSA–2009–0059. "Energy Information Administration's Annual Energy Outlook 2009 and 2010." March 24, 2010.

[99] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 2 during calendar year 2001, and to reach their maximum age of 26 years during calendar year 2025. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 26 years, while light trucks have a maximum lifetime of 36 years. See Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8–11 (January 2006). Available at *http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf* (last accessed Feb. 15, 2010).

[100] For a description of the Survey, *see http://nhts.ornl.gov/quickStart.shtml* (last accessed July 27, 2009).

approximately 1.1 percent per year.[101] This rate was applied to the mileage figures derived from the 2001 NHTS to estimate annual mileage during each year of the expected lifetimes of MY 2012–2016 cars and light trucks.[102] While commenters requested further detail on the assumptions regarding total vehicle use, no specific issues were raised.

Accounting for the rebound effect of higher fuel economy—The rebound effect refers to the fraction of fuel savings expected to result from an increase in vehicle fuel economy—particularly an increase required by the adoption of more stringent CAFE and GHG standards—that is offset by additional vehicle use. The increase in vehicle use occurs because higher fuel economy reduces the fuel cost of driving, typically the largest single component of the monetary cost of operating a vehicle, and vehicle owners respond to this reduction in operating costs by driving slightly more. We received comments supporting our proposed value of 10 percent, although we also received comments recommending higher and lower values. However, we did not receive any new data or comments that justify revising the 10 percent value for the rebound effect at this time.

Benefits from increased vehicle use—The increase in vehicle use from the rebound effect provides additional benefits to their owners, who may make more frequent trips or travel farther to reach more desirable destinations. This additional travel provides benefits to drivers and their passengers by improving their access to social and economic opportunities away from home. These benefits are measured by the net "consumer surplus" resulting from increased vehicle use, over and above the fuel expenses associated with this additional travel. We estimate the economic value of the consumer surplus provided by added driving using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel economy, the value of benefits from increased vehicle use changes by model year and varies among alternative standards.

The value of increased driving range—By reducing the frequency with which drivers typically refuel their vehicles, and by extending the upper limit of the range they can travel before requiring refueling, improving fuel economy and reducing GHG emissions thus provides some additional benefits to their owners. No direct estimates of the value of extended vehicle range are readily available, so the agencies' analysis calculates the reduction in the annual number of required refueling cycles that results from improved fuel economy, and applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value.[103] *Please see* the Chapter 4 of the Joint TSD for details.

Added costs from congestion, crashes and noise—Although it provides some benefits to drivers, increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed over the day and on where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled during peak periods. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses, increased costs associated with traffic accidents, and increased traffic noise. The agencies rely on estimates of congestion, accident, and noise costs caused by automobiles and light trucks developed by the Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[104]

Petroleum consumption and import externalities—U.S. consumption and imports of petroleum products also impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. In economics literature on this subject, these costs include (1) higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price ("monopsony costs"); (2) the expected costs from the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion against resulting price increases.[105] Reducing U.S. imports of crude petroleum or refined fuels can reduce the magnitude of these external costs. Any reduction in their total value that results from lower fuel consumption and petroleum imports represents an economic benefit of setting more stringent standards over and above the dollar value of fuel savings itself. Since the agencies are taking a global perspective with respect to the estimate of the social cost of carbon for this rulemaking, the agencies do not include the value of any reduction in monopsony payments as a benefit from lower fuel consumption, because those payments from a global perspective represent a transfer of income from consumers of petroleum products to oil suppliers rather than a savings in real economic resources. Similarly, the agencies do not include any savings in budgetary outlays to support U.S. military activities among the benefits of higher fuel economy and the resulting fuel savings. Based on a recently-updated ORNL study, we estimate that each gallon of fuel saved that results in a reduction in U.S. petroleum imports (either crude petroleum or refined fuel) will reduce the expected costs of oil supply disruptions to the U.S. economy by $0.169 (2007$). Each gallon of fuel saved as a consequence of higher standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.[106]

[101] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

[102] While the adjustment for future fuel prices reduces average mileage at each age from the values derived from the 2001 NHTS, the adjustment for expected future growth in average vehicle use increases it. The net effect of these two adjustments is to increase expected lifetime mileage by about 18 percent for passenger cars and about 16 percent for light trucks.

[103] Department of Transportation, Guidance Memorandum, "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations," Apr. 9, 1997. *http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf* (last accessed Feb. 15, 2010); update *available at http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf* (last accessed Feb. 15, 2010).

[104] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study; http://www.fhwa.dot.gov/policy/hcas/final/index.htm* (last accessed Feb. 15, 2010).

[105] See, *e.g.,* Bohi, Douglas R. and W. David Montgomery (1982). Oil Prices, Energy Security, and Import Policy Washington, DC: Resources for the Future, Johns Hopkins University Press; Bohi, D. R., and M. A. Toman (1993). "Energy and Security: Externalities and Policies," Energy Policy 21:1093–1109; and Toman, M. A. (1993). "The Economics of Energy Security: Theory, Evidence, Policy," in A. V. Kneese and J. L. Sweeney, eds. (1993). Handbook of Natural Resource and Energy Economics, Vol. III. Amsterdam: North-Holland, pp. 1167–1218.

[106] Each gallon of fuel saved is assumed to reduce imports of refined fuel by 0.5 gallons, and the volume of fuel refined domestically by 0.5 gallons. Domestic fuel refining is assumed to utilize 90 percent imported crude petroleum and 10 percent

Continued

The energy security analysis conducted for this rule estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products outside the U.S., which would in turn lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. While additional information would be needed to analyze this "leakage effect" in detail, NHTSA provides a sample estimate of its potential magnitude in its Final EIS.[107] This analysis indicates that the leakage effect is likely to offset only a modest fraction of the reductions in emissions projected to result from the rule.

EPA and NHTSA received comments about the treatment of the monopsony effect, macroeconomic disruption effect, and the military costs associated with the energy security benefits of this rule. The agencies did not receive any comments that justify changing the energy security analysis. As a result, the agencies continue to only use the macroeconomic disruption component of the energy security analysis under a global context when estimating the total energy security benefits associated with this rule. Further, the Agencies did not receive any information that they could use to quantity that component of military costs directly related to energy security, and thus did not modify that part of its analysis. A more complete discussion of the energy security analysis can be found in Chapter 4 of the Joint TSD, and Sections III and IV of this preamble.

Air pollutant emissions

○ *Impacts on criteria air pollutant emissions*—While reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of criteria pollutants, additional vehicle use associated with the rebound effect will increase emissions of these pollutants. Thus the net effect of stricter standards on emissions of each criteria pollutant depends on the relative magnitudes of reduced emissions from fuel refining and distribution, and increases in emissions resulting from added vehicle use. Criteria air pollutants emitted by vehicles and during fuel production include carbon monoxide (CO), hydrocarbon compounds (usually referred to as "volatile organic compounds," or VOC), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and sulfur oxides (SO_X). It is assumed that the emission rates (per mile) stay constant for future year vehicles.

○ *Economic value of reductions in criteria air pollutants*—For the purpose of the joint technical analysis, EPA and NHTSA estimate the economic value of the human health benefits associated with reducing exposure to $PM_{2.5}$ using a "benefit-per-ton" method. These $PM_{2.5}$-related benefit-per-ton estimates provide the total monetized benefits to human health (the sum of reductions in premature mortality and premature morbidity) that result from eliminating one ton of directly emitted $PM_{2.5}$, or one ton of a pollutant that contributes to secondarily-formed $PM_{2.5}$ (such as NO_X, SO_X, and VOCs), from a specified source. Chapter 4.2.9 of the Technical Support Document that accompanies this rule includes a description of these values. Separately, EPA also conducted air quality modeling to estimate the change in ambient concentrations of criteria pollutants and used this as a basis for estimating the human health benefits and their economic value. Section III.H.7 presents these benefits estimates.

○ *Reductions in GHG emissions*—Emissions of carbon dioxide and other GHGs occur throughout the process of producing and distributing transportation fuels, as well as from fuel combustion itself. By reducing the volume of fuel consumed by passenger cars and light trucks, higher standards will thus reduce GHG emissions generated by fuel use, as well as throughout the fuel supply cycle. The agencies estimated the increases of GHGs other than CO_2, including methane and nitrous oxide, from additional vehicle use by multiplying the increase in total miles driven by cars and light trucks of each model year and age by emission rates per vehicle-mile for these GHGs. These emission rates, which differ between cars and light trucks as well as between gasoline and diesel vehicles, were estimated by EPA using its recently-developed Motor Vehicle Emission Simulator (Draft MOVES 2010).[108] Increases in emissions of non-CO_2 GHGs are converted to equivalent increases in CO_2 emissions using estimates of the Global Warming Potential (GWP) of methane and nitrous oxide.

○ *Economic value of reductions in CO_2 emissions*—EPA and NHTSA assigned a dollar value to reductions in CO_2 emissions using the marginal dollar value (*i.e.,* cost) of climate-related damages resulting from carbon emissions, also referred to as "social cost of carbon" (SCC). The SCC is intended to measure the monetary value society places on impacts resulting from increased GHGs, such as property damage from sea level rise, forced migration due to dry land loss, and mortality changes associated with vector-borne diseases. Published estimates of the SCC vary widely as a result of uncertainties about future economic growth, climate sensitivity to GHG emissions, procedures used to model the economic impacts of climate change, and the choice of discount rates.

EPA and NHTSA received extensive comments about how to improve the characterization of the SCC and have since developed new estimates through an interagency modeling exercise. The comments addressed various issues, such as discount rate selection, treatment of uncertainty, and emissions and socioeconomic trajectories, and justified the revision of SCC for the final rule. The modeling exercise involved running three integrated assessment models using inputs agreed upon by the interagency group for climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A more complete discussion of SCC can be found in the Technical Support Document, *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (hereafter, "SCC TSD"); revised SCC estimates corresponding to assumed values of the discount rate are shown in Table II.F–1.[109]

domestically-produced crude petroleum as feedstocks. Together, these assumptions imply that each gallon of fuel saved will reduce imports of refined fuel and crude petroleum by 0.50 gallons + 0.50 gallons*90 percent = 0.50 gallons + 0.45 gallons = 0.95 gallons.

[107] NHTSA Final Environmental Impact Statement: Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2012–2016, February 2010, page 3–14.

[108] The MOVES model assumes that the per-mile rates at which cars and light trucks emit these GHGs are determined by the efficiency of fuel combustion during engine operation and chemical reactions that occur during catalytic after-treatment of engine exhaust, and are thus independent of vehicles' fuel consumption rates. Thus MOVES' emission factors for these GHGs, which are expressed per mile of vehicle travel, are assumed to be unaffected by changes in fuel economy.

[109] Interagency Working Group on Social Cost of Carbon, U.S. Government, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury, "*Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,*" February 2010, available in docket EPA–HQ–OAR–2009–0472.

TABLE II.F–1—SOCIAL COST OF CO_2, 2010

[In 2007 dollars]

Discount Rate	5%	3%	2.5%	3%
Source of Estimate	Mean of Estimates Values			95th percentile estimate.
2010 Estimate	$5	$21	$35	$65.

Discounting future benefits and costs—Discounting future fuel savings and other benefits is intended to account for the reduction in their value to society when they are deferred until some future date, rather than received immediately. The discount rate expresses the percent decline in the value of these benefits—as viewed from today's perspective—for each year they are deferred into the future. In evaluating the non-climate related benefits of the final standards, the agencies have employed discount rates of both 3 percent and 7 percent. We received some comments on the discount rates used in the proposal, most of which were directed at the discount rates used to value future fuel savings and the rates used to value of the social cost of carbon. In general, commenters were supporting one of the discount rates over the other, although some suggested that our rates were too high or too low. We have revised the discounting used when calculating the net present value of social cost of carbon as explained in Sections III.H. and VI but have not revised our discounting procedures for other costs or benefits.

For the reader's reference, Table II.F–2 below summarizes the values used to calculate the impacts of each final standard. The values presented in this table are summaries of the inputs used for the models; specific values used in the agencies' respective analyses may be aggregated, expanded, or have other relevant adjustments. See the respective RIAs for details.

The agencies recognize that each of these values has some degree of uncertainty, which the agencies further discuss in the Joint TSD. The agencies have conducted a range of sensitivities and present them in their respective RIAs. For example, NHTSA has conducted a sensitivity analysis on several assumptions including (1) forecasts of future fuel prices, (2) the discount rate applied to future benefits and costs, (3) the magnitude of the rebound effect, (4) the value to the U.S. economy of reducing carbon dioxide emissions, (5) inclusion of the monopsony effect, and (6) the reduction in external economic costs resulting from lower U.S. oil imports. This information is provided in NHTSA's RIA.

TABLE II.F–2—ECONOMIC VALUES FOR BENEFITS COMPUTATIONS

[2007$]

Fuel Economy Rebound Effect	10%.
"Gap" between test and on-road MPG	20%.
Value of refueling time per ($ per vehicle-hour)	$24.64.
Average tank volume refilled during refueling stop	55%.
Annual growth in average vehicle use	1.15%.
Fuel Prices (2012–50 average, $/gallon):	
Retail gasoline price	$3.66.
Pre-tax gasoline price	$3.29.
Economic Benefits From Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$0.00.
Price Shock Component	$0.17.
Military Security Component	$0.00.
Total Economic Costs ($/gallon)	$0.17.
Emission Damage Costs (2020, $/ton or $/metric ton)	
Carbon monoxide	$0.
Volatile organic compounds (VOC)	$1,300.
Nitrogen oxides (NO_X)—vehicle use	$5,100.
Nitrogen oxides (NO_X)—fuel production and distribution	$ 5,300.
Particulate matter ($PM_{2.5}$)—vehicle use	$ 240,000.
Particulate matter ($PM_{2.5}$)—fuel production and distribution	$ 290,000.
Sulfur dioxide (SO_2)	$ 31,000.
Carbon dioxide (CO_2) emissions in 2010	$5. $21. $35. $65.
Annual Increase in CO_2 Damage Cost	variable, depending on estimate.
External Costs From Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.054.
Accidents	$ 0.023.
Noise	$ 0.001.

TABLE II.F–2—ECONOMIC VALUES FOR BENEFITS COMPUTATIONS—Continued

[2007$]

Total External Costs	$ 0.078.
External Costs From Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.048.
Accidents	$0.026.
Noise	$0.001.
Total External Costs	$0.075.
Discount Rates Applied to Future Benefits	3%, 7%.

G. What are the estimated safety effects of the final MYs 2012–2016 CAFE and GHG standards?

The primary goals of the final CAFE and GHG standards are to reduce fuel consumption and GHG emissions, but in addition to these intended effects, the agencies must consider the potential of the standards to affect vehicle safety,[110] which the agencies have assessed in evaluating the appropriate levels at which to set the final standards. Safety trade-offs associated with fuel economy increases have occurred in the past, and the agencies must be mindful of the possibility of future ones. These past safety trade-offs occurred because manufacturers chose, at the time, to build smaller and lighter vehicles—partly in response to CAFE standards—rather than adding more expensive fuel-saving technologies (and maintaining vehicle size and safety), and the smaller and lighter vehicles did not fare as well in crashes as larger and heavier vehicles. Historically, as shown in FARS data analyzed by NHTSA, the safest vehicles have been heavy and large, while the vehicles with the highest fatal-crash rates have been light and small, both because the crash rate is higher for small/light vehicles and because the fatality rate per crash is higher for small/light vehicle crashes.

Changes in relative safety are related to shifts in the distribution of vehicles on the road. A policy that induces a widening in the size distribution of vehicles on the road, could result in negative impacts on safety, The primary mechanism in this rulemaking for mitigating the potential negative effects on safety is the application of footprint-based standards, which create a disincentive for manufacturers to produce smaller-footprint vehicles. This is because as footprint decreases, the corresponding fuel economy/GHG emission target becomes more stringent.[111] The shape of the footprint curves themselves have also been designed to be approximately "footprint neutral" within the sloped portion of the functions—that is, to neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. Upsizing also is discouraged through a "cut-off" at larger footprints. For both cars and light trucks there is a "cut-off" that affects vehicles smaller than 41 square feet. The agencies recognize that for manufacturers who make small vehicles in this size range, this cut off creates some incentive to downsize (*i.e.* further reduce the size and/or increase the production of models currently smaller than 41 square feet) to make it easier to meet the target. The cut off may also create some incentive for manufacturers who do not currently offer such models to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars smaller than 41 square feet—most consumers likely have some minimum expectation about interior volume, among other things. In addition, vehicles in this market segment are the lowest price point for the light-duty automotive market, with a number of models in the $10,000 to $15,000 range. In order to justify selling more vehicles in this market in order to generate fuel economy or CO_2 credits (that is, for this final rule to be the incentive for selling more vehicles in this small car segment), a manufacturer would need to add additional technology to the lowest price segment vehicles, which could be challenging. Therefore, due to these two reasons (a likely limit in the market place for the smallest sized cars and the potential consumer acceptance difficulty in adding the necessary technologies in order to generate fuel economy and CO_2 credits), the agencies believe that the incentive for manufacturers to increase the sale of vehicles smaller than 41 square feet due to this rulemaking, if present, is small. For further discussion on these aspects of the standards, *please see* Section II.C above and Chapter 2 of the Joint TSD.

Manufacturers have stated, however, that they will reduce vehicle weight as one of the cost-effective means of increasing fuel economy and reducing CO_2 emissions, and the agencies have incorporated this expectation into our modeling analysis supporting today's final standards. NHTSA's previous analyses examining the relationship between vehicle mass and fatalities found fatality increases as vehicle weight and size were reduced, but these previous analyses did not differentiate between weight reductions and size (*i.e.,* weight and footprint) reductions.

The question of the effect of changes in vehicle mass on safety in the context of fuel economy is a complex question that poses serious analytic challenges and has been a contentious issue for many years, as discussed by a number of commenters to the NPRM. This contentiousness arises, at least in part, from the difficulty of isolating vehicle mass from other confounding factors (*e.g.,* driver behavior, or vehicle factors such as engine size and wheelbase). In addition, several vehicle factors have been closely related historically, such as vehicle mass, wheelbase, and track width. The issue has been reviewed and analyzed in the literature for more than two decades. For the reader's reference, much more information about safety in the CAFE context is available in Chapter IX of NHTSA's FRIA. Chapter 7.6 of EPA's final RIA also contained

[110] In this rulemaking document, vehicle safety is defined as *societal* fatality rates which include fatalities to occupants of all the vehicles involved in the collisions, plus any pedestrians.

[111] We note, however, that vehicle footprint is not synonymous with vehicle size. Since the footprint is only that portion of the vehicle between the front and rear axles, footprint-based standards do not discourage downsizing the portions of a vehicle in front of the front axle and to the rear of the rear axle, or to other portions of the vehicle outside the wheels. The crush space provided by those portions of a vehicle can make important contributions to managing crash energy. At least one manufacturer has confidentially indicated plans to reduce overhang as a way of reducing mass on some vehicles during the rulemaking time frame. Additionally, simply because footprint-based standards create no incentive to downsize vehicles, does not mean that manufacturers may not choose to do so if doing so makes it easier to meet the overall standard (as, for example, if the smaller vehicles are so much lighter that they exceed their targets by much greater amounts).

additional discussion on mass and safety.

Over the past several years, as also discussed by a number of commenters to the NPRM, contention has arisen with regard to the applicability of analysis of historical crash data to future safety effects due to mass reduction. The agencies recognize that there are a host of factors that may make future mass reduction different than what is reflected in the historical data. For one, the footprint-based standards have been carefully developed by the agencies so that they do not encourage vehicle footprint reductions as a way of meeting the standards, but so that they do encourage application of fuel-saving technologies, including mass reduction. This in turn encourages manufacturers to find ways to separate mass reduction from footprint reduction, which will very likely result in a future relationship between mass and fatalities that is safer than the historical relationship. However, as manufacturers pursue these methods of mass reduction, the fleet moves further away from the historical trends, which the agencies recognize.

NHTSA's NPRM analysis of the safety effects of the proposed CAFE standards was based on NHTSA's 2003 report concerning mass and size reduction in MYs 1991–1999 vehicles, and evaluated a "worst-case scenario" in which the safety effects of the combined reductions of both mass and size for those vehicles were determined for the future passenger car and light truck fleets.[112] In the NPRM analysis, mass and size could not be separated from one another, resulting in what NHTSA recognized was a larger safety disbenefit than was likely under the MYs 2012–2016 footprint-based CAFE standards. NHTSA emphasized, however, that actual fatalities would likely be less than these "worst-case" estimates, and possibly significantly less, based on the various factors discussed in the NPRM that could reduce the estimates, such as careful mass reduction through material substitution, etc.

For the final rule, as discussed in the NPRM and in recognition of the importance of conducting analysis that better reflects, within the limits of our current knowledge, the potential safety effects of future mass reduction in response to the final CAFE and GHG standards that is highly unlikely to involve concurrent reductions in footprint, NHTSA has revised its analysis in consultation with EPA. Perhaps the most important change has been that NHTSA agreed with commenters that it was both possible and appropriate to separate the effect of mass reductions from the effect of footprint reductions. NHTSA thus performed a new statistical analysis, hereafter referred to as the 2010 Kahane analysis, of the MYs 1991–99 vehicle database from its 2003 report (now including rather than excluding 2-door cars in the passenger car fleet), assessing relationships between fatality risk, mass, and footprint for both passenger cars and LTVs (light trucks and vans).[113] As part of its results, the new report presents an "upper-estimate scenario," a "lower-estimate scenario," as well as an "actual regression result scenario" representing potential safety effects of future mass reductions without corresponding vehicle size reductions, that assume, by virtue of being a cross-sectional analysis of historical data, that historical relationships between vehicle mass and fatalities are maintained. The "upper-estimate scenario" and "lower-estimate scenario" are based on NHTSA's judgment as a vehicle safety agency, and are not meant to convey any more or less likelihood in the results, but more to convey a sense of bounding for potential safety effects of reducing mass while holding footprint constant. The upper-estimate scenario reflects potential safety effects given the report's finding that, using the one-step regression method of the 2003 Kahane report, the regression coefficients show that mass and footprint each accounted for about half the fatality increase associated with downsizing in a cross-sectional analysis of MYs 1991–1999 cars. A similar effect was found for lighter LTVs. Applying the same regression method to heavier LTVs, however, the coefficients indicated a significant societal fatality reduction when mass, but not footprint, is reduced in the heavier LTVs.[114] Fatalities are reduced primarily because mass reduction in the heavier LTVs will reduce risk to occupants of the other cars and lighter LTVs involved in collisions with these heavier LTVs.[115] Thus, even in the "upper-estimate scenario," the potential fatality increases associated with mass reduction in the passenger cars would be to a large extent offset by the benefits of mass reduction in the heavier LTVs.

The lower-estimate scenario, in turn, reflects NHTSA's estimate of potential safety effects if future mass reduction is accomplished entirely by material substitution, smart design,[116] and component integration, among other things, that can reduce mass without perceptibly changing a vehicle's shape, functionality, or safety performance, maintaining structural strength without compromising other aspects of safety. If future mass reduction follows this path, it could limit the added risk close to only the effects of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision), resulting in estimated effects in passenger cars that are substantially smaller than in the upper-estimate scenario based directly on the regression results. The lower-estimate scenario also covers both passenger cars and LTVs.

Overall, based on the new analyses, NHTSA estimated that fatality effects could be markedly less than those estimated in the "worst-case scenario" presented in the NPRM. The agencies believe that the overall effect of mass reduction in cars and LTVs may be close to zero, and may possibly be beneficial in terms of the fleet as a whole if mass reduction is carefully applied in the future (as with careful material substitution and other methods of mass reduction that can reduce mass without perceptibly changing a car's shape, functionality, or safety performance,

[112] The analysis excluded 2-door cars.

[113] "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991–1999 and Other Passenger Cars and LTVs," Charles J. Kahane, NCSA, NHTSA, March 2010. The text of the report may be found in Chapter IX of NHTSA's FRIA, where it constitutes a section of that chapter. We note that this report has not yet been externally peer-reviewed, and therefore may be changed or refined after it has been subjected to peer review. The results of the report have not been included in the tables summarizing the costs and benefits of this rulemaking and did not affect the stringency of the standards. NHTSA has begun the process for obtaining peer review in accordance with OMB guidance. The agency will ensure that concerns raised during the peer review process are addressed before relying on the report for future rulemakings. The results of the peer review and any subsequent revisions to the report will be made available in a public docket and on NHTSA's Web site as they are completed.

[114] Conversely, the coefficients indicate a significant increase if footprint is reduced.

[115] We note that there may be some (currently non-quantifiable) welfare losses for purchasers of these heavier LTVs, the mass of which is reduced in response to these final standards. This is due to the fact that in certain crashes, as discussed below and in greater detail in Chapter IX of the NHTSA FRIA, more mass will always be helpful (although certainly in other crashes, the amount of mass reduction modeled by the agency will not be enough to have any significant effect on driver/occupant safety). However, we believe the effects of this will likely be minor. Consumer welfare impacts of the final rule are discussed in more detail in Chapter VIII of the NHTSA FRIA.

[116] Manufacturers may reduce mass through smart design using computer aided engineering (CAE) tools that can be used to better optimize load paths within structures by reducing stresses and bending moments applied to structures. This allows better optimization of the sectional thicknesses of structural components to reduce mass while maintaining or improving the function of the component. Smart designs also integrate separate parts in a manner that reduces mass by combining functions or the reduced use of separate fasteners. In addition, some "body on frame" vehicles are redesigned with a lighter "unibody" construction.

and maintain its structural strength without making it excessively rigid). This is especially important if the mass reduction in the heavier LTVs is greater (in absolute terms) than in passenger cars, as discussed further below and in the 2010 Kahane report.

The following sections will address how the agencies addressed potential safety effects in the NPRM for the proposed standards, how commenters responded, and the work that NHTSA has done since the NPRM to revise its estimates of potential safety effects for the final rule. The final section discusses some of the agencies' plans for the future with respect to potential analysis and studies to further enhance our understanding of this important and complex issue.

1. What did the agencies say in the NPRM with regard to potential safety effects?

In the NPRM preceding these final standards, NHTSA's safety assessment derived from the agency's belief that some of these vehicle factors, namely vehicle mass and footprint, could not be accurately separated. NHTSA relied on the 2003 study by Dr. Charles Kahane, which estimates the effect of 100-pound reductions in MYs 1991–1999 heavy light trucks and vans (LTVs), light LTVs, heavy passenger cars, and light passenger cars.[117] The study compares the fatality rates of LTVs and cars to quantify differences between vehicle types, given drivers of the same age/gender, etc. In that analysis, the effect of "weight reduction" is not limited to the effect of mass *per se,* but includes all the factors, such as length, width, structural strength, safety features, and size of the occupant compartment, that were naturally or historically confounded with mass in MYs 1991–1999 vehicles. The rationale was that adding length, width, or strength to a vehicle historically also made it heavier.

NHTSA utilized the relationships between mass and safety from Kahane (2003), expressed as percentage increases in fatalities per 100-pound mass reduction, and examined the mass effects assumed in the NPRM modeling analysis. While previous CAFE rulemakings had limited mass reduction as a "technology option" to vehicles over 5,000 pounds GVWR, both NHTSA's and EPA's modeling analyses in the NPRM included mass reduction of up to 5–10 percent of baseline curb weight, depending on vehicle subclass, in response to recently-submitted manufacturer product plans as well as public statements indicating that these levels were possible and likely. 5–10 percent represented a maximum bound; EPA's modeling, for example, included average vehicle weight reductions of 4 percent between MYs 2011 and 2016, although the average per-vehicle mass reduction was greater in absolute terms for light trucks than for passenger cars. NHTSA's assumptions for mass reduction were also limited by lead time such that mass reductions of 1.5 percent were included for redesigns occurring prior to MY 2014, and mass reductions of 5–10 percent were only "achievable" in redesigns occurring in MY 2014 or later. NHTSA further assumed that mass reductions would be limited to 5 percent for small vehicles (*e.g.,* subcompact passenger cars), and that reductions of 10 percent would only be applied to the larger vehicle types (*e.g.,* large light trucks).

Based on these assumptions of how manufacturers might comply with the standards, NHTSA examined the effects of the identifiable safety trends over the lifetime of the vehicles produced in each model year. The effects were estimated on a year-by-year basis, assuming that certain known safety trends would result in a reduction in the target population of fatalities from which the mass effects are derived.[118] Using this method, NHTSA found a 12.6 percent reduction in fatality levels between 2007 and 2020. The estimates derived from applying Kahane's 2003 percentages to a baseline of 2007 fatalities were then multiplied by 0.874 to account for changes that the agency believed would take place in passenger car and light truck safety between the 2007 baseline on-road fleet used for that particular analysis and year 2020.[119]

NHTSA and EPA both emphasized that the safety effect estimates in the NPRM needed to be understood in the context of the 2003 Kahane report, which is based upon a cross-sectional analysis of the actual on-road safety experience of 1991–1999 vehicles. For those vehicles, heavier usually also meant larger-footprint. Hence, the numbers in those analyses were used to predict the safety-related fatalities that could occur in the unlikely event that weight reduction for MYs 2012–2016 is accomplished entirely by reducing mass *and* reducing footprint. Any estimates derived from those analyses represented a "worst-case" estimate of safety effects, for several reasons.

First, manufacturers are far less likely to reduce mass by "downsizing" (making vehicles smaller overall) under the current attribute-based standards, because the standards are based on vehicle footprint. The selection of footprint as the attribute in setting CAFE and GHG standards helps to reduce the incentive to alter a vehicle's physical dimensions. This is because as footprint decreases, the corresponding fuel economy/GHG emission target becomes more stringent.[120] The shape of the footprint curves themselves have also been designed to be approximately "footprint neutral" within the sloped portion of the functions—that is, to neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. For further discussion on these aspects of the standards, *please see* Section II.C above and Chapter 2 of the Joint TSD. However, as discussed in Sections III.H.1 and IV.G.6 below, the agencies acknowledge some uncertainty regarding how consumer purchases will change in response to the vehicles

[117] Kahane, Charles J., PhD, "Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991–99 Passenger Cars and Light Trucks," DOT HS 809 662, October 2003, Executive Summary. *Available at http://www.nhtsa.dot.gov/cars/rules/regrev/evaluate/809662.html* (last accessed March 10, 2010).

[118] NHTSA explained that there are several identifiable safety trends that are already in place or expected to occur in the foreseeable future and that were not accounted for in the study. For example, two important new safety standards that have already been issued and will be phasing in during the rulemaking time frame. Federal Motor Vehicle Safety Standard No. 126 (49 CFR 571.126) will require electronic stability control in all new vehicles by MY 2012, and the upgrade to Federal Motor Vehicle Safety Standard No. 214 (Side Impact Protection, 49 CFR 571.214) will likely result in all new vehicles being equipped with head-curtain air bags by MY 2014. Additionally, the agency stated that it anticipates continued improvements in driver (and passenger) behavior, such as higher safety belt use rates. All of these will tend to reduce the absolute number of fatalities resulting from mass reductions. Thus, while the percentage increases in Kahane (2003) was applied, the reduced base resulted in smaller absolute increases than those that were predicted in the 2003 report.

[119] Blincoe, L. and Shankar, U, "The Impact of Safety Standards and Behavioral Trends on Motor Vehicle Fatality Rates," DOT HS 810 777, January 2007. See Table 4 comparing 2020 to 2007 (37,906/43,363 = 12.6% reduction (1-.126 = .874)

[120] We note, however, that vehicle footprint is not synonymous with vehicle size. Since the footprint is only that portion of the vehicle between the front and rear axles, footprint-based standards do not discourage downsizing the portions of a vehicle in front of the front axle and to the rear of the rear axle, or to other portions of the vehicle outside the wheels. The crush space provided by those portions of a vehicle can make important contributions to managing crash energy. NHTSA noted in the NPRM that at least one manufacturer has confidentially indicated plans to reduce overhang as a way of reducing mass on some vehicles during the rulemaking time frame. Additionally, simply because footprint-based standards create no incentive to downsize vehicles, does not mean that manufacturers may not choose to do so if doing so makes it easier to meet the overall standard (as, for example, if the smaller vehicles are so much lighter that they exceed their targets by much greater amounts).

designed to meet the MYs 2012–2016 standards. This could potentially affect the mix of vehicles sold in the future, including the mass and footprint distribution.

As a result, the agencies found it likely that a significant portion of the mass reduction in the MY 2012–2016 vehicles would be accomplished by strategies, such as material substitution, smart design, reduced powertrain requirements,[121] and mass compounding, that have a lesser safety effect than the prevalent 1980s strategy of simply making the vehicles smaller. The agencies noted that to the extent that future mass reductions could be achieved by these methods—without any accompanying reduction in the size or structural strength of the vehicle—then the fatality increases associated with the mass reductions anticipated by the model as a result of the proposed standards could be significantly smaller than those in the worst-case scenario.

However, even though the agencies recognized that these methods of mass reduction could be technologically feasible in the rulemaking time frame, and included them as such in our modeling analyses, the agencies diverged as to how potential safety effects accompanying such methods of mass reduction could be evaluated, particularly in relation to the worst-case scenario presented by NHTSA. NHTSA stated that it could not predict how much smaller those increases would be for any given mixture of mass reduction methods, since the data on the safety effects of mass reduction alone (without size reduction) was not available due to the low numbers of vehicles in the current on-road fleet that have utilized these technologies extensively. Further, to the extent that mass reductions were accomplished through use of light, high-strength materials, NHTSA emphasized that there would be significant additional costs that would need to be determined and accounted for than were reflected in the agency's proposal.

Additionally, NHTSA emphasized that while it thought material substitution and other methods of mass reduction could considerably lessen the potential safety effects compared to the historical trend, NHTSA also stated that it did not believe the effects in passenger cars would be smaller than zero. EPA disagreed with this, and stated in the NPRM that the safety effects could very well be smaller than zero. Even though footprint-based standards discourage downsizing as a way of "balancing out" sales of larger/heavier vehicles, they do not discourage manufacturers from reducing crush space in overhang areas or from reducing structural support as a way of taking out mass.[122] Moreover, NHTSA's analysis had also found that lighter cars have a higher involvement rate in fatal crashes, even after controlling for the driver's age, gender, urbanization, and region of the country. Being unable to explain this clear trend in the crash data, NHTSA stated that it must assume that mass reduction is likely to be associated with higher fatal-crash rates, no matter how the weight reduction is achieved.

NHTSA also noted in the NPRM that several studies by Dynamic Research, Inc. (DRI) had been repeatedly cited to the agency in support of the proposition that reducing vehicle mass while maintaining track width and wheelbase would lead to significant safety benefits. In its 2005 studies, one of which was published and peer-reviewed through the Society of Automotive Engineers as a technical paper, DRI attempted to assess the independent effects of vehicle weight and size (in terms of wheelbase and track width) on safety, and presented results indicating that reducing vehicle weight tends to reduce fatalities, but that reducing vehicle wheelbase and track width tends to increase fatalities. DRI's analysis was based on FARS data for MYs 1985–1998 passenger cars and 1985–1997 light trucks, similar to the MYs 1991–1999 car and truck data used in the 2003 Kahane report. However, DRI included 2-door passenger cars, while the 2003 Kahane report excluded those vehicles out of concern that their inclusion could bias the results of the regression analysis, because a significant proportion of MYs 1991–1999 2-door cars were sports and "muscle" cars, which have particularly high fatal crash rates for their relatively short wheelbases compared to the rest of the fleet. While in the NPRM NHTSA rejected the results of the DRI studies based in part on this concern, the agencies note that upon further consideration, NHTSA has agreed for this final rule that the inclusion of 2-door cars in regression analysis of historical data is appropriate, and indeed has no overly-biasing effects.

The 2005 DRI studies also differed from the 2003 Kahane report in terms of their estimates of the effect of vehicle weight on rollover fatalities. The 2003 Kahane report analyzed a single variable, curb weight, as a surrogate for both vehicle size and weight, and found that curb weight reductions would increase rollover fatalities. The DRI study, in contrast, attempted to analyze curb weight, wheelbase, and track width separately, and found that curb weight reduction would *decrease* rollover fatalities, while wheelbase reduction and track width reduction would increase them. DRI suggested that heavier vehicles may have higher rollover fatalities for two reasons: first, because taller vehicles tend to be heavier, so the correlation between vehicle height and weight and vehicle center-of-gravity height may make heavier vehicles more rollover-prone; and second, because heavier vehicles may have been less rollover-crashworthy due to FMVSS No. 216's constant (as opposed to proportional) requirements for MYs 1995–1999 vehicles weighing more than 3,333 lbs unloaded.

Overall, DRI's 2005 studies found a reduction in fatalities for cars (580 in the first study, and 836 in the second study) and for trucks (219 in the first study, 682 in the second study) for a 100 pound reduction in curb weight without accompanying wheelbase or track width reductions. In the NPRM, NHTSA disagreed with the results of the DRI studies, out of concern that DRI's inclusion of 2-door cars in its analysis biased the results, and because NHTSA was unable to reproduce DRI's results despite repeated attempts. NHTSA stated that it agreed intuitively with DRI's conclusion that vehicle mass reductions without accompanying size reductions (as through substitution of a heavier material for a lighter one) would be less harmful than downsizing, but without supporting real-world data and unable to verify DRI's results, NHTSA stated that it could not conclude that mass reductions would result in safety benefits. EPA, in contrast, believed that DRI's results contained some merit, in particular because the study separated the effects of mass and size and EPA stated that applying them using the curb weight reductions in EPA's modeling analysis would show an overall reduction of fatalities for the proposed standards.

On balance, both agencies recognized that mass reduction could be an important tool for achieving higher levels of fuel economy and reducing CO_2 emissions, and emphasized that NHTSA's fatality estimates represented a worst-case scenario for the potential effects of the proposed standards, and

[121] Reduced powertrain requirements do not include a reduction in performance. When vehicle mass is reduced, engine torque and transmission gearing can be altered so that acceleration performance is held constant instead of improving. A detailed discussion is included in Chapter 3 of the Technical Support Document.

[122] However, we recognize that FMVSS and NCAP ratings may limit the manufacturer's ability to reduce crush space or structural support.

that actual fatalities will be less than these estimates, possibly significantly less, based on the various factors discussed in the NPRM that could reduce the estimates. The agencies sought comment on the safety analysis and discussions presented in the NPRM.

2. What public comments did the agencies receive on the safety analysis and discussions in the NPRM?

Several dozen commenters addressed the safety issue. Claims and arguments made by commenters in response to the safety effects analysis and discussion in the NPRM tended to follow several general themes, as follows:

NHTSA's safety effects estimates are inaccurate because they do not account for:

- While NHTSA's study only considers vehicles from MYs 1991–1999, more recently-built vehicles are safer than those, and future vehicles will be safer still;
- Lighter vehicles are safer than heavier cars in terms of crash-avoidance, because they handle and brake better;
- Fatalities are linked more to other factors than mass;
- The structure of the standards reduces/contributes to potential safety effects from mass reduction;
- NHTSA could mitigate additional safety effects from mass reduction, if there are any, by simply regulating safety more;
- Casualty risks range widely for vehicles of the same weight or footprint, which skews regression analysis and makes computer simulation a better predictor of the safety effects of mass reduction;

DRI's analysis shows that lighter vehicles will save lives, and NHTSA reaches the opposite conclusion without disproving DRI's analysis;

- Possible reasons that NHTSA and DRI have reached different conclusions:
  - NHTSA's study should distinguish between reductions in size and reductions in weight like DRI's;
  - NHTSA's study should include two-door cars;
  - NHTSA's study should have used different assumptions;
  - NHTSA's study should include confidence intervals;

NHTSA should include a "best-case" estimate in its study;

NHTSA should not include a "worst-case" estimate in its study;

The agencies recognize that the issue of the potential safety effects of mass reduction, which was one of the many factors considered in the balancing that led to the agencies' conclusion as to appropriate stringency levels for the MYs 2012–2016 standards, is of great interest to the public and could possibly be a more significant factor in regulators' and manufacturers' decisions with regard to future standards beyond MY 2016. The agencies are committed to analyzing this issue thoroughly and holistically going forward, based on the best available science, in order to further their closely related missions of safety, energy conservation, and environmental protection. We respond to the issues and claims raised by commenters in turn below.

NHTSA's estimates are inaccurate because NHTSA's study only considers vehicles from MYs 1991–1999, but more recently-built vehicles are safer than those, and future vehicles will be safer still

A number of commenters (CAS, Adcock, NACAA, NJ DEP, NY DEC, UCS, and Wenzel) argued that the 2003 Kahane report, on which the "worst-case scenario" in the NPRM was based, is outdated because it considers the relationship between vehicle weight and safety in MYs 1991–1999 passenger cars. These commenters generally stated that data from MYs 1991–1999 vehicles provide an inaccurate basis for assessing the relationship between vehicle weight and safety in current or future vehicles, because the fleets of vehicles now and in the future are increasingly different from that 1990s fleet (more crossovers, fewer trucks, lighter trucks, etc.), with different vehicle shapes and characteristics, different materials, and more safety features. Several of these commenters argued that NHTSA should conduct an updated analysis for the final rule using more recent data—Wenzel, for example, stated that an updated regression analysis that accounted for the recent introduction of crossover SUVs would likely find reduced casualty risk, similar to DRI's previous finding using fatality data. CEI, in contrast, argued that the "safety trade-off" would not be eliminated by new technologies and attribute-based standards, because additional weight inherently makes a vehicle safer to its own occupants, citing the 2003 Kahane report, while AISI argued that Desapriya had found that passenger car drivers and occupants are two times more likely to be injured than drivers and occupants in larger pickup trucks and SUVs.

Several commenters (Adcock, CARB, Daimler, NESCAUM, NRDC, Public Citizen, UCS, Wenzel) suggested that NHTSA's analysis was based on overly pessimistic assumptions about how manufacturers would choose to reduce mass in their vehicles, because manufacturers have a strong incentive in the market to build vehicles safely. Many of these commenters stated that several manufacturers have already committed publicly to fairly ambitious mass reduction goals in the mid-term, but several stated further that NHTSA should not assume that manufacturers will reduce the same amount of mass in all vehicles, because it is likely that they will concentrate mass reduction in the heaviest vehicles, which will improve compatibility and decrease aggressivity in the heaviest vehicles. Daimler emphasized that all vehicles will have to comply with the Federal Motor Vehicle Safety Standards, and will likely be designed to test well in NHTSA's NCAP tests.

Other commenters (Aluminum Association, CARB, CAS, ICCT, MEMA, NRDC, U.S. Steel) also emphasized the need for NHTSA to account for the safety benefits to be expected in the future from use of advanced materials for lightweighting purposes and other engineering advances. The Aluminum Association stated that advanced vehicle design and construction techniques using aluminum can improve energy management and minimize adverse safety effects of their use,[123] but that NHTSA's safety analysis could not account for those benefits if it were based on MYs 1991–1999 vehicles. CAS, ICCT, and U.S. Steel discussed similar benefits for more recent and future vehicles built with high strength steel (HSS), although U.S. Steel cautioned that given the stringency of the proposed standards, manufacturers would likely be encouraged to build smaller and lighter vehicles in order to achieve compliance, which fare worse in head-on collisions than larger, heavier vehicles. AISI, in contrast to U.S. Steel, stated that in its research with the Auto/Steel Partnership and in programs supported by DOE, it had found that the use of new Advanced HSS steel grades could enable mass of critical crash structures, such as front rails and bumper systems, to be reduced by 25 percent without degrading performance in standard NHTSA frontal or IIHS offset

[123] The Aluminum Association (NHTSA–2009–0059–0067.3) stated that its research on vehicle safety compatibility between an SUV and a mid-sized car, done jointly with DRI, shows that reducing the weight of a heavier SUV by 20% (a realistic value for an aluminum-intensive vehicle) could reduce the combined injury rate for both vehicles by 28% in moderately severe crashes. The commenter stated that it would keep NHTSA apprised of its results as its research progressed. Based on the information presented, NHTSA believes that this research appears to agree with NHTSA's latest analysis, which finds that a reduction in weight for the heaviest vehicles may improve overall fleet safety.

instrumented crash tests compared to their "heavier counterparts."

Agencies' response: NHTSA, in consultation with EPA and DOE, plans to begin updating the MYs 1991–1999 database on which NHTSA's safety analyses in the NPRM and final rule are based in the next several months in order to analyze the differences in safety effects against vehicles built in more recent model years. As this task will take at least a year to complete, beginning it immediately after the NPRM would not have enabled the agency to complete it and then conduct a new analysis during the period between the NPRM and the final rule.

For purposes of this final rule, however, we believe that using the same MYs 1991–1999 database as that used in the 2003 Kahane study provides a reasonable basis for attempting to estimate safety effects due to reductions in mass. While commenters often stated that updating the database would help to reveal the effect of recently-introduced lightweight vehicles with extensive material substitution, there have in fact not yet been a significant number of vehicles with substantial mass reduction/material substitution to analyze, and they must also show up in the crash databases for NHTSA to be able to add them to its analysis. Based on NHTSA's research, specifically, on three statistical analyses over a 12-year period (1991–2003) covering a range of 22 model years (1978–1999), NHTSA believes that the relationships between mass, size, and safety has only changed slowly over time, although we recognize that they may change somewhat more rapidly in the future.[124] As the on-road fleet gains increasing numbers of vehicles with increasing amounts of different methods of mass reduction applied to them, we may begin to discern changes in the crash databases due to the presence of these vehicles, but any such changes are likely to be slow and evolutionary, particularly in the context of MYs 2000–2009 vehicles. The agencies do expect that further analysis of historical data files will continue to provide a robust and practicable basis for estimating the potential safety effects that might occur with future reductions in vehicle mass. However, we recognize that estimates derived from analysis of historical data, like estimates from any other type of analysis (including simulation-based analysis, which cannot feasibly cover all relevant scenarios), will be uncertain in terms of predicting actual future outcomes with respect to a vehicle fleet, driving population, and operating environment that does not yet exist.

The agencies also recognize that more recent vehicles have more safety features than 1990s vehicles, which are likely to make them safer overall. To account for this, NHTSA did adjust the results of both its NPRM and final rule analysis to include known safety improvements, like ESC and increases in seat belt use, that have occurred since MYs 1991–1999.[125] However, simply because newer vehicles have more safety countermeasures, does not mean that the weight/safety relationship necessarily changes. More likely, it would change the target population (the number of fatalities) to which one would apply the weight/safety relationship. Thus, we still believe that some mass reduction techniques for both passenger cars and light trucks can make them less safe, in certain crashes as discussed in NHTSA's FRIA, than if mass had not been reduced.[126]

As for NHTSA's assumptions about mass reduction, in its analysis, NHTSA generally assumed that lighter vehicles could be reduced in weight by 5 percent while heavier light trucks could be reduced in weight by 10 percent. NHTSA recognizes that manufacturers might choose a different mass reduction scheme than this, and that its quantification of the estimated effect on safety would be different if they did. We emphasize that our estimates are based on the assumptions we have employed and are intended to help the agency consider the potential effect of the final standards on vehicle safety. Thus, based on the 2010 Kahane analysis, reductions in weight for the heavier light trucks would have positive overall safety effects,[127] while mass reductions for passenger cars and smaller light trucks would have negative overall safety effects.

NHTSA's estimates are inaccurate because they do not account for the fact that lighter vehicles are safer than heavier cars in terms of crash-avoidance, because they handle and brake better

ICCT stated that lighter vehicles are better able to avoid crashes because they "handle and brake slightly better," arguing that size-based standards encourage lighter-weight car-based SUVs with "significantly better handling and crash protection" than 1996–1999 mid-size SUVs, which will reduce both fatalities and fuel consumption. ICCT stated that NHTSA did not include these safety benefits in its analysis. DRI also stated that its 2005 report found that crash avoidance improves with reduction in curb weight and/or with increases in wheelbase and track, because "Crash avoidance can depend, amongst other factors, on the vehicle directional control and rollover characteristics." DRI argued that, therefore, "These results indicate that vehicle weight reduction tends to decrease fatalities, but vehicle wheelbase and track reduction tends to increase fatalities."

Agencies' response: In fact, NHTSA's regression analysis of crash fatalities per million registration years measures the effects of crash avoidance, if there are any, as well as crashworthiness. Given that the historical empirical data for passenger cars show a trend of higher crash rates for lighter cars, it is unclear whether lighter cars have, in the net, superior crash avoidance, although the agencies recognize that they may have advantages in certain individual situations. EPA presents a discussion of improved accident avoidance as vehicle mass is reduced in Chapter 7.6 of its final RIA. The important point to emphasize is that it depends on the situation—it would oversimplify drastically to point to one situation in which extra mass helps or hurts and then extrapolate effects for crash avoidance across the board based on only that.

For example, the relationship of vehicle mass to rollover and directional stability is more complex than commenters imply. For rollover, it is true that if heavy pickups were always more top-heavy than lighter pickups of the same footprint, their higher center of gravity could make them more rollover-prone, yet some mass can be placed so as to lower a vehicle's center of gravity and make it less rollover-prone. For mass reduction to be beneficial in rollover crashes, then, it must take

[124] NHTSA notes the CAS' comments regarding changes in the vehicle fleets since the introduction of CAFE standards in the late 1970s, but believes they apply more to the differences between late 1970s through 1980s vehicles and 2010s vehicles than to the differences between 1990s and 2010s vehicles. NHTSA believes that the CAS comments regarding the phase-out of 1970s vehicles and their replacement with safer, better fuel-economy-achieving 1980s vehicles paint with rather too large a brush to be relevant to the main discussion of whether the 2003 Kahane report database can reasonably be used to estimate safety effects of mass reduction for the MYs 2012–2016 fleet.

[125] See NHTSA FRIA Chapter IX.

[126] If one has a vehicle (vehicle A), and both reduces the vehicle's mass and adds new safety equipment to it, thus creating a variant (vehicle A_1), the variant might conceivably have a level of overall safety for its occupants equal to that of the original vehicle (vehicle A). However, vehicle A_1 might not be as safe as second variant (vehicle A_2) of vehicle A, one that is produced by adding to vehicle A the same new safety equipment added to the first variant, but this time without any mass reduction.

[127] This is due to the beneficial effect on the occupants of vehicles struck by the downweighted larger vehicles.

center of gravity height into account along with other factors such as passenger compartment design and structure, suspension, the presence of various safety equipment, and so forth.

Similarly, for directional stability, it is true that having more mass increases the "understeer gradient" of cars—*i.e.,* it reinforces their tendency to proceed in a straight line and slows their response to steering input, which would be harmful where prompt steering response is essential, such as in a double-lane-change maneuver to avoid an obstacle. Yet more mass and a higher understeer gradient could help when it is better to remain on a straight path, such as on a straight road with icy patches where wheel slip might impair directional stability. Thus, while less vehicle mass can sometimes improve crash avoidance capability, there can also be situations when more vehicle mass can help in other kinds of crash avoidance.

Further, NHTSA's research suggests that additional vehicle mass may be even more helpful, as discussed in Chapter IX of NHTSA's FRIA, when the average driver's response to a vehicle's maneuverability is taken into account. Lighter cars have historically (1976–2009) had higher collision-involvement rates than heavier cars—even in multi-vehicle crashes where directional and rollover stability is not particularly an issue.[128] Based on our analyses using nationally-collected FARS and GES data, drivers of lighter cars are more likely to be the culpable party in a 2-vehicle collision, even after controlling for footprint, the driver's age, gender, urbanization, and region of the country.

Thus, based on this data, it appears that lighter cars may not be driven as well as heavier cars, although it is unknown why this is so. If poor drivers intrinsically chose light cars (self-selection), it might be evidenced by an increase in antisocial driving behavior (such as DWI, drug involvement, speeding, or driving without a license) as car weight decreases, after controlling for driver age and gender—in addition to the increases in merely culpable driver behavior (such as failure to yield the right of way). But analyses in NHTSA's 2003 report did not show an increase in antisocial driver behavior in the lighter cars paralleling their increase in culpable involvements.

NHTSA also hypothesizes that certain aspects of lightness and/or smallness in a car may give a driver a perception of greater maneuverability that ultimately results in driving with less of a "safety margin," *e.g.,* encouraging them to weave in traffic. That may appear paradoxical at first glance, as maneuverability is, in the abstract, a safety plus. Yet the situation is not unlike powerful engines that could theoretically enable a driver to escape some hazards, but in reality have long been associated with high crash and fatality rates.[129]

NHTSA's estimates are inaccurate because fatalities are linked more to other factors than mass

Tom Wenzel stated that the safety record of recent model year crossover SUVs indicates that weight reduction in this class of vehicles (small to mid-size SUVs) resulted in a reduction in fatality risk. Wenzel argued that NHTSA should acknowledge that other vehicle attributes may be as important, if not more important, than vehicle weight or footprint in terms of occupant safety, such as unibody construction as compared to ladder-frame, lower bumpers, and less rigid frontal structures, all of which make crossover SUVs more compatible with cars than truck-based SUVs.

Marc Ross commented that fatalities are linked more strongly to intrusion than to mass, and stated that research by safety experts in Japan and Europe suggests the main cause of serious injuries and deaths is intrusion due to the failure of load-bearing elements to properly protect occupants in a severe crash. Ross argued that the results from this project have "overturned the original views about compatibility," which thought that mass and the mass ratio were the dominant factors. Since footprint-based standards will encourage the reduction of vehicle weight through materials substitution while maintaining size, Ross stated, they will help to reduce intrusion and consequently fatalities, as the lower weight reduces crash forces while maintaining size preserves crush space. Ross argued that this factor was not considered by NHTSA in its discussion of safety. ICCT agreed with Ross' comments on this issue.

In previous comments on NHTSA rulemakings and in several studies, Wenzel and Ross have argued generally that vehicle design and "quality" is a much more important determinant of vehicle safety than mass. In comments on the NPRM, CARB, NRDC, Sierra Club, and UCS echoed this theme.

ICCT commented as well that fatality rates in the EU are much lower than rates in the U.S., even though the vehicles in the EU fleet tend to be smaller and lighter than those in the U.S. fleet. Thus, ICCT argued, "This strongly supports the idea that vehicle and highway design are far more important factors than size or weight in vehicle safety." ICCT added that "It also suggests that the rise in SUVs in the U.S. has not helped reduce fatalities." CAS also commented that Germany's vehicle fleet is both smaller and lighter than the American fleet, and has lower fatality rates.

Agencies' response: NHTSA and EPA agree that there are many features that affect safety. While crossover SUVs have lower fatality rates than truck-based SUVs, there are no analyses that attribute the improved safety to mass alone, and not to other factors such as the lower center of gravity or the unibody construction of these vehicles. While a number of improvements in safety can be made, they do not negate the potential that another 100 lbs. could make a passenger car or crossover vehicle safer for its occupants, because of the effects of mass per se as discussed in NHTSA's FRIA, albeit similar mass reductions could make heavier LTVs safer to other vehicles without necessarily harming their own drivers and occupants. Moreover, in the 2004 response to docket comments, NHTSA explained that the significant relationship between mass and fatality risk persisted even after controlling for vehicle price or nameplate, suggesting that vehicle "quality" as cited by Wenzel and Ross is not necessarily more important than vehicle mass.

As for reductions in intrusions due to material substitution, the agencies agree generally that the use of new and innovative materials may have the potential to reduce crash fatalities, but such vehicles have not been introduced in large numbers into the vehicle fleet. The agencies will continue to monitor the situation, but ultimately the effects of different methods of mass reduction on overall safety in the real world (not just in simulations) will need to be analyzed when vehicles with these types of mass reduction are on the road in sufficient quantities to provide statistically significant results. For example, a vehicle that is designed to be

[128] See, *e.g.,* NHTSA (2000). *Traffic Safety Facts 1999.* Report No. DOT HS 809 100. Washington, DC: National Highway Traffic Safety Administration, p. 71; Najm, W.G., Sen, B., Smith, J.D., and Campbell, B.N. (2003). *Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System,* Report No. DOT HS 809 573. Washington, DC: National Highway Traffic Safety Administration, p. 48.

[129] Robertson, L.S. (1991), "How to Save Fuel and Reduce Injuries in Automobiles," *The Journal of Trauma,* Vol. 31, pp. 107–109; Kahane, C.J. (1994). Correlation of NCAP Performance with Fatality Risk in Actual Head-On Collisions, NHTSA Technical Report No. DOT HS 808 061. Washington, DC: National Highway Traffic Safety Administration, *http://www-nrd.nhtsa.dot.gov/Pubs/808061.PDF,* pp. 4–7.

much stiffer to reduce intrusion is likely to have a more severe crash pulse and thus impose greater forces on the occupants during a crash, and might not necessarily be good for elderly and child occupant safety in certain types of crashes. Such trade-offs make it difficult to estimate overall results accurately without real world data. The agencies will continue to evaluate and analyze such real world data as it becomes available, and will keep the public informed as to our progress.

ICCT's comment illustrates the fact that different vehicle fleets in different countries can face different challenges. NHTSA does not believe that the fact that the EU vehicle fleet is generally lighter than the U.S. fleet is the exclusive reason, or even the primary factor, for the EU's lower fatality rates. The data ICCT cites do not account for significant differences between the U.S. and EU such as in belt usage, drunk driving, rural/urban roads, driving culture, etc.

The structure of the standards reduces/ contributes to potential safety risks from mass reduction

Since switching in 2006 to setting attribute-based light truck CAFE standards, NHTSA has emphasized that one of the benefits of a footprint-based standard is that it discourages manufacturers from building smaller, less safe vehicles to achieve CAFE compliance by "balancing out" their larger vehicles, and thus avoids a negative safety consequence of increasing CAFE stringency.[130] Some commenters on the NPRM (Daimler, IIHS, NADA, NRDC, Sierra Club *et al.*) agreed that footprint-based standards would protect against downsizing and help to mitigate safety risks, while others stated that there would still be safety risks even with footprint-based standards—CEI, for example, argued that mass reduction inherently creates safety risks, while IIHS and Porsche expressed concern about footprint-based standards encouraging manufacturers to manipulate wheelbase, which could reduce crush space and worsen vehicle handling. U.S. Steel and AISI both commented that the "aggressive schedule" for the proposed increases in stringency could encourage manufacturers to build smaller, lighter vehicles in order to comply.

Some commenters also focused on the shape and stringency of the target curves and their potential effect on vehicle safety. IIHS agreed with the agencies' tentative decision to cut off the target curves at the small-footprint end. Regarding the safety effect of the curves requiring less stringent targets for larger vehicles, while IIHS stated that increasing footprint is good for safety, CAS, Wenzel, and the UCSB students stated that decreasing footprint may be better for safety in terms of risk to occupants of other vehicles. Daimler, Wenzel, and the University of PA Environmental Law Project commented generally that more similar passenger car and light truck targets at identical footprints (as Wenzel put it, a single target curve) would improve fleet compatibility and thus, safety, by encouraging manufacturers to build more passenger cars instead of light trucks.

Agencies' response: The agencies continue to believe that footprint-based standards help to mitigate potential safety risks from downsizing if the target curves maintain sufficient slope, because, based on NHTSA's analysis, larger-footprint vehicles are safer than smaller-footprint vehicles.[131] The structure of the footprint-based curves will also discourage the upsizing of vehicles. Nevertheless, we recognize that footprint-based standards are not a panacea—NHTSA's analysis continues to show that there was a historical relationship between lower vehicle mass and increased safety risk in passenger cars even if footprint is maintained, and there are ways that manufacturers may increase footprint that either improve or reduce vehicle safety, as indicated by IIHS and Porsche.

With regard to whether the agencies should set separate curves or a single one, NHTSA also notes in Section II.C that EPCA requires NHTSA to establish standards separately for passenger cars and light trucks, and thus concludes that the standards for each fleet should be based on the characteristics of vehicles in each fleet. In other words, the passenger car curve should be based on the characteristics of passenger cars, and the light truck curve should be based on the characteristics of light trucks—thus to the extent that those characteristics are different, an artificially-forced convergence would not accurately reflect those differences. However, such convergence could be appropriate depending on future trends in the light vehicle market, specifically further reduction in the differences between passenger car and light truck characteristics. While that trend was more apparent when car-like 2WD SUVs were classified as light trucks, it seems likely to diminish for the model year vehicles subject to these rules as the truck fleet will be more purely "truck-like" than has been the case in recent years.

NHTSA's estimates are inaccurate because NHTSA could mitigate additional safety risks from mass reduction, if there are any, by simply regulating safety more

Since NHTSA began considering the potential safety risks from mass reduction in response to increased CAFE standards, some commenters have suggested that NHTSA could mitigate those safety risks, if any, by simply regulating more.[132] In response to the safety analysis presented in the NPRM, several commenters stated that NHTSA should develop additional safety regulations to require vehicles to be designed more safely, whether to improve compatibility (Adcock, NY DEC, Public Citizen, UCS), to require seat belt use (CAS, UCS), to improve rollover and roof crush resistance (UCS), or to improve crashworthiness generally by strengthening NCAP and the star rating system (Adcock). Wenzel commented further that "Improvements in safety regulations will have a greater effect on occupant safety than FE standards that are structured to maintain, but may actually increase, vehicle size."

Agencies' response: NHTSA appreciates the commenters' suggestions and notes that the agency is continually striving to improve motor vehicle safety consistent with its mission. As noted above, improving safety in other areas affects the target population that the mass/footprint relationship could affect, but it does not necessarily change the relationship.

The 2010 Kahane analysis discussed in this final rule evaluates the relative safety risk when vehicles are made lighter than they might otherwise be absent the final MYs 2012–2016 standards. It does consider the effect of known safety regulations as they are projected to affect the target population.

Casualty risks range widely for vehicles of the same weight or footprint, which skews regression analysis and makes computer simulation a better predictor of the safety effects of mass reduction

[130] We note that commenters were divided on whether they believed there was a clear correlation between vehicle size/weight and safety (CEI, Congress of Racial Equality, Heritage Foundation, IIHS, Spurgeon, University of PA Environmental Law Project) or whether they believed that the correlation was less clear, for example, because they believed that vehicle design was more important than vehicle mass (CARB, Public Citizen).

[131] *See* Chapter IX of NHTSA's FRIA.

[132] *See, e.g.,* MY 2011 CAFE final rule, 74 FR 14403–05 (Mar. 30, 2009).

Wenzel commented that he had found, in his most recent work, after accounting for drivers and crash location, that there is a wide range in casualty risk for vehicles with the same weight or footprint. Wenzel stated that for drivers, casualty risk does generally decrease as weight or footprint increases, especially for passenger cars, but the degree of variation in the data for vehicles (particularly light trucks) at a given weight or footprint makes it difficult to say that a decrease in weight or footprint will necessarily result in increased casualty risk. In terms of risk imposed on the drivers of other vehicles, Wenzel stated that risk increases as light truck weight or footprint increases.

Wenzel further stated that because a regression analysis can only consider the average trend in the relationship between vehicle weight/size and risk, it must "ignore" vehicles that do not follow that trend. Wenzel therefore recommended that the agency employ computer crash simulations for analyzing the effect of vehicle weight reduction on safety, because they can "pinpoint the effect of specific vehicle designs on safety," and can model future vehicles which do not yet exist and are not bound to analyzing historical data. Wenzel cited, as an example, a DRI simulation study commissioned by the Aluminum Association (Kebschull 2004), which used a computer model to simulate the effect of changing SUV mass or footprint (without changing other attributes of the vehicle) on crash outcomes, and showed a 15 percent net decrease in injuries, while increasing wheelbase by 4.5 inches while maintaining weight showed a 26 percent net decrease in serious injuries.

Agencies' response: The agencies have reviewed Mr. Wenzel's draft report for DOE to which he referred in his comments, but based on NHTSA's work do not find such a wide range of safety risk for vehicles with the same weight, although we agree there is a range of risk for a given footprint. Wenzel found that for drivers, casualty risk does generally decrease as weight or footprint increases, especially for passenger cars, and that in terms of risk imposed on the drivers of other vehicles, risk increases as light truck weight or footprint increases, but concluded that the variation in the data precluded the possibility of drawing any conclusions. In the 2010 Kahane study presented in the FRIA, NHTSA undertook a similar analysis in which it correlated weight to fatality risk for vehicles of essentially the same footprint.[133] The "decile analysis," provided as a check on the trend/direction of NHTSA's regression analysis, shows that societal fatality risk generally increases and rarely decreases for lighter relative to heavier cars of the same footprint. Thus, while Mr. Wenzel was reluctant to draw a conclusion, NHTSA believes that both our research and Mr. Wenzel's appear to point to the same conclusion. We agree that there is a wide range in casualty risk among cars of the same footprint, but we find that that casualty risk is correlated with weight. The correlation shows that heavier cars have lower overall societal fatality rates than lighter cars of very similar footprint.

The agencies agree that simulation can be beneficial in certain circumstances. NHTSA cautions, however, that it is difficult for a simulation analysis to capture the full range of variations in crash situations in the way that a statistical regression analysis does. Vehicle crash dynamics are complex, and small changes in initial crash conditions (such as impact angle or closing speed) can have large effects on injury outcome. This condition is a consequence of variations in the deformation mode of individual components (*e.g.,* buckling, bending, crushing, material failure, etc.) and how those variations affect the creation and destruction of load paths between the impacting object and the occupant compartment during the crash event. It is therefore difficult to predict and assess structural interactions using computational methods when one does not have a detailed, as-built geometric and material model. Even when a complete model is available, prudent engineering assessments require extensive physical testing to verify crash behavior and safety. Despite all this, the agencies recognize that detailed crash simulations can be useful in estimating the relative structural effects of design changes over a limited range of crash conditions, and will continue to evaluate the appropriate use of this tool in the future.

Simplified crash simulations can also be valuable tools, but only when employed as part of a comprehensive analytical program. They are especially valuable in evaluating the relative effect and associated confidence intervals of feasible design alternatives. For example, the method employed by Nusholtz *et al.*[134] could be used by a vehicle designer to estimate the benefit of incremental changes in mass or wheelbase as well as the tradeoffs that might be made between them once that designer has settled on a preliminary design. A key difference between the research by Nusholtz and the research by Kebschull that Mr. Wenzel cited[135] is in their suggested applications. The former is useful in evaluating proposed alternatives early in the design process—Nusholtz specifically warns that the model provides only "general insights into the overall risk * * * and cannot be used to obtain specific response characteristics." Mr. Wenzel implies the latter can "isolate the effect of specific design changes, such as weight reduction" and thus quantify the fleet-wide effect of substantial vehicle redesigns. Yet while Kebschull reports injury reductions to three significant digits, there is no validation that vehicle structures of the proposed weight and stiffness are even feasible with current technology. Thus, while the agencies agree that computer simulations can be useful tools, we also recognize the value of statistical regression analysis for determining fleet-wide effects, because it inherently incorporates real-world factors in historical safety assessments.

DRI's analysis shows that lighter vehicles will save lives, and NHTSA reaches the opposite conclusion without disproving DRI's analysis

The difference between NHTSA's results and DRI's results for the relationship between vehicle mass and vehicle safety has been at the crux of this issue for several years. While NHTSA offered some theories in the NPRM as to why DRI might have found a safety benefit for mass reduction, NHTSA's work since then has enabled it to identify what we believe is the most likely reason for DRI's findings.

[133] Subsections 2.4 and 3.3 of new report.

[134] Nusholtz, G.S., G. Rabbiolo, and Y. Shi, "Estimation of the Effects of Vehicle Size and Mass on Crash-Injury Outcome Through Parameterized Probability Manifolds," Society of Automotive Engineers (2003), Document No. 2003–01–0905. *Available at http://www.sae.org/technical/papers/2003–01–0905* (last accessed Feb. 15, 2010).

[135] Mr. Wenzel cites the report by Kebschull et al. [2004, DRI–TR–04–04–02] as an example of what he regards as the effective use of computer crash simulation. NHTSA does not concur that this analysis represents a viable analytical method for evaluating the fleet-wide tradeoffs between vehicle mass and societal safety. The simulation method employed was not a full finite element representation of each major structural component in the vehicles in question. Instead, an Articulated Total Body (ATB) representation was constructed for each of two representative vehicles. In the ATB model, large structural subsystems were represented by a single ellipsoid. Consolidated load-deflection properties of these subsystems and the joints that tie them together were "calibrated" for an ATB vehicle model by requiring that it reproduce the acceleration pulse of a physical NHTSA crash test. NHTSA notes that vehicle simulation models that are calibrated to a single crash test configuration (*e.g.,* a longitudinal NCAP test into a rigid wall) are often ill-equipped to analyze alternative crash scenarios (*e.g.,* vehicle-to-vehicle crashes at arbitrary angles and lateral offsets).

The potential near multicollinearity of the variables of curb weight, track width, and wheelbase creates some degree of concern that any regression models with those variables could inaccurately calibrate their effects. However, based on its own experience with statistical analysis, NHTSA believes that the specific two-step regression model used by DRI increases this concern, because it weakens relationships between curb weight and dependent variables by splitting the effect of curb weight across the two regression steps.

The comments below are in response to NHTSA's theories in the NPRM about the source of the differences between NHTSA's and DRI's results. The majority of them are answered more fully in the 2010 Kahane report included in NHTSA's FRIA, but we respond to them in this document as well for purposes of completeness.

NHTSA and DRI may have reached different conclusions because NHTSA's study does not distinguish between reductions in size and reductions in weight like DRI's

Several commenters (CARB, CBD, EDF, ICCT, NRDC, and UCS) stated that DRI had been able to separate the effect of size and weight in its analysis, and in so doing proved that there was a safety benefit to reducing weight without reducing size. The commenters suggested that if NHTSA properly distinguished between reductions in size and reductions in weight, it would find the same result as DRI.

Agencies' response: In the 2010 Kahane analysis presented in the FRIA, NHTSA did attempt to separate the effects of vehicle size and weight by performing regression analyses with footprint (or alternatively track width and wheelbase) and curb weight as separate independent variables. For passenger cars, NHTSA found that the regressions attribute the fatality increase due to downsizing about equally to mass and footprint—that is, the effect of reducing mass alone is about half the effect of reducing mass *and* reducing footprint. Unlike DRI's results, NHTSA's regressions for passenger cars and for lighter LTVs did not find a safety benefit to reducing weight without reducing size; while NHTSA did find a safety benefit for reducing weight in the heaviest LTVs, the magnitude of the benefit as compared to DRI's was significantly smaller. NHTSA believes that these differences in results may be an artifact of DRI's two-step regression model, as explained above.

NHTSA and DRI may have reached different conclusions because NHTSA's study does not include two-door cars like DRI's

One of NHTSA's primary theories in the NPRM as to why NHTSA and DRI's results differed related to DRI's inclusion in its analysis of 2-door cars. NHTSA had excluded those vehicles from its analysis on the grounds that 2-door cars had a disproportionate crash rate (perhaps due to their inclusion of muscle and sports cars) which appeared likely to skew the regression. Several commenters argued that NHTSA should have included 2-door cars in its analysis. DRI and James Adcock stated that 2-door cars should not be excluded because they represent a significant portion of the light-duty fleet, while CARB and ICCT stated that because DRI found safety benefits whether 2-door cars were included or not, NHTSA should include 2-door cars in its analysis. Wenzel also commented that NHTSA should include 2-door cars in subsequent analyses, stating that while his analysis of MY 2000–2004 crash data from 5 states indicates that, in general, 4-door cars tend to have lower fatality risk than 2-door cars, the risk is even lower when he accounts for driver age/gender and crash location. Wenzel suggested that the increased fatality risk in the 2-door car population seemed primarily attributable to the sports cars, and that that was not sufficient grounds to exclude all 2-door cars from NHTSA's analysis.

Agencies' response: The agencies agree that 2-door cars can be included in the analysis, and NHTSA retracts previous statements that DRI's inclusion of them was incorrect. In its 2010 analysis, NHTSA finds that it makes little difference to the results whether 2-door cars are included, partially included, or excluded from the analysis. Thus, analyses of 2-door and 4-door cars combined, as well as other combinations, have been included in the analysis. That said, no combination of 2-door and 4-door cars resulted in NHTSA's finding a safety benefit for passenger cars due to mass reduction.

NHTSA and DRI may have reached different conclusions due to different assumptions

DRI commented that the differences found between its study and NHTSA's may be due to the different assumptions about the linearity of the curb weight effect and control variable for driver age, vehicle age, road conditions, and other factors. NHTSA's analysis was based on a two-piece linear model for curb weight with two different weight groups (less than 2,950 lbs., and greater than or equal to 2.950 lbs). The DRI analysis assumed a linear model for curb weight with a single weight group. Additionally, DRI stated that NHTSA's use of eight control variables (rather than three control variables like DRI used) for driver age introduces additional degrees of freedom into the regressions, which it suggested may be correlated with the curb weight, wheelbase, and track width, and/or other control variables. DRI suggested that this may also affect the results and cause or contribute to the differences in outcomes between NHTSA and DRI.

Agencies' response: NHTSA's FRIA documents that NHTSA analyzed its database using both a single parameter for weight (a linear model) and two parameters for weight (a two-piece linear model). In both cases, the logistic regression responded identically, allocating the same way between weight, wheelbase, track width, or footprint.[136] Thus, NHTSA does not believe that the differences between its results and DRI's results are due to whether the studies used a single weight group or two weight groups.

The FRIA also documents that NHTSA examined NHTSA's use of eight control variables for driver age (ages 14–30, 30–50, 50–70, 70+ for males and females separately, versus DRI's use of three control variables for age (FEMALE = 1 for females, 0 for males, YOUNGDRV = 35–AGE for drivers under 35, 0 for all others, OLDMAN = AGE–50 for males over 50, 0 for all others; OLDWOMAN = AGE–45 for females over 45, 0 for all others) to see if that affected the results. NHTSA ran its analysis using the eight control variables and again using three control variables for age, and obtained similar results each time.[137] Thus, NHTSA does not believe that the differences between its results and DRI's results are due to the number of control variables used for driver age.

NHTSA's and DRI's conclusions may be similar if confidence intervals are taken into account

DRI commented that NHTSA has not reported confidence intervals, while DRI has reported them in its studies. Thus, DRI argued, it is not possible to determine whether the confidence intervals overlap and whether the differences between NHTSA's and DRI's analyses are statistically significant.

Agencies' response: NHTSA has included confidence intervals for the main results of the 2010 Kahane analysis, as shown in Chapter IX of NHTSA's FRIA. For passenger cars, the NHTSA results are a statistically

[136] Subsections 2.2 and 2.3 of new report.

[137] *Id.*

significant increase in fatalities with a 100 pound reduction while maintaining track width and wheelbase (or footprint); the DRI results are a statistically significant decrease in fatalities with a 100 pound reduction while maintaining track width and wheelbase. The DRI results are thus outside the confidence bounds of the NHTSA results and do not overlap.

NHTSA should include a "best-case" estimate in its study

Several commenters (Center for Auto Safety, NRDC, Public Citizen, Sierra Club *et al.,* and Wenzel) urged NHTSA to include a "best-case" estimate in the final rule, showing scenarios in which lives were saved rather than lost. Public Citizen stated that there would be safety benefits to reducing the weight of the heaviest vehicles while leaving the weight of the lighter vehicles unchanged, and that increasing the number of smaller vehicles would provide safety benefits to pedestrians, bicyclists, and motorcyclists. Sierra Club *et al.* stated that new materials, smart design, and lighter, more advanced engines can all improve fuel economy while maintaining or increasing vehicle safety. Both Center for Auto Safety and Sierra Club argued that the agency should have presented a "best-case" scenario to balance out the "worst-case" scenario presented in the NPRM, especially if NHTSA itself believed that the worst-case scenario was not inevitable. NRDC requested that NHTSA present both a "best-case" and a "most likely" scenario. Wenzel simply stated that NHTSA did not present a "best-case" scenario, despite DRI's finding in 2005 that fatalities would be reduced if track width was held constant.

Agencies' response: NHTSA has included an "upper estimate" and a "lower estimate" in the new 2010 Kahane analysis. The lower estimate assumes that mass reduction will be accomplished entirely by material substitution or other techniques that do not perceptibly change a vehicle's shape, structural strength, or ride quality. The lower estimate examines specific crash modes and is meant to reflect the increase in fatalities for the specific crash modes in which a reduction in mass *per se* in the case vehicle would result in a reduction in safety: namely, collisions with larger vehicles not covered by the regulations (*e.g.,* trucks with a GVWR over 10,000 lbs), collisions with partially-movable objects (*e.g.,* some trees, poles, parked cars, etc.), and collisions of cars or light LTVs with heavier LTVs—as well as the specific crash modes where a reduction in mass *per se* in the case vehicle would benefit safety: namely, collisions of heavy LTVs with cars or lighter LTVs. NHTSA believes that this is the effect of mass *per se, i.e.,* the effects of reduced mass will generally persist in these crashes regardless of how the mass is reduced. The lower estimate attempts to quantify that scenario, although any such estimate is hypothetical and subject to considerable uncertainty. NHTSA believes that a "most likely" scenario cannot be determined with any certainty, and would depend entirely upon agency assumptions about how manufacturers intend to reduce mass in their vehicles. While we can speculate upon the potential effects of different methods of mass reduction, we cannot predict with certainty what manufacturers will ultimately do.

NHTSA should not include a "worst-case" estimate in its study

NRDC, Public Citizen and Sierra Club *et al.* commented that NHTSA should remove the "worst-case scenario" estimate from the rulemaking, generally because it was based on an analysis that evaluated historical vehicles, and future vehicles would be sufficiently different to render the "worst-case scenario" inapplicable.

Agencies' response: NHTSA stated in the NPRM that the "worst-case scenario" addressed the effect of a kind of downsizing (*i.e.,* mass reduction accompanied by footprint reduction) that was not likely to be a consequence of attribute-based CAFE standards, and that the agency would refine its analysis of such a scenario for the final rule. NHTSA has not used the "worst-case scenario" in the final rule. Instead, we present three scenarios: the first is an estimate based directly on the regression coefficients of weight reduction *while maintaining footprint* in the statistical analyses of historical data. As discussed above, presenting this scenario is possible because NHTSA attempted to separate the effects of weight and footprint reduction in the new analysis. However, even the new analysis of LTVs produced some coefficients that NHTSA did not consider entirely plausible. NHTSA also presents an "upper estimate" in which those coefficients for the LTVs were adjusted based on additional analyses and expert opinion as a safety agency and a "lower estimate," which estimates the effect if mass reduction is accomplished entirely by safety-conscious technologies such as material substitution.

3. How has NHTSA refined its analysis for purposes of estimating the potential safety effects of this Final Rule?

During the past months, NHTSA has extensively reviewed the literature on vehicle mass, size, and fatality risk. NHTSA now agrees with DRI and other commenters that it is essential to analyze the effect of mass independently from the effects of size parameters such as wheelbase, track width, or footprint—and that the NPRM's "worst-case" scenario based on downsizing (in which weight, wheelbase, and track width could all be changed) is not useful for that purpose. The agency should instead provide estimates that better reflect the more likely effect of the regulation—estimating the effect of mass reduction that maintains footprint.

Yet it is more difficult to analyze multiple, independent parameters than a single parameter (*e.g.,* curb weight), because there is a potential concern that the near multicollinearity of the parameters—the strong, natural and historical correlation of mass and size—can lead to inaccurate statistical estimates of their effects.[138] NHTSA has performed new statistical analyses of its historical database of passenger cars, light trucks, and vans (LTVs) from its 2003 report (now including also 2-door cars), assessing relationships between fatality risk, mass, and footprint. They are described in Subsections 2.2 (cars) and 3.2 (LTVs) of the 2010 Kahane report presented in Chapter IX of the FRIA. While the potential concerns associated with near multicollinearity are inherent in regression analyses with multiple size/mass parameters, NHTSA believes that the analysis approach in the 2010 Kahane report, namely a single-step regression analysis, generally reduces those concerns [139] and models the trends in the historical data. The results differ substantially from DRI's, based on a two-step regression analysis. Subsections 2.3 and 2.4 of the 2010

[138] Greene, W. H. (1993). *Econometric Analysis,* Second Edition. New York: Macmillan Publishing Company, pp. 266–268; Allison, P.D. (1999), *Logistic Regression Using the SAS System.* Cary, NC: SAS Institute Inc., pp. 48–51. The report shows variance inflation factor (VIF) scores in the 5–7 range for curb weight, wheelbase, and track width (or, alternatively, curb weight and footprint) in NHTSA's database, exceeding the 2.5 level where near multicollinearity begins to become a concern in logistic regression analyses.

[139] NHTSA believes that, given the near multicollinearity of the independent variables, the two-step regression augments the possibility of estimating inaccurate coefficients for curb weight, because it weakens relationships between curb weight and dependent variables by splitting the effect of curb weight across the two regression steps as discussed further in Subsection 2.3 of NHTSA's report.

Kahane report attempt to account for the differences primarily by applying selected techniques from DRI's analyses to NHTSA's database.

The statistical analyses—logistic regressions—of trends in MYs 1991–1999 vehicles generate one set of estimates of the possible effects of reducing mass by 100 pounds while maintaining footprint. While these effects might conceivably carry over to future mass reductions, there are two reasons that future safety effects of mass reduction could differ from projections from historical data:

The statistical analyses are "cross-sectional" analyses that estimate the increase in fatality rates for vehicles weighing n-100 pounds relative to vehicles weighing n pounds, across the spectrum of vehicles on the road, from the lightest to the heaviest. They do not directly compare the fatality rates for a specific make and model before and after a 100-pound reduction from that model. Instead, they use the differences across makes and models as a surrogate for the effects of actual reductions within a specific model; those cross-sectional differences could include trends that are statistically, but not causally related to mass.

The manner in which mass changed across MY 1991–1999 vehicles might not be consistent with future mass reductions, due to the availability of newer materials and design methods.

Therefore, Subsections 2.5 and 3.4 of the 2010 Kahane report supplement those estimates with one or more scenarios in which some of the logistic regression coefficients are replaced by numbers based on additional analyses and NHTSA's judgment of the likely effect of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision) and of what trends in the historical data could be avoided by current mass-reduction technologies such as materials substitution. The various scenarios may be viewed as a plausible range of point estimates for the effects of mass reduction while maintaining footprint, but they should not be construed as upper and lower bounds. Furthermore, being point estimates, they are themselves subject to uncertainties, such as, for example, the sampling errors associated with statistical analyses.

The principal findings and conclusions of the 2010 Kahane report are as follows:

Passenger cars: This database with the one-step regression method of the 2003 Kahane report estimates an increase of 700–800 fatalities when curb weight is reduced by 100 pounds *and* footprint is reduced by 0.65 square feet (the historic average footprint reduction per 100-pound mass reduction in cars). The regression attributes the fatality increase *about equally to curb weight and to footprint.* The results are approximately the same whether 2-door cars are fully included or partially included in the analysis or whether only 4-door cars are included (as in the 2003 report). Regressions by curb weight, track width and wheelbase produce findings quite similar to the regressions by curb weight and footprint, but the results with the single "size" variable, footprint, rather than the two variables, track width and wheelbase vary even less with the inclusion or exclusion of 2-door cars.

In Subsection 2.3 of the new report, a two-step regression method that resembles (without exactly replicating) the approach by DRI, *when applied to the same (NHTSA's) crash and registration data,* estimates a large *benefit* when mass is reduced, offset by even larger fatality increases when track width and wheelbase (or footprint) are reduced. NHTSA believes that the benefit estimated by this method is inaccurate, due to the potential concerns with the near multicollinearity of the parameters (curb weight, track width, and wheelbase)[140] even though the analysis is theoretically unbiased.[141] Almost any analysis incorporating those parameters has a possibility of inaccurate coefficients due to near multicollinearity; however, based on our own experience with other regression analyses of crash data, NHTSA believes a DRI-type two-step method augments the possibility of estimating inaccurate coefficients for curb weight, because it weakens relationships between curb weight and dependent variables by splitting the effect of curb weight across the two regression steps.

In Subsection 2.4 of the new report, as a check on the results from the regression methods, NHTSA also performed what we refer to as "decile" analyses: Simpler, tabular data analysis that compares fatality rates of cars of different mass but similar footprint. Decile analysis is not a precise tool because it does not control for confounding factors such as driver age/gender or the specific type of car, but it may be helpful in identifying the general directional trend in the data when footprint is held constant and curb weight varies. The decile analyses show that fatality risk in MY 1991–1999 cars generally increased and rarely decreased for lighter relative to heavier cars *of the same footprint.* They suggest that the historical, cross-sectional trend was generally in the lighter ↔ more fatalities direction and not in the opposite direction, as might be suggested by the regression coefficients from the method that resembles DRI's approach.

The regression coefficients from NHTSA's one-step method suggest that mass and footprint each accounted for about half the fatality increase associated with downsizing in a cross-sectional analysis of 1991–1999 cars. They estimate the historical difference in *societal* fatality rates (*i.e.,* including fatalities to occupants of all the vehicles involved in the collisions, plus any pedestrians) of cars of different curb weights but the same footprint. They may be considered an "upper-estimate scenario" of the effect of future mass reduction—if it were accomplished in a manner that resembled the historical cross-sectional trend—*i.e.,* without any particular regard for safety (other than not to reduce footprint).

However, NHTSA believes that future vehicle design is likely to take advantage of safety-conscious technologies such as materials substitution that can reduce mass without perceptibly changing a car's shape or ride and maintain its structural strength. This could avoid much of the risk associated with lighter and smaller vehicles in the historical analyses, especially the historical trend toward higher crash-involvement rates for lighter and smaller vehicles.[142] It could thereby shrink the added risk close to just the effects of mass *per se* (the ability to transfer momentum to other vehicles or objects in a collision). Subsection 2.5 of the 2010 Kahane report attempts to quantify a "lower-estimate scenario" for the potential effect of mass reduction achieved by safety-conscious technologies; the estimated effects are substantially smaller than in the upper-

[140] As evidenced by VIF scores in the 5–7 range, exceeding the 2.5 level where near multicollinearity begins to become a concern in logistic regression analyses.

[141] Subsection 2.3 of the 2010 Kahane report attempts to explain why the two-step method, when applied to NHTSA's 2003 database, produces results a lot like DRI's, but it does not claim that DRI obtained its results from its own database for exactly those reasons. NHTSA did not analyze DRI's database. The two-step method is "theoretically unbiased" in the sense that it seeks to estimate the same parameters as the one-step analysis.

[142] This is discussed in greater depth in Subsections 2.1 and 2.5 of the 2010 Kahane report. The historic trend toward higher crash-involvement rates for lighter and smaller vehicles is documented in IIHS Advisory No. 5, July 1988, *http://www.iihs.org/research/advisories/iihs_advisory_5.pdf*; IIHS News Release, February 24, 1998, *http://www.iihs.org/news/1998/iihs_news_022498.pdf*; Auto Insurance Loss Facts, September 2009, *http://www.iihs.org/research/hldi/fact_sheets/CollisionLoss_0909.pdf.*

estimate scenario based directly on the regression results.

We note, again, that the preceding paragraph is conditional. Nothing in the CAFE standard requires manufacturers to use material substitution or, more generally, take a safety-conscious approach to mass reduction.[143] Federal Motor Vehicle Safety Standards include performance tests that verify historical improvements in structural strength and crashworthiness, but few FMVSS provide test information that sheds light about how a vehicle rides or otherwise helps explain the trend toward higher crash-involvement rates for lighter and smaller vehicles. It is possible that using material substitution and other current mass reduction methods could avoid the historical trend in this area, but that remains to be studied as manufacturers introduce more of these vehicles into the on-road fleet in coming years. A detailed discussion of methods currently used for reducing the mass of passenger cars and light trucks is included in Chapter 3 of the Technical Support Document.

LTVs: The principal difference between LTVs and passenger cars is that mass reduction in the heavier LTVs is estimated to have significant societal benefits, in that it reduces the fatality risk for the occupants of cars and light LTVs that collide with the heavier LTVs. By contrast, footprint (size) reduction in LTVs has a harmful effect (for the LTVs' own occupants), as in cars. The regression method of the 2003 Kahane report applied to the database of that report estimates a societal increase of 231 fatalities when curb weight is reduced by 100 pounds *and* footprint is reduced by 0.975 square feet (the historic average footprint reduction per 100-pound mass reduction in LTVs). But the regressions attribute an overall *reduction* of 266 fatalities to the 100-pound mass reduction and an increase of 497 fatalities to the .975-square-foot footprint reduction. The regression results constitute one of the scenarios for the possible societal effects of future mass reduction in LTVs.

However, NHTSA cautions that some of the regression coefficients, even by NHTSA's preferred method, might not accurately model the historical trend in the data, possibly due to near multicollinearity of curb weight and footprint or because of the interaction of both of these variables with LTV type.[144] Based on supplementary analyses and discussion in Subsections 3.3 and 3.4, the new report defines an additional upper-estimate scenario that NHTSA believes may more accurately reflect the historical trend in the data and a lower-estimate scenario that may come closer to the effects of mass *per se.* All three scenarios, however, attribute a societal fatality reduction to mass reduction in the heavier LTVs.

Overall effects of mass reduction while maintaining footprint in cars and LTVs: The immediate purpose of the new report's analyses of relationships between fatality risk, mass, and footprint is to develop the four parameters that the Volpe model needs in order to predict the safety effects, if any, of the modeled mass reductions in MYs 2012–2016 cars and LTVs over the lifetime of those vehicles. The four numbers are the overall percentage increases or decreases, per 100-pound mass reduction while holding footprint constant, in crash fatalities involving: (1) Cars < 2,950 pounds (which was the median curb weight of cars in MY 1991–1999), (2) cars ≥ 2,950 pounds, (3) LTVs < 3,870 pounds (which was the median curb weight of LTVs in those model years), and (4) LTVs ≥ 3,870 pounds. Here are the percentage effects for each of the three alternative scenarios, again, the "upper-estimate scenario" and the "lower-estimate scenario" have been developed based on NHTSA's expert opinion as a vehicle safety agency:

FATALITY INCREASE PER 100-POUND REDUCTION (%) [145]

	Actual regression result scenario	NHTSA expert opinion upper-estimate scenario [146]	NHTSA expert opinion lower-estimate scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	0.90	0.90	0.44
LTVs < 3,870 pounds	0.17	0.55	0.41
LTVs ≥ 3,870 pounds	−1.90	−0.62	−0.73

In all three scenarios, the estimated effects of a 100-pound mass reduction while maintaining footprint are an increase in fatalities in cars < 2,950 pounds, substantially smaller increases in cars ≥ 2,950 pounds and LTVs < 3,870 pounds, and a societal benefit for LTVs ≥ 3,870 pounds (because it reduces fatality risk to occupants of cars and lighter LTVs they collide with). These are the estimated effects of reducing each vehicle by exactly 100pounds. However, the actual mass reduction will vary by make, model, and year. The aggregate effect on fatalities can only be estimated by attempting to forecast, as NHTSA has using inputs to the Volpe model, the mass reductions by make and model. It should be noted, however, that a 100-pound reduction would be 5 percent of the mass of a 2000-pound car but only 2 percent of a 5000-pound LTV. Thus, a forecast that mass will decrease by an equal or greater percentage in the heavier vehicles than in the lightest cars would be proportionately more influenced by the benefit for mass reduction in the heavy LTVs than by the fatality increases in the other groups; it is likely to result in an estimated net benefit under one or more of the scenarios. It should also be noted, again, that the

[143] Footprint-based standards do not specify how or where to remove mass while maintaining footprint, nor do they categorically forbid footprint reductions, even if they discourage them.

[144] For example, mid-size SUVs of the 1990s typically had high mass relative to their short wheelbase and footprint (and exceptionally high rates of fatal rollovers); minivans typically have low mass relative to their footprint (and low fatality rates); heavy-duty pickup trucks used extensively for work tend to have more mass, for the same footprint, as basic full-sized pickup trucks that are more often used for personal transportation.

[145] Reducing mass by 100 pounds in these vehicles is estimated to have the listed percentage effect on fatalities in crashes involving these vehicles. For example, if these vehicles are involved in crashes that result in 10,000 fatalities, 2.21 means that if mass is reduced by 100 pounds, fatalities will increase to 10,221 and −0.73 means fatalities will decrease to 9,927. In the scenario based on actual regression results, the 1.96-sigma sampling errors in the above estimates are ±0.91 percentage points for cars < 2,950 pounds and also for cars ≥ 2,950 pounds, ±0.82 percentage points for LTVs < 3,870 pounds, and ±1.18 percentage points for LTVs ≥ 3,870 pounds. In other words, the fatality increase in the cars < 2,950 pounds and the societal fatality reduction attributed to mass reduction in the LTVs ≥ 3,870 pounds are statistically significant. The sampling errors associated with the scenario based on actual regression results perhaps also indicate the general level of statistical noise in the other two scenarios.

[146] For passenger cars, the upper-estimate scenario *is* the actual-regression-result scenario.

three scenarios are point estimates and are subject to uncertainties, such as the sampling errors associated with the regression results. In the scenario based on actual regression results, the 1.96-sigma sampling errors in the above estimates are ± 0.91 percentage points for cars < 2,950 pounds and also for cars ≥ 2,950 pounds, ± 0.82 percentage points for LTVs < 3,870 pounds, and ± 1.18 percentage points for LTVs ≥ 3,870 pounds. In other words, the fatality increase in the cars < 2,950 pounds and the societal fatality reduction attributed to mass reduction in the LTVs ≥ 3,870 pounds are statistically significant. The sampling errors associated with the scenario based on actual regression results perhaps also indicate the general level of statistical noise in the other two scenarios.

4. What are the estimated safety effects of this Final Rule?

The table below shows the estimated safety effects of the modeled reduction in vehicle mass provided in the NPRM and in this final rule in order to meet the MYs 2012–2016 standards, based on the analysis described briefly above and in much more detail in Chapter IX of the FRIA. These are combined results for passenger cars and light trucks. A positive number is an estimated increase in fatalities and a negative number (shown in parentheses) is an estimated reduction in fatalities over the lifetime of the model year vehicles compared to the MY 2011 baseline fleet.

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
NPRM "Worst Case"	34	54	194	313	493
NHTSA Expert Opinion Final Rule Upper Estimate	9	14	26	24	22
NHTSA Expert Opinion Final Rule Lower Estimate	2	4	(17)	(53)	(80)
Actual Regression Result Scenario	0	2	(94)	(206)	(301)

NHTSA emphasizes that the table above is based on the NHTSA's assumptions about how manufacturers might choose to reduce the mass of their vehicles in response to the final rule, which are very similar to EPA's assumptions. In general, as discussed above, the agencies assume that mass will be reduced by as much as 10 percent in the heaviest LTVs but only by as much as 5 percent in other vehicles and that substantial mass reductions will take place only in the year that models are redesigned. The actual mass reduction that is likely to occur in response to the standards will of course vary by make and model, depending on each manufacturer's particular approach, with likely more opportunity for the largest LTVs that still use separate frame construction.

The "upper estimate" presented above, as discussed in the FRIA, assumes only that manufacturers will reduce vehicle mass without reducing footprint. Thus, under such a scenario, safety effects could be somewhat adverse if, for example, manufacturers chose to reduce crush space associated with vehicle overhang as a way of reducing mass without changing footprint. The "lower estimate," in turn, is based on the assumption that manufacturers will reduce vehicle mass solely through methods like material substitution, which (under these assumptions) fully maintain not only footprint but also all structural integrity, and other aspects of vehicle safety. Under these scenarios, safety effects could be worse if mass reduction was not undertaken thoughtfully to maintain existing safety levels, but could also be better if it was undertaken with a thorough and extensive vehicle redesign to maximize both mass reduction and safety.

And finally, while NHTSA does not believe that the "worst-case" scenario presented in the NPRM is likely to occur during the MYs 2012–2016 timeframe, we cannot guarantee that manufacturers will never choose to reduce vehicle footprint, particularly if market forces lead to increased sales of small vehicles in response to sharp increases in the price of petroleum, though this situation would not be in direct response to the CAFE/GHG standards. Thus, we cannot completely reject the worst-case scenario for all vehicles, although we can and do recognize that the footprint-based standards will significantly limit the likelihood of its occurrence within the context of this rulemaking.

In summary, the agencies recognize the balancing inherent in achieving higher levels of fuel economy and lower levels of CO_2 emissions through reduction of vehicle mass. Based on the 2010 Kahane analysis that attempts to separate the effects of mass reductions and footprint reductions, and to account better for the possibility that mass reduction will be accomplished entirely through methods that preserves structural strength and vehicle safety, the agencies now believe that the likely deleterious safety effects of the MYs 2012–2016 standards may be much lower than originally estimated. They may be close to zero, or possibly beneficial if mass reduction is carefully undertaken in the future and if the mass reduction in the heavier LTVs is greater (in absolute terms) than in passenger cars. In light of these findings, we believe that the balancing is reasonable.

5. How do the agencies plan to address this issue going forward?

NHTSA and EPA believe that it is important for the agencies to conduct further study and research into the interaction of mass, size and safety to assist future rulemakings. The agencies intend to begin working collaboratively and to explore with DOE, CARB, and perhaps other stakeholders an interagency/intergovernmental working group to evaluate all aspects of mass, size and safety. It would also be the goal of this team to coordinate government supported studies and independent research, to the extent possible, to help ensure the work is complementary to previous and ongoing research and to guide further research in this area. DOE's EERE office has long funded extensive research into component advanced vehicle materials and vehicle mass reduction. Other agencies may have additional expertise that will be helpful in establishing a coordinated work plan. The agencies are interested in looking at the weight-safety relationship in a more holistic (complete vehicle) way, and thanks to this CAFE rulemaking NHTSA has begun to bring together parts of the agency—crashworthiness, and crash avoidance rulemaking offices and the agency's Research & Development office—in an interdisciplinary way to better leverage the expertise of the agency. Extending this effort to other agencies will help to ensure that all aspects of the weight-safety relationship are considered completely and carefully with our future research. The agencies also intend to carefully consider comments received in response to the NPRM in developing plans for future studies and research and to solicit input from stakeholders.

The agencies also plan to watch for safety effects as the U.S. light-duty vehicle fleet evolves in response both to the CAFE/GHG standards and to consumer preferences over the next several years. Additionally, as new and advanced materials and component smart designs are developed and commercialized, and as manufacturers implement them in more vehicles, it will be useful for the agencies to learn more about them and to try to track these vehicles in the fleet to understand the relationship between vehicle design and injury/fatality data. Specifically, the agencies intend to follow up with study and research of the following:

First, NHTSA is in the process of contracting with an independent institution to review the statistical methods that NHTSA and DRI have used to analyze historical data related to mass, size and safety, and to provide recommendation on whether the existing methods or other methods should be used for future statistical analysis of historical data. This study will include a consideration of potential near multicollinearity in the historical data and how best to address it in a regression analysis. This study is being initiated because, in response to the NPRM, NHTSA received a number of comments related to the methodology NHTSA used for the NPRM to determine the relationship between mass and safety, as discussed in detail above.

Second, NHTSA and EPA, in consultation with DOE, intend to begin updating the MYs 1991–1999 database on which the safety analyses in the NPRM and final rule are based with newer vehicle data in the next several months. This task will take at least a year to complete. This study is being initiated in response to the NPRM comments related to the use of data from MYs 1991–1999 in the NHTSA analysis, as discussed in detail above.

Third, in order to assess if the design of recent model year vehicles that incorporate various mass reduction methods affect the relationships among vehicle mass, size and safety, NHTSA and EPA intend to conduct collaborative statistical analysis, beginning in the next several months. The agencies intend to work with DOE to identify vehicles that are using material substitution and smart design. After these vehicles are identified, the agencies intend to assess if there are sufficient data for statistical analysis. If there are sufficient data, statistical analysis would be conducted to compare the relationship among mass, size and safety of these smart design vehicles to vehicles of similar size and mass with more traditional designs. This study is being initiated because, in response to the NPRM, NHTSA received comments related to the use of data from MYs 1991–1999 in the NHTSA analysis that did not include new designs that might change the relationship among mass, size and safety, as discussed in detail above.

NHTSA may initiate a two-year study of the safety of the fleet through an analysis of the trends in structural stiffness and whether any trends identified impact occupant injury response in crashes. Vehicle manufacturers may employ stiffer light weight materials to limit occupant compartment intrusion while controlling for mass that may expose the occupants to higher accelerations resulting in a greater chance of injury in real-world crashes. This study would provide information that would increase the understanding of the effects on safety of newer vehicle designs.

In addition, NHTSA and EPA, possibly in collaboration with DOE, may conduct a longer-term computer modeling-based design and analysis study to help determine the maximum potential for mass reduction in the MYs 2017–2021 timeframe, through direct material substitution and smart design while meeting safety regulations and guidelines, and maintaining vehicle size and functionality. This study may build upon prior research completed on vehicle mass reduction. This study would further explore the comprehensive vehicle effects, including dissimilar material joining technologies, manufacturer feasibility of both supplier and OEM, tooling costs, and crash simulation and perhaps eventual crash testing.

III. EPA Greenhouse Gas Vehicle Standards

A. Executive Overview of EPA Rule

1. Introduction

The Environmental Protection Agency (EPA) is establishing GHG emissions standards for the largest sources of transportation GHGs—light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles (hereafter light vehicles). These vehicle categories, which include cars, sport utility vehicles, minivans, and pickup trucks used for personal transportation, are responsible for almost 60% of all U.S. transportation related emissions of the six gases discussed above (Section I.A). This action represents the first-ever EPA rule to regulate vehicle GHG emissions under the Clean Air Act (CAA) and will establish standards for model years 2012–2016 and later light vehicles sold in the United States.

EPA is adopting three separate standards. The first and most important is a set of fleet-wide average carbon dioxide (CO_2) emission standards for cars and trucks. These standards are CO_2 emissions-footprint curves, where each vehicle has a different CO_2 emissions compliance target depending on its footprint value. Vehicle CO_2 emissions will be measured over the EPA city and highway tests. The rule allows for credits based on demonstrated improvements in vehicle air conditioner systems, including both efficiency and refrigerant leakage improvement, which are not captured by the EPA tests. The EPA projects that the average light vehicle tailpipe CO_2 level in model year 2011 will be 325 grams per mile while the average vehicle fleetwide average CO_2 emissions compliance level for the model year 2016 standard will be 250 grams per mile, an average reduction of 23 percent from today's CO_2 levels.

EPA is also finalizing standards that will cap tailpipe nitrous oxide (N_2O) and methane (CH_4) emissions at 0.010 and 0.030 grams per mile, respectively. Even after adjusting for the higher relative global warming potencies of these two compounds, nitrous oxide and methane emissions represent less than one percent of overall vehicle greenhouse gas emissions from new vehicles. Accordingly, the goal of these two standards is to limit any potential increases of tailpipe emissions of these compounds in the future but not to force reductions relative to today's low levels.

This final rule responds to the Supreme Court's 2007 decision in *Massachusetts* v. *EPA*[147] which found that greenhouse gases fit within the definition of air pollutant in the Clean Air Act. The Court held that the Administrator must determine whether or not emissions from new motor vehicles cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, or whether the science is too uncertain to make a reasoned decision. The Court further ruled that, in making these decisions, the EPA Administrator is required to follow the language of section 202(a) of the CAA. The case was remanded back to the Agency for reconsideration in light of the court's decision.

The Administrator has responded to the remand by issuing two findings under section 202(a) of the Clean Air

[147] 549 U.S.C. 497 (2007). For further information on *Massachusetts* v. *EPA* see the Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) the Clean Air Act, published in the Federal Register on December 15, 2009 (74 FR 66496). There is a comprehensive discussion of the litigation's history, the Supreme Court's findings, and subsequent actions undertaken by the Bush Administration and the EPA from 2007–2008 in response to the Supreme Court remand. This information is also available at: *http://www.epa.gov/climatechange/endangerment.html.*

Act.[148] First, the Administrator found that the science supports a positive endangerment finding that the mix of six greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)) in the atmosphere endangers the public health and welfare of current and future generations. This is referred to as the endangerment finding. Second, the Administrator found that the combined emissions of the same six gases from new motor vehicles and new motor vehicle engines contribute to the atmospheric concentrations of these key greenhouse gases and hence to the threat of climate change. This is referred to as the cause and contribute finding. Motor vehicles and new motor vehicle engines emit carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons. EPA provides more details below on the legal and scientific bases for this final rule.

As discussed in Section I, this GHG rule is part of a joint National Program such that a large majority of the projected benefits are achieved jointly with NHTSA's CAFE rule which is described in detail in Section IV of this preamble. EPA projects total CO_2 equivalent emissions savings of approximately 960 million metric tons as a result of the rule, and oil savings of 1.8 billion barrels over the lifetimes of the MY 2012–2016 vehicles subject to the rule. EPA projects that over the lifetimes of the MY 2012–2016 vehicles, the rule will cost $52 billion but will result in benefits of $240 billion at a 3 percent discount rate, or $192 billion at a 7 percent discount rate (both values assume the average SCC value at 3%, *i.e.,* the $21/ton SCC value in 2010). Accordingly, these light vehicle greenhouse gas emissions standards represent an important contribution under the Clean Air Act toward meeting long-term greenhouse gas emissions and import oil reduction goals, while providing important economic benefits as well. The results of our analysis of 2012–2016 MY vehicles, which we refer to as our "model year analysis," are summarized in Tables III.H.10–4 to III.H.10–7.

We have also looked beyond the lifetimes of 2012–2016 MY vehicles at annual costs and benefits of the program for the 2012 through 2050 timeframe. We refer to this as our "calendar year" analysis (as opposed to the costs and benefits mentioned above which we refer to as our "model year analysis"). In our calendar year analysis, the new 2016 MY standards are assumed to apply to all vehicles sold in model years 2017 and later. The net present values of annual costs for the 2012 through 2050 timeframe are $346 billion for new vehicle technology which will provide $1.5 billion in fuel savings, both values at a 3 percent discount rate. At a 7 percent discount rate over the same period, the technology costs are estimated at $192 billion which will provide $673 billion in fuel savings. The social benefits during the 2012 through 2050 timeframe are estimated at $454 billion and $305 billion at a 3 and 7 percent discount rate, respectively. Both of these benefit estimates assume the average SCC value at 3% (*i.e.,* the $21/ton SCC value in 2010). The net benefits during this time period are then $1.7 billion and $785 million at a 3 and 7 percent discount rate, respectively. The results of our "calendar year" analysis are summarized in Tables III.H 10–1 to III.H.10–3.

2. Why is EPA establishing this Rule?

This rule addresses only light vehicles. EPA is addressing light vehicles as a first step in control of greenhouse gas emissions under the Clean Air Act for four reasons. First, light vehicles are responsible for almost 60% of all mobile source GHG emissions, a share three times larger than any other mobile source subsector, and represent about one-sixth of all U.S. greenhouse gas emissions. Second, technology exists that can be readily and cost-effectively applied to these vehicles to reduce their greenhouse gas emissions in the near term. Third, EPA already has an existing testing and compliance program for these vehicles, refined since the mid-1970s for emissions compliance and fuel economy determinations, which would require only minor modifications to accommodate greenhouse gas emissions regulations. Finally, this rule is an important step in responding to the Supreme Court's ruling in *Massachusetts* v. *EPA,* which applies to other emissions sources in addition to light-duty vehicles. In fact, EPA is currently evaluating controls for motor vehicles other than those covered by this rule, and is also reviewing seven motor vehicle related petitions submitted by various states and organizations requesting that EPA use its Clean Air Act authorities to take action to reduce greenhouse gas emissions from aircraft (under § 231(a)(2)), ocean-going vessels (under § 213(a)(4)), and other nonroad engines and vehicle sources (also under § 213(a)(4)).

a. Light Vehicle Emissions Contribute to Greenhouse Gases and the Threat of Climate Change

Greenhouse gases are gases in the atmosphere that effectively trap some of the Earth's heat that would otherwise escape to space. Greenhouse gases are both naturally occurring and anthropogenic. The primary greenhouse gases of concern that are directly emitted by human activities include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

These gases, once emitted, remain in the atmosphere for decades to centuries. Thus, they become well mixed globally in the atmosphere and their concentrations accumulate when emissions exceed the rate at which natural processes remove greenhouse gases from the atmosphere. The heating effect caused by the human-induced buildup of greenhouse gases in the atmosphere is very likely the cause of most of the observed global warming over the last 50 years.[149] The key effects of climate change observed to date and projected to occur in the future include, but are not limited to, more frequent and intense heat waves, more severe wildfires, degraded air quality, heavier and more frequent downpours and flooding, increased drought, greater sea level rise, more intense storms, harm to water resources, continued ocean acidification, harm to agriculture, and harm to wildlife and ecosystems. A detailed explanation of observed and projected changes in greenhouse gases and climate change and its impact on health, society, and the environment is included in EPA's technical support document for the recently promulgated Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act.[150]

Mobile sources represent a large and growing share of United States greenhouse gases and include light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, heavy duty trucks, airplanes, railroads, marine vessels and a variety of other sources. In 2007, all mobile sources emitted 31% of

[148] *See* 74 FR 66496 (Dec. 15, 2009), "Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act".

[149] "Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act" Docket: EPA–HQ–OAR–2009–0472–11292.

[150] 74 FR 66496 (Dec. 15, 2009). Both the **Federal Register** Notice and the Technical Support Document for Endangerment and Cause or Contribute Findings are found in the public docket No. EPA–OAR–2009–0171, in the public docket established for this rulemaking, and at *http://epa.gov/climatechange/endangerment.html.*

all U.S. GHGs, and were the fastest-growing source of U.S. GHGs in the U.S. since 1990. Transportation sources, which do not include certain off-highway sources such as farm and construction equipment, account for 28% of U.S. GHG emissions, and Section 202(a) sources, which include light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, heavy-duty trucks, buses, and motorcycles account for 23% of total U.S. GHGs.[151]

Light vehicles emit carbon dioxide, methane, nitrous oxide and hydrofluorocarbons. Carbon dioxide (CO_2) is the end product of fossil fuel combustion. During combustion, the carbon stored in the fuels is oxidized and emitted as CO_2 and smaller amounts of other carbon compounds.[152] Methane (CH_4) emissions are a function of the methane content of the motor fuel, the amount of hydrocarbons passing uncombusted through the engine, and any post-combustion control of hydrocarbon emissions (such as catalytic converters).[153] Nitrous oxide (N_2O) (and nitrogen oxide (NO_X)) emissions from vehicles and their engines are closely related to air-fuel ratios, combustion temperatures, and the use of pollution control equipment. For example, some types of catalytic converters installed to reduce motor vehicle NO_X, carbon monoxide (CO) and hydrocarbon emissions can promote the formation of N_2O.[154] Hydrofluorocarbons (HFC) emissions are progressively replacing chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) in these vehicles' cooling and refrigeration systems as CFCs and HCFCs are being phased out under the Montreal Protocol and Title VI of the CAA. There are multiple emissions pathways for HFCs with emissions occurring during charging of cooling and refrigeration systems, during operations, and during decommissioning and disposal.[155]

[151] Inventory of U.S. Greenhouse Gases and Sinks: 1990–2007.

[152] Mobile source carbon dioxide emissions in 2006 equaled 26 percent of total U.S. CO_2 emissions.

[153] In 2006, methane emissions equaled 0.32 percent of total U.S. methane emissions. Nitrous oxide is a product of the reaction that occurs between nitrogen and oxygen during fuel combustion.

[154] In 2006, nitrous oxide emissions for these sources accounted for 8 percent of total U.S. nitrous oxide emissions.

[155] In 2006, HFC from these source categories equaled 56 percent of total U.S. HFC emissions, making it the single largest source category of U.S. HFC emissions.

b. Basis for Action Under the Clean Air Act

Section 202(a)(1) of the Clean Air Act (CAA) states that "the Administrator shall by regulation prescribe (and from time to time revise) * * * standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles * * *, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare." As noted above, the Administrator has found that the elevated concentrations of greenhouse gases in the atmosphere may reasonably be anticipated to endanger public health and welfare.[156] The Administrator defined the "air pollution" referred to in CAA section 202(a) to be the combined mix of six long-lived and directly emitted GHGs: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The Administrator has further found under CAA section 202(a) that emissions of the single air pollutant defined as the aggregate group of these same six greenhouse gases from new motor vehicles and new motor vehicle engines contribute to air pollution. As a result of these findings, section 202(a) requires EPA to issue standards applicable to emissions of that air pollutant. New motor vehicles and engines emit CO_2, methane, N_2O and HFC. This preamble describes the provisions that control emissions of CO_2, HFCs, nitrous oxide, and methane. For further discussion of EPA's authority under section 202(a), see Section I.C.2 of the preamble to the proposed rule (74 FR at 49464–66).

There are a variety of other CAA Title II provisions that are relevant to standards established under section 202(a). The standards are applicable to motor vehicles for their useful life. EPA has the discretion in determining what standard applies over the vehicles' useful life and has exercised that discretion in this rule. See Section III*.E.*4 below.

The standards established under CAA section 202(a) are implemented and enforced through various mechanisms. Manufacturers are required to obtain an EPA certificate of conformity before they may sell or introduce their new motor vehicle into commerce, according to CAA section 206(a). The introduction into commerce of vehicles without a certificate of conformity is a prohibited act under CAA section 203 that may subject a manufacturer to civil penalties and injunctive actions (see CAA sections 204 and 205). Under CAA section 206(b), EPA may conduct testing of new production vehicles to determine compliance with the standards. For in-use vehicles, if EPA determines that a substantial number of vehicles do not conform to the applicable regulations then the manufacturer must submit and implement a remedial plan to address the problem (see CAA section 207(c)). There are also emissions-based warranties that the manufacturer must implement under CAA section 207(a). Section III.E describes the rule's certification, compliance, and enforcement mechanisms.

[156] 74 FR 66496 (Dec. 15, 2009).

c. EPA's Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act

On December 7, 2009 EPA's Administrator signed an action with two distinct findings regarding greenhouse gases under section 202(a) of the Clean Air Act. On December 15, 2009, the final findings were published in the Federal Register. This action is called the Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act (Endangerment Finding).[157] Below are the two distinct findings:

Endangerment Finding: The Administrator finds that the current and projected concentrations of the six key well-mixed greenhouse gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—in the atmosphere threaten the public health and welfare of current and future generations.

Cause or Contribute Finding: The Administrator finds that the combined emissions of these well-mixed greenhouse gases from new motor vehicles and new motor vehicle engines contribute to the greenhouse gas pollution which threatens public health and welfare.

Specifically, the Administrator found, after a thorough examination of the scientific evidence on the causes and impact of current and future climate change, and careful review of public comments, that the science compellingly supports a positive finding that atmospheric concentrations of these greenhouse gases result in air pollution which may reasonably be anticipated to endanger both public health and welfare. In her finding, the Administrator relied heavily upon the major findings and conclusions from the

[157] 74 FR 66496 (Dec. 15, 2009)

recent assessments of the U.S. Climate Change Science Program and the U.N. Intergovernmental Panel on Climate Change.[158] The Administrator made a positive endangerment finding after considering both observed and projected future effects of climate change, key uncertainties, and the full range of risks and impacts to public health and welfare occurring within the United States. In addition, the finding focused on impacts within the U.S. but noted that the evidence concerning risks and impacts occurring outside the U.S. provided further support for the finding.

The key scientific findings supporting the endangerment finding are that:

— Concentrations of greenhouse gases are at unprecedented levels compared to recent and distant past. These high concentrations are the unambiguous result of anthropogenic emissions and are very likely the cause of the observed increase in average temperatures and other climatic changes.
— The effects of climate change observed to date and projected to occur in the future include more frequent and intense heat waves, more severe wildfires, degraded air quality, heavier downpours and flooding, increasing drought, greater sea level rise, more intense storms, harm to water resources, harm to agriculture, and harm to wildlife and ecosystems. These impacts are effects on public health and welfare within the meaning of the Clean Air Act.

The Administrator found that emissions of the single air pollutant defined as the aggregate group of these same six greenhouse gases from new motor vehicles and new motor vehicle engines contribute to the air pollution and hence to the threat of climate change. Key facts supporting this cause and contribute finding for on-highway vehicles regulated under section 202(a) of the Clean Air Act are that these sources are responsible for 24% of total U.S. greenhouse gas emissions, and more than 4% of total global greenhouse gas emissions.[159] As noted above, these findings require EPA to issue standards under section 202(a) "applicable to emission" of the air pollutant that EPA found causes or contributes to the air pollution that endangers public health and welfare. The final emissions standards satisfy this requirement for greenhouse gases from light-duty vehicles. Under section 202(a) the Administrator has significant discretion in how to structure the standards that apply to the emission of the air pollutant at issue here, the aggregate group of six greenhouse gases. EPA has the discretion under section 202(a) to adopt separate standards for each gas, a single composite standard covering various gases, or any combination of these. In this rulemaking EPA is finalizing separate standards for nitrous oxide and methane, and a CO_2 standard that provides for credits based on reductions of HFCs, as the appropriate way to issue standards applicable to emission of the single air pollutant, the aggregate group of six greenhouse gases. EPA is not setting any standards for perfluorocarbons (PFCs) or sulfur hexafluoride (SF_6) as they are not emitted by motor vehicles.

3. What is EPA adopting?

a. Light-Duty Vehicle, Light-Duty Truck, and Medium-Duty Passenger Vehicle Greenhouse Gas Emission Standards and Projected Compliance Levels

The following section provides an overview of EPA's final rule. The key public comments are not discussed here, but are discussed in the sections that follow which provide the details of the program. Comments are also discussed in the Response to Comments document.

The CO_2 emissions standards are by far the most important of the three standards and are the primary focus of this summary. As proposed, EPA is adopting an attribute-based approach for the CO_2 fleet-wide standard (one for cars and one for trucks), using vehicle footprint as the attribute. These curves establish different CO_2 emissions targets for each unique car and truck footprint. Generally, the larger the vehicle footprint, the higher the corresponding vehicle CO_2 emissions target. Table III.A.3–1 shows the greenhouse gas standards for light vehicles that EPA is finalizing for model years (MY) 2012 and later:

TABLE III.A.3–1—INDUSTRY-WIDE GREENHOUSE GAS EMISSIONS STANDARDS

Standard/covered compounds	Form of standard	Level of standard	Credits	Test cycles
CO_2 Standard:[160] Tailpipe CO_2.	Fleetwide average footprint CO_2-curves for cars and trucks.	Projected Fleetwide CO_2 level of 250 g/mi (See footprint curves in Sec. III.B.2).	CO_2-e credits[161]	EPA 2-cycle (FTP and HFET test cycles).[162]
N_2O Standard: Tailpipe N_2O.	Cap per vehicle	0.010 g/mi	None *	EPA FTP test.
CH_4 Standard: Tailpipe CH_4.	Cap per vehicle	0.030 g/mi	None *	EPA FTP test.

* For N_2O and CH_4, manufacturers may optionally demonstrate compliance with a CO_2-equivalent standard equal to its footprint-based CO_2 target level, using the FTP and HFET tests.

One important flexibility associated with the CO_2 standard is the option for

[158] The U.S. Climate Change Science Program (CCSP) is now called the U.S. Global Change Research Program (GCRP).

[159] This figure includes the greenhouse gas contributions of light vehicles, heavy duty vehicles, and remaining on-highway mobile sources. Light-duty vehicles are responsible for over 70 percent of Section 202(a) mobile source GHGs, or about 17% of total U.S. greenhouse gas emissions. U.S. EPA.2009 Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC. pp. 180–194. Available at *http://epa.gov/climatechange/endangerment/downloads/Endangerment%20TSD.pdf.*

[160] While over 99 percent of the carbon in automotive fuels is converted to CO_2 in a properly functioning engine, compliance with the CO_2 standard will also account for the very small levels of carbon associated with vehicle tailpipe hydrocarbon (HC) and carbon monoxide (CO) emissions, converted to CO_2 on a mass basis, as discussed further in Section III.B.

[161] CO_2-e refers to CO_2-equivalent, and is a metric that allows non-CO_2 greenhouse gases (such as hydrofluorocarbons used as automotive air conditioning refrigerants) to be expressed as an equivalent mass (*i.e.,* corrected for relative global warming potency) of CO_2 emissions.

[162] FTP is the Federal Test Procedure which uses what is commonly referred to as the "city" driving schedule, and HFET is the Highway Fuel Economy Test which uses the "highway" driving schedule. Compliance with the CO_2 standard will be based on the same 2-cycle values that are currently used for

Continued

manufacturers to obtain credits associated with improvements in their air conditioning systems. EPA is adopting the air conditioning provisions with minor modifications. As will be discussed in greater detail in later sections, EPA is establishing test procedures and design criteria by which manufacturers can demonstrate improvements in both air conditioner efficiency (which reduces vehicle tailpipe CO_2 by reducing the load on the engine) and air conditioner refrigerants (using lower global warming potency refrigerants and/or improving system design to reduce GHG emissions associated with leaks). Neither of these strategies to reduce GHG emissions from air conditioners will be reflected in the EPA FTP or HFET tests. These improvements will be translated to a g/mi CO_2-equivalent credit that can be subtracted from the manufacturer's tailpipe CO_2 compliance value. EPA expects a high percentage of manufacturers to use this flexibility to earn air conditioning-related credits for MY 2012–2016 vehicles such that the average credit earned is about 11 grams per mile CO_2-equivalent in 2016.

A second flexibility, being finalized essentially as proposed, is CO_2 credits for flexible and dual fuel vehicles, similar to the CAFE credits for such vehicles which allow manufacturers to gain up to 1.2 mpg in their overall CAFE ratings. The Energy Independence and Security Act of 2007 (EISA) mandated a phase-out of these flexible fuel vehicle CAFE credits beginning in 2015, and ending after 2019. EPA is allowing comparable CO_2 credits for flexible fuel vehicles through MY 2015, but for MY 2016 and beyond, the GHG rule treats flexible and dual fuel vehicles on a CO_2-performance basis, calculating the overall CO_2 emissions for flexible and dual fuel vehicles based on a fuel use-weighted average of the CO_2 levels on gasoline and on the alternative fuel, and on a manufacturer's demonstration of actual usage of the alternative fuel in its vehicle fleet.

Table III.A.3–2 summarizes EPA projections of industry-wide 2-cycle CO_2 emissions and fuel economy levels that will be achieved by manufacturer compliance with the GHG standards for MY 2012–2016.

For MY 2011, Table III.A.3–2 uses the NHTSA projections of the average fuel economy level that will be achieved by the MY 2011 fleet of 30.8 mpg for cars and 23.3 mpg for trucks, converted to an equivalent combined car and truck CO_2 level of 326 grams per mile.[163] EPA believes this is a reasonable estimate with which to compare the MY 2012–2016 CO_2 emission standards. Identifying the proper MY 2011 estimate is complicated for many reasons, among them being the turmoil in the current automotive market for consumers and manufacturers, uncertain and volatile oil and gasoline prices, the ability of manufacturers to use flexible fuel vehicle credits to meet MY 2011 CAFE standards, and the fact that most manufacturers have been surpassing CAFE standards (particularly the car standard) in recent years. Taking all of these considerations into account, EPA believes that the MY 2011 projected CAFE achieved values, converted to CO_2 emissions levels, represent a reasonable estimate.

Table III.A.3–2 shows projected industry-wide average CO_2 emissions values. The Projected CO_2 Emissions for the Footprint-Based Standard column shows the CO_2 g/mi level corresponding with the footprint standard that must be met. It is based on the promulgated CO_2-footprint curves and projected footprint values, and will decrease each year to 250 grams per mile (g/mi) in MY 2016. For MY 2012–2016, the emissions impact of the projected utilization of flexible fuel vehicle (FFV) credits and the temporary lead-time allowance alternative standard (TLAAS, discussed below) are shown in the next two columns. The Projected CO_2 Emissions column gives the CO_2 emissions levels projected to be achieved given use of the flexible fuel credits and temporary lead-time allowance program. This column shows that, relative to the MY 2011 estimate, EPA projects that MY 2016 CO_2 emissions will be reduced by 23 percent over five years. The Projected A/C Credit column represents the industry wide average air conditioner credit manufacturers are expected to earn on an equivalent CO_2 gram per mile basis in a given model year. In MY 2016, the projected A/C credit of 10.6 g/mi represents 14 percent of the 76 g/mi CO_2 emissions reductions associated with the final standards. The Projected 2-cycle CO_2 Emissions column shows the projected CO_2 emissions as measured over the EPA 2-cycle tests, which will allow compliance with the standard assuming projected utilization of the FFV, TLAAS, and A/C credits.

TABLE III.A.3–2—PROJECTED FLEETWIDE CO_2 EMISSIONS VALUES

[Grams per mile]

Model year	Projected CO_2 emissions for the footprint-based standard	Projected FFV credit	Projected TLAAS credit	Projected CO_2 emissions	Projected A/C credit	Projected 2-cycle CO_2 emissions
2011				(326)		(326)
2012	295	6.5	1.2	303	3.5	307
2013	286	5.8	0.9	293	5.0	298
2014	276	5.0	0.6	282	7.5	290
2015	263	3.7	0.3	267	10.0	277
2016	250	0.0	0.1	250	10.6	261

EPA is also finalizing a series of flexibilities for compliance with the CO_2 standard which are not expected to significantly affect the projected compliance and achieved values shown above, but which should reduce the costs of achieving those reductions. These flexibilities include the ability to earn: Annual credits for a manufacturer's over-compliance with its unique fleet-wide average standard, early credits from MY 2009–2011, credit for "off-cycle" CO_2 reductions from new and innovative technologies that are not reflected in CO_2/fuel economy tests, as

CAFE standards compliance; EPA projects that fleet-wide in-use or real world CO_2 emissions are approximately 25 percent higher, on average, than 2-cycle CO_2 values. Separate mechanisms apply for A/C credits.

[163] As discussed in Section IV of this preamble.

well as the carry-forward and carry-backward of credits, and the ability to transfer credits between a manufacturer's car and truck fleets. These flexibilities are being adopted with only very minor changes from the proposal, as discussed in Section III.C.

EPA is finalizing an incentive to encourage the commercialization of advanced GHG/fuel economy control technologies, including electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs), for model years 2012–2016. EPA's proposal included an emissions compliance value of zero grams/mile for EVs and FCVs, and the electric portion of PHEVs, and a multiplier in the range of 1.2 to 2.0, so that each advanced technology vehicle would count as greater than one vehicle in a manufacturer's fleet-wide compliance calculation. Several commenters were very concerned about these credits and upon considering the public comments on this issue, EPA is finalizing an advanced technology vehicle incentive program to assign a zero gram/mile emissions compliance value for EVs and FCVs, and the electric portion of PHEVs, for up to the first 200,000 EV/PHEV/FCV vehicles produced by a given manufacturer during MY 2012–2016. For any production greater than this amount, the compliance value for the vehicle will be greater than zero gram/mile, set at a level that reflects the vehicle's average net increase in upstream greenhouse gas emissions in comparison to the gasoline or diesel vehicle it replaces. EPA is not finalizing a multiplier based on the concerns potentially excessive credits using that incentive. EPA agrees that the multiplier, in combination with the zero grams/mile compliance value, would be excessive. EPA will also allow this early advanced technology incentive program beginning in MYs 2009 through 2011. Further discussion on the advanced technology vehicle incentives, including more detail on the public comments and EPA's response, is found in Section III.C.

EPA is also finalizing a temporary lead-time allowance (TLAAS) for manufacturers that sell vehicles in the U.S. in MY 2009 and for which U.S. vehicle sales in that model year are below 400,000 vehicles. This allowance will be available only during the MY 2012–2015 phase-in years of the program. A manufacturer that satisfies the threshold criteria will be able to treat a limited number of vehicles as a separate averaging fleet, which will be subject to a less stringent GHG standard.[164] Specifically, a standard of 125 percent of the vehicle's otherwise applicable foot-print target level will apply to up to 100,000 vehicles total, spread over the four-year period of MY 2012 through 2015. Thus, the number of vehicles to which the flexibility could apply is limited. EPA also is setting appropriate restrictions on credit use for these vehicles, as discussed further in Section III. By MY 2016, these allowance vehicles must be averaged into the manufacturer's full fleet (*i.e.,* they will no longer be eligible for a different standard). EPA discusses this in more detail in Section III.B of the preamble.

EPA received comments from several smaller manufacturers that the TLAAS program was insufficient to allow manufacturers with very limited product lines to comply. These manufacturers commented that they need additional lead-time to meet the standards, because their CO_2 baselines are significantly higher and their vehicle product lines are even more limited, reducing their ability to average across their fleets compared even to other TLAAS manufacturers. EPA fully summarizes the public comments on the TLAAS program, including comments not supporting the program, in Section III.B. In summary, in response to the lead time issues raised by manufacturers, EPA is modifying the TLAAS program that applies to manufacturers with between 5,000 and 50,000 U.S. vehicle sales in MY 2009. These manufactures would have an increased allotment of vehicles, a total of 250,000, compared to 100,000 vehicles for other TLAAS-eligible manufacturers. In addition, the TLAAS program for these manufacturers would be extended by one year, through MY 2016 for these vehicles, for a total of five years of eligibility. The other provisions of the TLAAS program would continue to apply, such as the restrictions on credit trading and the level of the standard. Additional restrictions would also apply to these vehicles, as discussed in Section III.B.5. In addition, for the smallest volume manufacturers, those with U.S. sales of below 5,000 vehicles, EPA is not setting standards at this time but is instead deferring standards until a future rulemaking. This is the same approach we are using for small businesses. The unique issues involved with these manufacturers will be addressed in that future rulemaking. Further discussion of the public comment on these issues and details on these changes from the proposed program are included in Section III.B.6. The agency received comments on its compliance with the Regulatory Flexibility Act. As stated in Section III.I.3, small entities are not significantly impacted by this rulemaking.

EPA is also adopting caps on the tailpipe emissions of nitrous oxide (N_2O) and methane (CH_4)—0.010 g/mi for N_2O and 0.030 g/mi for CH_4—over the EPA FTP test. While N_2O and CH_4 can be potent greenhouse gases on a relative mass basis, their emission levels from modern vehicle designs are extremely low and represent only about 1% of total late model light vehicle GHG emissions. These cap standards are designed to ensure that N_2O and CH_4 emissions levels do not rise in the future, rather than to force reductions in the already low emissions levels. Accordingly, these standards are not designed to require automakers to make any changes in current vehicle designs, and thus EPA is not projecting any environmental or economic costs or benefits associated with these standards.

EPA has attempted to build on existing practice wherever possible in designing a compliance program for the GHG standards. In particular, the program structure will streamline the compliance process for both manufacturers and EPA by enabling manufacturers to use a single data set to satisfy both the new GHG and CAFE testing and reporting requirements. Timing of certification, model-level testing, and other compliance activities also follow current practices established under the Tier 2 emissions and CAFE programs.

EPA received numerous comments on issues related to the impacts on stationary sources, due to the Clean Air Act's provisions for permitting requirements related to the issuance of the proposed GHG standards for new motor vehicles. Some comments suggested that EPA had underestimated the number of stationary sources that may be subject to GHG permitting requirements; other comments suggested that EPA did not adequately consider the permitting impact on small business sources. Other comments related to EPA's interpretation of the CAA's provisions for subjecting stationary sources to permit regulation after GHG standards are set. EPA's response to these comments is contained in the Response to Comments document; however, many of these comments pertain to issues that EPA is addressing in its consideration of the final Greenhouse Gas Permit Tailoring

[164] EPCA does not permit such an allowance. Consequently, manufacturers who may be able to take advantage of a lead-time allowance under the GHG standards would be required to comply with the applicable CAFE standard or be subject to penalties for non-compliance.

Rule, Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule; Proposed Rule, 74 FR 55292 (October 27, 2009) and will thus be fully addressed in that rulemaking.

Some of the comments relating to the stationary source permitting issues suggested that EPA should defer setting GHG standards for new motor vehicles to avoid such stationary source permitting impacts. EPA is issuing these final GHG standards for light-duty vehicles as part of its efforts to expeditiously respond to the Supreme Court's nearly three year old ruling in *Massachusetts* v. *EPA,* 549 U.S. 497 (2007). In that case, the Court held that greenhouse gases fit within the definition of air pollutant in the Clean Air Act, and that EPA is therefore compelled to respond to the rulemaking petition under section 202(a) by determining whether or not emissions from new motor vehicles cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, or whether the science is too uncertain to make a reasoned decision. The Court further ruled that, in making these decisions, the EPA Administrator is required to follow the language of section 202(a) of the CAA. The Court stated that under section 202(a), "[i]f EPA makes [the endangerment and cause or contribute findings], the Clean Air Act requires the agency to regulate emissions of the deleterious pollutant." 549 U.S. at 534. As discussed above, EPA has made the two findings on contribution and endangerment. 74 FR 66496 (December 15, 2009). Thus, EPA is required to issue standards applicable to emissions of this air pollutant from new motor vehicles.

The Court properly noted that EPA retained "significant latitude" as to the "timing * * * and coordination of its regulations with those of other agencies" (id.). However it has now been nearly three years since the Court issued its opinion, and the time for delay has passed. In the absence of these final standards, there would be three separate Federal and State regimes independently regulating light-duty vehicles to increase fuel economy and reduce GHG emissions: NHTSA's CAFE standards, EPA's GHG standards, and the GHG standards applicable in California and other states adopting the California standards. This joint EPA–NHTSA program will allow automakers to meet all of these requirements with a single national fleet because California has indicated that it will accept compliance with EPA's GHG standards as compliance with California's GHG standards. 74 FR at 49460. California has not indicated that it would accept NHTSA's CAFE standards by themselves. Without EPA's vehicle GHG standards, the states will not offer the Federal program as an alternative compliance option to automakers and the benefits of a harmonized national program will be lost. California and several other states have expressed strong concern that, without comparable Federal vehicle GHG standards, the states will not offer the Federal program as an alternative compliance option to automakers. Letter dated February 23, 2010 from Commissioners of California, Maine, New Mexico, Oregon and Washington to Senators Harry Reid and Mitch McConnell (Docket EPA–HQ–OAR–2009–0472–11400). The automobile industry also strongly supports issuance of these rules to allow implementation of the national program and avoid "a myriad of problems for the auto industry in terms of product planning, vehicle distribution, adverse economic impacts and, most importantly, adverse consequences for their dealers and customers." Letter dated March 17, 2010 from Alliance of Automobile Manufacturers to Senators Harry Reid and Mitch McConnell, and Representatives Nancy Pelosi and John Boehner (Docket EPA–HQ–OAR–2009–0472–11368). Thus, without EPA's GHG standards as part of a Federal harmonized program, important GHG reductions as well as benefits to the automakers and to consumers would be lost.[165] In addition, delaying the rule would impose significant burdens and uncertainty on automakers, who are already well into planning for production of MY 2012 vehicles, relying on the ability to produce a single national fleet. Delaying the issuance of this final rule would very seriously disrupt the industry's plans.

Instead of delaying the LDV rule and losing the benefits of this rule and the harmonized national program, EPA is directly addressing concerns about stationary source permitting in other actions that EPA is taking with regard to such permitting. That is the proper approach to address the issue of stationary source permitting, as compared to delaying the issuance of this rule for some undefined, indefinite time period.

Some parties have argued that EPA's issuance of this light-duty vehicle rule amounts to a denial of various administrative requests pending before EPA, in which parties have requested that EPA reconsider and stay the GHG endangerment finding published on December 15, 2009. That is not an accurate characterization of the impact of this final rule. EPA has not taken final action on these administrative requests, and issuance of this vehicle rule is not final agency action, explicitly or implicitly, on those requests. Currently, while we carefully consider the pending requests for reconsideration on endangerment, these final findings on endangerment and contribution remain in place. Thus under section 202(a) EPA is obligated to promulgate GHG motor vehicle standards, although there is no statutory deadline for issuance of the light-duty vehicle rule or other motor vehicle rules. In that context, issuance of this final light-duty vehicle rule does no more than recognize the current status of the findings—they are final and impose a rulemaking obligation on EPA, unless and until we change them. In issuing the vehicle rule we are not making a decision on requests to reconsider or stay the endangerment finding, and are not in any way prejudicing or limiting EPA's discretion in making a final decision on these administrative requests.

For discussion of comments on impacts on small entities and EPA's compliance with the Regulatory Flexibility Act, see the discussion in Section III.I.3.

b. Environmental and Economic Benefits and Costs of EPA's Standards

In Table III.A.3–3 EPA presents estimated annual net benefits for the indicated calendar years. The table also shows the net present values of those benefits for the calendar years 2012–2050 using both a 3 percent and a 7 percent discount rate. As discussed previously, EPA recognizes that much of these same costs and benefits are also attributable to the CAFE standard contained in this joint final rule.

[165] As discussed elsewhere, EPA's GHG standards achieve greater overall reductions in GHGs than NHTSA's CAFE standards.

TABLE III.A.3–3—PROJECTED QUANTIFIABLE BENEFITS AND COSTS FOR CO_2 STANDARD

[In million 2007$]

	2020	2030	2040	2050	NPV, 3% [a]	NPV, 7% [a]
Quantified Annual Costs [b]	−$20,100	−$64,000	−$101,900	−$152,200	−$1,199,700	−$480,700
Benefits From Reduced CO_2 Emissions at Each Assumed SCC Value [c d e]						
Avg SCC at 5%	900	2,700	4,600	7,200	34,500	34,500
Avg SCC at 3%	3,700	8,900	14,000	21,000	176,700	176,700
Avg SCC at 2.5%	5,800	14,000	21,000	30,000	299,600	299,600
95th percentile SCC at 3%	11,000	27,000	43,000	62,000	538,500	538,500
Other Impacts						
Criteria Pollutant Benefits [f g h i]	B	1,200–1,300	1,200–1,300	1,200–1,300	21,000	14,000
Energy Security Impacts (price shock)	2,200	4,500	6,000	7,600	81,900	36,900
Reduced Refueling	2,400	4,800	6,300	8,000	87,900	40,100
Value of Increased Driving [j]	4,200	8,800	13,000	18,400	171,500	75,500
Accidents, Noise, Congestion	−2,300	−4,600	−6,100	−7,800	−84,800	−38,600
Quantified Net Benefits at Each Assumed SCC Value [c d e]						
Avg SCC at 5%	27,500	81,500	127,000	186,900	1,511,700	643,100
Avg SCC at 3%	30,300	87,700	136,400	200,700	1,653,900	785,300
Avg SCC at 2.5%	32,400	92,800	143,400	209,700	1,776,800	908,200
95th percentile SCC at 3%	37,600	105,800	165,400	241,700	2,015,700	1,147,100

[a] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.F for more detail.

[b] Quantified annual costs are negative because of fuel savings (see Table III.H.10–1 for a breakdown of the vehicle technology costs and fuel savings). The fuel savings outweigh the vehicle technology costs and, therefore, the costs are presented here are negative values.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC Technical Support Document (TSD) notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[d] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $35–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

[e] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

[f] Note that "B" indicates unquantified criteria pollutant benefits in the year 2020. For the final rule, we only modeled the rule's $PM_{2.5}$- and ozone-related impacts in the calendar year 2030. For the purposes of estimating a stream of future-year criteria pollutant benefits, we assume that the benefits out to 2050 are equal to, and no less than, those modeled in 2030 as reflected by the stream of estimated future emission reductions. The NPV of criteria pollutant-related benefits should therefore be considered a conservative estimate of the potential benefits associated with the final rule.

[g] The benefits presented in this table include an estimate of PM-related premature mortality derived from Laden et al., 2006, and the ozone-related premature mortality estimate derived from Bell et al., 2004. If the benefit estimates were based on the ACS study of PM-related premature mortality (Pope et al., 2002) and the Levy et al., 2005 study of ozone-related premature mortality, the values would be as much as 70% smaller.

[h] The calendar year benefits presented in this table assume either a 3% discount rate in the valuation of PM-related premature mortality ($1,300 million) or a 7% discount rate ($1,200 million) to account for a twenty-year segmented cessation lag. Note that the benefits estimated using a 3% discount rate were used to calculate the NPV using a 3% discount rate and the benefits estimated using a 7% discount rate were used to calculate the NPV using a 7% discount rate. For benefits totals presented at each calendar year, we used the mid-point of the criteria pollutant benefits range ($1,250).

[i] Note that the co-pollutant impacts presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. The full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (*e.g.,* changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.

[j] Calculated using pre-tax fuel prices.

4. Basis for the GHG Standards Under Section 202(a)

EPA statutory authority under section 202(a)(1) of the Clean Air Act (CAA) is discussed in more detail in Section I.C.2 of the proposed rule (74 FR at 49464–65). The following is a summary of the basis for the final GHG standards under section 202(a), which is discussed in more detail in the following portions of Section III.

With respect to CO_2 and HFCs, EPA is adopting attribute-based light-duty car and truck standards that achieve large and important emissions reductions of GHGs. EPA has evaluated the technological feasibility of the standards, and the information and analysis performed by EPA indicates that these standards are feasible in the lead time provided. EPA and NHTSA have carefully evaluated the effectiveness of individual technologies as well as the interactions when technologies are combined. EPA's projection of the technology that would be used to comply with the standards indicates that manufacturers will be able to meet the standards by employing a wide variety of technologies that are already commercially available and can be incorporated into their vehicles at the time of redesign. In addition to the consideration of the manufacturers' redesign cycle, EPA's analysis also takes into account certain flexibilities that will facilitate compliance especially in the early years of the program when potential lead time constraints are most challenging. These flexibilities include averaging, banking, and trading of various types of credits. For the industry as a whole, EPA's projections indicate that the standards can be met using technology that will be available in the lead-time provided. At the same time, it must be noted that because technology is commercially available today does not mean it can automatically be incorporated fleet-wide during the model years in question. As discussed below, and in detail in Section III.D.7, EPA and NHTSA carefully analyzed issues of adequacy of lead time in determining the level of the standards, and the agencies are convinced both that lead time is sufficient to meet the standards but that major further additions of technology across the fleet is not possible during these model years.

To account for additional lead-time concerns for various manufacturers of typically higher performance vehicles, EPA is adopting a Temporary Lead-time Allowance similar to that proposed that will further facilitate compliance for limited volumes of such vehicles in the program's initial years. For a few very small volume manufacturers, EPA is deferring standards pending later rulemaking.

EPA has also carefully considered the cost to manufacturers of meeting the standards, estimating piece costs for all candidate technologies, direct manufacturing costs, cost markups to account for manufacturers' indirect costs, and manufacturer cost reductions attributable to learning. In estimating manufacturer costs, EPA took into account manufacturers' own practices such as making major changes to model technology packages during a planned redesign cycle. EPA then projected the average cost across the industry to employ this technology, as well as manufacturer-by-manufacturer costs. EPA considers the per vehicle costs estimated from this analysis to be within a reasonable range in light of the emissions reductions and benefits received. EPA projects, for example, that the fuel savings over the life of the vehicles will more than offset the increase in cost associated with the technology used to meet the standards.

EPA has also evaluated the impacts of these standards with respect to reductions in GHGs and reductions in oil usage. For the lifetime of the model year 2012–2016 vehicles we estimate GHG reductions of approximately 960 million metric tons CO_2 eq. and fuel reductions of 1.8 billion barrels of oil. These are important and significant reductions. EPA has also analyzed a variety of other impacts of the standards, ranging from the standards' effects on emissions of non-GHG pollutants, impacts on noise, energy, safety and congestion. EPA has also quantified the cost and benefits of the standards, to the extent practicable. Our analysis to date indicates that the overall quantified benefits of the standards far outweigh the projected costs. Utilizing a 3% discount rate, we estimate the total net social benefits over the life of the model year 2012–2016 vehicles is $192 billion, and the net present value of the net social benefits of the standards through the year 2050 is $1.9 trillion dollars.[166] These values are estimated at $136 billion and $787 billion, respectively, using a 7% discount rate and the SCC discounted at 3 percent.[167]

Under section 202(a) EPA is called upon to set standards that provide adequate lead-time for the development and application of technology to meet the standards. EPA's standards satisfy this requirement, as discussed above. In setting the standards, EPA is called upon to weigh and balance various factors, and to exercise judgment in setting standards that are a reasonable balance of the relevant factors. In this case, EPA has considered many factors, such as cost, impacts on emissions (both GHG and non-GHG), impacts on oil conservation, impacts on noise, energy, safety, and other factors, and has, where practicable, quantified the costs and benefits of the rule. In summary, given the technical feasibility of the standard, the moderate cost per vehicle in light of the savings in fuel costs over the life time of the vehicle, the very significant reductions in emissions and in oil usage, and the significantly greater quantified benefits compared to quantified costs, EPA is confident that the standards are an appropriate and reasonable balance of the factors to consider under section 202(a). See *Husqvarna AB* v. *EPA,* 254 F. 3d 195, 200 (DC Cir. 2001) (great discretion to balance statutory factors in considering level of technology-based standard, and statutory requirement "to [give appropriate] consideration to the cost of applying * * * technology" does not mandate a specific method of cost analysis); see also *Hercules Inc.* v. *EPA,* 598 F. 2d 91, 106 (DC Cir. 1978) ("In reviewing a numerical standard we must ask whether the agency's numbers are within a zone of reasonableness, not whether its numbers are precisely right"); *Permian Basin Area Rate Cases,* 390 U.S. 747, 797 (1968) (same); *Federal Power Commission* v. *Conway Corp.,* 426 U.S. 271, 278 (1976) (same); *Exxon Mobil Gas Marketing Co.* v. *FERC,* 297 F. 3d 1071, 1084 (DC Cir. 2002) (same).

EPA recognizes that the vast majority of technologies which we are considering for purposes of setting standards under section 202(a) are commercially available and already being utilized to a limited extent across the fleet. The vast majority of the emission reductions, which would result from this rule, would result from the increased use of these technologies. EPA also recognizes that this rule would enhance the development and limited use of more advanced technologies, such as PHEVs and EVs. In this technological context, there is no clear cut line that indicates that only one projection of technology penetration could potentially be considered feasible for purposes of section 202(a), or only one standard that could potentially be considered a reasonable balancing of the factors relevant under section 202(a). EPA therefore evaluated two sets of alternative standards, one more stringent than the promulgated standards and one less stringent.

The alternatives are 4% per year increase in standards which would be less stringent and a 6% per year increase in the standards which would be more stringent. EPA is not adopting either of these. As discussed in Section III.D.7, the 4% per year forgoes CO_2 reductions which can be achieved at reasonable cost and are achievable by the industry within the rule's timeframe. The 6% per year alternative requires a significant increase in the projected required technology penetration which appears inappropriate in this timeframe due to the limited available lead time and the current difficult financial condition of the automotive industry. (See Section III.D.7 for a detailed discussion of why EPA is not adopting either of the alternatives.) EPA also believes that the no backsliding standards it is adopting

[166] Based on the mean SCC at 3 percent discount rate, which is $21 per metric ton CO_2 in 2010 rising to $45 per metric ton CO_2 in 2050.

[167] SCC was discounted at 3 percent to maintain internal consistency in the SCC calculations while all other benefits were discounted at 7 percent. Specifically, the same discount rate used to discount the value of damages from future CO_2 emissions is used to calculate net present value of SCC.

for N_2O and CH_4 are appropriate under section 202(a).

B. GHG Standards for Light-Duty Vehicles, Light-Duty Trucks, and Medium-Duty Passenger Vehicles

EPA is finalizing new emission standards to control greenhouse gases (GHGs) from light-duty vehicles. First, EPA is finalizing an emission standard for carbon dioxide (CO_2) on a gram per mile (g/mile) basis that will apply to a manufacturer's fleet of cars, and a separate standard that will apply to a manufacturer's fleet of trucks. CO_2 is the primary greenhouse gas resulting from the combustion of vehicular fuels, and the amount of CO_2 emitted is directly correlated to the amount of fuel consumed. Second, EPA is providing auto manufacturers with the opportunity to earn credits toward the fleet-wide average CO_2 standards for improvements to air conditioning systems, including both hydrofluorocarbon (HFC) refrigerant losses (*i.e.,* system leakage) and indirect CO_2 emissions related to the increased load on the engine. Third, EPA is finalizing separate emissions standards for two other GHGs: Methane (CH_4) and nitrous oxide (N_20). CH_4 and N_2O emissions relate closely to the design and efficient use of emission control hardware (*i.e.,* catalytic converters). The standards for CH_4 and N_2O will be set as a cap that will limit emissions increases and prevent backsliding from current emission levels. The final standards described below will apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles (MDPVs). As an overall group, they are referred to in this preamble as light vehicles or simply as vehicles. In this preamble section passenger cars may be referred to simply as "cars", and light-duty trucks and MDPVs as "light trucks" or "trucks."[168]

EPA's program includes a number of credit opportunities and other flexibilities to help manufacturers comply, especially in the early years of the program. EPA is establishing a system of averaging, banking, and trading of credits integral to the fleet averaging approach, based on manufacturer fleet average CO_2 performance, as discussed in Section III.B.4. This approach is similar to averaging, banking, and trading (ABT) programs EPA has established in other programs and is also similar to provisions in the CAFE program. In addition to traditional ABT credits based on the fleet emissions average, EPA is also including A/C credits as an aspect of the standards, as mentioned above. EPA is also including several additional credit provisions that apply only in the initial model years of the program. These include flex fuel vehicle credits, incentives for the early commercialization of certain advanced technology vehicles, credits for new and innovative "off-cycle" technologies that are not captured by the current test procedures, and generation of credits prior to model year 2012. The A/C credits and additional credit opportunities are described in Section III.C. These credit programs will provide flexibility to manufacturers, which may be especially important during the early transition years of the program. EPA will also allow a manufacturer to carry a credit deficit into the future for a limited number of model years. A parallel provision, referred to as credit carry-back, will be part of the CAFE program. Finally, EPA is finalizing an optional compliance flexibility, the Temporary Leadtime Allowance Alternative Standard program, for intermediate volume manufacturers, and is deferring standards for the smallest manufacturers, as discussed in Sections III.B.5 and 6 below.

1. What fleet-wide emissions levels correspond to the CO_2 standards?

The attribute-based CO_2 standards are projected to achieve a national fleet-wide average, covering both light cars and trucks, of 250 grams/mile of CO_2 in model year (MY) 2016. This includes CO_2-equivalent emission reductions from A/C improvements, reflected as credits in the standard. The standards will begin with MY 2012, with a generally linear increase in stringency from MY 2012 through MY 2016. EPA will have separate standards for cars and light trucks. The tables in this section below provide overall fleet average levels that are projected for both cars and light trucks over the phase-in period which is estimated to correspond with the standards. The actual fleet-wide average g/mi level that will be achieved in any year for cars and trucks will depend on the actual production for that year, as well as the use of the various credit and averaging, banking, and trading provisions. For example, in any year, manufacturers may generate credits from cars and use them for compliance with the truck standard. Such transfer of credits between cars and trucks is not reflected in the table below. In Section III.F, EPA discusses the year-by-year estimate of emissions reductions that are projected to be achieved by the standards.

In general, the schedule of standards acts as a phase-in to the MY 2016 standards, and reflects consideration of the appropriate lead-time for each manufacturer to implement the requisite emission reductions technology across its product line.[169] Note that 2016 is the final model year in which standards become more stringent. The 2016 CO_2 standards will remain in place for 2017 and later model years, until revised by EPA in a future rulemaking.

EPA estimates that, on a combined fleet-wide national basis, the 2016 MY standards will achieve a level of 250 g/mile CO_2, including CO_2-equivalent credits from A/C related reductions. The derivation of the 250 g/mile estimate is described in Section III.B.2.

EPA has estimated the overall fleet-wide CO_2-equivalent emission levels that correspond with the attribute-based standards, based on the projections of the composition of each manufacturer's fleet in each year of the program. Tables III.B.1–1 and III.B.1–2 provides these estimates for each manufacturer.[170]

As a result of public comments and updated economic and future fleet projections, the attribute based curves have been updated for this final rule, as discussed in detail in Section II.B of this preamble and Chapter 2 of the Joint TSD. This update in turn affects costs, benefits, and other impacts of the final standards—thus EPA's overall projection of the impacts of the final rule standards have been updated and the results are different than for the NPRM, though in general not by a large degree.

[168] As described in Section III.B.2., GHG emissions standards will use the same vehicle category definitions as are used in the CAFE program.

[169] *See* CAA section 202(a)(2).

[170] These levels do not include the effect of flexible fuel credits, transfer of credits between cars and trucks, temporary lead time allowance, or any other credits.

TABLE III.B.1–1—ESTIMATED FLEET CO_2-EQUIVALENT LEVELS CORRESPONDING TO THE STANDARDS FOR CARS

[g/mile]

Manufacturer	Model year				
	2012	2013	2014	2015	2016
BMW	266	259	250	239	228
Chrysler	269	262	254	243	232
Daimler	274	267	259	249	238
Ford	267	259	251	240	229
General Motors	268	261	252	241	230
Honda	260	252	244	233	222
Hyundai	260	254	246	233	222
Kia	263	255	247	235	224
Mazda	260	252	243	232	221
Mitsubishi	257	249	241	230	219
Nissan	263	256	248	237	226
Porsche	244	237	228	217	206
Subaru	253	246	237	226	215
Suzuki	245	238	230	218	208
Tata	288	280	272	261	250
Toyota	259	251	243	232	221
Volkswagen	256	249	240	229	219

TABLE III.B.1–2—ESTIMATED FLEET CO_2-EQUIVALENT LEVELS CORRESPONDING TO THE STANDARDS FOR LIGHT TRUCKS

[g/mile]

Manufacturer	Model year				
	2012	2013	2014	2015	2016
BMW	330	320	310	297	283
Chrysler	342	333	323	309	295
Daimler	343	332	323	308	294
Ford	354	344	334	319	305
General Motors	364	354	344	330	316
Honda	327	318	309	295	281
Hyundai	325	316	307	292	278
Kia	335	327	318	303	289
Mazda	319	308	299	285	271
Mitsubishi	316	306	297	283	269
Nissan	343	334	323	308	294
Porsche	334	325	315	301	287
Subaru	315	305	296	281	267
Suzuki	320	310	300	286	272
Tata	321	310	301	287	272
Toyota	342	333	323	308	294
Volkswagen	341	331	322	307	293

These estimates were aggregated based on projected production volumes into the fleet-wide averages for cars and trucks (Table III.B.1–3).[171]

TABLE III.B.1–3—ESTIMATED FLEET-WIDE CO_2-EQUIVALENT LEVELS CORRESPONDING TO THE STANDARDS

Model year	Cars	Trucks
	CO_2 (g/mi)	CO_2 (g/mi)
2012	263	346
2013	256	337
2014	247	326
2015	236	312
2016 and later	225	298

As shown in Table III.B.1–3, fleet-wide CO_2-equivalent emission levels for cars under the approach are projected to decrease from 263 to 225 grams per mile between MY 2012 and MY 2016. Similarly, fleet-wide CO_2-equivalent

[171] Due to rounding during calculations, the estimated fleet-wide CO_2-equivalent levels may vary by plus or minus 1 gram.

emission levels for trucks are projected to decrease from 346 to 398 grams per mile. These numbers do not include the effects of other flexibilities and credits in the program. The estimated achieved values can be found in Chapter 5 of the Regulatory Impact Analysis (RIA).

EPA has also estimated the average fleet-wide levels for the combined car and truck fleets. These levels are provided in Table III.B.1–4. As shown, the overall fleet average CO_2 level is expected to be 250 g/mile in 2016.

TABLE III.B.1–4—ESTIMATED FLEET-WIDE COMBINED CO_2-EQUIVALENT LEVELS CORRESPONDING TO THE STANDARDS

Model year	Combined car and truck CO_2 (g/mi)
2012	295
2013	286
2014	276
2015	263
2016	250

As noted above, EPA is finalizing standards that will result in increasingly stringent levels of CO_2 control from MY 2012 though MY 2016—applying the CO_2 footprint curves applicable in each model year to the vehicles expected to be sold in each model year produces fleet-wide annual reductions in CO_2 emissions. Comments from the Center for Biological Diversity (CBD) challenged EPA to increase the stringency of the standards for all of the years of the program, and even argued that 2016 standards should be feasible in 2012. Other commenters noted the non-linear increase in the standards from 2011 (CAFE) to the 2012 GHG standards. As explained in greater detail in Section III.D below and the relevant support documents, EPA believes that the level of improvement achieves important CO_2 emissions reductions through the application of feasible control technology at reasonable cost, considering the needed lead time for this program. EPA further believes that the averaging, banking and trading provisions, as well as other credit-generating mechanisms, allow manufacturers further flexibilities which reduce the cost of the CO_2 standards and help to provide adequate lead time. EPA believes this approach is justified under section 202(a) of the Clean Air Act.

EPA has analyzed the feasibility under the CAA of achieving the CO_2 standards, based on projections of what actions manufacturers are expected to take to reduce emissions. The results of the analysis are discussed in detail in Section III.D below and in the RIA. EPA also presents the estimated costs and benefits of the car and truck CO_2 standards in Section III.H. In developing the final rule, EPA has evaluated the kinds of technologies that could be utilized by the automobile industry, as well as the associated costs for the industry and fuel savings for the consumer, the magnitude of the GHG reductions that may be achieved, and other factors relevant under the CAA.

With respect to the lead time and cost of incorporating technology improvements that reduce GHG emissions, EPA and NHTSA place important weight on the fact that during MYs 2012–2016 manufacturers are expected to redesign and upgrade their light-duty vehicle products (and in some cases introduce entirely new vehicles not on the market today). Over these five model years there will be an opportunity for manufacturers to evaluate almost every one of their vehicle model platforms and add technology in a cost-effective way to control GHG emissions and improve fuel economy. This includes redesign of the air conditioner systems in ways that will further reduce GHG emissions. The time-frame and levels for the standards, as well as the ability to average, bank and trade credits and carry a deficit forward for a limited time, are expected to provide manufacturers the time needed to incorporate technology that will achieve GHG reductions, and to do this as part of the normal vehicle redesign process. This is an important aspect of the final rule, as it will avoid the much higher costs that will occur if manufacturers needed to add or change technology at times other than these scheduled redesigns. This time period will also provide manufacturers the opportunity to plan for compliance using a multi-year time frame, again in accord with their normal business practice. Further details on lead time, redesigns and feasibility can be found in Section III–D.

Consistent with the requirement of CAA section 202(a)(1) that standards be applicable to vehicles "for their useful life," EPA is finalizing CO_2 vehicle standards that will apply for the useful life of the vehicle. Under section 202(i) of the Act, which authorized the Tier 2 standards, EPA established a useful life period of 10 years or 120,000 miles, whichever first occurs, for all Tier 2 light-duty vehicles and light-duty trucks.[172] Tier 2 refers to EPA's standards for criteria pollutants such as NO_X, HC, and CO. EPA is finalizing new CO_2 standards for the same group of vehicles, and therefore the Tier 2 useful life will apply for CO_2 standards as well. The in-use emission standard will be 10% higher than the model-level certification emission test results, to address issues of production variability and test-to-test variability. The in-use standard is discussed in Section II*I.E.*

EPA is requiring manufacturers to measure CO_2 for certification and compliance purposes using the same test procedures currently used by EPA for measuring fuel economy. These procedures are the Federal Test Procedure (FTP or "city" test) and the Highway Fuel Economy Test (HFET or "highway" test).[173] This corresponds with the data used to develop the footprint-based CO_2 standards, since the data on control technology efficiency was also developed in reference to these test procedures. Although EPA recently updated the test procedures used for fuel economy labeling, to better reflect the actual in-use fuel economy achieved by vehicles, EPA is not using these test procedures for the CO_2 standards in this final rule, given the lack of data on control technology effectiveness under these procedures.[174] There were a number of commenters that advocated for a change in either the test procedures or the fuel economy calculation weighting factors. The U.S. Coalition for Advanced Diesel Cars urged a changing of the city/highway weighting factors from their current values of 45/55 to 43/57 to be more consistent with the EPA (5-cycle) fuel economy labeling rule. EPA has decided that such a change would not be appropriate, nor consistent with the technical analyses supporting the 5-cycle fuel economy label rulemaking. The city/highway weighting of 43/57 was found to be appropriate when the city fuel economy is based on a combination of Bags 2 and 3 of the FTP and the city portion of the US06 test cycle, and when the highway fuel economy is based on a combination of the HFET and the highway portion of the US06 cycle. When city and highway fuel economy are based on the FTP and HFET cycles, respectively, the appropriate city/highway weighting is not 43/57, but very close to 55/45. Therefore, the weighting of the city and

[172] *See* 65 FR 6698 (February 10, 2000).

[173] EPA established the FTP for emissions measurement in the early 1970s. In 1976, in response to the Energy Policy and Conservation Act (EPCA) statute, EPA extended the use of the FTP to fuel economy measurement and added the HFET. The provisions in the 1976 regulation, effective with the 1977 model year, established procedures to calculate fuel economy values both for labeling and for CAFE purposes.

[174] *See* 71 FR 77872, December 27, 2006.

highway fuel economy values contained in this rule is appropriate for and consistent with the use of the FTP and HFET cycles to measure city and highway fuel economy.

The American Council for an Energy-Efficient Economy (ACEEE), Cummins, and Sierra Club all suggested using more real-world test procedures. It is not feasible at this time to base the final CO_2 standards on EPA's five-cycle fuel economy formulae. Consistent with its name, these formulae require vehicle testing over five test cycles, the two cycles associated with the proposed CO_2 standards, plus the cold temperature FTP, the US06 high speed, high acceleration cycle and the SC03 air conditioning test. EPA considered employing the five-cycle calculation of fuel economy and GHG emissions for this rule, but there were a number of reasons why this was not practical. As discussed extensively in the Joint TSD, setting the appropriate levels of CO_2 standards requires extensive knowledge of the CO_2 emission control effectiveness over the certification test cycles. Such knowledge has been gathered over the FTP and HFET cycles for decades, but is severely lacking for the other three test cycles. EPA simply lacks the technical basis to project the effectiveness of the available technologies over these three test cycles and therefore, could not adequately support a rule which set CO_2 standards based on the five-cycle formulae. The benefits of today's rule do presume a strong connection between CO_2 emissions measured over the FTP and HFET cycles and onroad operation. Since CO_2 emissions determined by the five-cycle formulae are believed to correlate reasonably with onroad emissions, this implies a strong connection between emissions over the FTP and HFET cycles and the five cycle formulae. However, while we believe that this correlation is reasonable on average for the vehicle fleet, it may not be reasonable on a per vehicle basis, nor for any single manufacturer's vehicles. Thus, we believe that it is reasonable to project a direct relationship between the percentage change in CO_2 emissions over the two certification cycles and onroad emissions (a surrogate of which is the five-cycle formulae), but not reasonable to base the certification of specific vehicles on that untested relationship. Furthermore, EPA is allowing for off-cycle credits to encourage technologies that may not be not properly captured on the 2-cycle city/highway test procedure (although these credits could apply toward compliance with EPA's standards, not toward compliance with the CAFE standards). For future analysis, EPA will consider examining new drive cycles and test procedures for fuel economy.[175]

EPA is finalizing standards that include hydrocarbons (HC) and carbon monoxide (CO) in its CO_2 emissions calculations on a CO_2-equivalent basis. It is well accepted that HC and CO are typically oxidized to CO_2 in the atmosphere in a relatively short period of time and so are effectively part of the CO_2 emitted by a vehicle. In terms of standard stringency, accounting for the carbon content of tailpipe HC and CO emissions and expressing it as CO_2-equivalent emissions will add less than one percent to the overall CO_2-equivalent emissions level. This will also ensure consistency with CAFE calculations since HC and CO are included in the "carbon balance" methodology that EPA uses to determine fuel usage as part of calculating vehicle fuel economy levels.

2. What are the CO_2 attribute-based standards?

EPA is finalizing the same vehicle category definitions that are used in the CAFE program for the 2011 model year standards.[176] This approach allows EPA's CO_2 standards and the CAFE standards to be harmonized across all vehicles. In other words, vehicles will be subject to either car standards or truck standards under both programs, and not car standards under one program and trucks standards under the other. The CAFE vehicle category definitions differ slightly from the EPA definitions for cars and light trucks used for the Tier 2 program and other EPA vehicle programs. However, EPA is not changing the vehicle category definitions for any other light-duty mobile source programs, except the GHG standards.

EPA is finalizing separate car and truck standards, that is, vehicles defined as cars have one set of footprint-based curves for MY 2012–2016 and vehicles defined as trucks have a different set for MY 2012–2016. In general, for a given footprint the CO_2 g/mi target for trucks is less stringent then for a car with the same footprint.

Some commenters requested a single or converging curve for both cars and trucks.[177] EPA is not finalizing a single fleet standard where all cars and trucks are measured against the same footprint curve for several reasons. First, some vehicles classified as trucks (such as pick-up trucks) have certain attributes not common on cars which attributes contribute to higher CO_2 emissions—notably high load carrying capability and/or high towing capability.[178] Due to these differences, it is reasonable to separate the light-duty vehicle fleet into two groups. Second, EPA wishes to harmonize key program design elements of the GHG standards with NHTSA's CAFE program where it is reasonable to do so. NHTSA is required by statute to set separate standards for passenger cars and for non-passenger cars. As discussed in Section IV, EPCA does not preclude NHTSA from issuing converging standards if its analysis indicates that these are the appropriate standards under the statute applicable separately to each fleet.

Finally, most of the advantages of a single standard for all light duty vehicles are also present in the two-fleet standards finalized here. Because EPA is allowing unlimited credit transfer between a manufacturer's car and truck fleets, the two fleets can essentially be viewed as a single fleet when manufacturers consider compliance strategies. Manufacturers can thus choose on which vehicles within their fleet to focus GHG reducing technology and then use credit transfers as needed to demonstrate compliance, just as they will if there was a single fleet standard. The one benefit of a single light-duty fleet not captured by a two-fleet approach is that a single fleet prevents potential "gaming" of the car and truck definitions to try and design vehicles which are more similar to passenger cars but which may meet the regulatory definition of trucks. Although this is of concern to EPA, we do not believe at this time that concern is sufficient to outweigh the other reasons for finalizing separate car and truck fleet standards. However, it is possible that in the future, recent trends may continue such that cars may become more truck-like and trucks may become more car-like. Therefore, EPA will reconsider whether it is appropriate to use converging curves if justified by future analysis.

For model years 2012 and later, EPA is finalizing a series of CO_2 standards that are described mathematically by a family of piecewise linear functions

[175] There were also a number of comments on air conditioner test procedures; these will be discussed in Section III.C and the RIA.

[176] *See* 49 CFR 523.

[177] CBD, ICCT and NESCAUM supported a single curve and the students at UC Santa Barbara commented on converging curves.

[178] There is a distinction between body-on-frame trucks and unibody cars and trucks that make them technically different in a number of ways. Also, 2WD vehicles tend to have lower CO_2 emissions than their 4WD counterparts (all other things being equal). More discussion of this can be found in the TSD and RIA.

(with respect to vehicle footprint).[179] The form of the function is as follows:

CO_2 = a, if x ≤ l

CO_2 = cx + d, if l < x ≤ h

CO_2 = b, if x > h

Where:

CO_2 = the CO_2 target value for a given footprint (in g/mi)
a = the minimum CO_2 target value (in g/mi)
b = the maximum CO_2 target value (in g/mi)
c = the slope of the linear function (in g/mi per sq ft)
d = is the zero-offset for the line (in g/mi CO_2)
x = footprint of the vehicle model (in square feet, rounded to the nearest tenth)
l & h are the lower and higher footprint limits, constraints, or the boundary ("kinks") between the flat regions and the intermediate sloped line

EPA's parameter values that define the family of functions for the CO_2 fleetwide average car and truck standards are as follows:

TABLE III.B.2–1—PARAMETER VALUES FOR CARS

[For CO_2 gram per mile targets]

Model year	a	b	c	d	Lower constraint	Upper constraint
2012	244	315	4.72	50.5	41	56
2013	237	307	4.72	43.3	41	56
2014	228	299	4.72	34.8	41	56
2015	217	288	4.72	23.4	41	56
2016 and later	206	277	4.72	12.7	41	56

TABLE III.B.2–2—PARAMETER VALUES FOR TRUCKS

[For CO_2 gram per mile targets]

Model year	a	b	c	d	Lower constraint	Upper constraint
2012	294	395	4.04	128.6	41	66
2013	284	385	4.04	118.7	41	66
2014	275	376	4.04	109.4	41	66
2015	261	362	4.04	95.1	41	66
2016 and later	247	348	4.04	81.1	41	66

The equations can be shown graphically for each vehicle category, as shown in Figures III.B.2–1 and III.B.2–2. These standards (or functions) decrease from 2012–2016 with a vertical shift.

The EPA received a number of comments on both the attribute and the shape of the curve. For reasons described in Section IIC and Chapter 2 of the TSD, the EPA feels that footprint is the most appropriate choice of attribute for this rule. More background discussion on other alternative attributes and curves EPA explored can be found in the EPA RIA. EPA recognizes that the CAA does not mandate that EPA use an attribute based standard, as compared to NHTSA's obligations under EPCA. The EPA believes that a footprint-based program will harmonize EPA's program and the CAFE program as a single national program, resulting in reduced compliance complexity for manufacturers. EPA's reasons for using an attribute based standard are discussed in more detail in the Joint TSD. Also described in these other sections are the reasons why EPA is finalizing the slopes and the constraints as shown above. For future analysis, EPA will consider other options and suggestions made by commenters.

EPA also received public comments from three manufacturers, General Motors, Ford Motor Company, and Chrysler, suggesting that the GHG program should harmonize with an EPCA provision that allows a manufacturer to exclude emergency vehicles from its CAFE fleet by providing written notice to NHTSA.[180] These manufacturers believe this provision is necessary because law enforcement vehicles (*e.g.,* police cars) must be designed with special performance and features necessary for police work—but which tend to raise GHG emissions and reduce fuel economy relative to the base vehicle. These commenters provided several examples of features unique to these special purpose vehicles that negatively impact GHG emissions, such as heavy-duty suspensions, unique engine and transmission calibrations, and heavy-duty components (*e.g.,* batteries, stabilizer bars, engine cooling). These manufacturers believe consistency in addressing these vehicles between the EPA and NHTSA programs is critical, as a manufacturer may be challenged to continue providing the performance needs of the Federal, State, and local government purchasers of emergency vehicles.

EPA is not finalizing such an emergency vehicle provision in this rule, since we believe that it is feasible for manufacturers to apply the same types of technologies to the base emergency vehicle as they would to other vehicles in their fleet. However, EPA also recognizes that, because of the unique "performance upgrading" needed to convert a base vehicle into one that meets the performance demands of the law enforcement community—which tend to reduce GHGs relative to the base vehicles—there could be situations where a manufacturer is more challenged in meeting the GHG standards than the CAFE standards, simply due to inclusion of these higher-emitting vehicles in the GHG program fleet. While EPA is not finalizing such an exclusion for emergency vehicles today, we do believe it is important to assess this issue in the future. EPA plans to assess the unique characteristics of these emergency vehicles and whether special provisions for addressing them are warranted. EPA plans to undertake this evaluation as part of a follow-up rulemaking in the next 18 months (this rulemaking is discussed in the context of small

[179] *See* final regulations at 40 CFR 86.1818–12.

[180] 49 U.S.C. 32902(e).

volume manufacturers in Section III.B.6. below).

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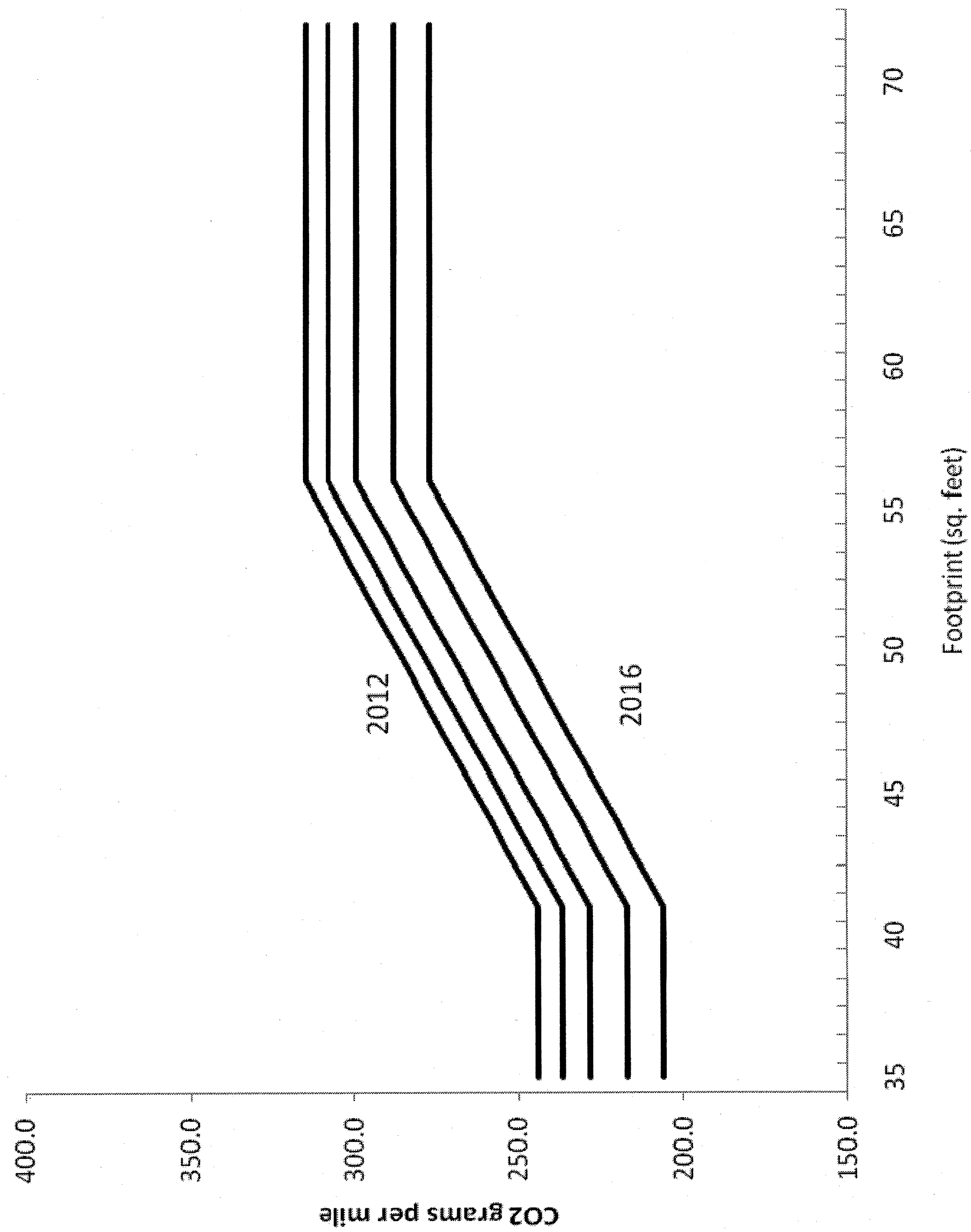

Figure III.B.2-1. CO_2 (g/mi) Car standard curves.

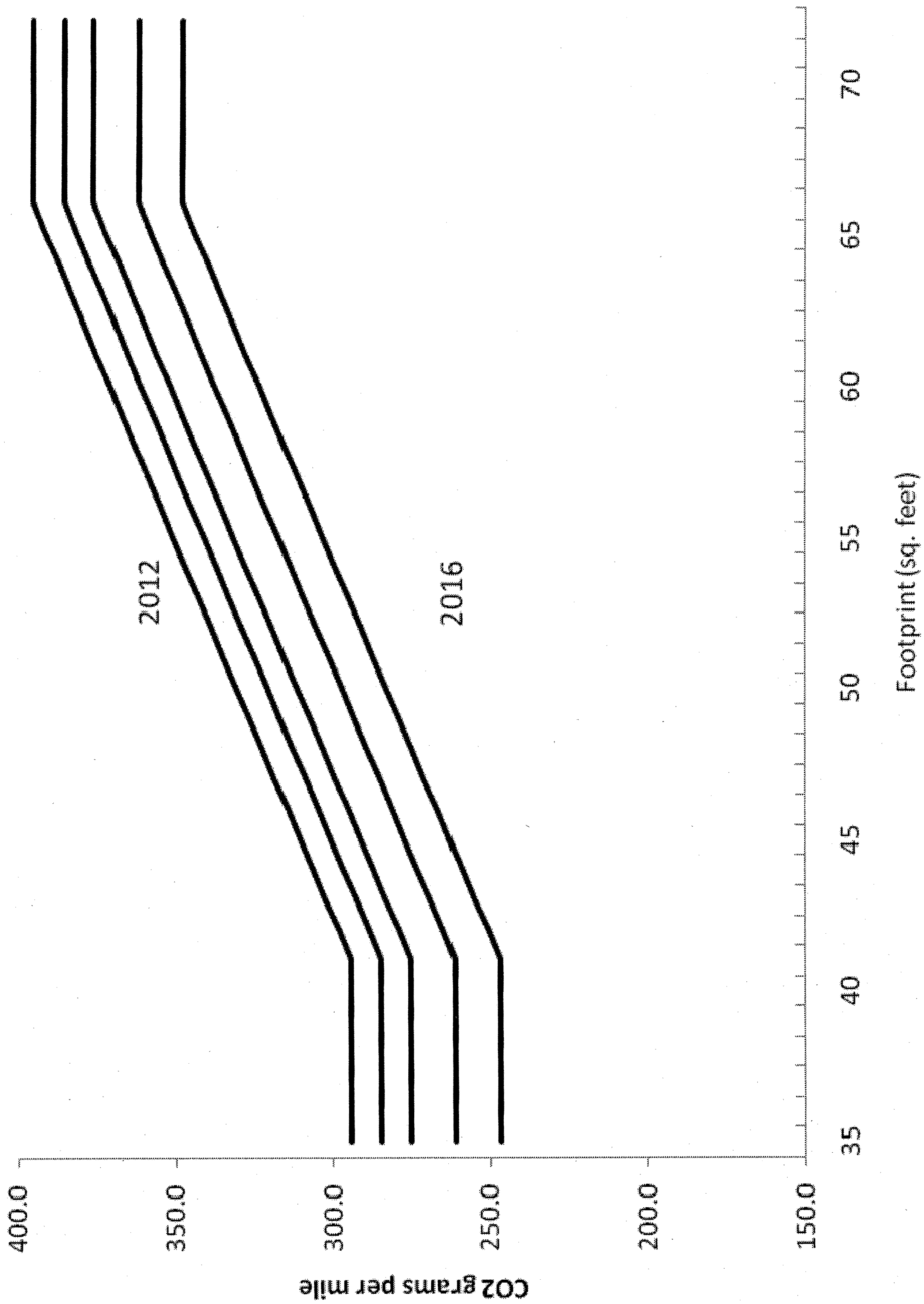

Figure III.B.2-2. CO_2 (g/mi) Truck standard curves.

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3. Overview of How EPA's CO_2 Standards Will Be Implemented for Individual Manufacturers

This section provides a brief overview of how EPA will implement the CO_2 standards. Section III.E explains EPA's approach to certification and compliance in detail. As proposed, EPA is finalizing two kinds of standards—fleet average standards determined by a manufacturer's fleet makeup, and in-use standards that will apply to the individual vehicles that make up the manufacturer's fleet. Although this is similar in concept to the current light-duty vehicle Tier 2 program, there are important differences. In explaining EPA's CO_2 standards, it is useful to summarize how the Tier 2 program works.

Under Tier 2, manufacturers select a test vehicle prior to certification and test the vehicle and/or its emissions hardware to determine both its emissions performance when new and the emissions performance expected at the end of its useful life. Based on this testing, the vehicle is assigned to one of several specified bins of emissions levels, identified in the Tier 2 rule, and this bin level becomes the emissions standard for the test group the test vehicle represents. All of the vehicles in the group must meet the emissions level for that bin throughout their useful life. The emissions level assigned to the bin is also used in calculating the manufacturer's fleet average emissions performance.

Since compliance with the Tier 2 fleet average depends on actual test group sales volumes and bin levels, it is not possible to determine compliance at the time the manufacturer applies for and receives a certificate of conformity for a test group. Instead, at certification, the manufacturer demonstrates that the vehicles in the test group are expected to comply throughout their useful life with the emissions bin assigned to that test group, and makes a good faith demonstration that its fleet is expected to comply with the Tier 2 average when the model year is over. EPA issues a certificate for the vehicles covered by the test group based on this demonstration, and includes a condition in the certificate that if the manufacturer does not comply with the fleet average then production vehicles from that test group will be treated as not covered by the certificate to the extent needed to bring the manufacturer's fleet average into compliance with Tier 2.

EPA is retaining the Tier 2 approach of requiring manufacturers to demonstrate in good faith at the time of certification that vehicles in a test group will meet applicable standards throughout useful life. EPA is also retaining the practice of conditioning certificates upon attainment of the fleet average standard. However, there are several important differences between a Tier 2 type of program and the CO_2 standards program. These differences and resulting modifications to EPA's certification protocols are summarized below and are described in detail in Section II*I.E.*

EPA will continue to certify test groups as it does for Tier 2, and the CO_2 emission results for the test vehicle will serve as the initial or default standard for all of the vehicles in the test group. However, manufacturers will later collect and submit data for individual vehicle model types [181] within each test group, based on the extensive fuel economy testing that occurs through the course of the model year. This model type data will be used to assign a distinct certification level for each model type, thus replacing the initial test group data as the compliance value for each model. It is these model type values that will be used to calculate the fleet average after the end of the model year.[182] The option to substitute model type data for the test group data is at the manufacturer's discretion, except they are required, as they are under the CAFE test protocols, to submit sufficient vehicle test data to represent no less than 90 percent of their actual model year production. The test group emissions data will continue to apply for any model type that is not covered by vehicle test data specific to that model type.

EPA's CO_2 standards also differ from Tier 2 in that the fleet average calculation for Tier 2 is based on test group bin levels and test group sales whereas under the CO_2 program the CO_2 fleet average could be based on a combination of test group and model type emissions and model type production. For the new CO_2 standards, the final regulations use production rather than sales in calculating the fleet average in order to closely conform with the CAFE program, which is a production-based program.[183] Production as defined in the regulations is relatively easy for manufacturers to track, but once the vehicle is delivered to dealerships the manufacturer becomes once step removed from the sale to the ultimate customer, and it becomes more difficult to track that final transaction. There is no environmental impact of using production instead of actual sales, and many commenters supported maintaining alignment between EPA's program and the CAFE program where possible.

4. Averaging, Banking, and Trading Provisions for CO_2 Standards

As explained above, EPA is finalizing a fleet average CO_2 program for passenger cars and light trucks. EPA has previously implemented similar averaging programs for a range of motor vehicle types and pollutants, from the Tier 2 fleet average for NO_X to motorcycle hydrocarbon (HC) plus oxides of nitrogen (NO_X) emissions to NO_X and particulate matter (PM) emissions from heavy-duty engines.[184] The program will operate much like EPA's existing averaging programs in that manufacturers will calculate production-weighted fleet average emissions at the end of the model year and compare their fleet average with a fleet average emission standard to determine compliance. As in other EPA averaging programs, the Agency is also finalizing a comprehensive program for averaging, banking, and trading of credits which together will help manufacturers in planning and implementing the orderly phase-in of emissions control technology in their production, consistent with their typical redesign schedules.[185]

Averaging, Banking, and Trading (ABT) of emissions credits has been an important part of many mobile source programs under CAA Title II, both for fuels programs as well as for engine and vehicle programs. ABT is important because it can help to address many issues of technological feasibility and lead-time, as well as considerations of cost. ABT is an integral part of the standard setting itself, and is not just an add-on to help reduce costs. In many cases, ABT resolves issues of lead-time

[181] "Model type" is defined in 40 CFR 600.002–08 as "* * * a unique combination of car line, basic engine, and transmission class." A "car line" is essentially a model name, such as "Camry," "Malibu," or "F150." The fleet average is calculated on the basis of model type emissions.

[182] The final in-use vehicle standards for each vehicle will also be based on the testing used to determine the model type values. As discussed in Section II*I.E.*4, an in-use adjustment factor will be applied to the vehicle test results to determine the in-use standard that will apply during the useful life of the vehicle.

[183] "Production" is defined as "vehicles produced and delivered for sale" and is not a measure of the number of vehicles actually sold.

[184] For example, *see* the Tier 2 light-duty vehicle emission standards program (65 FR 6698, February 10, 2000), the 2010 and later model year motorcycle emissions program (69 FR 2398, January 15, 2004), and the 2007 and later model year heavy-duty engine and vehicle standards program (66 FR 5001, January 18, 2001).

[185] *See* final regulations at 40 CFR 86.1865–12.

or technical feasibility, allowing EPA to set a standard that is either numerically more stringent or goes into effect earlier than could have been justified otherwise. This provides important environmental benefits and at the same time it increases flexibility and reduces costs for the regulated industry. A wide range of commenters expressed general support for the ABT provisions. Some commenters noted issues regarding specific provisions of the ABT program, which will be discussed in the appropriate context below. Several commenters requested that EPA publicly release manufacturer-specific ABT data to improve the transparency of credit transactions. These comments are addressed in Section II*I.E.*

This section discusses generation of credits by achieving a fleet average CO_2 level that is lower than the manufacturer's CO_2 fleet average standard. The final rule includes a variety of additional ways credits may be generated by manufacturers. Section III.C describes these additional opportunities to generate credits in detail. Manufacturers may earn credits through A/C system improvements beyond a specified baseline. Credits can also be generated by producing alternative fuel vehicles, by producing advanced technology vehicles including electric vehicles, plug-in hybrids, and fuel cell vehicles, and by using technologies that improve off-cycle emissions. In addition, early credits can be generated prior to the program's MY 2012 start date. The credits will be used to determine a manufacturer's compliance at the end of the model year. These credit generating opportunities are described below in Section III.C.

As explained earlier, manufacturers will determine the fleet average standard that applies to their car fleet and the standard for their truck fleet from the applicable attribute-based curve. A manufacturer's credit or debit balance will be determined by comparing their fleet average with the manufacturer's CO_2 standard for that model year. The standard will be calculated from footprint values on the attribute curve and actual production levels of vehicles at each footprint. A manufacturer will generate credits if its car or truck fleet achieves a fleet average CO_2 level lower than its standard and will generate debits if its fleet average CO_2 level is above that standard. At the end of the model year, each manufacturer will calculate a production-weighted fleet average for each averaging set (cars and trucks). A manufacturer's car or truck fleet that achieves a fleet average CO_2 level lower than its standard will generate credits, and if its fleet average CO_2 level is above that standard its fleet will generate debits.

The regulations will account for the difference in expected lifetime vehicle miles traveled (VMT) between cars and trucks in order to preserve CO_2 reductions when credits are transferred between cars and trucks. As directed by EISA, NHTSA accomplishes this in the CAFE program by using an adjustment factor that is applied to credits when they are transferred between car and truck compliance categories. The CAFE adjustment factor accounts for two different influences that can cause the transfer of car and truck credits (expressed in tenths of a mpg), if left unadjusted, to potentially negate fuel reductions. First, mpg is not linear with fuel consumption, *i.e.,* a 1 mpg improvement above a standard will imply a different amount of actual fuel consumed depending on the level of the standard. Second, NHTSA's conversion corrects for the fact that the typical lifetime miles for cars is less than that for trucks, meaning that credits earned for cars and trucks are not necessarily equal. NHTSA's adjustment factor essentially converts credits into vehicle lifetime gallons to ensure preservation of fuel savings and the transfer credits on an equal basis, and then converts back to the statutorily-required credit units of tenths of a mile per gallon. To convert to gallons NHTSA's conversion must take into account the expected lifetime mileage for cars and trucks. Because EPA's standards are expressed on a CO_2 gram per mile basis, which is linear with fuel consumption, EPA's credit calculations do not need to account for the first issue noted above. However, EPA is accounting for the second issue by expressing credits when they are generated in total lifetime Megagrams (metric tons), rather than through the use of conversion factors that would apply at certain times. In this way credits may be freely exchanged between car and truck compliance categories without the need for adjustment. Additional detail regarding this approach, including a discussion of the vehicle lifetime mileage estimates for cars and trucks can be found in Section II*I.E.*5. A discussion of the derivation of the estimated vehicle lifetime miles traveled can be found in Chapter 4 of the Joint Technical Support Document.

A manufacturer that generates credits in a given year and vehicle category may use those credits in essentially four ways, although with some limitations. These provisions are very similar to those of other EPA averaging, banking, and trading programs. These provisions have the potential to reduce costs and compliance burden, and support the feasibility of the standards in terms of lead time and orderly redesign by a manufacturer, thus promoting and not reducing the environmental benefits of the program.

First, EPA proposed that the manufacturer must use any credits earned to offset any deficit that had accrued in the current year or in a prior model year that had been carried over to the current model year. NRDC commented that such a provision is necessary to prevent credit "shell games" from delaying the adoption of new technologies. EPA's Tier 2 program includes such a restriction, and EPA is applying an identical restriction to the GHG program. Simply stated, a manufacturer may not bank (or carry forward) credits if that manufacturer is also carrying a deficit. In such a case, the manufacturer is obligated to use any current model year credits to offset that deficit. Using current model year credits to offset a prior model year deficit is referred to in the CAFE program as credit carry-back. EPA's deficit carry-forward, or credit carry-back provisions are described further, below.

Second, after satisfying any needs to offset pre-existing deficits, remaining credits may be banked, or saved for use in future years. Credits generated in this program will be available to the manufacturer for use in any of the five model years after the model year in which they were generated, consistent with the CAFE program under EISA. This is also referred to as a credit carry-forward provision.

EPA received a number of comments regarding the credit carry-back and carry-forward provisions. Many supported the proposed consistency of these provisions with EISA and the flexibility provided by these provisions, and several offered qualified or tentative support. For example, NRDC encouraged EPA to consider further restrictions in the 2017 and later model years. Public Citizen expressed concern regarding the complexity of the program and how these provisions might obscure a straightforward determination of compliance in any given model year. At least two automobile manufacturers suggested modeling the program after California, which allows credits to be carried forward for three additional years following a discounting schedule.

For other new emission control programs, EPA has sometimes initially restricted credit life to allow time for the Agency to assess whether the credit program is functioning as intended. When EPA first offered averaging and banking provisions in its light-duty emissions control program (the National Low Emission Vehicle Program), credit life was restricted to three years. The same is true of EPA's early averaging and banking program for heavy-duty engines. As these programs matured and were subsequently revised, EPA became confident that the programs were functioning as intended and that the standards were sufficiently stringent to remove the restrictions on credit life. EPA is therefore acting consistently with our past practice in finalizing reasonable restrictions on credit life in this new program. The Agency believes that a credit life of five years represents an appropriate balance between promoting orderly redesign and upgrade of the emissions control technology in the manufacturer's fleet and the policy goal of preventing large numbers of credits accumulated early in the program from interfering with the incentive to develop and transition to other more advanced emissions control technologies. As discussed below in Section III.C, early credits generated by a manufacturer are also be subject to the five year credit carry-forward restriction based on the year in which they are generated. This limits the effect of the early credits on the long-term emissions reductions anticipated to result from the new standards.

Third, the new program enables manufacturers to transfer credits between the two averaging sets, passenger cars and trucks, within a manufacturer. For example, credits accrued by over-compliance with a manufacturer's car fleet average standard may be used to offset debits accrued due to that manufacturer's not meeting the truck fleet average standard in a given year. EPA believes that such cross-category use of credits by a manufacturer provides important additional flexibility in the transition to emissions control technology without affecting overall emission reductions. Comments regarding the credit transfer provisions expressed general support, noting that it does not matter to the environment whether a gram of greenhouse gas is generated from a car or a truck. Additional comments regarding EPA's streamlined megagram approach and method of accounting for expected vehicle lifetime miles traveled are summarized in Section II*I.E.*

Finally, accumulated credits may be traded to another vehicle manufacturer. As with intra-company credit use, such inter-company credit trading provides flexibility in the transition to emissions control technology without affecting overall emission reductions. Trading credits to another vehicle manufacturer could be a straightforward process between the two manufacturers, but could also involve third parties that could serve as credit brokers. Brokers may not own the credits at any time. These sorts of exchanges are typically allowed under EPA's current emission credit programs, *e.g.,* the Tier 2 light-duty vehicle NO_X fleet average standard and the heavy-duty engine NO_X fleet average standards, although manufacturers have seldom made such exchanges. Comments generally reflected support for the credit trading flexibility, although some questioned the extent to which trading might actually occur. As noted above, comments regarding program transparency are addressed in Section II*I.E.*

If a manufacturer has accrued a deficit at the end of a model year—that is, its fleet average level failed to meet the required fleet average standard—the manufacturer may carry that deficit forward (also referred to credit carry-back) for a total of three model years after the model year in which that deficit was generated. EPA continues to believe that three years is an appropriate amount of time that gives the manufacturers adequate time to respond to a deficit situation but does not create a lengthy period of prolonged non-compliance with the fleet average standards.[186] As noted above, such a deficit carry-forward may only occur after the manufacturer has applied any banked credits or credits from another averaging set. If a deficit still remains after the manufacturer has applied all available credits, and the manufacturer did not obtain credits elsewhere, the deficit may be carried forward for up to three model years. No deficit may be carried into the fourth model year after the model year in which the deficit occurred. Any deficit from the first model year that remains after the third model year will constitute a violation of the condition on the certificate, which will constitute a violation of the Clean Air Act and will be subject to enforcement action.

The averaging, banking, and trading provisions are generally consistent with those included in the CAFE program, with a few notable exceptions. As with EPA's approach, CAFE allows five year carry-forward of credits and three year carry-back. Under CAFE, transfers of credits across a manufacturer's car and truck averaging sets are also allowed, but with limits established by EISA on the use of transferred credits. The amount of transferred credits that can be used in a year is limited, and transferred credits may not be used to meet the CAFE minimum domestic passenger car standard. CAFE allows credit trading, but again, traded credits cannot be used to meet the minimum domestic passenger car standard. EPA did not propose, and is not finalizing, these constraints on the use of transferred credits.

Additional details regarding the averaging, banking, and trading provisions and how EPA will implement these provisions can be found in Section II*I.E.*

5. CO_2 Temporary Lead-Time Allowance Alternative Standards

EPA proposed adopting a limited and narrowly prescribed option, called the Temporary Lead-time Allowance Alternative Standards (TLAAS), to provide additional lead time for a certain subset of manufacturers. As noted in the proposal, this option was designed to address two different situations where we project that more lead time is needed, based on the level of emissions control technology and emissions control performance currently exhibited by certain vehicles. One situation involves manufacturers who have traditionally paid CAFE fines instead of complying with the CAFE fleet average, and as a result at least part of their vehicle production currently has significantly higher CO_2 and lower fuel economy levels than the industry average. More lead time is needed in the program's initial years to upgrade these vehicles to meet the aggressive CO_2 emissions performance levels required by the final rule. The other situation involves manufacturers who have a limited line of vehicles and are therefore unable to average emissions performance across a full line of production. For example, some smaller volume manufacturers produce only vehicles with emissions above the corresponding CO_2 footprint target, and do not have other types of vehicles (that exceed their compliance targets) in their production mix with which to average. Often, these manufacturers also pay fines under the CAFE program rather than meeting the applicable CAFE standard. Because voluntary non-compliance through payment of civil penalties is impermissible for the GHG standards under the CAA, both of these types of manufacturers need additional lead time to upgrade vehicles and meet the standards. EPA proposed that this subset of manufacturers be allowed to

[186] EPA emission control programs that incorporate ABT provisions (*e.g.,* the Tier 2 program and the Mobile Source Air Toxics program) have provided this three-year deficit carry-forward provision for this reason. *See* 65 FR 6745 (February 10, 2000), and 71 FR 8427 (February 26, 2007).

produce up to 100,000 vehicles over model years 2012–2015 that would be subject to a somewhat less stringent CO_2 standard of 1.25 times the standard that would otherwise apply to those vehicles. Only manufacturers with total U.S. sales of less than 400,000 vehicles per year in MY 2009 would be eligible for this allowance. Those manufacturers would have to exhaust designated program flexibilities in order to be eligible, and credit generating and trading opportunities for the eligible vehicles would be restricted. *See* 74 FR 49522–224.

EPA is finalizing the optional TLAAS provisions, with certain limited modifications, so that these manufacturers can have sufficient lead time to meet the tougher MY 2016 GHG standards, while preserving consumer choice of vehicles during this time.[187] EPA is finalizing modified provisions to address the unique lead-time issues of smaller volume manufacturers. One provision involves additional flexibility under the TLAAS program for manufacturers below 50,000 U.S. vehicle sales, as discussed further in Section III.B.5.b below. Another provision defers the CO_2 standards for the smallest volume manufacturers, those below 5,000 U.S. vehicle sales, as discussed in Section III.B.6.

Comments from several manufacturers strongly supported the TLAAS program as critical to provide the lead time needed for manufacturers to meet the standards. Volkswagen commented that TLAAS is an important aspect of EPA's proposal and that it responds to the needs of some smaller manufacturers for additional lead time and flexibility under the CAA. Daimler Automotive Group commented that TLAAS is a critical element of the program and falls squarely within EPA's discretion to provide appropriate lead time to limited-line low-volume manufacturers. BMW also commented that TLAAS is needed because most of the companies with limited lines will have to meet a more stringent fleet standard by 2016 than full-line manufacturers because they sell "feature-dense" vehicles (as opposed to light-weight large wheel-base vehicles) and no pick-up trucks. BMW commented that their MY 2016 footprint-based standard is projected to be 4 percent more stringent than the fleet average standard of 250 g/mile. The Alliance of Automobile Manufacturers supported the flexibilities proposed by EPA, including TLAAS. As discussed in detail below, EPA received extensive comments from many smaller volume manufacturers that the proposed TLAAS program was insufficient to address lead time and feasibility issues they will face under the program.

In contrast, EPA also received comments from the Center for Biological Diversity opposing the TLAAS program, commenting that an exception for high performance vehicles is not allowed under EPCA or the CAA and that it rewards manufacturers that pay penalties under CAFE and penalizes those that have complied with CAFE. This commenter suggests that manufacturers could decrease vehicle mass or power output of engines, purchase credits from another manufacturer, or earn off-cycle credits. EPA responds to these comments below.

After carefully considering the public comments, EPA continues to believe that the TLAAS program is essential in providing necessary lead time and flexibility to eligible manufacturers in the early years of the standards. First, EPA believes that it is acting well within its legal authority in adopting the various TLAAS provisions. EPA is required to provide sufficient lead time for industry as a whole for standards under section 202(a)(1), which mandates that standards are to take effect only "after providing such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period." Thus, although section 202(a)(1) does not explicitly authorize this or any other specific lead time provision, it affords ample leeway for EPA to craft provisions designed to provide adequate lead time, and to tailor those provisions as appropriate. We show below that the types of technology penetrations required for TLAAS-eligible vehicles in the program's earlier years raise critical issues as to adequacy of lead time. As discussed in the EPA feasibility analysis provided in Section III.D.6 and III.D.7 several manufacturers eligible for TLAAS are projected to face a compliance shortfall in MY 2016 without the TLAAS program, even with the full application of technologies assumed by the OMEGA Model, including hybrid use of up to 15 percent. These include BMW, Jaguar Land Rover, Daimler, Porsche, and Volkswagen In addition, the smaller volume manufacturers of this group (*i.e.,* Jaguar Land Rover and Porsche) face the greatest shortfall (see Table III.D.6–4). Even with TLAAS, these manufacturers will need to take technology steps to comply with standards above and beyond those of other manufacturers. These manufacturers have relatively few models with high baseline emissions and this flexibility allows them additional lead time to adapt to a longer term strategy of meeting the final standards within their vehicle redesign cycles.

Second, EPA has carefully evaluated other means of eligible manufacturers to meet the standards, such as utilizing available credit opportunities. Indeed, eligibility for the TLAAS, and for temporary deferral of regulation for very small volume manufacturers, is conditioned on first exhausting the various programmatic flexibilities including credit utilization. At the same time, a basic reason certain manufacturers are faced with special lead time difficulties is their inability to generate credits which can be then be averaged across their fleet because of limited product lines. And although purchasing credits is an option under the program, there are no guarantees that credits will be available. Historic practice in fact suggests that manufacturers do not sell credits to competitors. While some of the smaller manufacturers covered by the TLAAS program may be in a position to obtain credits, they are not likely to be available for the TLAAS manufacturers across the board in the volume needed to comply without the TLAAS provisions. At the same time the TLAAS provisions have been structured such that any credits that do become available would likely be used before a manufacturer would turn to the more restricted and limiting TLAAS provisions.

As discussed in Section III.C., off-cycle credits are available if manufacturers are able to employ new and innovative technologies not already in widespread use, which provide real-world emissions reductions not captured on the current test cycles. Further, these credits are eligible only for technologies that are newly introduced on just a few vehicle models, and are not yet in widespread use across the fleet. The magnitude of these credits are highly uncertain because they are based on new technologies, and EPA is not aware of any such technologies that would provide enough credits to bring these manufacturers into compliance without TLAAS lead time flexibility. Manufacturers first must develop these technologies and then demonstrate their emissions reductions capabilities, which will require lead time. Moreover, the technologies mentioned in the proposal which are the most likely to be eligible based on present knowledge, including solar panels and active

[187] *See* final regulations at 40 CFR 86.1818–12(e).

aerodynamics, are likely to provide only small incremental emissions reductions.

We agree with the comment that reducing vehicle mass or power are potential methods for reducing emissions that should be employed by TLAAS-eligible manufacturers to help them meet standards. However, based on our assessment of the lead time needed for these manufacturers to comply with the standards, especially given their more limited product offerings and higher baseline emissions, we believe that additional time is needed for them to come into compliance. EPA can permissibly consider the TLAAS and other manufacturers' lead time, cost, and feasibility issues in developing the primary standards and has discretion in setting the overall stringency of the standards to account for these factors. *Natural Resources Defense Council* v. *Thomas,* 805 F. 2d 410, 421 (DC Cir. 1986) (even when implementing technology-forcing provisions of Title II, EPA may base standards on an industry-wide capability "taking into account the broad spectrum of technological capabilities as well as cost and other factors" across the industry). EPA is not legally required to set standards that drive these manufacturers or their products out of the market, nor is EPA legally required to preserve a certain product line or vehicle characteristic. Instead EPA has broad discretion under section 202(a)(1) to set standards that reasonably balance lead time needs across the industry as a whole and vehicle availability. In this rulemaking, EPA has consistently emphasized the importance of obtaining very significant reductions in emissions of GHGs from the industry as a whole, and obtaining those reductions through regulatory approaches that avoid limiting the ability of manufacturers to provide model availability and choice for consumers. The primary mechanism to achieve this is the use of a footprint attribute curve in setting the increasingly stringent model year standards. The TLAAS provisions are a temporary and strictly limited modification to these attribute standards allowing the TLAAS manufacturers lead time to upgrade their product lines to meet the 2016 GHG standards. EPA has made a reasonable choice here to preserve the overall stringency of the program, and to afford increased flexibility in the program's early years to a limited class of vehicles to assure adequate lead time for all manufacturers to meet the strictest of the standards by MY 2016.

As described below, EPA also carefully considered the comments of smaller volume manufacturers and believes additional lead time is needed. Therefore, EPA is finalizing the TLAAS program, similar to that proposed, and is also finalizing an additional TLAAS option for manufacturers with annual U.S. sales under 50,000 vehicles. EPA is also deferring standards for manufacturers with annual sales of less than 5,000 vehicles. These new TLAAS provisions and the small volume manufacturer deferment are discussed in detail below and in Section III.B.6.

a. Base TLAAS Program

As proposed, EPA is establishing the TLAAS program for a specified subset of manufacturers. This alternative standard is an option only for manufacturers with total U.S. sales of less than 400,000 vehicles per year, using 2009 model year final sales numbers to determine eligibility for these alternative standards. For manufacturers with annual U.S. sales of 50,000 or more but less than 400,000 vehicles, EPA is finalizing the TLAAS program largely as proposed. EPA proposed that under the TLAAS, qualifying manufacturers would be allowed to produce up to 100,000 vehicles that would be subject to a somewhat less stringent CO_2 standard of 1.25 times the standard that would otherwise apply to those vehicles. This 100,000 volume is not an annual limit, but is an absolute limit for the total number of vehicles which can use the TLAAS program over the model years 2012–2015. Any additional production would be subject to the same standards as any other manufacturer. EPA is retaining this limit for manufacturers with baseline MY 2009 sales of 50,000 but less than 400,000. In addition, as discussed further below, EPA is finalizing a variety of restrictions on the use of the TLAAS program, to ensure that only manufacturers who need more lead time for the kinds of reasons noted above are likely to use the program.

Volvo and Saab commented that basing eligibility strictly on MY 2009 sales would be problematic for these companies, which are being spun-off from larger manufacturer in the MY 2009 time frame due to the upheaval in the auto industry over the past few years. These commenters offered a variety of suggestions including using MY 2010 as the eligibility cut-off instead of MY 2009, reassessing eligibility on a year-by-year basis as corporate relationships change, or allowing companies separated from a larger parent company by the end of 2010 to use their MY 2009 branded U.S. sales to qualify for TLAAS. In response to these concerns, EPA recognizes that these companies currently being sold by larger manufacturers will share the same characteristics of the manufacturers for which the TLAAS program was designed. As newly independent companies, these firms will face the challenges of a narrower fleet of vehicles across which to average, and may potentially be in a situation, at least in the first few years, of paying fines under CAFE. Lead time concerns in the program's initial years are in fact particularly acute for these manufacturers since they will be newly independent, and thus would have even less of an opportunity to modify their vehicles to meet the standards. Therefore, EPA is finalizing an approach that allows manufacturers with U.S. "branded sales" in MY 2009 under the umbrella of a larger manufacturer that become independent by the end of calendar year 2010 to use their MY 2009 branded sales to qualify for TLAAS eligibility. In other words, a manufacturer will be eligible for TLAAS if it produced vehicles for the U.S. market in MY 2009, its branded sales of U.S. vehicles were less than 400,000 in MY 2009 but whose vehicles were sold as part of a larger manufacturer, and it becomes independent by the end of calendar year 2010, if the new entity has sales below 400,000 vehicles.

Manufacturers with no U.S. sales in MY 2009 are not eligible to utilize the TLAAS program. EPA does not support the commenter's suggestion of a year-by-year eligibility determination because it opens up the TLAAS program to an unknown universe of potential eligible manufacturers, with the potential for gaming. EPA does not believe the TLAAS program should be available to new entrants to the U.S. market since these manufacturers are not transitioning from the CAFE regime which allows fine paying as a means of compliance to a CAA regime which does not, and hence do not present the same types of lead time issues. Manufacturers entering the U.S. market for the first time thus will be fully subject to the GHG fleet-average standards.

As proposed, manufacturers qualifying for TLAAS will be allowed to meet slightly less stringent standards for a limited number of vehicles. An eligible manufacturer could have a total of up to 100,000 units of cars or trucks combined over model years 2012–2015 which would be subject to a standard 1.25 times the standard that would otherwise apply to those vehicles under the primary program. In other words, the footprint curves upon which the individual manufacturer standards for the TLAAS fleets are based would be less stringent by a factor of 1.25 for up to 100,000 of an eligible manufacturer's vehicles for model years 2012–2015. EPA believes that 100,000 units over four model years achieves an appropriate balance, as the emissions impact is quite small, but does provide companies with necessary lead time during MY 2012–2015. For example, for a manufacturer producing 400,000 vehicles per year, this would be a total of up to 100,000 vehicles out of a total production of up to 1.6 million vehicles over the four year period, or about 6 percent of total production.

Finally, for manufacturers of 50,000 but less than 400,000 U.S. vehicles sales during 2009, the program expires at the end of MY 2015 as proposed. EPA continues to believe the program reasonably addresses a real world lead time constraint for these manufacturers, and does so in a way that balances the need for more lead time with the need to minimize any resulting loss in potential emissions reductions. In MY 2016, the TLAAS option thus ends for all but the smallest manufacturers opting for TLAAS, and manufacturers must comply with the same CO_2 standards as non-TLAAS manufacturers; under the CAFE program companies would continue to be allowed to pay civil penalties in lieu of complying with the CAFE standards. However, because companies must meet both the CAFE standards and the EPA CO_2 standards, the National Program will have the practical impact of providing a level playing field for almost all except the smallest companies beginning in MY 2016. This option, even with the modifications being adopted, thereby results in more fuel savings and CO_2 reductions than would be the case under the CAFE program by itself.

EPA proposed that manufacturers meeting the cut-point of below 400,000 sales for MY 2009 but whose U.S. sales grew above 400,000 in any subsequent model years would remain eligible for the TLAAS program. The total sales number applies at the corporate level, so if a corporation owns several vehicle brands the aggregate sales for the corporation must be used. These provisions would help prevent gaming of the provisions through corporate restructuring. Corporate ownership or control relationships would be based on determinations made under CAFE for model year 2009 (except in the case of a manufacturer being sold by a larger manufacturer by the end of calendar year 2010, as discussed above). In other words, corporations grouped together for purposes of meeting CAFE standards in MY 2009, must be grouped together for determining whether or not they are eligible under the 400,000 vehicle cut point. EPA is finalizing these provisions with the following modifications. EPA recognizes the dynamic corporate restructuring occurring in the auto industry and believes it is important to structure additional provisions to ensure there is no ability to game the TLAAS provisions and to ensure no unintended loss of feasible environmental benefits. Therefore, EPA is finalizing a provision that if two or more TLAAS eligible companies are later merged, with one company having at least 50% or more ownership of the other, or if the companies are combined for the purposes of EPA certification and compliance, the TLAAS allotment is not additive. The merged company will only be allowed the allotment for what is considered the parent company under the new corporate structure. Further, if the newly formed company would have exceeded the 400,000 vehicle cut point based on combined MY 2009 sales, the new entity is not eligible for TLAAS in the model year following the merger. EPA believes that such mergers and acquisitions would give the parent company additional opportunities to average across its fleet, eliminating one of the primary needs for the TLAAS program. This provision will not be retroactive and will not affect the TLAAS program in the year of the merger or for previous model years. EPA believes these additional provisions are essential to ensure the integrity of the TLAAS program by ensuring that it does not become available to large manufacturers through mergers and acquisitions.

As proposed, the TLAAS vehicles will be separate car and truck fleets for that model year and subject to the less stringent footprint-based standards of 1.25 times the primary fleet average that would otherwise apply. The manufacturer will determine what vehicles are assigned to these separate averaging sets for each model year. As proposed, credits from the primary fleet average program can be transferred and used in the TLAAS program. Credits generated within the TLAAS program may also be transferred between the TLAAS car and truck averaging sets (but not to the primary fleet as explained below) for use through MY 2015 when the TLAAS ends.

EPA is finalizing a number of restrictions on credit trading within the TLAAS program, as proposed. EPA is concerned that if credit use in the TLAAS program were unrestricted, some manufacturers would be able to place relatively clean vehicles in the TLAAS fleet, and generate credits for the primary program fleet. First, credits generated under TLAAS may not be transferred or traded to the primary program. Therefore, any unused credits under TLAAS expire after model year 2015 (or 2016 for manufacturers with annual sales less than 50,000 vehicles). EPA believes that this is necessary to limit the program to situations where it is needed and to prevent the allowance from being inappropriately transferred to the long-term primary program where it is not needed. EPA continues to believe this provision is necessary to prevent credits from being earned simply by removing some high-emitting vehicles from the primary fleet. Absent this restriction, manufacturers would be able to choose to use the TLAAS for these vehicles and also be able to earn credits under the primary program that could be banked or traded under the primary program without restriction. Second, EPA is finalizing two additional restrictions on the use of TLAAS by requiring that for any of the 2012–2015 model years for which an eligible manufacturer would like to use the TLAAS, the manufacturer must use two of the available flexibilities in the GHG program first in order to try and comply with the primary standard before accessing the TLAAS—*i.e.,* TLAAS eligibility is not available to those manufacturers with other readily-available means of compliance. Specifically, before using the TLAAS a manufacturer must: (1) Use any banked emission credits from previous model years; and, (2) use any available credits from the companies' car or truck fleet for the specific model year (*i.e.,* use credit transfer from cars to trucks or from trucks to cars). That is, before using the TLAAS for either the car fleet or the truck fleet, the company must make use of any available intra-manufacturer credit transfers first. Finally, EPA is restricting the use of banking and trading between companies of credits in the primary program in years in which the TLAAS is being used. No such restriction is in place for years when the TLAAS is not being used.

EPA received several comments in support of these credit restrictions for the TLAAS program. On the negative side, one manufacturer commented that the restrictions were not necessary, saying that the restrictions are counter to providing manufacturers with flexibility and that the emissions impacts estimated by EPA due to the full use of the program are small. However, EPA continues to believe that the restrictions are appropriate to prevent the potential gaming described above, and to ensure that the TLAAS program is used only by those manufacturers that have exhausted all other readily available compliance mechanisms and consequently have legitimate lead time issues.

One manufacturer commented that the program is restrictive due to the requirement that manufacturers must decide prior to the start of the model year whether or not and how to use the TLAAS program. EPA did not intend for manufactures to have to make this determination prior to the start of the model year. EPA expects that manufacturers will provide a best estimate of their plans to use the TLAAS program during certification based on projected model year sales, as part of their pre model year report projecting their overall plan for compliance (as required by § 600.514–12 of the regulations). Manufacturers must determine the program's actual use at the end of the model year during the process of demonstrating year-end compliance. EPA recognizes that depending on actual sales for a given model year, a manufacturer's use of TLAAS may change from the projections used in the pre-model year report.

b. Additional TLAAS Flexibility for Manufacturers With MY 2009 Sales of Less Than 50,000 Vehicles

EPA received extensive comments that the TLAAS program would not provide sufficient lead time and flexibility for companies with sales of significantly less than 400,000 vehicles. Jaguar Land Rover, which separated from Ford in 2008, commented that it sells products only in the middle and large vehicle segments and that its total product range remains significantly more limited in terms of segments in comparison with its main competitors which typically have approximately 75% of their passenger car fleet in the small and middle segments. Jaguar Land Rover also commented that it has already committed $1.3 billion of investment to reducing CO_2 from its vehicle fleet and that this investment is already delivering a range of technologies to improve the fuel economy and CO_2 performance of its existing vehicles. Jaguar Land Rover submitted confidential business information regarding their future product plans and emissions performance capabilities of their vehicles which documents their assertions.

Porsche commented that their passenger car footprint-based standard is the most stringent of any manufacturer and this, combined with their high baseline emissions level, means that it would need to reduce emissions by about 10 percent per year over the 2012–2016 time-frame. Porsche commented that such reductions were not feasible. They commented that their competitors will be able to continue to offer their full line of products because the competitors have a wider range of products with which to average. Porsche further commented that their product development cycles are longer than larger competitors. Porsche recommended for small limited line niche manufacturers that EPA require an annual 5 percent reduction in emissions from baseline up to a total reduction of 25 percent, or to modify the TLAAS program to require such reductions. Porsche noted that this percent reduction would be in line with the average emissions reductions required for larger manufacturers.

EPA also received comments from several very small volume manufacturers that, even with the TLAAS program, the proposed standards are not feasible for them, certainly not in the MY 2012–2016 MY time frame. These manufacturers included Aston Martin, McLaren, Lotus, and Ferrari. Their comments consistently focused on the need for separate, less stringent standards for small volume manufacturers. The manufacturers commented that they are willing to make progress in reducing emissions, but that separate, less-stringent small volume manufacturer standards are needed for them to remain in the U.S. market. The commenters note that their product line consists entirely of high end sports cars. Most of these manufacturers have only a few vehicle models, have annual sales on the order of a few hundred to a few thousand vehicles, and several have average baseline CO_2 emissions in excess of 500 g/mile—nearly twice the industry average. McLaren commented that its vehicle model to be introduced in MY 2011 will have class leading CO_2 performance but that it would not be able to offer the vehicle in the U.S. market because it does not have other vehicle models with which to average. Similarly, Aston Martin commented that it is of utmost importance that it is not required to reduce emissions significantly more than equivalent vehicles from larger manufacturers, which would render them uncompetitive due purely to the size of its business. Manufacturers also noted that they launch new products less frequently than larger manufacturers (*e.g.,* Ferrari noted that their production period for models is 7–8 years), and that suppliers serve large manufacturers first because they can buy in larger volumes. Some manufacturers also noted that they would be willing to purchase credits at a reasonable price, but they believed that credit availability from other manufacturers was highly unlikely due to the competitive nature of the auto industry. Several of these manufacturers provided confidential business information indicating their preliminary plans for reducing GHG emissions across their product lines through MY 2016 and beyond.

The Association of International Automobile Manufacturers (AIAM) also commented that, because of their essential features, vehicles produced by small volume manufacturers would not be able to meet the proposed greenhouse gas standards. AIAM commented that "while it is possible that these small volume manufacturers (SVMs) might be able to comply with greenhouse gas standards by purchasing credits from other manufacturers, this is far too speculative a solution. The market for credits is unpredictable at this point. Other than exiting the U.S. market, therefore, the only other possible solution for an independent SVM would be to sell an equity interest in the company to a larger, full-line manufacturer, so that the emissions of the luxury vehicles could be averaged in with the much larger volume of other vehicles produced by the major manufacturer. This cannot possibly be the outcome EPA intends, especially when measured against the minimal, if any, environmental benefit that would result." AIAM commented further that "there is ample legal authority for EPA to provide SVMs a more generous lead-time allowance or an alternative standard. Indeed, EPA recognizes such authority in the proposal for a small entity exemption (for those companies defined under the Small Business Administration's regulations), *see* 74 FR at 49574, and in the TLAAS. These provisions are consistent with previous EPA rulemaking under the Clean Air Act which offer relief to SVMs." AIAM recommended deferring standards for SVMs to a future rulemaking, providing EPA with adequate time to assess relevant product plans and technology feasibility information from SVMs, conduct the necessary reviews and modeling that may be needed, and consult with the stakeholders.

These commenters noted that standards for the smallest manufacturers were deferred in the California program until MY 2016 and that California's program would have established standards for small volume manufacturers in MY 2016 at a level that would be technologically feasible.

The commenters also suggested that California's approach is similar to the approach being taken by EPA for small business entities. Further, these commenters noted that in Tier 2 and other light-duty vehicle programs, EPA has allowed small volume manufacturers (SVMs) until the end of the phase-in period to comply with standards. The commenters recommended that EPA should defer standards for SVMs, and conduct a future rulemaking to establish appropriate standards for SVMs starting in model year 2016. Alternatively, some manufacturers recommended establishing much less stringent standards for SVMs as part of the current rulemaking.

In summary, the manufacturers commented that their range of products was insufficient to allow them to meet the standards in the time provided, even with the proposed TLAAS program. Many of these manufacturers have baseline emissions significantly higher than their larger-volume competitors, and thus the CO_2 reductions required from baseline under the program are larger for many of these companies than for other companies. Although they are investing substantial resources to reduce CO_2 emissions, they believe that they will not be able to achieve the standards under the proposed approach.

EPA also received comments urging us not to expand the TLAAS program. The commenters are concerned about the loss of benefits that would occur with any expansion.

EPA has considered the comments carefully and concludes that additional flexibility is needed for these companies. After assessing the issues raised by commenters, EPA believes there are two groups of manufacturers that need additional lead time. The first group includes manufacturers with annual U.S. sales of less than 5,000 vehicles per year. Standards for these small volume manufacturers are being deferred until a future rulemaking in the 2012 timeframe, as discussed in Section III.B.6, below. This will allow EPA to determine the appropriate level of standards for these manufacturers, as well as the small business entities, at a later time. The second group includes manufacturers with MY 2009 U.S. sales of less than 50,000 vehicles but above the 5,000 vehicle threshold being established for small volume manufacturers. EPA has selected a cut point of 50,000 vehicles in order to limit the additional flexibility to only the smaller manufacturers with much more limited product lines over which to average. EPA has tailored these provisions as narrowly as possible to provide additional lead time only as needed by these smaller manufacturers. We estimate that the TLAAS program, including the changes below will result in a total decrease in overall emissions reductions of about one percent of the total projected GHG program emission benefits. These estimates are provided in RIA Chapter 5 Appendix A.

For some of the companies, the reduction from baseline CO_2 emissions required to meet the standards is clearly greater than for other TLAAS-eligible manufacturers. Compared with other TLAAS-eligible manufacturers, these companies also have more limited fleets across which to average the standards. Some companies have only a few vehicle models all of a similar utility, and thus their averaging abilities are extremely limited posing lead time issues of greater severity than other TLAAS-eligible manufacturers. EPA's feasibility analysis provided in Section III.D., shows that these companies face a compliance shortfall significantly greater than other TLAAS companies (see Table III.D.6–4). This shortfall is primarily due to their narrow product lines and more limited ability to average across their vehicle fleets. In addition, with fewer models with which to average, there is a higher likelihood that phase-in requirements may conflict with normal product redesign cycles.

Therefore, for manufacturers with MY 2009 U.S. sales of less than 50,000 vehicles, EPA is finalizing additional TLAAS compliance flexibility through model year 2016. These manufacturers will be allowed to place up to 200,000 vehicles in the TLAAS program in MY 2012–2015 and an additional 50,000 vehicles in MY 2016. To be eligible for the additional allotment above the base TLAAS level of 100,000 vehicles, manufacturers must annually demonstrate that they have diligently made a good faith effort to purchase credits from other manufacturers in order to comply with the base TLAAS program, but that sufficient credits were not available. Manufacturers must secure credits to the extent they are reasonably available from other manufacturers to offset the difference between their emissions reductions obligations under the base TLAAS program and the expanded TLAAS program. Manufacturers must document their efforts to purchase credits as part of their end of year compliance report. All other aspects of the TLAAS program including the 1.25x adjustment to the standards and the credits provision restrictions remain the same as described above for the same reasons. This will still require the manufacturers to reduce emissions significantly in the 2012–2016 time-frame and to meet the final emissions standards in MY 2017. The standards remain very challenging for these manufacturers but these additional provisions will allow them the necessary lead time for implementing their strategy for compliance with the final, most stringent standards.

The eligibility limit of 50,000 vehicles will be treated in a similar way as the 400,000 vehicle eligibility limit is treated, as described above. Manufacturers with model year 2009 U.S. sales of less than 50,000 vehicles are eligible for the expanded TLAAS flexibility. Manufacturers whose sales grow in later years above 50,000 vehicles without merger or acquisition will continue to be eligible for the expanded TLAAS program. However, manufacturers that exceed the 50,000 vehicle limit through mergers or acquisitions will not be eligible for the expanded TLAAS program in the model year following the merger or acquisition, but may continue to be eligible for the base TLAAS program if the MY 2009 sales of the new company would have been below the 400,000 vehicle eligibility cut point. The use of TLAAS by all the entities within the company in years prior to the merger must be counted against the 100,000 vehicle limit of the base program. If the 100,000 vehicle limit has been exceeded, the company is no longer eligible for TLAAS.

6. Deferment of CO_2 Standards for Small Volume Manufacturers With Annual Sales Less Than 5,000 Vehicles

In the proposal, in the context of the TLAAS program, EPA recognized that there would be a wide range of companies within the eligible manufacturers with sales less than 400,000 vehicles in model year 2009. As noted in the proposal, some of these companies, while having relatively small U.S. sales volumes, are large global automotive firms, including companies such as Mercedes and Volkswagen. Other companies are significantly smaller niche firms, with sales volumes closer to 10,000 vehicles per year worldwide, such as Aston Martin. EPA anticipated that there is a small number of such smaller volume manufacturers, which may face greater challenges in meeting the standards due to their limited product lines across which to average. EPA requested comment on whether the proposed TLAAS program would provide sufficient lead-time for these smaller firms to incorporate the technology needed to comply with the proposed GHG standards. *See* 74 FR at 49524.

EPA received comments from several very small volume manufacturers that the TLAAS program would not provide sufficient lead time, as described above. EPA agrees with comments that the standards would be extremely challenging and potentially infeasible for these small volume manufacturers, absent credits from other manufacturers, and that credit availability at this point is highly uncertain—although these companies are planning to introduce significant GHG-reducing technologies to their product lines, they are still highly unlikely to meet the standards by MY 2016. Because the products produced by these manufacturers are so unique, these manufacturers were not included in EPA's OMEGA modeling assessment of the technology feasibility and costs to meet the proposed standards. As noted above, these manufacturers have only a few models and have very high baseline emissions. TLAAS manufacturers are projected to be required to reduce emissions by up to 39%, whereas SVMs in many cases would need to cut their emissions by more than half to comply with MY 2016 standards.

Given the unique feasibility issues raised for these manufacturers, EPA is deferring establishing CO_2 standards for manufacturers with U.S. sales of less than 5,000 vehicles.[188] This will provide EPA more time to consider the unique challenges faced by these manufacturers. EPA expects to conduct this rulemaking in the 2012 timeframe. The deferment only applies to CO_2 standards and SVMs must meet N_2O and CH_4 standards. EPA plans to set standards for these manufacturers as part of a future rulemaking in the next 18 months. This future rulemaking will allow EPA to fully examine the technologies and emissions levels of vehicles offered by small manufacturers and to determine the potential emissions control capabilities, costs, and necessary lead time. This timing may also allow a credits market to develop, so that EPA may consider the availability of credits during the rulemaking process. See *State of Mass.* v. *EPA,* 549 U.S. at 533 (EPA retains discretion as to timing of any regulations addressing vehicular GHG emissions under section 202(a)(1)). We expect that standards would begin to be implemented in the MY 2016 timeframe. This approach is consistent with that envisioned by California for these manufacturers. EPA estimates that eligible small volume manufacturers currently comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., and therefore the deferment will have a very small impact on the GHG emissions reductions from the standards.

In addition to the 5,000 vehicle per year cut point, to be eligible for deferment each year, manufacturers must also demonstrate due diligence in attempting to secure credits from other manufacturers. Manufacturers must make a good faith effort to secure credits to the extent they are reasonably available from other manufacturers to offset the difference between their baseline emissions and what their obligations would be under the TLAAS program starting in MY 2012.

Eligibility will be determined somewhat differently compared to the TLAAS program. Manufacturers with either MY 2008 or MY 2009 U.S. sales of less than 5,000 vehicles will be initially eligible. This includes "branded sales" for companies that sold vehicles under a larger manufacturer but has become independent by the end of calendar year 2010. EPA is including MY 2008 as well as MY 2009 because some manufacturers in this market segment have such limited sales that they often drop in and out of the market from year to year.

In determining eligibility, manufacturers must be aggregated according to the provisions of 40 CFR 86.1838–01(b)(3), which requires the sales of different firms to be aggregated in various situations, including where one firm has a 10% or more equity ownership of another firm, or where a third party has a 10% or more equity ownership of two or more firms. EPA received public comment from a manufacturer requesting that EPA should allow a manufacturer to apply to EPA to establish small volume manufacturer status based on the independence of its research, development, testing, design, and manufacturing from another firm that may have an ownership interest in that manufacturer. EPA has reviewed this comment, but is not finalizing such a provision at this time. EPA believes that this issue likely presents some competitive issues, which we would like to be fully considered through the public comment process. Therefore, EPA plans to consider this issue and seek public comments in our proposal for small volume manufacturer CO_2 standards, which we expect to complete within 18 months.

To remain eligible for the deferral from standards, the rolling average of three consecutive model years of sales must remain below 5,000 vehicles. EPA is establishing the 5,000 vehicle threshold to allow for some sales growth by SVMs, as SVMs typically have annual sales of below 2,000 vehicles. However, EPA wants to ensure that standards for as few vehicles as possible are deferred and therefore believes it is appropriate that manufacturers with U.S. sales growing to above 5,000 vehicles per year be required to comply with standards (including TLAAS, as applicable). Manufacturers with unusually strong sales in a given year would still likely remain eligible, based on the three year rolling average. However, if a manufacturer takes steps to expand in the U.S. market on a permanent basis such that they consistently sell more than 5,000 vehicles per year, they must meet the TLAAS standards. EPA believes a manufacturer will be able to consider these provisions, along with other factors, in its planning to significantly expand in the U.S. market.

For manufacturers exceeding the 5,000 vehicle rolling average through mergers or acquisitions of other manufacturers, those manufacturers will lose eligibility in the MY immediately following the last year of the rolling average. For manufacturers exceeding this level through sales growth, but remaining below a 50,000 vehicle threshold, the manufacturer will lose eligibility for the deferred standards in the second model year following the last year of the rolling average. For example, if the rolling average of MYs 2009–2011 exceeded 5,000 vehicles but was below 50,000 vehicles, the manufacturer would not be eligible for the deferred standards in MY 2013. For manufacturers with a 3-year rolling average exceeding 50,000 vehicles, the manufacturer would lose eligibility in the MY immediately following the last model year in the rolling average. For example, if the rolling average of MYs 2009–2011 exceeded 50,000 vehicles, the manufacturer would not be eligible for the deferred standards in MY 2012. Such manufacturers may continue to be eligible for TLAAS, or the expanded TLAAS program, per the provisions described above. EPA believes these provisions are needed to ensure that the SVM deferment remains targeted to true small volume manufacturers and does not become available to larger manufacturers through mergers or acquisitions. EPA is including the 50,000 vehicle criteria to differentiate between manufacturers that may slowly gain more sales and manufacturers that have taken major steps to significantly increase their presence in the U.S. market, such as by introducing new vehicle models. EPA believes manufacturers selling more than 50,000

[188] *See* final regulations at 40 CFR 86.1801–12(k).

vehicles should not be able to take advantage of the deferment, as they should be able to meet the applicable TLAAS standards through averaging across their larger product line.

EPA is requiring that potential SVMs submit a declaration to EPA containing a detailed written description of how the manufacturer qualifies as a small volume manufacturer. The declaration must contain eligibility information including MY 2008 and 2009 U.S. sales, the last three completed MYs sales information, detailed information regarding ownership relationships with other manufacturers, and documentation of efforts to purchase credits from other manufacturers. Because such manufacturers are not automatically exempted from other EPA regulations for light-duty vehicles and light-duty trucks, entities are subject to the greenhouse gas control requirements in this program until such a declaration has been submitted and approved by EPA. The declaration must be submitted annually at the time of vehicle emissions certification under the EPA Tier 2 program, beginning in MY 2012.

7. Nitrous Oxide and Methane Standards

In addition to fleet-average CO_2 standards, as proposed, EPA is establishing separate per-vehicle standards for nitrous oxide (N_2O) and methane (CH_4) emissions.[189] The agency's intention is to set emissions standards that act to cap emissions to ensure that future vehicles do not increase their N_2O and CH_4 emissions above levels typical of today's vehicles. EPA proposed to cap N_2O at a level of 0.010 g/mi and to cap CH_4 at a level of 0.03 g/mi. Both of these compounds are more potent contributors to global warming than CO_2; N_2O has a global warming potential, or GWP, of 298 and CH_4 has a GWP of 25.[190]

EPA received many comments on the proposed N_2O and CH_4 standards. A range of stakeholders supported the proposed approach of "cap" standards and the proposed emission levels, including most states and environmental organizations that addressed this topic, and the Manufacturers of Emissions Control Association. These commenters stated that EPA needs to address all mobile GHGs under the Clean Air Act, and N_2O and CH_4 are both more potent contributors to global warming than CO_2. The Center for Biological Diversity commented that in light of the potency of these GHGs, EPA should develop standards which reduce emissions over current levels and that EPA had not analyzed either the technologies or the costs of doing so. EPA discusses these comments and our responses below and in the Response to Comments Document.

Auto manufacturers generally did not support standards for these GHGs, stating that the levels of these GHGs from current vehicles are too small to warrant standards at this time. These commenters also stated that if EPA were to proceed with "cap" standards, the stringency of the proposed levels could restrict the introduction of some new technologies. Commenters specifically raised this concern with the examples of diesel and lean-burn gasoline for N_2O, or natural gas and ethanol fueled vehicles for CH_4. Only one manufacturer, Volkswagen, submitted actual test data to support these claims; very limited emission data on two concept vehicles—a CNG vehicle and a flexible-fuel vehicle—indicated measured emission levels near or above the proposed standards, but included no indication of whether any technological steps had been taken to reduce emissions below the cap levels. Many commenters support an approach of establishing a CO_2-equivalent standard, where N_2O and CH_4 could be averaged with CO_2 emissions to result in an overall CO_2-equivalent compliance value, similar to the approach California has used for its GHG standards [191] Under such an approach, the auto industry commenters supported using a default value for N_2O emissions in lieu of a measured test value. Several auto manufacturers also had concerns that a new requirement to measure N_2O would require significant equipment and facility upgrades and would create testing challenges with new measurement equipment with which they have little experience.

EPA has considered these comments and is finalizing the cap standards for N_2O and CH_4 as proposed. EPA agrees with the NGO, State, and other commenters that light-duty vehicle emissions are small but important contributors to the U.S. N_2O and CH_4 inventories, and that in the absence of a limitation, the potential for significant emission increases exists with the evolution of new vehicle and engine technologies. (Indeed, the industry commenters concede as much in stating that they are contemplating introducing vehicle technologies that could result in emissions exceeding the cap standard levels). EPA also believes that in most cases N_2O and CH_4 emissions from light-duty vehicles will remain well below the cap standards. Therefore, we are setting cap standards for these GHGs at the proposed levels. However, as described below, the agency is incorporating several provisions intended to address industry concerns about technological feasibility and leadtime, including an optional CO_2-equivalent approach and, for N_2O, more leadtime before testing will be required to demonstrate compliance with the emissions standard (in interim, manufacturers may certify based on a compliance statement based on good engineering judgment).

a. Nitrous Oxide (N_2O) Exhaust Emission Standard

As stated above, N_2O is a global warming gas with a high global warming potential.[192] It accounts for about 2.3% of the current greenhouse gas emissions from cars and light trucks.[193] EPA is setting a per-vehicle N_2O emission standard of 0.010 g/mi, measured over the traditional FTP vehicle laboratory test cycles. The standard will become effective in model year 2012 for all light-duty cars and trucks. The standard is designed to prevent increases in N_2O emissions from current levels; *i.e.,* it is a no-backsliding standard.

N_2O is emitted from gasoline and diesel vehicles mainly during specific catalyst temperature conditions conducive to N_2O formation. Specifically, N_2O can be generated during periods of emission hardware warm-up when rising catalyst temperatures pass through the temperature window when N_2O formation potential is possible. For current Tier 2 compatible gasoline engines with conventional three-way catalyst technology, N_2O is not generally produced in significant amounts because the time the catalyst spends at the critical temperatures during warm-up is short. This is largely due to the need to quickly reach the higher temperatures necessary for high catalyst efficiency to achieve emission compliance for criteria pollutants. As several auto manufacturer comments noted, N_2O is a more significant concern with diesel vehicles, and potentially future gasoline lean-burn engines, equipped with advanced catalytic NO_X

[189] *See* final regulations at 40 CFR 86.1818–12(f).

[190] The global warming potentials (GWP) used in this rule are consistent with the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4).

[191] California Environmental Protection Agency Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking Public Hearing To Consider Adoption of Regulations To Control Greenhouse Gas Emissions From Motor Vehicles, August 6, 2004.

[192] N_2O has a GWP of 298 according to the IPCC Fourth Assessment Report (AR4).

[193] *See* RIA Chapter 2.

emissions control systems. In the absence of N_2O emission standards, these systems could be designed in a way that emphasizes efficient NO_X control while at the same time allowing the formation of significant quantities of N_2O. Excess oxygen present in the exhaust during lean-burn conditions in diesel or lean-burn gasoline engines equipped with these advanced systems can favor N_2O formation if catalyst temperatures are not carefully controlled. Without specific attention to controlling N_2O emissions in the development of such new NO_X control systems, vehicles could have N_2O emissions many times greater than are emitted by current gasoline vehicles.

EPA is setting an N_2O emission standard that the agency believes will be met by current-technology gasoline vehicles at essentially no cost. As just noted, N_2O formation in current catalyst systems occurs, but the emission levels are relatively low, because the time the catalyst spends at the critical temperatures during warm-up when N_2O can form is short. At the same time, EPA believes that the standard will ensure that the design of advanced NO_X control systems, especially for future diesel and lean-burn gasoline vehicles, will control N_2O emission levels. While current NO_X control approaches used on current Tier 2 diesel vehicles do not tend to favor the formation of N_2O emissions, EPA believes that this N_2O standard will discourage new emission control designs that achieve criteria emissions compliance at the cost of increased N_2O emissions. Thus, the standard will cap N_2O emission levels, with the expectation that current gasoline and diesel vehicle control approaches that comply with the Tier 2 vehicle emission standards for NO_X will not increase their emission levels, and that the cap will ensure that future vehicle designs will be appropriately controlled for N_2O emissions.

The level of the N_2O standard is approximately two times the average N_2O level of current gasoline passenger cars and light-duty trucks that meet the Tier 2 NO_X standards. EPA has not previously regulated N_2O emissions, and available data on current vehicles is limited. However, EPA derived the standard from a combination of emission factor values used in modeling light duty vehicle emissions and limited recent EPA test data.[194] [195] Because the standard represents a level 100 percent higher than the average current N_2O level, we continue to believe that most if not all Tier 2 compliant gasoline and diesel vehicles will easily be able to meet the standards. Manufacturers typically use design targets for NO_X emission levels of about 50% of the standard, to account for in-use emissions deterioration and normal testing and production variability, and EPA expects that manufacturers will use a similar approach for N_2O emission compliance. EPA did not propose and is not finalizing a more stringent standard for current vehicles because we believe that the stringent Tier 2 program and the associated NO_X fleet average requirement already result in significant N_2O control, and the agency does not expect current N_2O levels to rise for these vehicles. Moreover, EPA believes that the CO_2 standards will be challenging for the industry and that these standards should be the industry's chief focus in this first phase of vehicular GHG emission controls. See *Massachusetts* v. *EPA,* 549 U.S. at 533 (EPA has significant discretion as to timing of GHG regulations); *see* also *Sierra Club* v. *EPA, 325 F. 3d 374, 379 (DC Cir. 2003)* (upholding anti-backsliding standards for air toxics under technology-forcing section 202 (l) because it is reasonable for EPA to assess the effects of its other regulations on the motor vehicle sector before aggressively regulating emissions of toxic vehicular air pollutants.

Diesel cars and light trucks with advanced emission control technology are in the early stages of development and commercialization. As this segment of the vehicle market develops, the N_2O standard will likely require these manufacturers to incorporate control strategies that minimize N_2O formation. Available approaches include using electronic controls to limit catalyst conditions that might favor N_2O formation and consider different catalyst formulations. While some of these approaches may have modest associated costs, EPA believes that they will be small compared to the overall costs of the advanced NO_X control technologies already required to meet Tier 2 standards.

In the proposal, EPA sought comment on an approach of expressing N_2O and CH_4 in common terms of CO_2-equivalent emissions and combining them into a single standard along with CO_2 emissions. 74 FR at 49524. California's "Pavley" program adopted such a CO_2-equivalent emissions standards approach to GHG emissions.[196] EPA was primarily concerned that such an approach could undermine the stringency of the CO_2 standards, as the proposed standards were designed to "cap" N_2O and CH_4 emissions, rather than reflecting a level either that is the industry fleet-wide average or that would effect reductions in these GHGs.

As noted above, several auto manufacturers expressed interest in such a CO_2-equivalent approach, due to concerns that the caps could be limiting for some advanced technology vehicles. While we continue to believe that the vast majority of light-duty vehicles will be able to easily meet the standards, we acknowledge that advanced diesel or lean-burn gasoline vehicles of the future may face slightly greater challenges. Therefore, after considering these comments, EPA is finalizing an optional compliance approach to provide flexibility for any advanced technologies that may have challenges in meeting the N_2O or CH_4 cap standards.

In lieu of complying with the separate N_2O and CH_4 cap standards, a manufacturer may choose to comply with a CO_2-equivalent standard. A manufacturer choosing this option will convert its N_2O and CH_4 test results (or, as described below, a default N_2O value for MY 2012–2014) into CO_2-equivalent values and add this sum to their CO_2 emissions. This CO_2-equivalent value will still need to comply with the manufacturer's footprint-based CO_2 target level. In other words, a manufacturer could offset any N_2O emissions (or any CH_4 emissions) by taking steps to further reduce CO_2. A manufacturer choosing this option will need to apply this approach to all of the test groups in its fleet. This approach is more environmentally protective overall than the cap standard approach, since the manufacturer will need to reduce its CO_2 emissions to offset the higher N_2O (or CH_4) levels, but will not be allowed to increase CO_2 above its footprint target level by reducing N_2O (or CH_4).

The compliance level in g/mi for the optional CO_2-equivalent approach for gasoline vehicles is calculated as $CO_2 + (CWF/0.273 \times NMHC) + (1.571 \times CO) + (298 \times N_2O) + (25 \times CH_4)$.[197] The N_2O and CH_4 values are the measured emission values for these GHGs, except N_2O in model years 2012 through 2014. For these model years, manufacturers may use a default N_2O value of 0.010

[194] Memo to docket "Derivation of Proposed N_2O and CH_4 Cap Standards," Tad Wysor, EPA, November 19, 2009. Docket EPA–HQ–OAR–2009–0472–6801.

[195] Memo to docket "EPA NVFEL N_2O Test Data," Tony Fernandez, EPA.

[196] California Environmental Protection Agency Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking Public Hearing To Consider Adoption of Regulations To Control Greenhouse Gas Emissions From Motor Vehicles, August 6, 2004.

[197] This equation will differ depending upon the fuel; see the final regulations for equations for other fuels.

g/mi, the same value as the N_2O cap standard. For MY 2015 and later, the manufacturer would need to provide actual test data on the emission data vehicle for each test group. (That is, N_2O data would not be required for each model type, since EPA believes that there will likely be little N_2O variability among model types within a test group.) EPA believes that its selection of 0.010 g/mi as the N_2O default value is an appropriately protective level, on the high end of current technologies, as further discussed below. Consistent with the other elements of the equation, N_2O and CH_4 must be included at full useful life deteriorated values. This requires testing using the highway test cycle in addition to the FTP during the manufacturer's deterioration factor (DF) development program. However, EPA recognizes that manufacturers may not be able to develop DFs for N_2O and CH_4 for all their vehicles in the 2012 model year, and thus EPA is allowing the use of alternative values through the 2014 model year. For N_2O the alternative value is the DF developed for NO_X emissions, and for CH_4 the alternative value is the DF developed for NMOG emissions. Finally, for manufacturers using this option, the CO_2-equivalent emission level would also be the basis for any credits that the manufacturer might generate.

Manufacturers expressed concerns about their ability to acquire and install N_2O analytical equipment. However, the agency continues to believe that such burdens, while not trivial, will also not be excessive. While many manufacturers do not appear to have invested yet in adding N_2O measurement equipment to their test facilities, EPA is not aware of any information to indicate that that suppliers will have difficulty providing sufficient hardware, or that such equipment is unusually expensive or complex compared to existing measurement hardware. EPA allows N_2O measurement using any of four methods, all of which are commercially available today. The costs of certification and other indirect costs of this rule are accounted for in the Indirect Cost Multipliers, discussed in Section III.H below.

Still, given the short lead-time for this rule and the newness of N_2O testing to this industry, EPA proposed that manufacturers be able to apply for a certificate of conformity with the N_2O standard for model year 2012 provided that they supply a compliance statement based on good engineering judgment. Under the proposal, beginning in MY 2013, manufacturers would have needed to base certification on actual N_2O testing data. This approach was intended to reasonably ensure that the emission standards are being met, while allowing manufacturers lead-time to purchase new N_2O emissions measurement equipment, modify certification test facilities, and begin N_2O testing. After consideration of the comments, EPA agrees with manufacturers that one year of additional lead-time to begin actual N_2O measurement across their vehicle fleets may still be insufficient for manufacturers to efficiently make the necessary facility changes and equipment purchases. Therefore, EPA is extending the ability to certify based on a compliance statement for two additional years, through model year 2014. For 2015 and later model years, manufacturers will need to submit measurements of N_2O for compliance purposes.

b. Methane (CH_4) Exhaust Emission Standard

Methane (CH_4) is a greenhouse gas with a high global warming potential.[198] It accounts for about 0.2% of the greenhouse gases from cars and light trucks.[199]

EPA is setting a CH_4 emission standard of 0.030 g/mi as measured on the FTP, to apply beginning with model year 2012 for both cars and trucks. EPA believes that this level for the standard will be met by current gasoline and diesel vehicles, and will prevent large increases in future CH_4 emissions. This is particularly a concern in the event that alternative fueled vehicles with high methane emissions, like some past dedicated compressed natural gas (CNG) vehicles and some flexible-fueled vehicles when operated on E85 fuel, become a significant part of the vehicle fleet. Currently EPA does not have separate CH_4 standards because unlike other hydrocarbons it does not contribute significantly to ozone formation.[200] However, CH_4 emissions levels in the gasoline and diesel car and light truck fleet have nevertheless generally been controlled by the Tier 2 standards for non-methane organic gases (NMOG). However, without an emission standard for CH_4, there is no guarantee that future emission levels of CH_4 will remain at current levels as vehicle technologies and fuels evolve.

The standard will cap CH_4 emission levels, with the expectation that emissions levels of current gasoline and diesel vehicles meeting the Tier 2 emission standards will not increase. The level of the standard will generally be achievable for typical vehicles through normal emission control methods already required to meet the Tier 2 emission standards for NMOG. Also, since CH_4 is already measured under the current Tier 2 regulations (so that it may be subtracted to calculate non-methane hydrocarbons), we believe that the standard will not result in any additional testing costs. Therefore, EPA is not attributing any costs to this part of this program. Since CH_4 is produced during fuel combustion in gasoline and diesel engines similarly to other hydrocarbon components, controls targeted at reducing overall NMOG levels are generally also effective in reducing CH_4 emissions. Therefore, for typical gasoline and diesel vehicles, manufacturer strategies to comply with the Tier 2 NMOG standards have to date tended to prevent increases in CH_4 emissions levels. The CH_4 standard will ensure that emissions will be addressed if in the future there are increases in the use of natural gas or other alternative fuels or technologies that may result in higher CH_4 emissions.

As with the N_2O standard, EPA is setting the level of the CH_4 standard to be approximately two times the level of average CH_4 emissions from Tier 2 gasoline passenger cars and light-duty trucks. EPA believes the standard will easily be met by current gasoline vehicles, and that flexible fuel vehicles operating on ethanol can be designed to resolve any potential CH_4 emissions concerns. Similarly, since current diesel vehicles generally have even lower CH_4 emissions than gasoline vehicles, EPA believes that diesels will also meet the CH_4 standard. However, EPA also believes that to set a CH_4 emission standard more stringent than the proposed standard could effectively make the Tier 2 NMOG standard more stringent and is inappropriate for that reason (and untimely as well, given the challenge of meeting the CO_2 standards, as noted above).

Some CNG-fueled vehicles have historically produced significantly higher CH_4 emissions than gasoline or diesel vehicles. This is because CNG fuel is essentially methane and any unburned fuel that escapes combustion and is not oxidized by the catalyst is emitted as methane. However, in recent model years, the few dedicated CNG vehicles sold in the U.S. meeting the Tier 2 standards have had CH_4 control as effective as that of gasoline or diesel vehicles. Still, even if these vehicles meet the Tier 2 NMOG standard and appear to have effective CH_4 control by

[198] CH_4 has a GWP of 25 according to the IPCC Fourth Assessment Report (AR4).

[199] *See* RIA Chapter 2.

[200] But *see Ford Motor Co.* v. *EPA,* 604 F. 2d 685 (D.C. Cir. 1979) (permissible for EPA to regulate CH_4 under CAA section 202(b)).

nature of the NMOG controls, Tier 2 standards do not require CH_4 control. Although EPA believes that in most cases that the CH_4 cap standard should not require any different emission control designs beyond what is already required to meet Tier 2 NMOG standards on a dedicated CNG vehicle, the cap will ensure that systems maintain the current level of CH_4 control.

Some manufacturers have also expressed some concerns about CH_4 emissions from flexible-fueled vehicles operating on E85 (85% ethanol, 15% gasoline). However, we are not aware of any information that would indicate that if engine-out CH_4 proves to be higher than for a typical gasoline vehicle, that such emissions could not be managed by reasonably available control strategies (perhaps similar to those used in dedicated CNG vehicles).

As described above, in response to the comments, EPA will also allow manufacturers to choose to comply with a CO_2-equivalent standard in lieu of complying with a separate CH_4 cap standard. A manufacturer choosing this option would convert its N_2O and CH_4 test results into CO_2-equivalent values (using the respective GWP values), and would then compare this value to the manufacturer's footprint-based CO_2 target level to determine compliance. However, as with N_2O, this approach will not permit a manufacturer to increase its CO_2 by reducing CH_4; the company's footprint-based CO_2 target level would remain the same.

8. Small Entity Exemption

As proposed, EPA is exempting from GHG emissions standards small entities meeting the Small Business Administration (SBA) size criteria of a small business as described in 13 CFR 121.201.[201] EPA will instead consider appropriate GHG standards for these entities as part of a future regulatory action. This includes both U.S.-based and foreign small entities in three distinct categories of businesses for light-duty vehicles: small volume manufacturers, independent commercial importers (ICIs), and alternative fuel vehicle converters.

EPA has identified about 13 entities that fit the Small Business Administration (SBA) size criterion of a small business. EPA estimates there currently are approximately two small volume manufacturers, eight ICIs, and three alternative fuel vehicle converters in the light-duty vehicle market. Further detail is provided in Section III.I.3, below. EPA estimates that these small entities comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., and therefore the exemption will have a negligible impact on the GHG emissions reductions from the standards.

To ensure that EPA is aware of which companies would be exempt, EPA proposed to require that such entities submit a declaration to EPA containing a detailed written description of how that manufacturer qualifies as a small entity under the provisions of 13 CFR 121.201. EPA has reconsidered the need for this additional submission under the regulations and is deleting it as not necessary. We already have information on the limited number of small entities that we expect would receive the benefits of the exemption, and do not need the proposed regulatory requirement to be able to effectively implement this exemption for those parties who in fact meet its terms. Small entities are currently covered by a number of EPA motor vehicle emission regulations, and they routinely submit information and data on an annual basis as part of their compliance responsibilities.

EPA did not receive adverse comments regarding the proposed small entity exemption. EPA received comments concerning whether or not the small entity exemption applies to foreign manufacturers. EPA clarifies that foreign manufacturers meeting the SBA size criteria are eligible for the exemption, as was EPA's intent during the proposal.

C. Additional Credit Opportunities for CO_2 Fleet Average Program

The final standards represent a significant multi-year challenge for manufacturers, especially in the early years of the program. Section III.B.4 above describes EPA's provisions for manufacturers to be able to generate credits by achieving fleet average CO_2 emissions below their fleet average standard, and also how manufacturers can use credits to comply with the standards. As described in Section III.B.4, credits can be carried forward five years, carried back three years, transferred between vehicle categories, and traded between manufacturers. The credits provisions described below provide manufacturers with additional ways to earn credits starting in MY 2012. EPA is also including early credits provisions for the 2009–2011 model years, as described below in Section III.C.5.

The provisions described below provide additional flexibility, especially in the early years of the program. This helps to address issues of lead-time or technical feasibility for various manufacturers and in several cases provides an incentive for promotion of technology pathways that warrant further development. EPA is finalizing a variety of credit opportunities because manufacturers are not likely to be in a position to use every credit provision. EPA expects that manufacturers are likely to select the credit opportunities that best fit their future plans.

EPA believes it is critical that manufacturers have options to ease the transition to the final MY 2016 standards. At the same time, EPA believes these credit programs must be and are designed in a way to ensure that they achieve emission reductions that achieve real-world reductions over the full useful life of the vehicle (or, in the case of FFV credits and Advanced Technology incentives, to incentivize the introduction of those vehicle technologies) and are verifiable. In addition, EPA believes that these credit programs do not provide an opportunity for manufacturers to earn "windfall" credits. Comments on the proposed EPA credit programs are summarized below along with EPA's response, and are detailed in the Response to Comments document.

1. Air Conditioning Related Credits

Manufacturers will be able to generate and use credits for improved air conditioner (A/C) systems in complying with the CO_2 fleetwide average standards described above (or otherwise to be able to bank or trade the credits). EPA expects that most manufacturers will choose to utilize the A/C provisions as part of its compliance demonstration (and for this reason cost of compliance with A/C related emission reductions are assumed in the cost analysis). The A/C provisions are structured as credits, unlike the CO_2 standards for which manufacturers will demonstrate compliance using 2-cycle (city/highway) tests (see Sections III.B and III.E.). Those tests do not measure either A/C leakage or tailpipe CO_2 emissions attributable to A/C load. Thus, it is a manufacturer's option to include A/C GHG emission reductions as an aspect of its compliance demonstration. Since this is an elective alternative, EPA is referring to the A/C part of the rule as a credit.

EPA estimates that direct A/C GHG emissions—emissions due to the leakage of the hydrofluorocarbon refrigerant in common use today—account for 5.1% of CO_2-equivalent GHGs from light-duty cars and trucks. This includes the direct leakage of refrigerant as well as the subsequent leakage associated with maintenance and servicing, and with disposal at the end of the vehicle's life.

[201] *See* final regulations at 40 CFR 86.1801–12(j).

The emissions that are associated with leakage reductions are the direct leakage and the leakage associated with maintenance and servicing. Together these are equivalent to CO_2 emissions of approximately 13.6 g/mi per car and light-truck. EPA also estimates that indirect GHG emissions (additional CO_2 emitted due to the load of the A/C system on the engine) account for another 3.9% of light-duty GHG emissions.[202] This is equivalent to CO_2 emissions of approximately 14.2 g/mi per vehicle. The derivation of these figures can be found in Chapter 2.2 of the EPA RIA.

EPA believes that it is important to address A/C direct and indirect emissions because the technologies that manufacturers will employ to reduce vehicle exhaust CO_2 will have little or no impact on A/C related emissions. Without addressing A/C related emissions, as vehicles become more efficient, the A/C related contribution will become a much larger portion of the overall vehicle GHG emissions.

Over 95% of the new cars and light trucks in the United States are equipped with A/C systems and, as noted, there are two mechanisms by which A/C systems contribute to the emissions of greenhouse gases: Through leakage of refrigerant into the atmosphere and through the consumption of fuel to provide mechanical power to the A/C system. With leakage, it is the high global warming potential (GWP) of the current automotive refrigerant (HFC–134a, with a GWP of 1430) that results in the CO_2-equivalent impact of 13.6 g/mi.[203] Due to the high GWP of this HFC, a small leakage of the refrigerant has a much greater global warming impact than a similar amount of emissions of CO_2 or other mobile source GHGs. Manufacturers can reduce A/C leakage emissions by using leak-tight components. Also, manufacturers can largely eliminate the global warming impact of leakage emissions by adopting systems that use an alternative, low-GWP refrigerant, as discussed below.[204] The A/C system also contributes to increased CO_2 emissions through the additional work required to operate the compressor, fans, and blowers. This additional work typically is provided through the engine's crankshaft, and delivered via belt drive to the alternator (which provides electric energy for powering the fans and blowers) and the A/C compressor (which pressurizes the refrigerant during A/C operation). The additional fuel used to supply the power through the crankshaft necessary to operate the A/C system is converted into CO_2 by the engine during combustion. This incremental CO_2 produced from A/C operation can thus be reduced by increasing the overall efficiency of the vehicle's A/C system, which in turn will reduce the additional load on the engine from A/C operation.[205]

Manufacturers can make very feasible improvements to their A/C systems to address A/C system leakage and efficiency. EPA is finalizing two separate credit approaches to address leakage reductions and efficiency improvements independently. A leakage reduction credit will take into account the various technologies that could be used to reduce the GHG impact of refrigerant leakage, including the use of an alternative refrigerant with a lower GWP. An efficiency improvement credit will account for the various types of hardware and control of that hardware available to increase the A/C system efficiency. For purposes of use of A/C credits at certification, manufacturers will be required to attest to the durability of the leakage reduction and the efficiency improvement technologies over the full useful life of the vehicle.

EPA believes that both reducing A/C system leakage and increasing efficiency are highly cost-effective and technologically feasible. EPA expects most manufacturers will choose to use these A/C credit provisions, although some may not find it necessary to do so.

a. A/C Leakage Credits

The refrigerant used in vehicle A/C systems can get into the atmosphere by many different means. These refrigerant emissions occur from the slow leakage over time that all closed high pressure systems will experience. Refrigerant loss occurs from permeation through hoses and leakage at connectors and other parts where the containment of the system is compromised. The rate of leakage can increase due to deterioration of parts and connections as well. In addition, there are emissions that occur during accidents and maintenance and servicing events. Finally, there are end-of-life emissions if, at the time of vehicle scrappage, refrigerant is not fully recovered.

Because the process of refrigerant leakage has similar root causes as those that cause fuel evaporative emissions from the fuel system, some of the emission control technologies are similar (including hose materials and connections). There are, however, some fundamental differences between the systems that require a different approach, both to controlling and to documenting that control. The most notable difference is that A/C systems are completely closed systems and always under significant pressure, whereas the fuel system is not. Fuel systems are meant to be refilled as liquid fuel is consumed by the engine, while the A/C system ideally should never require "recharging" of the contained refrigerant. Thus it is critical that the A/C system leakages be kept to an absolute minimum. As a result, these emissions are typically too low to accurately measure in most current SHED chambers designed for fuel evaporative emissions measurement, especially for A/C systems that are new or early in life.

A few commenters suggested that we allow manufacturers, as an option, to use an industry-developed "mini-shed" test procedure (SAE J2763—Test Procedure for Determining Refrigerant Emissions from Mobile Air Conditioning Systems) to measure and report annual refrigerant leakage.[206] However, while EPA generally prefers performance testing, for an individual vehicle A/C system or component, there is not a strong inherent correlation between a performance test using SAE J2763 and the design-based approach we are adopting (based on SAE J2727, as discussed below).[207] Establishing such a correlation would require testing of a fairly broad range of current-technology systems in order to establish the effects of such factors as production variability and assembly practices (which are included in J2727 scores, but not in J2763 measurements). To EPA's knowledge, such a correlation study has not been done. At the same time, as discussed below, there are indications that much of the industry will eventually be moving toward alternative refrigerants with very low GWPs. EPA believes such a transition would diminish the value of any correlation

[202] *See* Chapter 2, Section 2.2.1.2 of the RIA.

[203] The global warming potentials (GWP) used in this rule are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). (At this time, the IPCC Second Assessment Report (SAR) GWP values are used in the official U.S. greenhouse gas inventory submission to the climate change framework.)

[204] Refrigerant emissions during maintenance and at the end of the vehicle's life (as well as emissions during the initial charging of the system with refrigerant) are also addressed by the CAA Title VI stratospheric ozone program, as described below.

[205] We chose not to address changes to the weight of the A/C system, since the issue of CO_2 emissions from the fuel consumption of normal (non-A/C) operation, including basic vehicle weight, is inherently addressed by the primary CO_2 standards (Section III.B above).

[206] Honeywell and Volvo supported this view; most other commenters did not.

[207] However, there is a correlation in the fleet between J2763 measurements and J2727 scores.

studies that might be done to confirm the appropriateness of the SAE J2763 procedure as an option in this rule. For these reasons, EPA is therefore not adopting such an optional direct measurement approach to addressing refrigerant leakage at this time.

Instead, as proposed, EPA is adopting a design-based method for manufacturers to demonstrate improvements in their A/C systems and components.[208] Manufacturers implementing system designs expected to result in reduced refrigerant leakage will be eligible for credits that could then be used to meet their CO_2 emission compliance requirements (or otherwise banked or traded). The A/C Leakage Credit provisions will generally assign larger credits to system designs that would result in greater leakage reductions. In addition, proportionately larger A/C Leakage Credits will be available to manufacturers that substitute a refrigerant with lower GWP than the current HFC–134a refrigerant.

Our method for calculating A/C Leakage Credits is based closely on an industry-consensus leakage scoring method, described below. This leakage scoring method is correlated to experimentally-measured leakage rates from a number of vehicles using the different available A/C components. Under the approach, manufacturers will choose from a menu of A/C equipment and components used in their vehicles in order to establish leakage scores which will characterize their A/C system leakage performance. Credits will be generated from leakage reduction improvements that exceed average fleetwide leakage rates.

EPA believes that the design-based approach will result in estimates of leakage emissions reductions that will be comparable to those that will eventually result from performance-based testing. We believe that this method appropriately approximates the real-world leakage rates for the expected MY 2012–2016 A/C systems.

The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program[209] has demonstrated that new-vehicle leakage emissions can be reduced by 50%. This program has shown that this level of improvement can be accomplished by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system. All of these technologies are already in commercial use and exist on some of today's systems.

As proposed, a manufacturer wishing to generate A/C Leakage Credits will compare the components of its A/C system with a set of leakage-reduction technologies and actions based closely on that developed through IMAC and the Society of Automotive Engineers (as SAE Surface Vehicle Standard J2727, August 2008 version). The J2727 approach was developed from laboratory testing of a variety of A/C related components, and EPA believes that the J2727 leakage scoring system generally represents a reasonable correlation with average real-world leakage in new vehicles. The EPA credit approach addresses the same A/C components as does SAE J2727 and associates each component with the same gram-per-year leakage rate as the SAE method, although, as described below, EPA limits the credits allowed and also modifies it for other factors such as alternative refrigerants.

A manufacturer choosing to generate A/C Leakage Credits will sum the leakage values for an A/C system for a total A/C leakage score according to the following formula. Because the primary GHG program standards are expressed in terms of vehicle exhaust CO_2 emissions as measured in grams per mile, the credits programs adopted in this rule, including A/C related credits, must ultimately be converted to a common metric for proper calculation of credits toward compliance with the primary vehicle standards. This formula describes the conversion of the grams-per-year leakage score to a grams-per-mile CO_2eq value, taking vehicle miles traveled (VMT) and the GWP of the refrigerant into account:

$$\text{A/C Leakage Credit} = (\text{MaxCredit}) * [1 - (\text{LeakScore}/\text{AvgImpact}) * (\text{GWPRefrigerant}/1430)]$$

Where:

MaxCredit is 12.6 and 15.6 g/mi CO_2eq for cars and trucks, respectively. These values become 13.8 and 17.2 for cars and trucks, respectively, if low-GWP refrigerants are used, since this would generate additional credits from reducing emissions during maintenance events, accidents, and at end-of-life.

LeakScore is the leakage score of the A/C system as measured according to the EPA leakage method (based on the J2727 procedure, as discussed above) in units of g/yr. The minimum score that EPA considers feasible is fixed at 8.3 and 10.4 g/yr for cars and trucks respectively (4.1 and 5.2 g/yr for systems using electric A/C compressors) as discussed below.

Avg Impact is the average current A/C leakage emission rate, which is 16.6 and 20.7 g/yr for cars and trucks, respectively.

GWPRefrigerant is the global warming potential (GWP) for direct radiative forcing of the refrigerant. For purposes of this rule, the GWP of HFC–134a is 1430, the GWP of HFC–152a is 124, the GWP of HFO–1234yf is 4, and the GWP of CO_2 as a refrigerant is 1.

The EPA Final RIA elaborates further on the development of each of the values incorporated in the A/C Leakage Credit formula above, as summarized here. First, as proposed, EPA estimates that leakage emission rates for systems using the current refrigerant (HFC–134a) could be feasibly reduced to rates no less than 50% of current rates—or 8.3 and 10.4 g/yr for cars and trucks, respectively—based on the conclusions of the IMAC study as well as consideration of refrigerant emissions over the full life of the vehicle.

Also, some commenters noted that A/C compressors powered by electric motors (*e.g.* as used today in several hybrid vehicle models) were not included in the IMAC study and yet allow for leakage emission rate reductions beyond EPA's estimates for systems with conventional belt-driven compressors. EPA agrees with these comments, and we have incorporated lower minimum emission rates into the formula above—4.1 and 5.2 g/yr for cars and trucks, respectively—in order to allow additional leakage reduction credits for vehicles that use sealed electric A/C compressors. The maximum available credits for these two approaches are summarized in Table III.C.1–1 below.

AIAM commented that EPA should not set a lower limit on the leakage score, even for non-electric compressors. EPA has determined not to do so. First, although there do exist vehicles in the Minnesota data with lower scores than our proposed (and now final) minimum scores, there are very few car models that have scores less than 8.3, and these range from 7.0 to about 8.0 and the difference are small compared to our minimum score.[210] More important, lowering the leakage limit would necessarily increase credit opportunities for equipment design changes, and EPA believes that these changes could discourage the environmentally optimal result of using low GWP refrigerants. Introduction of low GWP refrigerants could be discouraged because it may be less costly to reduce leakage than to replace many of the A/C system components. Moreover, due to the likelihood of in-use factors, even a leakless (according to

[208] *See* final regulations at 40 CFR 86.1866–12(b).

[209] Team 1–Refrigerant Leakage Reduction: Final Report to Sponsors, SAE, 2007.

[210] The Minnesota refrigerant leakage data can be found at *http://www.pca.state.mn.us/climatechange/mobileair.html#leakdata.*

J2727) R134a system will have some emissions due to manufacturing variability, accidents, deterioration, maintenance, and end of life emissions, a further reason to cap the amount of credits available through equipment design. The only way to guarantee a near zero emission system in-use is to use a low GWP refrigerant. The EPA has therefore decided for the purposes of this final rule to not change the minimum score for belt driven compressors due to the reason cited above and to the otherwise overwhelming support for the program as proposed from commenters.

In addition, as discussed above, EPA recognizes that substituting a refrigerant with a significantly lower GWP will be a very effective way to reduce the impact of all forms of refrigerant emissions, including maintenance, accidents, and vehicle scrappage. To address future GHG regulations in Europe and California, systems using alternative refrigerants—including HFO1234yf, with a GWP of 4 and CO_2 with a GWP of 1—are under serious development and have been demonstrated in prototypes by A/C component suppliers. The European Union has enacted regulations phasing in alternative refrigerants with GWP less than 150 starting this year, and the State of California proposed providing credits for alternative refrigerant use in its GHG rule. Within the timeframe of MYs 2012–2016, EPA is not expecting widespread use of low-GWP refrigerants. However, EPA believes that these developments are promising, and, as proposed, has included in the A/C Leakage Credit formula above a factor to account for the effective GHG reductions that could be expected from refrigerant substitution. The A/C Leakage Credits that will be available will be a function of the GWP of the alternative refrigerant, with the largest credits being available for refrigerants with GWPs at or approaching a value of 1. For a hypothetical alternative refrigerant with a GWP of 1 (*e.g.,* CO_2 as a refrigerant), effectively eliminating leakage as a GHG concern, our credit calculation method could result in maximum credits equal to total average emissions, or credits of 13.8 and 17.2 g/mi CO_2eq for cars and trucks, respectively, as incorporated into the A/C Leakage Credit formula above as the "MaxCredit" term.

Table III.C.1–1 summarizes the maximum A/C leakage credits available to a manufacturer, according to the formula above.

TABLE III.C.1–1—MAXIMUM LEAKAGE CREDIT AVAILABLE TO MANUFACTURERS

	Car (g/mi)	Truck (g/mi)
R–134a refrigerant with belt-driven compressor	6.3	7.8
R–134a refrigerant with electric motor-driven compressor	9.5	11.7
Lowest-GWP refrigerant (GWP=1)	13.8	17.2

It is possible that alternative refrigerants could, without compensating action by the manufacturer, reduce the efficiency of the A/C system (see related discussion of the A/C Efficiency Credit below.) However, as noted at proposal and discussed further in the following section, EPA believes that manufacturers will have substantial incentives to design their systems to maintain the efficiency of the A/C system. Therefore EPA is not accounting for any potential efficiency degradation due to the use of alternative refrigerants.

Beyond the comments mentioned above, commenters generally supported or were silent about EPA's refrigerant leakage methodology (as based on SAE J2727), including the maximum leakage credits available, the technologies eligible for credit and their associated leakage reduction values, and the potential for alternative refrigerants. All comments related to A/C credits are addressed in the Response to Comments Document.

b. A/C Efficiency Credits

Manufacturers that make improvements in their A/C systems to increase efficiency and thus reduce CO_2 emissions due to A/C system operation may be eligible for A/C Efficiency Credits. As with A/C Leakage Credits, manufacturers could apply A/C Efficiency Credits toward compliance with their overall CO_2 standards (or otherwise bank and trade the credits).

As mentioned above, EPA estimates that the CO_2 emissions due to A/C related loads on the engine account for approximately 3.9% of total greenhouse gas emissions from passenger vehicles in the United States. Usage of A/C systems is inherently higher in hotter and more humid months and climates; however, vehicle owners may use their A/C systems all year round in all parts of the nation. For example, people commonly use A/C systems to cool and dehumidify the cabin air for passenger comfort on hot humid days, but they also use the systems to de-humidify cabin air to assist in defogging/de-icing the front windshield and side glass in cooler weather conditions for improved visibility. A more detailed discussion of seasonal and geographical A/C usage rates can be found in the RIA.

Most of the additional load on the engine from A/C system operation comes from the compressor, which pumps the refrigerant around the system loop. Significant additional load on the engine may also come from electric or hydraulic fans, which are used to move air across the condenser, and from the electric blower, which is used to move air across the evaporator and into the cabin. Manufacturers have several currently-existing technology options for improving efficiency, including more efficient compressors, fans, and motors, and system controls that avoid over-chilling the air (and subsequently re-heating it to provide the desired air temperature with an associated loss of efficiency). For vehicles equipped with automatic climate-control systems, real-time adjustment of several aspects of the overall system (such as engaging the full capacity of the cooling system only when it is needed, and maximizing the use of recirculated air) can result in improved efficiency. Table III.C.1–2 below lists some of these technologies and their respective efficiency improvements.

As discussed in the proposal, EPA is adopting a design-based "menu" approach for estimating efficiency improvements and, thus, quantifying A/C Efficiency Credits.[211] However, EPA's ultimate preference is performance-based standards and credit mechanisms (*i.e.,* using actual measurements) as typically providing a more accurate measure of performance. However, EPA has concluded that a practical, performance-based procedure for the purpose of accurately quantifying A/C-related CO_2 emission reductions, and thus efficiency improvements for assigning credits, is not yet available. Still, EPA is introducing a new specialized performance-based test for the more limited purpose of demonstrating that

[211] *See* final regulations at 40 CFR 86.1866–12(c).

actual efficiency improvements are being achieved by the design improvements for which a manufacturer is seeking A/C credits. As discussed below, beginning in MY 2014, manufacturers wishing to generate A/C Efficiency Credits will need to show improvement on the new A/C Idle Test in order to then use the "menu" approach to quantify the number of credits attributable to those improvements.

In response to comments concerning the applicability and effectiveness of technologies that were or were not included in our analysis, we have made several changes to the design-based menu.[212] First, we have separated the credit available for 'recirculated air' [213] technologies into those with closed-loop control of the air supply and those with open-loop control. By "closed-loop" control, we mean a system that uses feedback from a sensor, or sensors, (*e.g.,* humidity, glass fogging, CO_2, etc.) to actively control the interior air quality. For those systems that use "open-loop" control of the air supply, we project that since this approach cannot precisely adjust to varying ambient humidity or passenger respiration levels, the relative effectiveness will be less than that for systems using closed-loop control.

Second, many commenters indicated that the electronic expansion valve, or EXV, should not be included in the menu of technologies, as its effectiveness may not be as high as we projected. Commenters noted that the SAE IMAC report stated efficiency improvements for an EXV used in conjunction with a more efficient compressor, and not as a stand alone technology and that no manufacturers are considering this technology for their products within the timeframe of this rulemaking. We believe other technologies (improved compressor controls for example) can achieve the same benefit as an EXV, without the need for this unique component, and therefore are not adopting it as an option in the design menu of efficiency-improving A/C technologies.

Third, many commenters requested that an internal heat exchanger, or IHX, be added to the design menu. EPA initially considered adding this technology, but in our initial review of studies on this component, we had understood that the value of the technology is limited to systems using the alternative refrigerant HFO–1234yf. Some manufacturers, however, commented that an IHX can also be used with systems using the current refrigerant HFC–134a to improve efficiency, and that they plan on implementing this technology as part their strategy to improve A/C efficiency. Based on these comments, and projections in a more recent SAE Technical Paper, we project that an IHX in a conventional HFC–134a system can improve system efficiency by 20%, resulting in a credit of 1.1 g/mi.[214] Further discussion of IHX technology can be found in the RIA.

Fourth, we have modified the definition of 'improved evaporators and condensers' to recognize that improved versions of these heat exchangers may be used separately or in conjunction with one another, and that an engineering analysis must indicate a COP improvement of 10% or better when using either or both components (and not a 10% COP improvement for each component). Furthermore, we have modified the regulation text to clarify what is considered to be the 'baseline' components for this analysis. We consider the baseline component to be the version which a manufacturer most recently had in production on the same vehicle or a vehicle in a similar EPA vehicle classification. The dimensional characteristics (*e.g.* tube configuration/thickness/spacing, and fin density) of the baseline components are then compared to the new components, and an engineering analysis is required to demonstrate the COP improvement.

For model years 2012 and 2013, a manufacturer wishing to generate A/C Efficiency Credits for a group of its vehicles with similar A/C systems will compare several of its vehicle A/C-related components and systems with a list of efficiency-related technology improvements (see Table III.C.1–2 below). Based on the technologies the manufacturer chooses, an A/C Efficiency Credit value will be established. This design-based approach will recognize the relationships and synergies among efficiency-related technologies. Manufacturers could receive credits based on the technologies they chose to incorporate in their A/C systems and the associated credit value for each technology. The total A/C Efficiency Credit will be the total of these values, up to a maximum allowable credit of 5.7 g/mi CO_2eq. This will be the maximum improvement from current average efficiencies for A/C systems (see the RIA for a full discussion of our derivation of the reductions and credit values for individual technologies and for the maximum total credit available). Although the total of the individual technology credit values may exceed 5.7 g/mi CO_2eq, synergies among the technologies mean that the values are not additive. A/C Efficiency Credits as adopted may not exceed 5.7 g/mi CO_2eq.

TABLE III.C.1–2—EFFICIENCY-IMPROVING A/C TECHNOLOGIES AND CREDITS

Technology description	Estimated reduction in A/C CO_2 emissions (%)	A/C efficiency credit (g/mi CO_2)
Reduced reheat, with externally-controlled, variable-displacement compressor	30	1.7
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable-displacement compressor	20	1.1
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30	1.7
Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature 75 F or higher lower temperatures are allowed	20	1.1
Blower motor controls which limit wasted electrical energy (*e.g.,* pulse width modulated power controller)	15	0.9
Internal heat exchanger	20	1.1
Improved condensers and/or evaporators (with system analysis on the component(s) indicating a COP improvement greater than 10%, when compared to previous industry standard designs)	20	1.1

[212] Commenters included the Alliance of Automobile Manufacturers, Jaguar Land Rover, Denso, and the Motor and Equipment Manufacturers Association, among others.

[213] Recirculated air is defined as air present in the passenger compartment of the vehicle (versus outside air) available for the A/C system to cool or condition.

[214] Mathur, Gursaran D., "Experimental Investigation with Cross Fluted Double-Pipe Suction Line Heat Exchanger to Enhance A/C System Performance," SAE 2009–01–0970, 2009.

TABLE III.C.1–2—EFFICIENCY-IMPROVING A/C TECHNOLOGIES AND CREDITS—Continued

Technology description	Estimated reduction in A/C CO_2 emissions (%)	A/C efficiency credit (g/mi CO_2)
Oil separator (with engineering analysis demonstrating effectiveness relative to the baseline design)	10	0.6

The proposal requested comment on adjusting the efficiency credit for alternative refrigerants. Although a few commenters noted that the efficiency of an HFO1234yf system may differ from a current HFC–134a system,[215] we believe that this difference does not take into account any efficiency improvements that may be recovered or gained when the overall system is specifically designed with consideration of the new refrigerant properties (as compared to only substituting the new refrigerant). EPA is therefore not adjusting the credits based on efficiency differences for this rule.

As noted above, for model years 2014 and later, manufacturers seeking to generate design-based A/C Efficiency Credits will also need to use a specific new EPA performance test to confirm that the design changes are resulting in improvements in A/C system efficiency as integrated into the vehicle. As proposed, beginning in MY 2014 manufacturers will need to perform an A/C CO_2 Idle Test for each A/C system (family) for which it desires to generate Efficiency Credits. Manufacturers will need to demonstrate an improvement over current average A/C CO_2 levels (21.3 g/minute on the Idle Test) to qualify for the menu approach credits. Upon qualifying on the Idle Test, the manufacturer will be eligible to use the menu approach above to quantify the potential credits it could generate. To earn the full amount of credits available in the menu approach (limited to the maximum), the test must demonstrate a 30% or greater improvement in CO_2 levels over the current average.

For A/C systems that achieve an improvement between 0-and-30% (or a result between 21.3 and 14.9 g/minute result on the A/C CO_2 Idle Test), a credit can still be earned, but a multiplicative credit adjustment factor will be applied to the eligible credits. As shown in Figure III.C.1–1 this factor will be scaled from 1.0 to 0, with vehicles demonstrating a 30% or better improvement (14.9 g/min or lower) receiving 100% of the eligible credit (adj. factor = 1.0), and vehicles demonstrating a 0% improvement—21.3 g/min or higher result—receiving no credit (adj. factor = 0). We adopted this adjustment factor in response to commenters who were concerned that a vehicle which incorporated many efficiency-improving technologies may not achieve the full 30% improvement, and as a result would receive no credit (thus discouraging them from using any of the technologies). Because there is environmental benefit (reduced CO_2) from the use of even some of these efficiency-improving technologies, EPA believes it is appropriate to scale the A/C efficiency credits to account for these partial improvements.

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[215] Ford noted that “the physical properties of the alternative refrigerant R1234yf could result in a reduction of efficiency by 5 to 10 percent compared to R134a in use today with a similar refrigerant system and controls technology.”

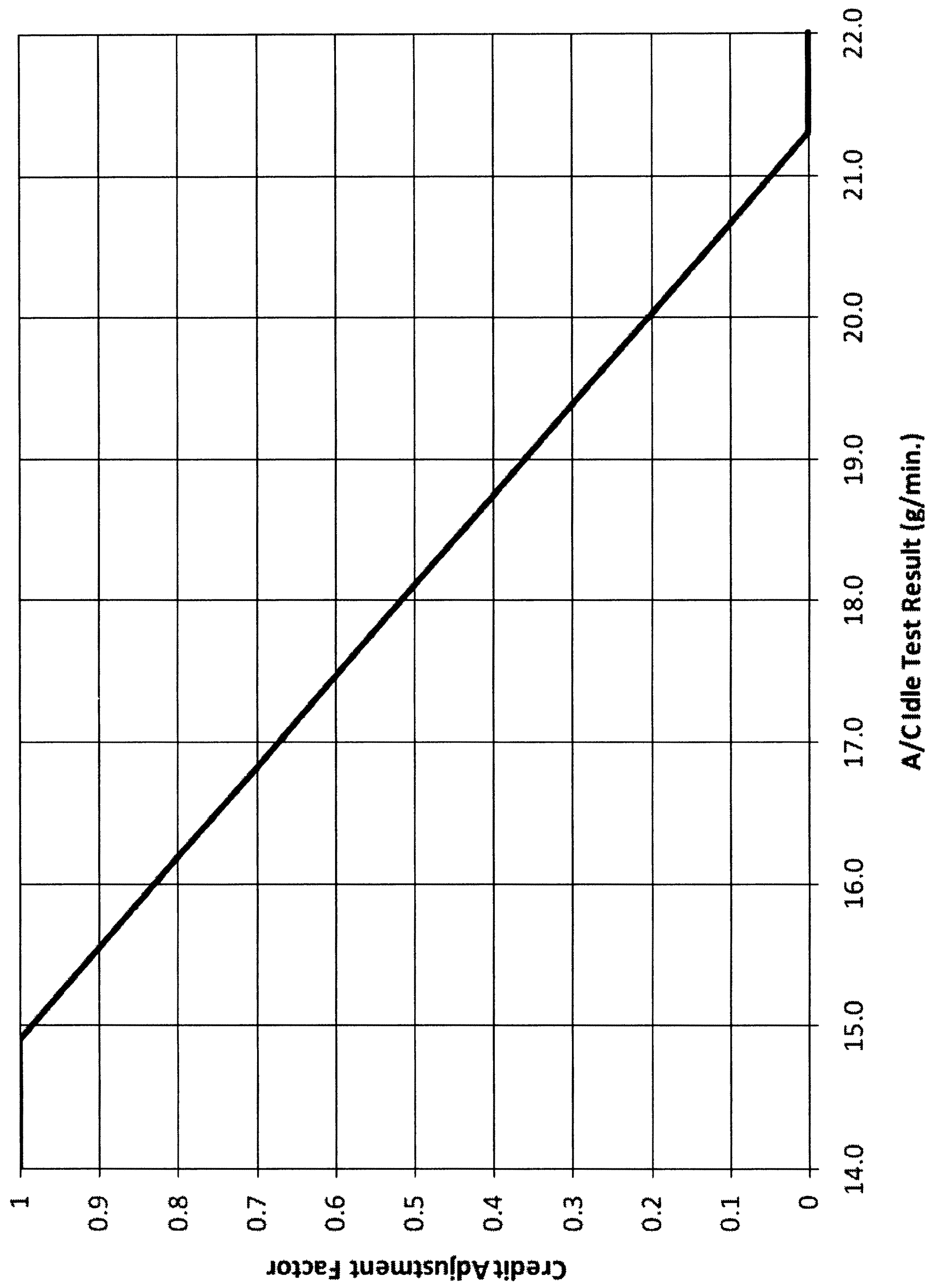

Figure III.C.1-1 A/C Credit Adjustment Factor

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EPA is adopting the A/C CO_2 Idle Test procedure as proposed in most respects. This laboratory idle test is performed while the vehicle is at idle, similar to the idle carbon monoxide (CO) test that was once a part of EPA vehicle certification. The test determines the additional CO_2 generated at idle when the A/C system is operated. The A/C CO_2 Idle Test will be run with and without the A/C system cooling the interior cabin while the vehicle's engine is operating at idle and with the system under complete control of the engine and climate control system. The test includes tighter restrictions on test cell temperatures and humidity levels than apply for the basic FTP test procedure in order to more closely control the loads from operation of the A/C system. EPA is also adopting additional refinements to the required in-vehicle blower fan settings for manually controlled systems to more closely represent "real world" usage patterns.

Many commenters questioned the ability of this test to measure the improved efficiency of certain A/C technologies, and stated that the test was not representative of real-world driving conditions. However, although EPA acknowledges that this test directly simulates a relatively limited range of technologies and conditions, we determined that it is sufficiently robust for the purpose of demonstrating that the system design changes are indeed implemented properly and are resulting in improved efficiency of a vehicle's A/C system, at idle as well as under a range of operating conditions. Further details of the A/C Idle Test can be found in the RIA and the regulations, as well as in the Response to Comments Document.

The design of the A/C CO_2 Idle Test represents a balancing of the need for performance tests whenever possible to ensure the most accurate quantification of efficiency improvements, with practical concerns for testing burden and facility requirements. EPA believes that the Idle Test adds to the robust quantification of A/C credits that will result in real-world efficiency improvements and reductions in A/C-related CO_2 emissions. The Idle Test will not be required in order to generate A/C Efficiency Credits until MY 2014 to allow sufficient time for manufacturers to make the necessary facilities improvements and to gain experience with the test.

EPA also considered and invited comment on a more comprehensive testing approach to quantifying A/C CO_2 emissions that could be somewhat more technically robust, but would require more test time and test facility improvements for many manufacturers. EPA invited comment on using an adapted version of the SCO3, an existing test procedure that is part of the Supplemental Federal Test Procedure. EPA discussed and invited comment on the various benefits and concerns associated with using an adapted SCO3 test. There were many comments opposed to this proposal, and very few supporters. Most of the comments opposing this approach echoed the concerns made by in the NPRM. These included excessive testing burden, limited test facilities and the cost of adding new ones, and the concern that the SC03 test may not be sufficiently representative of in use A/C usage. Some commenters supported a derivative of the SCO3 test or multiple runs of other urban cycles (such as the LA–4) for quantifying A/C system efficiency. While EPA considers a test cycle that covers a broader range of vehicle speed and climatic conditions to be ideal, developing such a representative A/C test would involve the work of many stakeholders, and would require a significant amount of time, exceeding the scope of this rule. EPA expects to continue working with industry, the California Air Resources Board, and other stakeholders to move toward increasingly robust performance tests and methods for determining the efficiency of mobile A/C systems and the related impact on vehicle CO_2 emissions, including a potential adapted SC03 test.

c. Interaction With Title VI Refrigerant Regulations

Title VI of the Clean Air Act deals with the protection of stratospheric ozone. Section 608 establishes a comprehensive program to limit emissions of certain ozone-depleting substances (ODS). The rules promulgated under section 608 regulate the use and disposal of such substances during the service, repair or disposal of appliances and industrial process refrigeration. In addition, section 608 and the regulations promulgated under it, prohibit knowingly venting or releasing ODS during the course of maintaining, servicing, repairing or disposing of an appliance or industrial process refrigeration equipment. Section 609 governs the servicing of motor vehicle A/C systems. The regulations promulgated under section 609 (40 CFR part 82, subpart B) establish standards and requirements regarding the servicing of A/C systems. These regulations include establishing standards for equipment that recovers and recycles (or, for refrigerant blends, only recovers) refrigerant from A/C systems; requiring technician training and certification by an EPA-approved organization; establishing recordkeeping requirements; imposing sales restrictions; and prohibiting the venting of refrigerants. Section 612 requires EPA to review substitutes for class I and class II ozone depleting substances and to consider whether such substitutes will cause an adverse effect to human health or the environment as compared with other substitutes that are currently or potentially available. EPA promulgated regulations for this program in 1992 and those regulations are located at 40 CFR part 82, subpart G. When reviewing substitutes, in addition to finding them acceptable or unacceptable, EPA may also find them acceptable so long as the user meets certain use conditions. For example, all motor vehicle air conditioning systems must have unique fittings and a uniquely colored label for the refrigerant being used in the system.

On September 14, 2006, EPA proposed to approve R–744 (CO_2) for use in motor vehicle A/C systems (71 FR 55140) and on October 19, 2009, EPA proposed to approve the low-GWP refrigerant HFO–1234yf for these systems (74 FR 53445), both subject to certain requirements. Final action on both of these proposals is expected later this year. EPA previously issued a final rule allowing the use of HFC–152a as a refrigerant in motor vehicle A/C systems subject to certain requirements (June 12, 2008; 73 FR 33304). As discussed above, manufacturers transitioning to any of the approved refrigerants would be eligible for A/C Leakage Credits, the value of which would depend on the GWP of their refrigerant and the degree of leakage reduction of their systems.

EPA views this rule as complementing these Title VI programs, and not conflicting with them. To the extent that manufacturers choose to reduce refrigerant leakage in order to earn A/C Leakage Credits, this will dovetail with the Title VI section 609 standards which apply to maintenance events, and to end-of-vehicle life disposal. In fact, as noted, a benefit of the A/C credit provisions is that there should be fewer and less impactive maintenance events for MVACs, since there will be less leakage. In addition, the credit provisions will not conflict (or overlap) with the Title VI section 609 standards. EPA also believes the menu of leak control technologies described in this rule will complement the section 612 requirements, because these control technologies will help ensure that HFC–134a (or other refrigerants) will be used in a manner that further minimizes potential adverse effects on human health and the environment.

2. Flexible Fuel and Alternative Fuel Vehicle Credits

EPA is finalizing its proposal to allow flexible-fuel vehicles (FFVs) and alternative fuel vehicles to generate credits for purposes of the GHG rule starting in the 2012 model year. FFVs are vehicles that can run on both an alternative fuel and a conventional fuel. Most FFVs are E85 vehicles, which can run on a mixture of up to 85 percent ethanol and gasoline. Dedicated alternative fuel vehicles are vehicles that run exclusively on an alternative fuel (*e.g.,* compressed natural gas). These credits are designed to complement the treatment of FFVs under CAFE, consistent with the emission reduction objectives of the CAA. As explained at proposal, EPCA includes an incentive under the CAFE program for production of dual-fueled vehicles or FFVs, and dedicated alternative fuel vehicles.[216] For FFVs and dual-fueled vehicles, the EPCA/EISA credits have three elements: (1) The assumption that the vehicle is operated 50% of the time on the conventional fuel and 50% of the time on the alternative fuel, (2) that 1 gallon of alternative fuel is treated as 0.15 gallon of fuel, essentially increasing the fuel economy of a vehicle on alternative fuel by a factor of 6.67, and (3) a "cap" provision that limits the maximum fuel economy increase that can be applied to a manufacturer's overall CAFE compliance value for all CAFE compliance categories (*i.e.,* domestic passenger cars, import passenger cars, and light trucks) to 1.2 mpg through 2014 and 1.0 mpg in 2015. EPCA's provisions were amended by the EISA to extend the period of availability of the FFV credits, but to begin phasing them out by annually reducing the amount of FFV credits that can be used in demonstrating compliance with the CAFE standards.[217] EPCA does not premise the availability of the FFV credits on actual use of alternative fuel. Under EPCA, after MY 2019 no FFV credits will be available for CAFE compliance.[218] Under EPCA, for dedicated alternative fuel vehicles, there are no limits or phase-out. As proposed, FFV and Alternative Fuel Vehicle Credits will be calculated as a part of the calculation of a manufacturer's overall fleet average fuel economy and fleet average carbon-related exhaust emissions (§ 600.510–12).

Manufacturers supported the inclusion of FFV credits in the program. Chrysler noted that the credits encourage manufacturers to continue production of vehicles capable of running on alternative fuels as the production and distribution systems of such fuels are developed. Chrysler believes the lower carbon intensity of such fuels is an opportunity for further greenhouse gas reductions and increased energy independence, and the continuance of such incentives recognizes the important potential of this technology to reduce GHGs. Toyota noted that because actions taken by manufacturers to comply with EPA's regulation will, to a large extent, be the same as those taken to comply with NHTSA's CAFE regulation, it is appropriate for EPA to consider flexibilities contained in the CAFE program that clearly impact product plans and technology deployment plans already in place or nearly in place. Toyota believes that adopting the FFV credit for a transitional period of time appears to recognize this reality, while providing a pathway to eventually phase-out the flexibility.

As proposed, electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) are not eligible to generate this type of credit. These vehicles are covered by the advanced technology vehicle incentives provisions described in Section III.C.3, so including them here would lead to a double counting of credits.

a. Model Year 2012–2015 Credits

i. FFVs

For the GHG program, EPA is allowing FFV credits corresponding to the amounts allowed by the amended EPCA but only during the period from MYs 2012 to 2015. (As discussed below in Section III.E., EPA is not allowing CAFE-based FFV credits to be generated as part of the early credits program.) As noted at proposal, several manufacturers have already taken the availability of FFV credits into account in their near-term future planning for CAFE and this reliance indicates that these credits need to be considered in assessing necessary lead time for the CO_2 standards. Manufacturers commented that the credits are necessary in allowing them to transition to the new standards. EPA thus believes that allowing these credits, in the near term, would help provide adequate lead time for manufacturers to implement the new multi-year standards, but that for the longer term there is adequate lead time without the use of such credits. This will also tend to harmonize the GHG and the CAFE program during these interim years. As discussed below, EPA is requiring for MY 2016 and later that manufacturers will need to reliably estimate the extent to which the alternative fuel is actually being used by vehicles in order to count the alternative fuel use in the vehicle's CO_2 emissions level determination. Beginning in MY 2016, the FFV credits as described above for MY 2012–2015 will no longer be available for EPA's GHG program. Rather, GHG compliance values will be based on actual emissions performance of the FFV on conventional and alternative fuels, weighted by the actual use of these fuels in the FFVs.

As with the CAFE program, EPA will base MY 2012–2015 credits on the assumption that the vehicles would operate 50% of the time on the alternative fuel and 50% of the time on conventional fuel, resulting in CO_2 emissions that are based on an arithmetic average of alternative fuel and conventional fuel CO_2 emissions.[219] In addition, the measured CO_2 emissions on the alternative fuel will be multiplied by a 0.15 volumetric conversion factor which is included in the CAFE calculation as provided by EPCA. Through this mechanism a gallon of alternative fuel is deemed to contain 0.15 gallons of fuel. For example, for a flexible-fuel vehicle that emitted 330 g/mi CO_2 operating on E85 and 350 g/mi CO_2 operating on gasoline, the resulting CO_2 level to be used in the manufacturer's fleet average calculation would be:

$$CO_2 = \frac{[(330 \times 0.15) + 350]}{2} = 199.8\,g/mi$$

EPA understands that by using the CAFE approach—including the 0.15 factor—the CO_2 emissions value for the vehicle is calculated to be significantly lower than it actually would be otherwise, even if the vehicle were assumed to operate on the alternative fuel at all times. This represents a "credit" being provided to FFVs.

EPA notes also that the above equation and example are based on an FFV that is an E85 vehicle. EPCA, as amended by EISA, also establishes the use of this approach, including the 0.15 factor, for all alternative fuels, not just

[216] 49 U.S.C. 32905.

[217] *See* 49 U.S.C. 32906. The mechanism by which EPCA provides an incentive for production of FFVs is by specifying that their fuel economy is determined using a special calculation procedure that results in those vehicles being assigned a higher fuel economy level than would otherwise occur. 49 U.S.C. 32905(b). This is typically referred to as an FFV credit.

[218] 49 U.S.C. 32906.

[219] 49 U.S.C. 32905(b).

E85.[220] The 0.15 factor is used for B–20 (20 percent biofuel and 80 percent diesel) FFVs. EPCA also establishes this approach, including the 0.15 factor, for gaseous-fueled dual-fueled vehicles, such as a vehicle able to operate on gasoline and CNG.[221] (For natural gas dual-fueled vehicles, EPCA establishes a factor of 0.823 gallons of fuel for every 100 cubic feet a natural gas used to calculate a gallons equivalent.[222]) The EISA's use of the 0.15 factor in this way provides a similar regulatory treatment across the various types of alternative fuel vehicles. EPA also will use the 0.15 factor for all FFVs in order not to disrupt manufacturers' near-term compliance planning and assure sufficient lead time. EPA, in any case, expects the vast majority of FFVs to be E85 vehicles, as is the case today.

The FFV credit limits for CAFE are 1.2 mpg for model years 2012–2014 and 1.0 mpg for model year 2015.[223] In CO_2 terms, these CAFE limits translate to declining CO_2 credit limits over the four model years, as the CAFE standards increase in stringency. As the CAFE standard increases numerically, the limit becomes a smaller fraction of the standard. EPA proposed, but is not adopting, credit limits based on the overall industry average CO_2 standards for cars and trucks. EPA also requested comments on basing the calculated CO_2 credit limits on the individual manufacturer fleet-average standards calculated from the footprint curves. EPA received comment from one manufacturer supporting this approach. EPA also received comments from another manufacturer recommending that the credit limits for an individual manufacturer be based instead on that manufacturer's fleet average performance. The commenter noted that this approach is in line with how CAFE FFV credit limits are applied. This is due to the fact that the GHG-equivalent of the CAFE 1.2 mpg cap will vary due to the non-linear relationship between fuel economy and GHGs/fuel consumption. EPA agrees with this approach since it best harmonizes how credit limits are determined in CAFE. EPA intended and continues to believe it is appropriate to provide essentially the same FFV credits under both programs for MYs 2012–2015. Therefore, EPA is finalizing FFV credits limits for MY 2012–2015 based on a manufacturer's fleet-average performance. For example, if a manufacturer's 2012 car fleet average emissions performance was 260 g/mile (34.2 mpg), the credit limit in CO_2 terms would be 9.5 g/mile (34.2 mpg − 1.2 mpg = 33.0 mpg = 269.5 g/mile) and if it were 270 g/mile the limit would be 10.2 g/mile.

ii. Dedicated Alternative Fuel Vehicles

As proposed, EPA will calculate CO_2 emissions from dedicated alternative fuel vehicles for MY 2012–2015 by measuring the CO_2 emissions over the test procedure and multiplying the results by the 0.15 conversion factor described above. For example, for a dedicated alternative fuel vehicle that would achieve 330 g/mi CO_2 while operating on alcohol (ethanol or methanol), the effective CO_2 emissions of the vehicle for use in determining the vehicle's CO_2 emissions would be calculated as follows:

$$CO_2 = 330 \times 0.15 = 49.5\ g/mi$$

b. Model Years 2016 and Later

i. FFVs

EPA is treating FFV credits the same as under EPCA for model years 2012–2015, but is applying a different approach starting with model year 2016. EPA recognizes that under EPCA automatic FFV credits are entirely phased out of the CAFE program by MY 2020, and apply in the prior model years with certain limitations, but without a requirement that the manufacturers demonstrate actual use of the alternative fuel. Unlike EPCA, CAA section 202(a) does not mandate that EPA treat FFVs in a specific way. Instead EPA is required to exercise its own judgment and determine an appropriate approach that best promotes the goals of this CAA section. Under these circumstances, EPA will treat FFVs for model years 2012–2015 the same as under EPCA, as part of providing sufficient lead time given manufacturers' compliance strategies which rely on the existence of these EPCA statutory credits, as explained above.

Starting with model year 2016, as proposed, EPA will no longer allow manufacturers to base FFV emissions on the use of the 0.15 factor credit described above, and on the use of an assumed 50% usage of alternative fuel. Instead, EPA believes the appropriate approach is to ensure that FFV emissions are based on demonstrated emissions performance. This will promote the environmental goals of the final program. EPA received several comments in support of EPA's proposal to use this approach instead of the EPCA approach for MY 2016 and later. Under the EPA program in MY 2016 and later, manufacturers will be allowed to base an FFV's emissions compliance value in part on the vehicle test values run on the alternative fuel, for that portion of its fleet for which the manufacturer demonstrates utilized the alternative fuel in the field. In other words, the default is to assume FFVs operate on 100% gasoline, and the emissions value for the FFV vehicle will be based on the vehicle's tested value on gasoline. However, if a manufacturer can demonstrate that a portion of its FFVs are using an alternative fuel in use, then the FFV emissions compliance value can be calculated based on the vehicle's tested value using the alternative fuel, prorated based on the percentage of the fleet using the alternative fuel in the field. An example calculation is described below. EPA believes this approach will provide an actual incentive to ensure that such fuels are used. The incentive arises since actual use of the flexible fuel typically results in lower tailpipe GHG emissions than use of gasoline and hence improves the vehicles' performance, making it more likely that its performance will improve a manufacturers' average fleetwide performance. Based on existing certification data, E85 FFV CO_2 emissions are typically about 5 percent lower on E85 than CO_2 emissions on 100 percent gasoline. Moreover, currently there is little incentive to optimize CO_2 performance for vehicles when running on E85. EPA believes the above approach would provide such an incentive to manufacturers and that E85 vehicles could be optimized through engine redesign and calibration to provide additional CO_2 reductions.

Under the EPCA credit provisions, there is an incentive to produce FFVs but no actual incentive to ensure that the alternative fuels are used, or that actual vehicle fuel economy improves. GHG and energy security benefits are only achieved if the alternative fuel is actually used and (for GHGs) that performance improves, and EPA's approach for MY 2016 and beyond will now provide such an incentive. This approach will promote greater use of alternative fuels, as compared to a situation where there is a credit but no usage requirement. This is also consistent with the agency's overall commitment to the expanded use of renewable fuels. Therefore, EPA is basing the FFV program for MYs 2016 and thereafter on real-world reductions: *i.e.,* actual vehicle CO_2 emissions levels based on actual use of the two fuels, without the 0.15 conversion factor specified under EISA.

[220] 49 U.S.C. 32905(c).

[221] 49 U.S.C. 32905(d).

[222] 49 U.S.C. 32905(c).

[223] 49 U.S.C. 32906(a).

For 2016 and later model years, EPA will therefore treat FFVs similarly to conventional fueled vehicles in that FFV emissions would be based on actual CO_2 results from emission testing on the fuels on which it operates. In calculating the emissions performance of an FFV, manufacturers may base FFV emissions on vehicle testing based on the alternative fuel emissions, if they can demonstrate that the alternative fuel is actually being used in the vehicles. Performance will otherwise be calculated assuming use only of conventional fuel. The manufacturer must establish the ratio of operation that is on the alternative fuel compared to the conventional fuel. The ratio will be used to weight the CO_2 emissions performance over the 2-cycle test on the two fuels. The 0.15 conversion factor will no longer be included in the CO_2 emissions calculation. For example, for a flexible-fuel vehicle that emitted 300 g/mi CO_2 operating on E85 ten percent of the time and 350 g/mi CO_2 operating on gasoline ninety percent of the time, the CO_2 emissions for the vehicles to be used in the manufacturer's fleet average would be calculated as follows:

$$CO_2 = (300 \times 0.10) + (350 \times 0.90) = 345 \text{ g/mi}$$

The most complex part of this approach is to establish what data are needed for a manufacturer to accurately demonstrate use of the alternative fuel, where the manufacturer intends for its performance to be calculated based on some use of alternative fuels. One option EPA is finalizing is establishing a rebuttable presumption using a national average approach based on national E85 fuel use. Manufacturers could use this value along with their vehicle emissions results demonstrating lower emissions on E85 to determine the emissions compliance values for FFVs sold by manufacturers under this program. For example, national E85 volumes and national FFV sales may be used to prorate E85 use by manufacturer sales volumes and FFVs already in-use. Upon a manufacturer's written request, EPA will conduct an analysis of vehicle miles travelled (VMT) by year for all FFVs using its emissions inventory MOVES model. Using the VMT ratios and the overall E85 sales, E85 usage will be assigned to each vehicle. This method accounts for the VMT of new FFVs and FFVs already in the existing fleet using VMT data in the model. The model will then be used to determine the ratio of E85 and gasoline for new vehicles being sold. Fluctuations in E85 sales and FFV sales will be taken into account to adjust the manufacturers' E85 actual use estimates annually. EPA plans to make this assigned fuel usage factor available through guidance prior to the start of MY 2016 and adjust it annually as necessary. EPA believes this is a reasonable way to apportion E85 use across the fleet.

If manufacturers decide not to use EPA's assigned fuel usage based on the national average analysis, they have a second option of presenting their own data for consideration as the basis for evaluating fuel usage. Manufacturers have suggested demonstrations using vehicle on-board data gathering through the use of on-board sensors and computers. California's program allows FFV credits based on FFV use and envisioned manufacturers collecting fuel use data from vehicles in fleets with on-site refueling. Manufacturers must present a statistical analysis of alternative fuel usage data collected on actual vehicle operation. EPA is not attempting to specify how the data is collected or the amount of data needed. However, the analysis must be based on sound statistical methodology. Uncertainty in the analysis must be accounted for in a way that provides reasonable certainty that the program does not result in loss of emissions reductions.

EPA received comments that the 2016 and later FFV emissions performance methodology should be based on the life cycle emissions (*i.e.,* including the upstream GHG emissions associated with fuel feedstocks, production, and transportation) associated with the use of the alternative fuel. Commenters are concerned that the use of ethanol will not result in lower GHGs on a lifecycle basis. After considering these comments, EPA is not including lifecycle emissions in the calculation of vehicle credits. EPA continues to believe that it is appropriate to base credits for MY 2012–2015 on the EPCA/CAFE credits and to base compliance values for MY 2016 on the demonstrated tailpipe emissions performance on gasoline and E85, and is finalizing this approach as proposed. EPA recently finalized its RFS2 rulemaking which addresses lifecycle emissions from ethanol and the upstream GHG benefits of E85 use are already captured by this program.[224]

ii. Dedicated Alternative Fuel Vehicles

As proposed, for model years 2016 and later dedicated alternative fuel vehicles, CO_2 will be measured over the 2-cycle test in order to be included in a manufacturer's fleet average CO_2 calculations. As noted above, this is different than CAFE methodology which provides a methodology for calculating a petroleum-based mpg equivalent for alternative fuel vehicles so they can be included in CAFE. However, because CO_2 can be measured directly from alternative fuel vehicles over the test procedure, EPA believes this is the simplest and best approach since it is consistent with all other vehicle testing under the CO_2 program. EPA did not receive comments on this approach.

3. Advanced Technology Vehicle Incentives for Electric Vehicles, Plug-in Hybrids, and Fuel Cell Vehicles

EPA is finalizing provisions that provide a temporary regulatory incentive for the commercialization of certain advanced vehicle power trains—electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs)—for model year 2012–2016 light-duty and medium-duty passenger vehicles.[225] The purpose of these provisions is to provide a temporary incentive to promote technologies which have the potential to produce very large GHG reductions in the future, but which face major challenges such as vehicle cost, consumer acceptance, and the development of low-GHG fuel production infrastructure. The tailpipe GHG emissions from EVs, PHEVs operated on grid electricity, and hydrogen-fueled FCVs are zero, and traditionally the emissions of the vehicle itself are all that EPA takes into account for purposes of compliance with standards set under section 202(a). Focusing on vehicle tailpipe emissions has not raised any issues for criteria pollutants, as upstream emissions associated with production and distribution of the fuel are addressed by comprehensive regulatory programs focused on the upstream sources of those emissions.[226] At this time, however, there is no such comprehensive program addressing upstream emissions of GHGs, and the upstream GHG emissions associated with production and distribution of electricity are higher than the corresponding upstream GHG emissions of gasoline or other petroleum based fuels. In the future, if there were a program to comprehensively control upstream GHG emissions, then the zero tailpipe levels from these vehicles have the potential to produce very large GHG reductions, and to transform the

[224] 75 FR 14670 (March 26, 2010).

[225] *See* final regulations at 40 CFR 86.1866–12(a).

[226] In this section, "upstream" means all fuel-related GHG emissions prior to the fuel being introduced to the vehicle.

transportation sector's contribution to nationwide GHG emissions.

This temporary incentive program applies only for the model years 2012–2016 covered by this final rule. EPA will reassess the issue of how to address EVs, PHEVs, and FCVs in rulemakings for model years 2017 and beyond, based on the status of advanced technology vehicle commercialization, the status of upstream GHG emissions control programs, and other relevant factors.

In the Joint Notice of Intent, EPA stated that "EPA is currently considering proposing additional credit opportunities to encourage the commercialization of advanced GHG/fuel economy control technology such as electric vehicles and plug-in hybrid electric vehicles. These 'super credits' could take the form of a multiplier that would be applied to the number of vehicles sold such that they would count as more than one vehicle in the manufacturer's fleet average." [227] Following through, EPA proposed two mechanisms by which these vehicles would earn credits: (1) A zero grams/mile compliance value for EVs, FCVs, and for PHEVs when operated on grid electricity, and (2) a vehicle multiplier in the range of 1.2 to 2.0.[228]

The zero grams/mile compliance value for EVs (and for PHEVs when operated on grid electricity, as well as for FCVs which involve similar upstream GHG issues with respect to hydrogen production) is an incentive that operates like a credit because, while it accurately accounts for tailpipe GHG emissions, it does not reflect the increase in upstream GHG emissions associated with the electricity used by EVs compared to the upstream GHG emissions associated with the gasoline or diesel fuel used by conventional vehicles.[229] For example, based on GHG emissions from today's national average electricity generation (including GHG emissions associated with feedstock extraction, processing, and transportation) and other key assumptions related to vehicle electricity consumption, vehicle charging losses, and grid transmission losses, a midsize EV might have an upstream GHG emissions of about 180 grams/mile, compared to the upstream GHG emissions of a typical midsize gasoline car of about 60 grams/mile. Thus, the EV would cause a net upstream GHG emissions increase of about 120 grams/mile (in general, the net upstream GHG increase would be less for a smaller EV and more for a larger EV). The zero grams/mile compliance value provides an incentive because it is less than the 120 grams/mile value that would fully account for the net increase in GHG emissions, counting upstream emissions.[230] The net upstream GHG impact could change over time, of course, based on changes in electricity generation or gasoline production.

The proposed vehicle multiplier incentive would also have operated like a credit as it would have allowed an EV, PHEV, or FCV to count as more than one vehicle in the manufacturer's fleet average. For example, combining a multiplier of 2.0 with a zero grams/mile compliance value for an EV would allow that EV to be counted as two vehicles, each with a zero grams/mile compliance value, in the manufacturer's fleet average calculations. In effect, a multiplier of 2.0 would double the overall credit associated with an EV, PHEV, or FCV.

EPA explained in the proposal that the potential for large future emissions benefits from these technologies provides a strong reason for providing incentives at this time to promote their commercialization in the 2012–2016 model years. At the same time, EPA acknowledged that the zero grams/mile compliance value did not account for increased upstream GHG emissions. EPA requested comment on providing some type of incentive, the appropriateness of both the zero grams/mile and vehicle multiplier incentive mechanisms, and on any alternative approaches for addressing advanced technology vehicle incentives. EPA received many comments on these issues, which will be briefly summarized below.

Although some environmental organizations and State agencies supported the principle of including some type of regulatory incentive mechanism, almost all of their comments were opposed to the combination of both the zero grams/mile compliance value and multipliers in the higher end of the proposed range of 1.2 to 2.0. The California Air Resources Board stated that the proposed credits "are excessive" and the Union of Concerned Scientists stated that it "strongly objects" to the approach that lacks "technical justification" by not "accounting for upstream emissions." The Natural Resources Defense Council (NRDC) stated that the credits could "undermine the emissions benefits of the program and will have the unintended consequence of slowing the development of conventional cleaner vehicle emission reduction technologies into the fleet." NRDC, along with several other commenters who made the same point, cited an example based on Nissan's public statements that it plans on producing up to 150,000 Nissan Leaf EVs in the near future at its plant in Smyrna, Tennessee.[231] NRDC's analysis showed that if EVs were to account for 10% of Nissan's car fleet in 2016, the combination of the zero grams/mile and 2.0 multiplier would allow Nissan to make only relatively small improvements to its gasoline car fleet and still be in compliance. NRDC described a detailed methodology for calculating "true full fuel cycle emissions impacts" for EVs. The Sierra Club suggested that the zero grams/mile credit would "taint" EVs as the public comes to understand that these vehicles are not zero-GHG vehicles, and that the zero grams/mile incentive would allow higher gasoline vehicle GHG emissions.

Most vehicle manufacturers were supportive of both the zero grams/mile compliance value and a higher vehicle multiplier. The Alliance of Automobile Manufacturers supported zero grams/mile "since customers need to receive a clear signal that they have made the right choice by preferring an EV, PHEV, or EREV. * * * However, the Alliance recognizes the need for a comprehensive approach with shared responsibility in order to achieve an overall carbon reduction." Nissan claimed that zero grams/mile is "legally required," stating that EPA's 2-cycle test procedures do not account for upstream GHG emissions, that accounting for upstream emissions from electric vehicles but not from other vehicles would be arbitrary, and that including upstream GHG would "disrupt the careful balancing embedded into the National Program." Several other manufacturers, including Ford, Chrysler, Toyota, and Mitsubishi, also supported the proposed zero grams/mile compliance value. BMW suggested a compliance value approach similar to

[227] Notice of Upcoming Joint Rulemaking to Establish Vehicle GHG Emissions and CAFE Standards, 74 FR 24007, 24011 (May 22, 2009).

[228] 74 FR 49533–34.

[229] *See* 74 FR 49533 ("EPA recognizes that for each EV that is sold, in reality the total emissions off-set relative to the typical gasoline or diesel powered vehicle is not zero, as there is a corresponding increase in upstream CO_2 emissions due to an increase in the requirements for electric utility generation").

[230] This 120 grams/mile value for a midsize EV is approximately similar to the compliance value for today's most efficient conventional hybrid vehicle, so the EV would not be significantly more "GHG-positive" than the most efficient conventional hybrid counterpart under a full accounting approach. It should be noted that these emission levels would still be well below the footprint targets for the vehicles in question.

[231] "Secretary Chu Announces Closing of $1.4 Billion Loan to Nissan," Department of Energy, January 28, 2010, *http://www.energy.gov/news/8581.htm.* EPA Docket EPA–HQ–OAR–2009–0472.

that used for CAFE compliance (described below), which would yield a very low, non-zero grams/mile compliance value. Honda opposed the zero grams/mile incentive. Honda suggested that EPA should fully account for upstream GHG and "should separate incentives and credits from the measurement of emissions." Automakers universally supported higher multipliers, many higher than the maximum 2.0 level proposed by EPA. Honda suggested a multiplier of 16.0 for FCVs. Mitsubishi supported the concept of larger, temporary incentives until advanced technology vehicle sales achieved a 10% market share. Finally, some commenters suggested that other technologies should also receive incentives, such as diesel vehicles, hydrogen-fueled internal combustion engines, and natural gas vehicles.

Based on a careful consideration of these comments, EPA is modifying its proposed advanced technology vehicle incentive program for EVs, PHEVs, and FCVs produced in 2012–2016. EPA is not extending the program to include additional technologies at this time. The final incentive program, and our rationale for it, are described below.

One, the incentive program retains the zero grams/mile value for EVs and FCVs, and for PHEVs when operated on grid electricity, subject to vehicle production caps discussed below. EPA acknowledges that, based on current electricity and hydrogen production processes, that EVs, PHEVs, and FCVs yield higher upstream GHG emissions than comparable gasoline vehicles. But EPA reiterates its support for temporarily rewarding advanced emissions control technologies by foregoing modest emissions reductions in the short term in order to lay the foundation for the potential for much larger emission reductions in the longer term.[232] EPA notes that EVs, PHEVs, and FCVs are potential GHG "game changers" if major cost and consumer barriers can be overcome and if there is a nationwide transformation to low-GHG electricity (or hydrogen, in the case of FCVs).

Although EVs and FCVs will have compliance values of zero grams/mile, PHEV compliance values will be determined by combining zero grams/mile for grid electricity operation with the GHG emissions from the 2-cycle test results during operation on liquid fuel, and weighting these values by the percentage of miles traveled that EPA believes will be performed on grid electricity and on liquid fuel, which will vary for different PHEVs. EPA is currently considering different approaches for determining the weighting factor to be used in calculating PHEV GHG emissions compliance values. EPA will consider the work of the Society of Automotive Engineers Hybrid Technical Standards Committee, as well as other relevant factors. EPA will issue a final rule on this methodology by the fall of 2010, when EPA expects some PHEVs to initially enter the market.

EPA agrees with the comments by the environmental organizations, States, and Honda that the zero grams/mile compliance value will reduce the overall GHG benefits of the program. However, EPA believes these reductions in GHG benefits will be relatively small based on the projected production of EVs, PHEVs, and FCVs during the 2012–2016 timeframe, along with the other changes that we are making in the incentive program. EPA believes this modest potential for reduction in near-term emissions control is more than offset by the potential for very large future emissions reductions that commercialization of these technologies could promote.

Two, the incentive program will not include any vehicle multipliers, *i.e.,* an EV's zero grams/mile compliance value will count as one vehicle in a manufacturer's fleet average, not as more than one vehicle as proposed. EPA has concluded that the combination of the zero grams/mile and multiplier credits would be excessive. Compared to the maximum multiplier of 2.0 that EPA had proposed, dropping this multiplier reduces the aggregate impact of the overall credit program by a factor of two (less so for lower multipliers, of course).

Three, EPA is placing a cumulative cap on the total production of EVs, PHEVs, and FCVs for which an individual manufacturer can claim the zero grams/mile compliance value during model years 2012–2016. The cumulative production cap will be 200,000 vehicles, except those manufacturers that sell at least 25,000 EVs, PHEVs, and FCVs in MY 2012 will have a cap of 300,000 vehicles for MY 2012–2016. This higher cap option is an additional incentive for those manufacturers that take an early leadership role in aggressively and successfully marketing advanced technology vehicles. These caps are a second way to limit the potential GHG benefit losses associated with the incentive program and therefore are another response to the concerns that the proposed incentives were excessive and could significantly undermine the program's GHG benefits. If, for example, 500,000 EVs were produced in 2012–2016 that qualified for the zero grams/mile compliance value, the loss in GHG benefits due to this program would be about 25 million metric tons, or less than 3 percent of the total projected GHG benefits of this program.[233] The rationale for these caps is that the incentive for EVs, PHEVs, and FCVs is most critical when individual automakers are beginning to introduce advanced technologies in the market, and less critical once individual automakers have successfully achieved a reasonable market share and technology costs decline due to higher production volumes and experience. EPA believes that cap levels of 200,000–300,000 vehicles over a five model year period are reasonable, as production greater than this would indicate that the manufacturer has overcome at least some of the initial market barriers to these advanced technologies. Further, EPA believes that it is unlikely that many manufacturers will approach these cap levels in the 2012–2016 timeframe.[234]

Production beyond the cumulative vehicle production cap for a given manufacturer in MY 2012–2016 would have its compliance values calculated according to a methodology that accounts in full for the net increase in upstream GHG emissions. For an EV, for example, this would involve: (1) Measuring the vehicle electricity consumption in watt-hours/mile over the 2-cycle test (in the example introduced earlier, a midsize EV might have a 2-cycle test electricity consumption of 230 watt-hours/mile), (2) adjusting this watt-hours/mile value upward to account for electricity losses during transmission and vehicle charging (dividing 230 watt-hours/mile by 0.93 to account for grid/transmission losses and by 0.90 to reflect losses during vehicle charging yields a value of 275 watt-hours/mile), (3) multiplying the adjusted watt-hours/mile value by a

[232] EPA has adopted this strategy in several of its most recent and important mobile source rulemakings, such as its Tier 2 Light-Duty Vehicle, 2007 Heavy-Duty Highway, and Tier 4 Nonroad Diesel rulemakings.

[233] *See* Regulatory Impact Analysis, Appendix 5.B. While it is, of course, impossible to predict the number of EVs, PHEVs, and FCVs that will be produced between 2012 and 2016 with absolute certainty, EPA believes that 500,000 "un-capped" EVs is an optimistic scenario. Fewer EVs, or a combination of 500,000 EVs and PHEVs, would lessen the short-term reduction in GHG benefits. Production of more than 500,000 "un-capped" EVs would increase the short-term reduction in GHG benefits.

[234] Fundamental power train changes in the automotive market typically evolve slowly over time. For example, over ten years after the U.S. introduction of the first conventional hybrid electric vehicle, total hybrid sales are approximately 300,000 units per year.

nationwide average electricity upstream GHG emissions rate of 0.642 grams/watt-hour at the powerplant[235] (275 watt-hours/mile multiplied by 0.642 grams GHG/watt-hour yields 177 grams/mile), and 4) subtracting the upstream GHG emissions of a comparable midsize gasoline vehicle of 56 grams/mile to reflect a true net increase in upstream GHG emissions (177 grams/mile for the EV minus 56 grams/mile for the gasoline vehicle yields a net increase and EV compliance value of 121 grams/mile).[236] [237] The full accounting methodology for the portion of PHEV operation on grid electricity would use this same approach.

EPA projects that the aggregate impact of the incentive program on advanced technology vehicle GHG compliance values will be similar to the way advanced technologies are treated under DOT's CAFE program. In the CAFE program, the mpg value for an EV is determined using a "petroleum equivalency factor" that has a 1/0.15 factor built into it similar to the flexible fuel vehicle credit.[238] For example, under current regulations, an EV with a 2-cycle electricity consumption of 230 watt-hours/mile would have a CAFE rating of about 360 miles per gallon, which would be equivalent to a gasoline vehicle GHG emissions value of 25 grams/mile, which is close to EPA's zero grams/mile for EV production that is below an individual automaker's cumulative vehicle production cap. The exception would be if a manufacturer exceeded its cumulative vehicle production cap during MY 2012–2016. Then, the same EV would have a GHG compliance value of about 120 grams/mile, which would be significantly higher than the 25 gram/mile implied by the 360 mile/gallon CAFE value.

EPA disagrees with Nissan that excluding upstream GHGs is legally required under section 202(a)(1). In this rulemaking, EPA is adopting standards under section 202(a)(1), which provides EPA with broad discretion in setting emissions standards. This includes authority to structure the emissions standards in a way that provides an incentive to promote advances in emissions control technology. This discretion includes the adjustments to compliance values adopted in the final rule, the multipliers we proposed, and other kinds of incentives. EPA recognizes that we have not previously made adjustments to a compliance value to account for upstream emissions in a section 202(a) vehicle emissions standard, but that does not mean we do not have authority to do so in this case. In addition, EPA is not directly regulating upstream GHG emissions from stationary sources, but instead is deciding how much value to assign to a motor vehicle for purposes of compliance calculations with the motor vehicle standard. While the logical place to start is the emissions level measured under the test procedure, section 202(a)(1) does not require that EPA limit itself to only that level. For vehicles above the production volume cap described above, EPA will adjust the measured value to a level that reflects the net difference in upstream GHG emissions compared to a comparable conventional vehicle. This will account for the actual GHG emissions increase associated with the use of the EV. As shown above, upstream GHG emissions attributable to increased electricity production to operate EVs or PHEVs currently exceed the upstream GHG emissions attributable to gasoline vehicles. There is a rational basis for EPA to account for this net difference, as that best reflects the real world effect on the air pollution problem we are addressing. For vehicles above the cap, EPA is reasonably and fairly accounting for the incremental increase in upstream GHG emissions from both the electric vehicles and the conventional vehicles. EPA is not, as Nissan suggested, arbitrarily counting upstream emissions for electric vehicles but not for conventional fuel vehicles.

EPA recognizes that every motor vehicle fuel and fuel production process has unique upstream GHG emissions impacts. EPA has discretion in this rulemaking under section 202(a) on whether to account for differences in net upstream GHG emissions relative to gasoline produced from oil, and intends to only consider upstream GHG emissions for those fuels that have significantly higher or lower GHG emissions impacts. At this time, EPA is only making such a determination for electricity, given that, as shown above in the example for a midsize car, electricity upstream GHG emissions are about three times higher than gasoline upstream GHG emissions. For example, the difference in upstream GHG emissions for both diesel fuel from oil and CNG from natural gas are relatively small compared to differences associated with electricity. Nor is EPA arbitrarily ignoring upstream GHG emissions of flexible fuel vehicles (FFVs) that can operate on E85. Data show that, on average, FFVs operate on gasoline over 99 percent of the time, and on E85 fuel less than 1 percent of the time.[239] EPA's recently promulgated Renewable Fuel Standard Program shows that, with respect to aggregate lifecycle emissions including non-tailpipe GHG emissions (such as feedstock growth, transportation, fuel production, and land use), lifecycle emissions for ethanol from corn using advanced production technologies are about 20 percent less GHG than gasoline from oil.[240] Given this difference, and that E85 is used in FFVs less than 1 percent of the time, EPA has concluded that it is not necessary to adopt a more complicated upstream accounting for FFVs. Accordingly, EPA's incentive approach here is both reasonable and authorized under section 202(a)(1).

In summary, EPA believes that this program for MY 2012–2016 strikes a reasoned balance by providing a temporary regulatory incentive to help promote commercialization of advanced vehicle technologies which are potential game-changers, but which also face major barriers, while effectively minimizing potential GHG losses by dropping the proposed multiplier and adding individual automaker

[235] The nationwide average electricity upstream GHG emissions rate of 0.642 grams GHG/watt-hour was calculated from 2005 nationwide powerplant data for CO_2, CH_4, and N_2O emissions from eGRID2007 (*http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html*), converting to CO_2 -e using Global Warming Potentials of 25 for CH_4 and 298 for N_2O, and multiplying by a factor of 1.06 to account for GHG emissions associated with feedstock extraction, transportation, and processing (based on Argonne National Laboratory's The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.8c.0, available at *http://www.transportation.anl.gov/modeling_simulation/GREET/*). EPA Docket EPA–HQ–OAR–2009–0472. EPA recognizes that there are many issues involved with projecting the electricity upstream GHG emissions associated with future EV and PHEV use including, but not limited to, average vs marginal, daytime vs nighttime vehicle charging, geographical differences, and changes in future electricity feedstocks. EPA chose to use the 2005 national average value because it is known and documentable. Values appropriate for future vehicle use may be higher or lower than this value. EPA will reevaluate this value in future rulemakings.

[236] A midsize gasoline vehicle with a footprint of 45 square feet would have a MY 2016 GHG target of about 225 grams/mile; dividing 8887 grams CO_2/gallon of gasoline by 225 grams/mile yields an equivalent fuel economy level of 39.5 mpg; and dividing 2208 grams upstream GHG/gallon of gasoline by 39.5 mpg yields a midsize gasoline vehicle upstream GHG value of 56 grams/mile. The 2208 grams upstream GHG/gallon of gasoline is calculated from 19,200 grams upstream GHG/mmBtu (Renewable Fuel Standard Program, Regulatory Impact Analysis, Section 2.5.8, February 2010) and multiplying by 0.115 mmBtu/gallon of gasoline.

[237] Manufacturers can utilize alternate calculation methodologies if shown to yield equivalent or superior results and if approved in advance by the Administrator.

[238] 65 FR 36987 (June 12, 2000).

[239] Renewable Fuel Standard Program (RFS2), Regulatory Impact Analysis, Section 1.7.4, February 2010.

[240] 75 FR 14670 (March 26, 2010).

production volume caps. In the future, if there were a program to control utility GHG emissions, then these advanced technology vehicles have the potential to produce very large reductions in GHG emissions, and to transform the transportation sector's contribution to nationwide GHG emissions. EPA will reassess the issue of how to address EVs, PHEVs, and FCVs in rulemakings for model years 2017 and beyond based on the status of advanced vehicle technology commercialization, the status of upstream GHG control programs, and other relevant factors.

Finally, the criteria and definitions for what vehicles qualify for the advanced technology vehicle incentives are provided in Section III.E. These definitions for EVs, PHEVs, and FCVs ensure that only credible advanced technology vehicles are provided the incentives.

4. Off-Cycle Technology Credits

As proposed, EPA is adopting an optional credit opportunity intended to apply to new and innovative technologies that reduce vehicle CO_2 emissions, but for which the CO_2 reduction benefits are not significantly captured over the 2-cycle test procedure used to determine compliance with the fleet average standards (*i.e.,* "off-cycle").[241] Eligible innovative technologies are those that are relatively newly introduced in one or more vehicle models, but that are not yet implemented in widespread use in the light-duty fleet. EPA will not approve credits for technologies that are not innovative or do not provide novel approaches to reducing greenhouse gas emissions. Manufacturers must obtain EPA approval for new and innovative technologies at the time of vehicle certification in order to earn credits for these technologies at the end of the model year. This approval must include the testing methodology to be used for quantifying credits. Further, any credits for these off-cycle technologies must be based on real-world GHG reductions not significantly captured on the current 2-cycle tests and verifiable test methods, and represent average U.S. driving conditions.

Similar to the technologies used to reduce A/C system indirect CO_2 emissions by increasing A/C efficiency, eligible technologies would not be primarily active during the 2-cycle test and therefore the associated improvements in CO_2 emissions would not be significantly captured. Because these technologies are not nearly so well developed and understood, EPA is not prepared to consider them in assessing the stringency of the CO_2 standards. However, EPA is aware of some emerging and innovative technologies and concepts in various stages of development with CO_2 reduction potential that might not be adequately captured on the FTP or HFET. EPA believes that manufacturers should be able to generate credit for the emission reductions these technologies actually achieve, assuming these reductions can be adequately demonstrated and verified. Examples include solar panels on hybrids or electric vehicles, adaptive cruise control, and active aerodynamics. EPA believes it would be appropriate to provide an incentive to encourage the introduction of these types of technologies, that bona fide reductions from these technologies should be considered in determining a manufacturer's fleet average, and that a credit mechanism is an effective way to do this. This optional credit opportunity would be available through the 2016 model year.

EPA received comments from a few manufacturers that the "new and innovative" criteria should be broadened. The commenters pointed out that there are technologies already in the marketplace that would provide emissions reductions off-cycle and that their use should be incentivized. One manufacturer suggested that off-cycle credits should be given for start-stop technologies. EPA does not agree that this technology, which EPA's modeling projects will be widely used by manufacturers in meeting the CO_2 standards, should qualify for off-cycle credits. Start-stop technology already achieves a significant CO_2 benefit on the current 2-cycle tests, which is why many manufacturers have announced plans to adopt it across large segments of the fleet. EPA recognizes there may be additional benefits to start-stop technology beyond the 2-cycle tests (*e.g.,* heavy idle use), and that this is likely the case for other technologies that manufacturers will rely on to meet the MY 2012–2016 standards. EPA plans to continue to assess the off-cycle potential for these technologies in the future. However, EPA does not believe that off-cycle credits should be granted for technologies which we expect manufacturers to rely on in widespread use throughout the fleet in meeting the CO_2 standards. Such credits could lead to double counting, as there is already significant CO_2 benefit over the 2-cycle tests. EPA expects that most if not all technologies that reduce CO_2 emission on the 2-cycle test will also reduce CO_2 emissions during the wide variety of in-use operation that is not directly captured in the 2-cycle test. This is no different than what occurs from the control technology on vehicles for criteria pollutants. We expect that the catalytic converter and other emission control technology will operate to reduce emissions throughout in-use driving, and not just when the vehicle is tested on the specified test procedure. The aim for this off-cycle credit provisions is to provide an incentive for technologies that normally would not be chosen as a GHG control strategy, as their GHG benefits are not measured on the specified 2-cycle test. It is not designed to provide credits for technology that does provide significant GHG benefits on the 2-cycle test and as expected will also typically provide GHG benefits in other kinds of operation. Thus, EPA is finalizing the "new and innovative" criteria as proposed. That is, the potential to earn off-cycle credits will be limited to those technologies that are new and innovative, are introduced in only a limited number of vehicle models (*i.e.,* not in widespread use), and are not captured on the current 2-cycle tests. This approach will encourage future innovation, which may lead to the opportunity for future emissions reductions.

As proposed, manufacturers would quantify CO_2 reductions associated with the use of the innovative off-cycle technologies such that the credits could be applied on a g/mile equivalent basis, as is the case with A/C system improvements. Credits must be based on real additional reductions of CO_2 emissions and must be quantifiable and verifiable with a repeatable methodology. As proposed, the technologies upon which the credits are based would be subject to full useful life compliance provisions, as with other emissions controls. Unless the manufacturer can demonstrate that the technology would not be subject to in-use deterioration over the useful life of the vehicle, the manufacturer must account for deterioration in the estimation of the credits in order to ensure that the credits are based on real in-use emissions reductions over the life of the vehicle.

As discussed below, EPA is finalizing a two-tiered process for demonstrating the CO_2 reductions of an innovative and novel technology with benefits not captured by the FTP and HFET test procedures. First, a manufacturer must determine whether the benefit of the technology could be captured using the 5-cycle methodology currently used to determine fuel economy label values. EPA established the 5-cycle test

[241] *See* final regulations at 40 CFR 86.1866–12(d).

methods to better represent real-world factors impacting fuel economy, including higher speeds and more aggressive driving, colder temperature operation, and the use of air conditioning. If this determination is affirmative, the manufacturer must follow the procedures described below (as codified in today's rules). If the manufacturer finds that the technology is such that the benefit is not adequately captured using the 5-cycle approach, then the manufacturer would have to develop a robust methodology, subject to EPA approval, to demonstrate the benefit and determine the appropriate CO_2 gram per mile credit. As discussed below, EPA is also providing opportunity for public comment as part of the approval process for such non-5-cycle credits.

a. Technology Demonstration Using EPA 5-Cycle Methodology

As noted above, the CO_2 reduction benefit of some innovative technologies could be demonstrated using the 5-cycle approach currently used for EPA's fuel economy labeling program. The 5-cycle methodology was finalized in EPA's 2006 fuel economy labeling rule,[242] which provides a more accurate fuel economy label estimate to consumers starting with 2008 model year vehicles. In addition to the FTP and HFET test procedures, the 5-cycle approach folds in the test results from three additional test procedures to determine fuel economy. The additional test cycles include cold temperature operation, high temperature, high humidity and solar loading, and aggressive and high-speed driving; thus these tests could be used to demonstrate the benefit of a technology that reduces CO_2 over these types of driving and environmental conditions. Using the test results from these additional test cycles collectively with the 2-cycle data provides a more precise estimate of the average fuel economy and CO_2 emissions of a vehicle for both the city and highway independently. A significant benefit of using the 5-cycle methodology to measure and quantify the CO_2 reductions is that the test cycles are properly weighted for the expected average U.S. operation, meaning that the test results could be used without further adjustments.

EPA continues to believe that the use of these supplemental cycles may provide a method by which technologies not demonstrated on the baseline 2-cycles can be quantified and is finalizing this approach as proposed. The cold temperature FTP can capture new technologies that improve the CO_2 performance of vehicles during colder weather operation. These improvements may be related to warm-up of the engine or other operation during the colder temperature. An example of such a new, innovative technology is a waste heat capture device that provides heat to the cabin interior, enabling additional engine-off operation during colder weather not previously enabled due to heating and defrosting requirements. The additional engine-off time would result in additional CO_2 reductions that otherwise would not have been realized without the heat capture technology.

Although A/C credits for efficiency improvements will largely be captured in the A/C credits provisions through the credit menu of known efficiency improving components and controls, certain new technologies may be able to use the high temperatures, humidity, and solar load of the SC03 test cycle to accurately measure their impact. An example of a new technology may be a refrigerant storage device that accumulates pressurized refrigerant during driving operation or uses recovered vehicle kinetic energy during deceleration to pressurize the refrigerant. Much like the waste heat capture device used in cold weather, this device would also allow additional engine-off operation while maintaining appropriate vehicle interior occupant comfort levels. SC03 test data measuring the relative impact of innovative A/C-related technologies could be applied to the 5-cycle equation to quantify the CO_2 reductions of the technology.

The US06 cycle may be used to capture innovative technologies designed to reduce CO_2 emissions during higher speed and more aggressive acceleration conditions, but not reflected on the 2-cycle tests. An example of this is an active aerodynamic technology. This technology recognizes the benefits of reduced aerodynamic drag at higher speeds and makes changes to the vehicle at those speeds. The changes may include active front or grill air deflection devices designed to redirect frontal airflow. Certain active suspension devices designed primarily to reduce aerodynamic drag by lowering the vehicle at higher speeds may also be measured on the US06 cycle. To properly measure these technologies on the US06, the vehicle would require unique load coefficients with and without the technologies. The different load coefficient (properly weighted for the US06 cycle) could effectively result in reduced vehicle loads at the higher speeds when the technologies are active. Similar to the previously discussed cycles, the results from the US06 test with and without the technology could then use the 5-cycle methodology to quantify CO_2 reductions.

If the 5-cycle procedures can be used to demonstrate the innovative technology, then the regulatory evaluation/approval process will be relatively simple. The manufacturer will simply test vehicles with and without the technology installed or operating and compare results. All 5-cycles must be tested with the technology enabled and disabled, and the test results will be used to calculate a combined city/highway CO_2 value with the technology and without the technology. These values will then be compared to determine the amount of the credit; the combined city/highway CO_2 value with the technology operating will be subtracted from the combined city/highway CO_2 value without the technology operating to determine the gram per mile CO_2 credit. It is likely that multiple tests of each of the five test procedures will need to be performed in order to achieve the necessary strong degree of statistical significance of the credit determination results. This will have to be done for each model type for which a credit is sought, unless the manufacturer could demonstrate that the impact of the technology was independent of the vehicle configuration on which it was installed. In this case, EPA may consider allowing the test to be performed on an engine family basis or other grouping. At the end of the model year, the manufacturer will determine the number of vehicles produced subject to each credit amount and report that to EPA in the final model year report. The gram per mile credit value determined with the 5-cycle comparison testing will be multiplied by the total production of vehicles subject to that value to determine the total number of credits.

EPA received a few comments regarding the 5-cycle approach. While not commenting directly on the 5-cycle testing methodology, the Alliance raised general concerns that the proposed approach did not offer manufacturers enough certainty with regard to credit applications and testing in order to take advantage of the credits. The Alliance further commented that the proposal did not provide a level playing field to all manufacturers in terms of possible credit availability. The Alliance recommended that rather than attempting to quantify CO_2 reductions with a prescribed test procedure on unknown technologies, EPA should

[242] Fuel Economy Labeling of Motor Vehicles: Revisions to Improve Calculation of Fuel Economy Estimates; Final Rule (71 FR 77872, December 27, 2006).

handle credit applications and testing guidelines via future guidance letters, as technologies emerge and are developed.

EPA believes that 5-cycle testing methodology is one clear and objective way to demonstrate certain off-cycle emissions control technologies, as discussed above. It provides certainty with regard to testing, and is available for all manufacturers. As discussed below, there are also other options for manufactures where the 5-cycle test is not appropriate. EPA is retaining this as a primary methodology for determining off-cycle credits. For technologies not able to be demonstrated on the 5-cycle test, EPA is finalizing an approach that will include a public comment opportunity, as discussed below, which we believe addresses commenter concerns regarding maintaining a level playing field.

b. Alternative Off-Cycle Credit Methodologies

As proposed, in cases where the benefit of a technological approach to reducing CO_2 emissions can not be adequately represented using existing test cycles, manufacturers will need to develop test procedures and analytical approaches to estimate the effectiveness of the technology for the purpose of generating credits. As discussed above, the first step must be a thorough assessment of whether the 5-cycle approach can be used to demonstrate a reduction in emissions. If EPA determines that the 5-cycle process is inadequate for the specific technology being considered by the manufacturer (*i.e.,* the 5-cycle test does not demonstrate any emissions reductions), then an alternative approach may be developed and submitted to EPA for approval. The demonstration program must be robust, verifiable, and capable of demonstrating the real-world emissions benefit of the technology with strong statistical significance.

The CO_2 benefit of some technologies may be able to be demonstrated with a modeling approach, using engineering principles. An example would be where a roof solar panel is used to charge the on-board vehicle battery. The amount of potential electrical power that the panel could supply could be modeled for average U.S. conditions and the units of electrical power could be translated to equivalent fuel energy or annualized CO_2 emission rate reduction from the captured solar energy. The CO_2 reductions from other technologies may be more challenging to quantify, especially if they are interactive with the driver, geographic location, environmental condition, or other aspect related to operation on actual roads. In these cases, manufacturers might have to design extensive on-road test programs. Any such on-road testing programs would need to be statistically robust and based on average U.S. driving conditions, factoring in differences in geography, climate, and driving behavior across the U.S.

Whether the approach involves on-road testing, modeling, or some other analytical approach, the manufacturer will be required to present a proposed methodology to EPA. EPA will approve the methodology and credits only if certain criteria are met. Baseline emissions and control emissions must be clearly demonstrated over a wide range of real world driving conditions and over a sufficient number of vehicles to address issues of uncertainty with the data. The analytical approach must be robust, verifiable, and capable of demonstrating the real-world emissions benefit with strong statistical significance. Data must be on a vehicle model-specific basis unless a manufacturer demonstrated model specific data was not necessary. Approval of the approach to determining a CO_2 benefit will not imply approval of the results of the program or methodology; when the testing, modeling, or analyses are complete the results will likewise be subject to EPA review and approval. EPA believes that manufacturers could work together to develop testing, modeling, or analytical methods for certain technologies, similar to the SAE approach used for A/C refrigerant leakage credits.

In addition, EPA received several comments recommending that the approval process include an opportunity for public comment. As noted above, some manufacturers are concerned that there be a level playing field in terms of all manufacturers having a reasonable opportunity to earn credits under an approved approach. Commenters also want an opportunity for input in the methodology to ensure the accuracy of credit determinations for these technologies. Commenters point out that there are a broad number of stakeholders with experience in the issues pertaining to the technologies that could add value in determining the most appropriate method to assess these technologies' performance. EPA agrees with these comments and is including an opportunity for public comment as part of the approval process. If and when EPA receives an application for off-cycle credits using an alternative non 5-cycle methodology, EPA will publish a notice of availability in the **Federal Register** with instructions on how to comment on draft off-cycle credit methodology. The public information available for review will focus on the methodology for determining credits but the public review obviously is limited to non-confidential business information. The timing for final approval will depend on the comments received. EPA also believes that a public review will encourage manufacturers to be thorough in their preparation prior to submitting their application for credits to EPA for approval. EPA will take comments into consideration, and where appropriate, work with the manufacturer to modify their approach prior to approving any off-cycle credits methodology. EPA will give final notice of its determination to the general public as well as the applicant. Off-cycle credits would be available in the model year following the final approval. Thus, it will be imperative for a manufacturer pursuing this option to begin the process as early as possible.

EPA also received comments that the off-cycle credits highlights the inadequacy of current test procedures, and that there is a clear need for updated certification test procedures. As discussed in Section III. B., EPA believes the current test procedures are adequate for implementing the standards finalized today. However, EPA is interested in improving test procedures in the future and believes that the off-cycle credits program has the potential to provide useful data and insights both for the 5-cycle test procedures and also other test procedures that capture off-cycle emissions.

5. Early Credit Options

EPA is finalizing a program to allow manufacturers to generate early credits in model years 2009–2011.[243] As described below, credits may be generated through early additional fleet average CO_2 reductions, early A/C system improvements, early advanced technology vehicle credits, and early off-cycle credits. As with other credits, early credits are subject to a five year carry-forward limit based on the model year in which they are generated. Manufacturers may transfer early credits between vehicle categories (*e.g.,* between the car and truck fleet). With the exception of MY 2009 early program credits, as discussed below, a manufacturer may trade other early credits to other manufacturers without limits. The agencies note that CAFE credits earned in MYs prior to MY 2011 will still be available to manufacturers

[243] *See* final regulations at 40 CFR 86.1867–12.

for use in the CAFE program in accordance with applicable regulations.

EPA is not adopting certification, compliance, or in-use requirements for vehicles generating early credits. Since manufacturers are already certifying MY 2010 and in some cases even MY 2011 vehicles, doing so would make certification, compliance, and in-use requirements unworkable. As discussed below, manufacturers are required to submit an early credits report to EPA for approval no later than 90 days after the end of MY 2011. This report must include details on all early credits the manufacturer generates, why the credits are bona fide, how they are quantified, and how they can be verified.

a. Credits Based on Early Fleet Average CO_2 Reductions

As proposed, EPA is finalizing opportunities for early credit generation in MYs 2009–2011 through over-compliance with a fleet average CO_2 baseline established by EPA. EPA is finalizing four pathways for doing so. In order to generate early CO_2 credits, manufacturers must select one of the four paths for credit generation for the entire three year period and may not switch between pathways for different model years. For two pathways, EPA is establishing the baseline equivalent to the California standards for the relevant model year. Generally, manufacturers that over-comply with those CARB standards would earn credits. Two additional pathways, described below, include credits based on over-compliance with CAFE standards in states that have not adopted the California standards.

EPA received comments from manufacturers in support of the early credits program as a necessary compliance flexibility. The Alliance commented that the early credits reward manufacturers for providing fleet performance that exceeds California and Federal standards and do not result in a windfall. AIAM commented that early credits are essential to assure the feasibility of the proposed standards and the need for such credits must be evaluated in the context of the dramatic changes the standards will necessitate in vehicle design and the current economic environment in which manufacturers are called upon to make the changes. Manufacturers also supported retaining all four pathways, commenting that eliminating pathways would diminish the flexibility of the program. EPA also received comments from many environmental organizations and states that the program would provide manufacturers with windfall credits because manufacturers will not have to take any steps to earn credits beyond those that are already planned and in some cases implemented. These commenters were particularly concerned that the California truck standards in MY 2009 are not as stringent as CAFE, so overcompliance with the California standards could be a windfall in MY 2009, and possibly even MY 2010. These commenters supported an early credits program based on overcompliance with the more stringent of either the CAFE or California standards in any given year. EPA is retaining the early credits program because EPA judges that they are not windfall credits, and manufacturers in some cases have reasonably relied on the availability of these credits, and have based early model year compliance strategies on their availability so that the credits are needed to provide adequate lead for the initial years of the program. However, as discussed below, EPA is restricting credit trading for MY 2009 credits earned under the California-based pathways.

Manufacturers selecting Pathway 1 will generate credits by over-complying with the California equivalent baseline established by EPA over the manufacturer's fleet of vehicles sold nationwide. Manufacturers selecting Pathway 2 will generate credits against the California equivalent baseline only for the fleet of vehicles sold in California and the CAA section 177 states.[244] This approach includes all CAA 177 states as of the date of promulgation of the Final Rule in this proceeding. Manufacturers are required to include both cars and trucks in the program. Under Pathways 1 and 2, EPA is requiring manufacturers to cover any deficits incurred against the baseline levels established by EPA during the three year period 2009–2011 before credits can be carried forward into the 2012 model year. For example, a deficit in 2011 would have to be subtracted from the sum of credits earned in 2009 and 2010 before any credits could be applied to 2012 (or later) model year fleets. EPA is including this provision to help ensure the early credits generated under this program are consistent with the credits available under the California program during these model years. In its comments, California supported such an approach.

Table III.C.5–1 provides the California equivalent baselines EPA is finalizing to be used as the basis for CO_2 credit generation under the California-based pathways. These are the California GHG standards for the model years shown. EPA proposed to adjust the California standards by 2.0 g/mile to account for the exclusion of N_2O and CH_4, which are included in the California GHG standards, but not included in the credits program. EPA received comments from one manufacturer that this adjustment is in error and should not be made. The commenter noted that EPA already includes total hydrocarbons in the carbon balance determination of carbon related exhaust emissions and therefore already accounts for CH_4. EPA also includes CO in the carbon related exhaust emissions determination which acts to offset the need for an N_20 adjustment. The commenter noted that THC and CO add about 0.8 to 3.0 g/mile to the determination of carbon related emissions and therefore EPA should not make the 2.0g/mile adjustment. The commenter is correct, and therefore the final levels shown in the table below are 2.0 g/mile higher than proposed. These comments are further discussed in the Response to Comments document. Manufacturers will generate CO_2 credits by achieving fleet average CO_2 levels below these baselines. As shown in the table, the California-based early credit pathways are based on the California vehicle categories. Also, the California-based baseline levels are not footprint-based, but universal levels that all manufacturers would use. Manufacturers will need to achieve fleet levels below those shown in the table in order to earn credits, using the California vehicle category definitions.

[244] CAA 177 states refers to states that have adopted the California GHG standards. At present, there are thirteen CAA 177 states: New York, Massachusetts, Maryland, Vermont, Maine, Connecticut, Arizona, New Jersey, New Mexico, Oregon, Pennsylvania, Rhode Island, Washington, as well as Washington, DC.

TABLE III.C.5–1—CALIFORNIA EQUIVALENT BASELINES CO_2 EMISSIONS LEVELS FOR EARLY CREDIT GENERATION

Model year	Passenger cars and light trucks with an LVW of 0–3,750 lbs	Light trucks with a LVW of 3,751 or more and a GVWR of up to 8,500 lbs plus medium-duty passenger vehicles
2009	323	439
2010	301	420
2011	267	390

Manufacturers using Pathways 1 or 2 above will use year-end car and truck sales in each category. Although production data is used for the program starting in 2012, EPA is using sales data for the early credits program in order to apportion vehicles by State. This is described further below. Manufacturers must calculate actual fleet average emissions over the appropriate vehicle fleet, either for vehicles sold nationwide for Pathway 1, or California plus 177 states sales for Pathway 2. Early CO_2 credits are based on the difference between the baseline shown in the table above and the actual fleet average emissions level achieved. Any early A/C credits generated by the manufacturer, described below in Section III.C.5.b, will be included in the fleet average level determination. In model year 2009, the California CO_2 standard for cars (323 g/mi CO_2) is equivalent to 323 g/mi CO_2, and the California light-truck standard (437 g/mi CO_2) is less stringent than the equivalent CAFE standard, recognizing that there are some differences between the way the California program and the CAFE program categorize vehicles. Manufacturers are required to show that they over comply over the entire three model year time period, not just the 2009 model year, to generate early credits under either Pathways 1, 2 or 3. A manufacturer cannot use credits generated in model year 2009 unless they offset any debits from model years 2010 and 2011.

EPA received comments that this approach will provide windfall credits to manufacturers because the MY 2009 California light truck standards are less stringent than the corresponding CAFE standards. While this could be accurate if credits were based on performance in just MY 2009, that is not how credits are determined. Credits are based on the performance over a three model year period, MY 2009–2011. As noted in the proposal, EPA expects that the requirement to over comply over the entire time period covering these three model years should mean that the credits that are generated are real and are in excess of what would have otherwise occurred. However, because of the circumstances involving the 2009 model year, in particular for companies with significant truck sales, there is some concern that under Pathways 1, 2, and 3, there is a potential for a large number of credits generated in 2009 against the California standard, in particular for a number of companies who have significantly over-achieved on CAFE in recent model years. Some commenters were very concerned about this issue and commented in support of restricting credit trading between firms of MY 2009 credits based on the California program. EPA requested comments on this approach and is finalizing this credit trading restriction based on continued concerns regarding the issue of windfall credits. EPA wants to avoid a situation where, contrary to expectation, some part of the early credits generated by a manufacturer are in fact not excess, where companies could trade such credits to other manufacturers, risking a delay in the addition of new technology across the industry from the 2012 and later EPA CO_2 standards. Therefore, manufacturers selecting Pathways 1, 2, or 3 will not be allowed to trade any MY 2009 credits that they may generate.

Commenters also recommended basing credits on the more stringent of the standards between CAFE and CARB, which for MY 2009, would be the CAFE standards. However, EPA believes that this would not be necessary in light of the credit provisions requiring manufacturers choosing the California based pathways to use the California pathway for all three MYs 2009–2011, and the credit trading restrictions for MY 2009 discussed above.

In addition, for Pathways 1 and 2, EPA is allowing manufacturers to include alternative compliance credits earned per the California alternative compliance program.[245] These alternative compliance credits are based on the demonstrated use of alternative fuels in flex fuel vehicles. As with the California program, the credits are available beginning in MY 2010. Therefore, these early alternative compliance credits are available under EPA's program for the 2010 and 2011 model years. FFVs are otherwise included in the early credit fleet average based on their emissions on the conventional fuel. This does not apply to EVs and PHEVs. The emissions of EVs and PHEVs are to be determined as described in Section III.C.3. Manufacturers may choose to either include their EVs and PHEVs in one of the four pathways described in this section or under the early advanced technology emissions credits described below, but not both due to issues of credit double counting.

EPA is also finalizing two additional early credit pathways manufacturers could select. Pathways 3 and 4 incorporate credits based on over-compliance with CAFE standards for vehicles sold outside of California and CAA 177 states in MY 2009–2011. Pathway 3 allows manufacturers to earn credits as under Pathway 2, plus earn CAFE-based credits in other states. Credits may not be generated for cars sold in California and CAA 177 states unless vehicle fleets in those states are performing better than the standards which otherwise would apply in those states, *i.e.,* the baselines shown in Table III.C.5–1 above.

Pathway 4 is for manufacturers choosing to forego California-based early credits entirely and earn only CAFE-based credits outside of California and CAA 177 states. Manufacturers may not include FFV credits under the CAFE-based early credit pathways since those credits do not automatically reflect actual reductions in CO_2 emissions.

The baselines for CAFE-based early pathways are provided in Table III.C.5–2 below. They are based on the CAFE standards for the 2009–2011 model years. For CAFE standards in 2009–2011 model years that are footprint-based, the baseline would vary by manufacturer. Footprint-based standards are in effect for the 2011 model year CAFE

[245] *See* Section 6.6.E, California Environmental Protection Agency Air Resources Board, Staff Report: Initial Statement of Reasons For Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions From Motor Vehicles, August 6, 2004.

standards.[246] Additionally, for Reform CAFE truck standards, footprint standards are optional for the 2009–2010 model years. Where CAFE footprint-based standards are in effect, manufacturers will calculate a baseline using the footprints and sales of vehicles outside of California and CAA 177 states. The actual fleet CO_2 performance calculation will also only include the vehicles sold outside of California and CAA 177 states, and as mentioned above, may not include FFV credits.

TABLE III.C.5–2—CAFE EQUIVALENT BASELINES CO_2 EMISSIONS LEVELS FOR EARLY CREDIT GENERATION

Model year	Cars	Trucks
2009	323	381 *
2010	323	376 *
2011	Footprint-based standard	Footprint-based standard.

* Must be footprint-based standard for manufacturers selecting footprint option under CAFE.

For the CAFE-based pathways, EPA is using the NHTSA car and truck definitions that are in place for the model year in which credits are being generated. EPA understands that the NHTSA definitions change starting in the 2011 model year, and therefore changes part way through the early credits program. EPA further recognizes that medium-duty passenger vehicles (MDPVs) are not part of the CAFE program until the 2011 model year, and therefore are not part of the early credits calculations for 2009–2010 under the CAFE-based pathways.

Pathways 2 through 4 involve splitting the vehicle fleet into two groups, vehicles sold in California and CAA 177 states and vehicles sold outside of these states. This approach requires a clear accounting of location of vehicle sales by the manufacturer. EPA believes it will be reasonable for manufacturers to accurately track sales by State, based on its experience with the National Low Emissions Vehicle (NLEV) Program. NLEV required manufacturers to meet separate fleet average standards for vehicles sold in two different regions of the country.[247] As with NLEV, the determination is to be based on where the completed vehicles are delivered as a point of first sale, which in most cases would be the dealer.[248]

As noted above, manufacturers choosing to generate early CO_2 credits must select one of the four pathways for the entire early credits program and would not be able to switch among them. Manufacturers must submit their early credits report to EPA when they submit their final CAFE report for MY 2011 (which is required to be submitted no later than 90 days after the end of the model year). Manufacturers will have until then to decide which pathway to select. This gives manufacturers enough time to determine which pathway works best for them. This timing may be necessary in cases where manufacturers earn credits in MY 2011 and need time to assess data and prepare an early credits submittal for final EPA approval.

The table below provides a summary of the four fleet average-based CO_2 early credit pathways EPA is finalizing:

TABLE III.C.5–3—SUMMARY OF EARLY FLEET AVERAGE CO_2 CREDIT PATHWAYS

Common Elements	—Manufacturers select a pathway. Once selected, may not switch among pathways. —All credits subject to 5 year carry-forward restrictions. —For Pathways 2–4, vehicles apportioned by State based on point of first sale.
Pathway 1: California-based Credits for National Fleet	—Manufacturers earn credits based on fleet average emissions compared with California equivalent baseline set by EPA. —Based on nationwide CO_2 sales-weighted fleet average. —Based on use of California vehicle categories. —FFV alternative compliance credits per California program may be included. —Once in the program, manufacturers must make up any deficits that are incurred prior to 2012 in order to carry credits forward to 2012 and later.
Pathway 2: California-based Credits for vehicles sold in California plus CAA 177 States.	—Same as Pathway 1, but manufacturers only includes vehicles sold in California and CAA 177 states in the fleet average calculation.
Pathway 3: Pathway 2 plus CAFE-based Credits outside of California plus CAA 177 States.	—Manufacturer earns credits as provided by Pathway 2: California-based credits for vehicles sold in California plus CAA 177 States, plus: —CAFE-based credits allowed for vehicles sold outside of California and CAA 177 states. —For CAFE-based credits, manufacturers earn credits based on fleet average emissions compared with baseline set by EPA. —CAFE-based credits based on NHTSA car and truck definitions. —FFV credits not allowed to be included for CAFE-based credits.
Pathway 4: Only CAFE-based Credits outside of California plus CAA 177 States.	—Manufacturer elects to only earn CAFE-based credits for vehicles sold outside of California and CAA 177 states. Earns no California and 177 State credits. —For CAFE-based credits, manufacturers earn credits based on fleet average emissions compared with baseline set by EPA. —CAFE-based credits based on NHTSA car and truck definitions. —FFV credits not allowed to be included for CAFE-based credits.

[246] 74 FR 14196, March 30, 2009.

[247] 62 FR 31211, June 6, 1997.

[248] 62 FR 31212, June 6, 1997.

b. Early A/C Credits

As proposed, EPA is finalizing provisions allowing manufacturers to earn early A/C credits in MYs 2009–2011 using the same A/C system design-based EPA provisions being finalized for MYs commencing in 2012, as described in Section III.C.1, above. Manufacturers will be able to earn early A/C CO_2-equivalent credits by demonstrating improved A/C system performance, for both direct and indirect emissions. To earn credits for vehicles sold in California and CAA 177 states, the vehicles must be included in one of the California-based early credit pathways described above in III.C.5.a. EPA is finalizing this constraint in order to avoid credit double counting with the California program in place in those states, which also allows A/C system credits in this time frame. Manufacturers must fold the A/C credits into the fleet average CO_2 calculations under the California-based pathway. For example, the MY 2009 California-based program car baseline would be 323 g/mile (see Table III.C.5–1). If a manufacturer under Pathway 1 had a MY 2009 car fleet average CO_2 level of 320 g/mile and then earned an additional 12 g/mile CO_2-equivalent A/C credit, the manufacturers would earn a total of 10 g/mile of credit. Vehicles sold outside of California and 177 states would be eligible for the early A/C credits whether or not the manufacturers participate in other aspects of the early credits program. The early A/C credits for vehicles sold outside of California and 177 states are based on the NHTSA vehicle categories established for the model year in which early A/C credits are being earned.

c. Early Advanced Technology Vehicle Incentive

As discussed in Section III.C.3, above, EPA is finalizing an incentive for sales of advanced technology vehicles including EVs, PHEVs, and fuel cell vehicles. EPA is not including a multiplier for these vehicles. However, EPA is allowing the use of the 0 g/mile value for electricity operation for up to 200,000 vehicles per manufacturer (or 300,000 vehicles for any manufacturer that sells 25,000 or more advanced technology vehicles in MY 2012). EPA believes that providing an incentive for the sales of such vehicles prior to MY 2012 is consistent with the goal encouraging the introduction of such vehicles as early as possible. Therefore, manufacturers may use the 0 g/mile value for vehicles sold in MY 2009–2011 consistent with the approach being finalized for MY 2012–2016. Any vehicles sold prior to MY 2012 under these provisions must be counted against the cumulative sales cap of 200,000 (or 300,000, if applicable) vehicles. Manufacturers selling such vehicles in MY 2009–2011 have the option of either folding them into the early credits calculation under Pathways 1 through 4 described in III.C.5.a above, or tracking the sales of these vehicles separately for use in their fleetwide average compliance calculation in MY 2012 or later years, but may not do both as this would lead to double counting. Manufacturers tracking the sales of vehicles not folded into Pathways 1–4, may choose to use the vehicle counts along with the 0 g/mi emissions value (up to the applicable vehicle sales cap) to comply with 2012 or later standards. For example, if a manufacturer sells 1,000 EVs in MY 2011, the manufacturer would then be able to include 1,000 vehicles at 0 g/mile in their MY 2012 fleet to decrease the fleet average for that model year. Again, these 1,000 vehicles would be counted against the cumulative cap of 200,000 or 300,000, as applicable, vehicles. Also, these 1,000 EVs would not be included in the early credit pathways discussed above in Section III.C.5.a, otherwise the vehicles would be double counted. As with early credits, these early advanced technology vehicles will be tracked by model year (2009, 2010, or 2011) and subject to the 5-year carry-forward restrictions.

d. Early Off-Cycle Credits

EPA's is finalizing off-cycle innovative technology credit provisions, as described in Section III.C.4. EPA requested comment on beginning these credits in the 2009–2011 time frame, provided manufacturers are able to make the necessary demonstrations outlined in Section III.C.4, above. EPA is finalizing this approach for early off-cycle credits as a way to encourage innovation to lower emissions as early as possible, including the requirements for public review described in Section III.C.4. Upon EPA approval of a manufacturer's application for credits, the credits may be earned retroactively. EPA did not receive comments specifically on early off-cycle credits.

D. Feasibility of the Final CO_2 Standards

This final rule is based on the need to obtain significant GHG emissions reductions from the transportation sector, and the recognition that there are cost-effective technologies to achieve such reductions for MY 2012–2016 vehicles. As in many prior mobile source rulemakings, the decision on what standard to set is largely based on the effectiveness of the emissions control technology, the cost and other impacts of implementing the technology, and the lead time needed for manufacturers to employ the control technology. The standards derived from assessing these factors are also evaluated in terms of the need for reductions of greenhouse gases, the degree of reductions achieved by the standards, and the impacts of the standards in terms of costs, quantified benefits, and other impacts of the standards. The availability of technology to achieve reductions and the cost and other aspects of this technology are therefore a central focus of this rulemaking.

EPA is taking the same basic approach in this rulemaking, although the technological problems and solutions involved in this rulemaking differ in some ways from prior mobile source rulemakings. Here, the focus of the emissions control technology is on reducing CO_2 and other greenhouse gases. Vehicles combust fuel to perform two basic functions: (1) To transport the vehicle, its passengers and its contents (and any towed loads), and (2) to operate various accessories during the operation of the vehicle such as the air conditioner. Technology can reduce CO_2 emissions by either making more efficient use of the energy that is produced through combustion of the fuel or reducing the energy needed to perform either of these functions.

This focus on efficiency calls for looking at the vehicle as an entire system, and the proposed and now final standards reflect this basic paradigm. In addition to fuel delivery, combustion, and aftertreatment technology, any aspect of the vehicle that affects the need to produce energy must also be considered. For example, the efficiency of the transmission system, which takes the energy produced by the engine and transmits it to the wheels, and the resistance of the tires to rolling both have major impacts on the amount of fuel that is combusted while operating the vehicle. The braking system, the aerodynamics of the vehicle, and the efficiency of accessories, such as the air conditioner, all affect how much fuel is combusted as well.

In evaluating vehicle efficiency, we have excluded fundamental changes in vehicles' size and utility. For example, we did not evaluate converting minivans and SUVs to station wagons, converting vehicles with four wheel drive to two wheel drive, or reducing headroom in order to lower the roofline and reduce aerodynamic drag. We have limited our assessment of technical feasibility and resultant vehicle cost to technologies which maintain vehicle utility as much as possible. Manufacturers may decide to alter the utility of the vehicles which they sell in response to this rule, but this is not a necessary consequence of the rule but rather a matter of automaker choice.

This need to focus on the efficient use of energy by the vehicle as a system leads to a broad focus on a wide variety of technologies that affect almost all the systems in the design of a vehicle. As discussed below, there are many technologies that are currently available which can reduce vehicle energy consumption. These technologies are already being commercially utilized to a limited degree in the current light-duty fleet. These technologies include hybrid technologies that use higher efficiency electric motors as the power source in combination with or instead of internal combustion engines. While already commercialized, hybrid technology continues to be developed and offers the potential for even greater efficiency improvements. Finally, there are other advanced technologies under development, such as lean burn gasoline engines, which offer the potential of improved energy generation through improvements in the basic combustion process. In addition, the available technologies are not limited to powertrain improvements but also include mass reduction, electrical system efficiencies, and aerodynamic improvements.

The large number of possible technologies to consider and the breadth of vehicle systems that are affected mean that consideration of the manufacturer's design and production process plays a major role in developing the final standards. Vehicle manufacturers typically develop many different models by basing them on a limited number of vehicle platforms. The platform typically consists of a common set of vehicle architecture and structural components. This allows for efficient use of design and manufacturing resources. Given the very large investment put into designing and producing each vehicle model, manufacturers typically plan on a major redesign for the models approximately every 5 years. At the redesign stage, the manufacturer will upgrade or add all of the technology and make most other changes supporting the manufacturer's plans for the next several years, including plans related to emissions, fuel economy, and safety regulations.

This redesign often involves a package of changes designed to work together to meet the various requirements and plans for the model for several model years after the redesign. This often involves significant engineering, development, manufacturing, and marketing resources to create a new product with multiple new features. In order to leverage this significant upfront investment, manufacturers plan vehicle redesigns with several model years' of production in mind. Vehicle models are not completely static between redesigns as limited changes are often incorporated for each model year. This interim process is called a refresh of the vehicle and generally does not allow for major technology changes although more minor ones can be done (*e.g.,* small aerodynamic improvements, valve timing improvements, etc.). More major technology upgrades that affect multiple systems of the vehicle thus occur at the vehicle redesign stage and not in the time period between redesigns. The Center for Biological Diversity commented on EPA's assumptions on redesign cycles, and these comments are addressed in Section III.D.7 below.

As discussed below, there are a wide variety of CO_2 reducing technologies involving several different systems in the vehicle that are available for consideration. Many can involve major changes to the vehicle, such as changes to the engine block and cylinder heads, redesign of the transmission and its packaging in the vehicle, changes in vehicle shape to improve aerodynamic efficiency and the application of aluminum (and other lightweight materials) in body panels to reduce mass. Logically, the incorporation of emissions control technologies would be during the periodic redesign process. This approach would allow manufacturers to develop appropriate packages of technology upgrades that combine technologies in ways that work together and fit with the overall goals of the redesign. It also allows the manufacturer to fit the process of upgrading emissions control technology into its multi-year planning process, and it avoids the large increase in resources and costs that would occur if technology had to be added outside of the redesign process.

This final rule affects five years of vehicle production, model years 2012–2016. Given the now-typical five year redesign cycle, nearly all of a manufacturer's vehicles will be redesigned over this period. However, this assumes that a manufacturer has sufficient lead time to redesign the first model year affected by this final rule with the requirements of this final rule in mind. In fact, the lead time available for the start of model year 2012 (January 2011) is relatively short, less than a year. The time between this final rule and the start of 2013 model year (January 2012) production is under two years. At the same time, manufacturer product plans indicate that they are planning on introducing many of the technologies EPA projects could be used to show compliance with the final CO_2 standards in both 2012 and 2013. In order to account for the relatively short lead time available prior to the 2012 and 2013 model years, albeit mitigated by their existing plans, EPA has factored this reality into how the availability is modeled for much of the technology being considered for model years 2012–2016 as a whole. If the technology to control greenhouse gas emissions is efficiently folded into this redesign process, then EPA projects that 85 percent of each manufacturer's sales will be able to be redesigned with many of the CO_2 emission reducing technologies by the 2016 model year, and as discussed below, to reduce emissions of HFCs from the air conditioner.

In determining the level of this first ever GHG emissions standard under the CAA for light-duty vehicles, EPA uses an approach that accounts for and builds on this redesign process. This provides the opportunity for several control technologies to be incorporated into the vehicle during redesign, achieving significant emissions reductions from the model at one time. This is in contrast to what would be a much more costly approach of trying to achieve small increments of reductions over multiple years by adding technology to the vehicle piece by piece outside of the redesign process.

As described below, the vast majority of technology required by this final rule is commercially available and already being employed to a limited extent across the fleet (although the final rule will necessitate far wider penetration of these technologies throughout the fleet). The vast majority of the emission reductions which will result from this final rule will be produced from the increased use of these technologies. EPA also believes that this final rule will encourage the development and limited use of more advanced technologies, such as PHEVs and EVs, and the final rule is structured to facilitate this result.

In developing the final standard, EPA built on the technical work performed by the State of California during its development of its statewide GHG program. EPA began by evaluating a nationwide CAA standard for MY 2016 that would require the levels of technology upgrade, across the country, which California standards would require for the subset of vehicles sold in California under Pavley 1. In essence, EPA developed an assessment of an equivalent national new vehicle fleet-wide CO_2 performance standards for model year 2016 which would result in the new vehicle fleet in the State of California having CO_2 performance equal to the performance from the California Pavley 1 standards. This assessment is documented in Chapter 3.1 of the RIA. The results of this assessment predicts that a national light-duty vehicle fleet which adopts technology that achieves performance of 250 g/mile CO_2 for model year 2016 will result in vehicles sold in California that would achieve the CO_2 performance equivalent to the Pavley 1 standards.

EPA then analyzed a level of 250 g/mi CO_2 in 2016 using the OMEGA model (described in more detail below), and the car and truck footprint curves' relative stringency discussed in Section II to determine what technology will be needed to achieve a fleet wide average of 250 g/mi CO_2. As discussed later in this section we believe this level of technology application to the light-duty vehicle fleet can be achieved in this time frame, that such standards will produce significant reductions in GHG emissions, and that the costs for both the industry and the costs to the consumer are reasonable. EPA also developed standards for the model years 2012 through 2015 that lead up to the 2016 level.

EPA's independent technical assessment of the technical feasibility of the final MY 2012–2016 standards is described below. EPA has also evaluated a set of alternative standards for these model years, one that is more stringent than the final standards and one that is less stringent. The technical feasibility of these alternative standards is discussed at the end of this section.

Evaluating the feasibility of these standards primarily includes identifying available technologies and assessing their effectiveness, cost, and impact on relevant aspects of vehicle performance and utility. The wide number of technologies which are available and likely to be used in combination requires a more sophisticated assessment of their combined cost and effectiveness. An important factor is also the degree that these technologies are already being used in the current vehicle fleet and thus, unavailable for use to improve energy efficiency beyond current levels. Finally, the challenge for manufacturers to design the technology into their products, and the appropriate lead time needed to employ the technology over the product line of the industry must be considered.

Applying these technologies efficiently to the wide range of vehicles produced by various manufacturers is a challenging task. In order to assist in this task, EPA has developed a computerized model called the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA) model. Broadly, the model starts with a description of the future vehicle fleet, including manufacturer, sales, base CO_2 emissions, footprint and the extent to which emission control technologies are already employed. For the purpose of this analysis, over 200 vehicle platforms were used to capture the important differences in vehicle and engine design and utility of future vehicle sales of roughly 16 million units in the 2016 timeframe. The model is then provided with a list of technologies which are applicable to various types of vehicles, along with their cost and effectiveness and the percentage of vehicle sales which can receive each technology during the redesign cycle of interest. The model combines this information with economic parameters, such as fuel prices and a discount rate, to project how various manufacturers would apply the available technology in order to meet various levels of emission control. The result is a description of which technologies are added to each vehicle platform, along with the resulting cost. While OMEGA can apply technologies which reduce CO_2 emissions and HFC refrigerant emissions associated with air conditioner use, this task is currently handled outside of the OMEGA model. The model can be set to account for various types of compliance flexibilities, such as FFV credits.

The remainder of this section describes the technical feasibility analysis in greater detail. Section III.D.1 describes the development of our projection of the MY 2012–2016 fleet in the absence of this final rule. Section III.D.2 describes our estimates of the effectiveness and cost of the control technologies available for application in the 2012–2016 timeframe. Section III.D.3 combines these technologies into packages likely to be applied at the same time by a manufacturer. In this section, the overall effectiveness of the technology packages vis-à-vis their effectiveness when combined individually is described. Section III.D.4 describes the process which manufacturers typically use to apply new technology to their vehicles. Section III.D.5 describes EPA's OMEGA model and its approach to estimating how manufacturers will add technology to their vehicles in order to comply with CO_2 emission standards. Section III.D.6 presents the results of the OMEGA modeling, namely the level of technology added to manufacturers' vehicles and its cost. Section III.D.7 discusses the feasibility of the alternative 4-percent-per-year and 6-percent-per-year standards. Further detail on all of these issues can be found in EPA and NHTSA's Joint Technical Support Document as well as EPA's Regulatory Impact Analysis.

1. How did EPA develop a reference vehicle fleet for evaluating further CO_2 reductions?

In order to calculate the impacts of this final rule, it is necessary to project the GHG emissions characteristics of the future vehicle fleet absent this regulation. This is called the "reference" fleet. EPA and NHTSA develop this reference fleet using a three step process. Step one develops a set of detailed vehicle characteristics and sales for a specific model year (in this case, 2008). This is called the baseline fleet. Step two adjusts the sales of these vehicles using projections made by AEO and CSM to account for expected changes in market conditions. Step three applies fuel saving and emission control technology to these vehicles to the extent necessary for manufacturers to comply with the MY 2011 CAFE standards. Thus, the reference fleet differs from the MY 2008 baseline fleet in both the level of technology utilized and in terms of the sales of any particular vehicle.

EPA and NHTSA perform steps one and two in an identical manner. The development of the characteristics of the baseline 2008 fleet and the adjustment of sales to match AEO and CSM forecasts is described in detail in Section II.B above. The two agencies perform step three in a conceptually identical manner, but each agency utilizes its own vehicle technology and emission model to project the technology needed to comply with the 2011 CAFE standards. The agencies use the same two models to project the technology and cost of the 2012–2016 standards. Use of the same model for both pre-control and post-control costs ensures consistency.

The agencies received one comment from the Center for Biological Diversity that the use of 2008 vehicles in our baseline and reference fleets inherently includes vehicle models which already have or will be discontinued by the time this rule takes effect and will be replaced by more advanced vehicle models. This is true. However, we believe that the use of 2008 vehicle designs is still the most appropriate approach available. First, as discussed in Section II.B above, the designs of these new vehicles at the level of detail required for emission and cost modeling are not publically available. Even the confidential descriptions of these vehicle designs are usually not of sufficient detail to facilitate the level of technology and emission modeling performed by both agencies. Second, steps two and three of the process used to create the reference fleet adjust both the sales and technology of the 2008 vehicles. Thus, our reference fleet reflects the extent that completely new vehicles are expected to shift the light vehicle market in terms of both segment and manufacturer. Also, by adding technology to facilitate compliance with the 2011 CAFE standards, we account for the vast majority of ways in which these new vehicles will differ from their older counterparts.

The agencies also received a comment that some manufacturers have already announced plans to introduce technology well beyond that required by the 2011 MY CAFE standards. This commenter indicated that the agencies' approach over-estimated the technology and cost required by the proposed standards and resulted in less stringent standards being proposed than a more realistic reference fleet would have supported. First, the agencies agree that limiting the application of additional technology beyond that already on 2008 vehicles to only that required by the 2011 CAFE standards could under-estimate the use of such technology absent this rule. However, it is difficult, if not impossible, to separate future fuel economy improvements made for marketing purposes from those designed to facilitate compliance with anticipated CAFE or CO_2 emission standards. For example, EISA was signed over two years ago, which contained specific minimum limits on light vehicle fuel economy in 2020, while also requiring ratable improvements in the interim. NHTSA proposed fuel economy standards for the 2012–2015 model years under the EISA provisions in April of 2008, although NHTSA finalized only 2011 standards for passenger vehicles. It is also true that manufacturers can change their plans based on market conditions and other factors. Thus, announcements of future plans are not certain. As mentioned above, these plans do not include specific vehicle characteristics. Thus, in order to avoid under-estimating the cost associated with this rule, the agencies have limited the fuel economy improvements in the reference fleet to those projected to result from the existing CAFE standards. We disagree with the commenter that this has caused the standards being promulgated today to be less stringent than would have been the case had we been able to confidently predict additional fuel economy and CO_2 emission improvements which will occur absent this rule. The inclusion of such technology in the reference fleet would certainly have reduced the cost of this final rule, as well as the benefits, but would not have changed the final level of technology required to meet the final standards. Also, we believe that the same impacts would apply to our evaluations of the two alternative sets of standards, the 4% per year and 6% per year standards. We are confident that the vast majority of manufacturers would not comply with the least stringent of these standards (the 4% per year standards) in the absence of this rule. Thus, changes to the reference fleet would not have affected the differences in technology, cost or benefits between the final standards and the two alternatives. As described below, our rejection of the two alternatives in favor of the final standards is based primarily on the relative technology, cost and benefits associated with the three sets of standards than the absolute cost or benefit relative to the reference fleet. Thus, we do not agree with the commenter that our choice of reference fleet adversely impacted the development of the final standards being promulgated today.

The addition of technology to the baseline fleet so that it complies with the MY 2011 CAFE standards is described later in Section III.D.4, as this uses the same methodology used to project compliance with the final CO_2 emission standards. In summary, the reference fleet represents vehicle characteristics and sales in the 2012 and later model years absent this final rule. Technology is then added to these vehicles in order to reduce CO_2 emissions to achieve compliance with the final CO_2 standards. As noted above, EPA did not factor in any changes to vehicle utility or characteristics, or sales in projecting manufacturers' compliance with this final rule.

After the reference fleet is created, the next step aggregates vehicle sales by a combination of manufacturer, vehicle platform, and engine design. As discussed in Section III.D.4 below, manufacturers implement major design changes at vehicle redesign and tend to implement these changes across a vehicle platform. Because the cost of modifying the engine depends on the valve train design (such as SOHC, DOHC, etc.), the number of cylinders and in some cases head design, the vehicle sales are broken down beyond the platform level to reflect relevant engine differences. The vehicle groupings are shown in Table III.D.1–1. These groupings are the same as those used in the NPRM.

TABLE III.D.1–1—VEHICLE GROUPINGS [a]

Vehicle description	Vehicle type	Vehicle description	Vehicle type
Large SUV (Car) V8+ OHV	13	Subcompact Auto I4	1
Large SUV (Car) V6 4v	16	Large Pickup V8+ DOHC	19
Large SUV (Car) V6 OHV	12	Large Pickup V8+ SOHC 3v	14
Large SUV (Car) V6 2v SOHC	9	Large Pickup V8+ OHV	13
Large SUV (Car) I4 and I5	7	Large Pickup V8+ SOHC	10
Midsize SUV (Car) V6 2v SOHC	8	Large Pickup V6 DOHC	18
Midsize SUV (Car) V6 S/DOHC 4v	5	Large Pickup V6 OHV	12
Midsize SUV (Car) I4	7	Large Pickup V6 SOHC 2v	11
Small SUV (Car) V6 OHV	12	Large Pickup I4 S/DOHC	7
Small SUV (Car) V6 S/DOHC	4	Small Pickup V6 OHV	12
Small SUV (Car) I4	3	Small Pickup V6 2v SOHC	8
Large Auto V8+ OHV	13	Small Pickup I4	7
Large Auto V8+ SOHC	10	Large SUV V8+ DOHC	17
Large Auto V8+ DOHC, 4v SOHC	6	Large SUV V8+ SOHC 3v	14
Large Auto V6 OHV	12	Large SUV V8+ OHV	13
Large Auto V6 SOHC 2/3v	5	Large SUV V8+ SOHC	10
Midsize Auto V8+ OHV	13	Large SUV V6 S/DOHC 4v	16

TABLE III.D.1–1—VEHICLE GROUPINGS [a]—Continued

Vehicle description	Vehicle type	Vehicle description	Vehicle type
Midsize Auto V8+ SOHC	10	Large SUV V6 OHV	12
Midsize Auto V7+ DOHC, 4v SOHC	6	Large SUV V6 SOHC 2v	9
Midsize Auto V6 OHV	12	Large SUV I4	7
Midsize Auto V6 2v SOHC	8	Midsize SUV V6 OHV	12
Midsize Auto V6 S/DOHC 4v	5	Midsize SUV V6 2v SOHC	8
Midsize Auto I4	3	Midsize SUV V6 S/DOHC 4v	5
Compact Auto V7+ S/DOHC	6	Midsize SUV I4 S/DOHC	7
Compact Auto V6 OHV	12	Small SUV V6 OHV	12
Compact Auto V6 S/DOHC 4v	4	Minivan V6 S/DOHC	16
Compact Auto I5	7	Minivan V6 OHV	12
Compact Auto I4	2	Minivan I4	7
Subcompact Auto V8+ OHV	13	Cargo Van V8+ OHV	13
Subcompact Auto V8+ S/DOHC	6	Cargo Van V8+ SOHC	10
Subcompact Auto V6 2v SOHC	8	Cargo Van V6 OHV	12
Subcompact Auto I5/V6 S/DOHC 4v	4		

[a] I4 = 4 cylinder engine, I5 = 5 cylinder engine, V6, V7, and V8 = 6, 7, and 8 cylinder engines, respectively, DOHC = Double overhead cam, SOHC = Single overhead cam, OHV = Overhead valve, v = number of valves per cylinder, "/" = and, "+" = or larger.

As mentioned above, the second factor which needs to be considered in developing a reference fleet against which to evaluate the impacts of this final rule is the impact of the 2011 MY CAFE standards. Since the vehicles which comprise the above reference fleet are those sold in the 2008 MY, when coupled with our sales projections, they do not necessarily meet the 2011 MY CAFE standards.

The levels of the 2011 MY CAFE standards are straightforward to apply to future sales fleets, as is the potential fine-paying flexibility afforded by the CAFE program (*i.e.,* $55 per mpg of shortfall). However, projecting some of the compliance flexibilities afforded by EISA and the CAFE program are less clear. Two of these compliance flexibilities are relevant to EPA's analysis: (1) The credit for FFVs, and (2) the limit on the transferring of credits between car and truck fleets. The FFV credit is limited to 1.2 mpg in 2011 and EISA gradually reduces this credit, to 1.0 mpg in 2015 and eventually to zero in 2020. In contrast, the limit on car-truck transfer is limited to 1.0 mpg in 2011, and EISA increases this to 1.5 mpg beginning in 2015 and then to 2.0 mpg beginning in 2020. The question here is whether to hold the 2011 MY CAFE provisions constant in the future or incorporate the changes in the FFV credit and car-truck credit trading limits contained in EISA.

As was done for the NPRM, EPA has decided to hold the 2011 MY limits on FFV credit and car-truck credit trading constant in projecting the fuel economy and CO_2 emission levels of vehicles in our reference case. This approach treats the changes in the FFV credit and car-truck credit trading provisions consistently with the other EISA-mandated changes in the CAFE standards themselves. All EISA provisions relevant to 2011 MY vehicles are reflected in our reference case fleet, while all post-2011 MY provisions are not. Practically, relative to the alternative, this increases both the cost and benefit of the final standards. In our analysis of this final rule, any quantified benefits from the presence of FFVs in the fleet are not considered. Thus, the only impact of the FFV credit is to reduce onroad fuel economy. By assuming that the FFV credit stays at 1.2 mpg in the future absent this rule, the assumed level of onroad fuel economy that would occur absent this final rule is reduced. As this final rule eliminates the FFV credit (for purposes of CO_2 emission compliance) starting in 2016, the net result is to increase the projected level of fuel savings from our final standards. Similarly, the higher level of FFV credit reduces projected compliance cost for manufacturers to meet the 2011 MY standards in our reference case. This increases the projected cost of meeting the final 2012 and later standards.

As just implied, EPA needs to project the technology (and resultant costs) required for the 2008 MY vehicles to comply with the 2011 MY CAFE standards in those cases where they do not automatically do so. The technology and costs are projected using the same methodology that projects compliance with the final 2012 and later CO_2 standards. The description of this process is described in the following four sections and is essentially the same process used for the NPRM.

A more detailed description of the methodology used to develop these sales projections can be found in the Joint TSD. Detailed sales projections by model year and manufacturer can also be found in the TSD.

2. What are the effectiveness and costs of CO_2-reducing technologies?

EPA and NHTSA worked together to jointly develop information on the effectiveness and cost of the CO_2-reducing technologies, and fuel economy-improving technologies, other than A/C related control technologies. This joint work is reflected in Chapter 3 of the Joint TSD and in Section II of this preamble. A summary of the effectiveness and cost of A/C related technology is contained here. For more detailed information on the effectiveness and cost of A/C related technology, please refer to Section III.C of this preamble and Chapter 2 of EPA's RIA.

A/C improvements are an integral part of EPA's technology analysis and have been included in this section along with the other technology options. While discussed in Section III.C as a credit opportunity, air conditioning-related improvements are included in Table III.D.2–1. because A/C improvements are a very cost-effective technology at reducing CO_2 (or CO_2-equivalent) emissions. EPA expects most manufacturers will choose to use AC improvement credit opportunities as a strategy for meeting compliance with the CO_2 standards. Note that the costs shown in Table III.D.2–1 do not include maintenance savings that would be expected from the new AC systems. Further, EPA does not include AC-related maintenance savings in our cost and benefit analysis presented in Section III.H. EPA discusses the likely maintenance savings in Chapter 2 of the RIA, though these savings are not included in our final cost estimates for the final rule. The EPA approximates that the level of the credits earned will increase from 2012 to 2016 as more vehicles in the fleet are redesigned. The penetrations and average levels of credit are summarized in Table III.D.2–2, though the derivation of these numbers (and the breakdown of car vs. truck credits) is described in the RIA. As demonstrated in the IMAC study (and described in Section III.C as well as the RIA), these levels are feasible and achievable with technologies that are available and cost-effective today.

These improvements are categorized as either leakage reduction, including use of alternative refrigerants, or system efficiency improvements. Unlike the majority of the technologies described in this section, A/C improvements will not be demonstrated in the test cycles used to quantify CO_2 reductions in this final rule. As described earlier, for this analysis A/C-related CO_2 reductions are handled outside of OMEGA model and therefore their CO_2 reduction potential is expressed in grams per mile rather than a percentage used by the OMEGA model. *See* Section III.C.1 for the method by which potential reductions are calculated or measured. Further discussion of the technological basis for these improvements is included in Chapter 2 of the RIA.

TABLE III.D.2–1—TOTAL CO_2 REDUCTION POTENTIAL AND 2016 COST FOR A/C RELATED TECHNOLOGIES FOR ALL VEHICLE CLASSES

[Costs in 2007 dollars]

	CO_2 reduction potential	Incremental compliance costs
A/C refrigerant leakage reduction	7.5 g/mi [249]	$17
A/C efficiency improvements	5.7 g/mi	53

TABLE III.D.2–2—A/C RELATED TECHNOLOGY PENETRATION AND CREDIT LEVELS EXPECTED TO BE EARNED

	Technology penetration (percent)	Average credit over entire fleet		
		Car	Truck	Fleet average
2012	[250] 28	3.4	3.8	3.5
2013	40	4.8	5.4	5.0
2014	60	7.2	8.1	7.5
2015	80	9.6	10.8	10.0
2016	85	10.2	11.5	10.6

3. How can technologies be combined into "packages" and what is the cost and effectiveness of packages?

Individual technologies can be used by manufacturers to achieve incremental CO_2 reductions. However, as mentioned in Section III.D.1, EPA believes that manufacturers are more likely to bundle technologies into "packages" to capture synergistic aspects and reflect progressively larger CO_2 reductions with additions or changes to any given package. In addition, manufacturers typically apply new technologies in packages during model redesigns that occur approximately once every five years, rather than adding new technologies one at a time on an annual or biennial basis. This way, manufacturers can more efficiently make use of their redesign resources and more effectively plan for changes necessary to meet future standards.

Therefore, as explained at proposal, the approach taken here is to group technologies into packages of increasing cost and effectiveness. EPA determined that 19 different vehicle types provided adequate representation to accurately model the entire fleet. This was the result of analyzing the existing light duty fleet with respect to vehicle size and powertrain configurations. All vehicles, including cars and trucks, were first distributed based on their relative size, starting from compact cars and working upward to large trucks. Next, each vehicle was evaluated for powertrain, specifically the engine size, I4, V6, and V8, and finally by the number of valves per cylinder. Note that each of these 19 vehicle types was mapped into one of the five classes of vehicles mentioned in Section III.D.2. While the five classes provide adequate representation for the cost basis associated with most technology application, they do not adequately account for all existing vehicle attributes such as base vehicle powertrain configuration and mass reduction. As an example, costs and effectiveness estimates for engine friction reduction for the small car class were used to represent cost and effectiveness for three vehicle types: Subcompact cars, compact cars, and small multi-purpose vehicles (MPV) equipped with a 4-cylinder engine, however the mass reduction associated for each of these vehicle types was based on the vehicle type sales-weighted average. In another example, a vehicle type for V8 single overhead cam 3-valve engines was created to properly account for the incremental cost in moving to a dual overhead cam 4-valve configuration. Note also that these 19 vehicle types span the range of vehicle footprint (smaller footprints for smaller vehicles and larger footprints for larger vehicles) which serve as the basis for the standards being promulgated today. A complete list of vehicles and their associated vehicle types is shown above in Table III.D.1–1.

Within each of the 19 vehicle types, multiple technology packages were created in increasing technology content resulting in increasing effectiveness. Important to note that the effort in creating the packages attempted to maintain a constant utility for each package as compared to the baseline package. As such, each package is meant to provide equivalent driver-perceived performance to the baseline package. The initial packages represent what a manufacturer will most likely implement on all vehicles, including low rolling resistance tires, low friction lubricants, engine friction reduction, aggressive shift logic, early torque converter lock-up, improved electrical

[249] This represents 50% improvement in leakage and thus 50% of the A/C leakage impact potential compared to a maximum of 15 g/mi credit that can be achieved through the incorporation of a low very GWP refrigerant.

[250] We assume slightly higher A/C penetration in 2012 than was assumed in the proposal to correct for rounding that occurred in the curve setting process.

accessories, and low drag brakes.[251] Subsequent packages include advanced gasoline engine and transmission technologies such as turbo/downsizing, GDI, and dual-clutch transmission. The most technologically advanced packages within a segment included HEV, PHEV and EV designs. The end result is a list of several packages for each of 19 different vehicle types from which a manufacturer could choose in order to modify its fleet such that compliance could be achieved.

Before using these technology packages as inputs to the OMEGA model, EPA calculated the cost and effectiveness for the package. The first step was to apply the scaling class for each technology package and vehicle type combination. The scaling class establishes the cost and effectiveness for each technology with respect to the vehicle size or type. The Large Car class was provided as an example in Section III.D.2. Additional classes include Small Car, Minivan, Small Truck, and Large Truck and each of the 19 vehicle types was mapped into one of those five classes. In the next step, the cost for a particular technology package was determined as the sum of the costs of the applied technologies. The final step, determination of effectiveness, requires greater care due to the synergistic effects mentioned in Section III.D.2. This step is described immediately below.

Usually, the benefits of the engine and transmission technologies can be combined multiplicatively. For example, if an engine technology reduces CO_2 emissions by five percent and a transmission technology reduces CO_2 emissions by four percent, the benefit of applying both technologies is 8.8 percent $(100\% - (100\% - 4\%) * (100\% - 5\%))$. In some cases, however, the benefit of the transmission-related technologies overlaps with many of the engine technologies. This occurs because the primary goal of most of the transmission technologies is to shift operation of the engine to more efficient locations on the engine map. This is accomplished by incorporating more ratio selections and a wider ratio span into the transmissions. Some of the engine technologies have the same goal, such as cylinder deactivation, advanced valvetrains, and turbocharging. In order to account for this overlap and avoid over-estimating emissions reduction effectiveness, EPA has developed a set of adjustment factors associated with specific pairs of engine and transmission technologies.

The various transmission technologies are generally mutually exclusive. As such, the effectiveness of each transmission technology generally supersedes each other. For example, the 9.5–14.5 percent reduction in CO_2 emissions associated with the automated manual transmission includes the 4.5–6.5 percent benefit of a 6-speed automatic transmission. Exceptions are aggressive shift logic and early torque converter lock-up that can be applied to vehicles with several types of automatic transmissions.

EPA has chosen to use an engineering approach known as the lumped-parameter technique to determine these adjustment factors. The results from this approach were then applied directly to the vehicle packages. The lumped-parameter technique is well documented in the literature, and the specific approach developed by EPA is detailed in Chapter 1 of the RIA.

Table III.D.3–1 presents several examples of the reduction in the effectiveness of technology pairs. A complete list and detailed discussion of these synergies is presented in Chapter 3 of the Joint TSD.

TABLE III.D.3–1—REDUCTION IN EFFECTIVENESS FOR SELECTED TECHNOLOGY PAIRS

Engine technology	Transmission technology	Reduction in combined effectiveness (percent)
Intake cam phasing	5 speed automatic	0.5
Coupled cam phasing	5 speed automatic	0.5
Coupled cam phasing	Aggressive shift logic	0.5
Cylinder deactivation	5 speed automatic	1.0
Cylinder deactivation	Aggressive shift logic	0.5

Table III.D.3–2 presents several examples of the CO_2-reducing technology vehicle packages used in the OMEGA model for the large car class. Similar packages were generated for each of the 19 vehicle types and the costs and effectiveness estimates for each of those packages are discussed in detail in Chapter 3 of the Joint TSD.

TABLE III.D.3–2—CO_2 REDUCING TECHNOLOGY VEHICLE PACKAGES FOR A LARGE CAR EFFECTIVENESS AND COSTS IN 2016

[Costs in 2007 dollars]

Engine technology	Transmission technology	Additional technology	CO_2 reduction	Package cost
3.3L V6	4 speed automatic	None	Baseline	
3.0L V6 + GDI + CCP	6 speed automatic	3% Mass Reduction	17.9%	$985
3.0L V6 + GDI + CCP + Deac	6 speed automatic	5% Mass Reduction	20.6%	1,238
2.2L I4 + GDI + Turbo + DCP	6 speed DCT	10% Mass Reduction Start-Stop	34.3%	1,903

[251] When making reference to low friction lubricants, the technology being referred to is the engine changes and possible durability testing that would be done to accommodate the low friction lubricants, not the lubricants themselves.

4. Manufacturer's Application of Technology

Vehicle manufacturers often introduce major product changes together, as a package. In this manner the manufacturers can optimize their available resources, including engineering, development, manufacturing and marketing activities to create a product with multiple new features. In addition, manufacturers recognize that a vehicle will need to remain competitive over its intended life, meet future regulatory requirements, and contribute to a manufacturer's CAFE requirements. Furthermore, automotive manufacturers are largely focused on creating vehicle platforms to limit the development of entirely new vehicles and to realize economies of scale with regard to variable cost. In very limited cases, manufacturers may implement an individual technology outside of a vehicle's redesign cycle.[252] In following with these industry practices, EPA has created set of vehicle technology packages that represent the entire light duty fleet.

In evaluating needed lead time, EPA has historically authorized manufacturers of new vehicles or nonroad equipment to phase in available emission control technology over a number of years. Examples of this are EPA's Tier 2 program for cars and light trucks and its 2007 and later PM and NO_X emission standards for heavy-duty vehicles. In both of these rules, the major modifications expected from the rules were the addition of exhaust aftertreatment control technologies. Some changes to the engine were expected as well, but these were not expected to affect engine size, packaging or performance. The CO_2 reduction technologies described above potentially involve much more significant changes to car and light truck designs. Many of the engine technologies involve changes to the engine block and heads. The transmission technologies could change the size and shape of the transmission and thus, packaging. Improvements to aerodynamic drag could involve body design and therefore, the dies used to produce body panels. Changes of this sort potentially involve new capital investment and the obsolescence of existing investment.

At the same time, vehicle designs are not static, but change in major ways periodically. The manufacturers' product plans indicate that vehicles are usually redesigned every 5 years on average.[253] Vehicles also tend to receive a more modest "refresh" between major redesigns, as discussed above. Because manufacturers are already changing their tooling, equipment and designs at these times, further changes to vehicle design at these times involve a minimum of stranded capital equipment. Thus, the timing of any major technological changes is projected to coincide with changes that manufacturers are already making to their vehicles. This approach effectively avoids the need to quantify any costs associated with discarding equipment, tooling, emission and safety certification, etc. when CO_2-reducing equipment is incorporated into a vehicle.

This final rule affects five years of vehicle production, model years 2012–2016. Given the now-typical five year redesign cycle, nearly all of a manufacturer's vehicles will be redesigned over this period. However, this assumes that a manufacturer has sufficient lead time to redesign the first model year affected by this final rule with the requirements of this final rule in mind. In fact, the lead time available for model year 2012 is relatively short. The time between a likely final rule and the start of 2013 model year production is likely to be just over two years. At the same time, the manufacturer product plans indicate that they are planning on introducing many of the technologies projected to be required by this final rule in both 2012 and 2013. In order to account for the relatively short lead time available prior to the 2012 and 2013 model years, albeit mitigated by their existing plans, EPA projects that only 85 percent of each manufacturer's sales will be able to be redesigned with major CO_2 emission-reducing technologies by the 2016 model year. Less intrusive technologies can be introduced into essentially all of a manufacturer's sales. This resulted in three levels of technology penetration caps, by manufacturer. Common technologies (*e.g.,* low friction lubes, aerodynamic improvements) had a penetration cap of 100%. More advanced powertrain technologies (*e.g.,* stoichiometric GDI, turbocharging) had a penetration cap of 85%. The most advanced technologies considered in this analysis (*e.g.,* diesel engines,[254] as well as IMA, powersplit and 2-mode hybrids) had a 15% penetration cap.

This is the same approach as was taken in the NPRM. EPA received several comments commending it on its approach to establishing technical feasibility via its use of the OMEGA model. The only adverse comment received regarding the application of technology was from the Center for Biological Diversity (CBD), which criticized EPA's use of the 5-year redesign cycle. CBD argued that manufacturers occasionally redesign vehicles sooner than 5 years and that EPA did not quantify the cost of shortening the redesign cycle to less than 5 years and compare this cost to the increased benefit of reduced CO_2 emissions. CBD also noted that manufacturers have been recently dropping vehicle lines and entire divisions with very little leadtime, indicating their ability to change product plans much quicker than projected above.

EPA did not explicitly evaluate the cost of reducing the average redesign cycle to less than 5 years for two reasons. One, in the past, manufacturers have usually shortened the redesign cycle to address serious problems with the current design, usually lower than anticipated sales. However, the amortized cost of the capital necessary to produce a new vehicle design will increase by 23%, from one-fifth of the capital cost to one-fourth (and assuming a 3% discount rate). This would be on top of the cost of the emission control equipment itself. The only benefit of this increase in societal cost will be earlier CO_2 emission reductions (and the other benefits associated with CO_2 emission control). The capital costs associated with vehicle redesign go beyond CO_2 emission control and potentially involve every aspect of the vehicle and can represent thousands of dollars. We believe that it would be an inefficient use of societal resources to incur such costs when they can be obtained much more cost effectively just one year later.

Two, the examples of manufacturers dropping vehicle lines and divisions with very short lead time is not relevant to the redesign of vehicles. There is no relationship between a manufacturer's ability to stop selling a vehicle model or to close a vehicle division and a manufacturer's ability to redesign a vehicle. A company could decide to stop selling all of its products within a few weeks—but it would still take a firm approximately 5 years to introduce a major new vehicle line. It is relatively easy to stop the manufacture of a particular product (though this too can

[252] The Center for Biological Diversity submitted comments disputing this distinction as well as the need for lead time. These comments are addressed in Section III.D.7.

[253] *See* discussion in Section III.D.7 with references.

[254] While diesel engines are a mature technology and not "advanced", the aftertreatment systems necessary for them in the U.S. market are advanced.

incur some cost—such as plant wind-down costs, employee layoff or relocation costs, and dealership related costs). It is much more difficult to perform the required engineering design and development, design, purchase, and install the necessary capital equipment and tooling for components and vehicle manufacturing and develop all the processes associated with the application of a new technology. Further discussion of the CBD comments can be found in III.D.7 below.

5. How is EPA projecting that a manufacturer decides between options to improve CO_2 performance to meet a fleet average standard?

EPA is generally taking the same approach to projecting the application of technology to vehicles as it did for the NPRM. With the exception of two comments, all commenters agreed with the modeling approach taken in the NPRM. One of these two comments is addressed is Section III.D.1 above, while the other is addressed in Section III.D.3. above.

There are many ways for a manufacturer to reduce CO_2-emissions from its vehicles. A manufacturer can choose from a myriad of CO_2 reducing technologies and can apply one or more of these technologies to some or all of its vehicles. Thus, for a variety of levels of CO_2 emission control, there are an almost infinite number of technology combinations which produce the desired CO_2 reduction. As noted earlier, EPA developed a new vehicle model, the OMEGA model in order to make a reasonable estimate of how manufacturers will add technologies to vehicles in order to meet a fleet-wide CO_2 emissions level. EPA has described OMEGA's specific methodologies and algorithms in a memo to the docket for this rulemaking (Docket EPA–HQ–OAR–2009–0472).

The OMEGA model utilizes four basic sets of input data. The first is a description of the vehicle fleet. The key pieces of data required for each vehicle are its manufacturer, CO_2 emission level, fuel type, projected sales and footprint. The model also requires that each vehicle be assigned to one of the 19 vehicle types, which tells the model which set of technologies can be applied to that vehicle. (For a description of how the 19 vehicle types were created, reference Section III.D.3.) In addition, the degree to which each vehicle already reflects the effectiveness and cost of each available technology must also be input. This avoids the situation, for example, where the model might try to add a basic engine improvement to a current hybrid vehicle. Except for this type of information, the development of the required data regarding the reference fleet was described in Section III.D.1 above and in Chapter 1 of the Joint TSD.

The second type of input data used by the model is a description of the technologies available to manufacturers, primarily their cost and effectiveness. Note that the five vehicle classes are not explicitly used by the model, rather the costs and effectiveness associated with each vehicle package is based on the associated class. This information was described in Sections III.D.2 and III.D.3 above as well as Chapter 3 of the Joint TSD. In all cases, the order of the technologies or technology packages for a particular vehicle type is determined by the model user prior to running the model. Several criteria can be used to develop a reasonable ordering of technologies or packages. These are described in the Joint TSD.

The third type of input data describes vehicle operational data, such as annual scrap rates and mileage accumulation rates, and economic data, such as fuel prices and discount rates. These estimates are described in Section II.F above, Section III.H below and Chapter 4 of the Joint TSD.

The fourth type of data describes the CO_2 emission standards being modeled. These include the CO_2 emission equivalents of the 2011 MY CAFE standards and the final CO_2 standards for 2016. As described in more detail below, the application of A/C technology is evaluated in a separate analysis from those technologies which impact CO_2 emissions over the 2-cycle test procedure. Thus, for the percent of vehicles that are projected to achieve A/C related reductions, the CO_2 credit associated with the projected use of improved A/C systems is used to adjust the final CO_2 standard which will be applicable to each manufacturer to develop a target for CO_2 emissions over the 2-cycle test which is assessed in our OMEGA modeling.

As mentioned above for the market data input file utilized by OMEGA, which characterizes the vehicle fleet, our modeling must and does account for the fact that many 2008 MY vehicles are already equipped with one or more of the technologies discussed in Section III.D.2 above. Because of the choice to apply technologies in packages, and 2008 vehicles are equipped with individual technologies in a wide variety of combinations, accounting for the presence of specific technologies in terms of their proportion of package cost and CO_2 effectiveness requires careful, detailed analysis. The first step in this analysis is to develop a list of individual technologies which are either contained in each technology package, or would supplant the addition of the relevant portion of each technology package. An example would be a 2008 MY vehicle equipped with variable valve timing and a 6-speed automatic transmission. The cost and effectiveness of variable valve timing would be considered to be already present for any technology packages which included the addition of variable valve timing or technologies which went beyond this technology in terms of engine related CO_2 control efficiency. An example of a technology which supplants several technologies would be a 2008 MY vehicle which was equipped with a diesel engine. The effectiveness of this technology would be considered to be present for technology packages which included improvements to a gasoline engine, since the resultant gasoline engines have a lower CO_2 control efficiency than the diesel engine. However, if these packages which included improvements also included improvements unrelated to the engine, like transmission improvements, only the engine related portion of the package already present on the vehicle would be considered. The transmission related portion of the package's cost and effectiveness would be allowed to be applied in order to comply with future CO_2 emission standards.

The second step in this process is to determine the total cost and CO_2 effectiveness of the technologies already present and relevant to each available package. Determining the total cost usually simply involves adding up the costs of the individual technologies present. In order to determine the total effectiveness of the technologies already present on each vehicle, the lumped parameter model described above is used. Because the specific technologies present on each 2008 vehicle are known, the applicable synergies and dis-synergies can be fully accounted for.

The third step in this process is to divide the total cost and CO_2 effectiveness values determined in step 2 by the total cost and CO_2 effectiveness of the relevant technology packages. These fractions are capped at a value of 1.0 or less, since a value of 1.0 causes the OMEGA model to not change either the cost or CO_2 emissions of a vehicle when that technology package is added.

As described in Section III.D.3 above, technology packages are applied to groups of vehicles which generally represent a single vehicle platform and which are equipped with a single engine size (*e.g.,* compact cars with four cylinder engine produced by Ford). These grouping are described in Table III.D.1–1. Thus, the fourth step is to combine the fractions of the cost and effectiveness of each technology package already present on the individual 2008 vehicles models for each vehicle grouping. For cost, percentages of each package already present are combined using a simple sales-weighting procedure, since the cost of each package is the same for each vehicle in a grouping. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO_2 emission level. This appropriately weights vehicle models with either higher sales or CO_2 emissions within a grouping. Once again, this process prevents the model from adding technology which is already present on vehicles, and thus ensures that the model does not double count technology effectiveness and cost associated with complying with the 2011 MY CAFE standards and the final CO_2 standards.

Conceptually, the OMEGA model begins by determining the specific CO_2 emission standard applicable for each manufacturer and its vehicle class (*i.e.,* car or truck). Since the final rule allows for averaging across a manufacturer's cars and trucks, the model determines the CO_2 emission standard applicable to each manufacturer's car and truck sales from the two sets of coefficients describing the piecewise linear standard functions for cars and trucks in the inputs, and creates a combined car-truck standard. This combined standard considers the difference in lifetime VMT of cars and trucks, as indicated in the final regulations which govern credit trading between these two vehicle classes. For both the 2011 CAFE and 2016 CO_2 standards, these standards are a function of each manufacturer's sales of cars and trucks and their footprint values. When evaluating the 2011 MY CAFE standards, the car-truck trading was limited to 1.2 mpg. When evaluating the final CO_2 standards, the OMEGA model was run only for MY 2016. OMEGA is designed to evaluate technology addition over a complete redesign cycle and 2016 represents the final year of a redesign cycle starting with the first year of the final CO_2 standards, 2012. Estimates of the technology and cost for the interim model years are developed from the model projections made for 2016. This process is discussed in Chapter 6 of EPA's RIA to this final rule. When evaluating the 2016 standards using the OMEGA model, the final CO_2 standard which manufacturers will otherwise have to meet to account for the anticipated level of A/C credits generated was adjusted. On an industry wide basis, the projection shows that manufacturers will generate 11 g/mi of A/C credit in 2016. Thus, the 2016 CO_2 target for the fleet evaluated using OMEGA was 261 g/mi instead of 250 g/mi.

As noted above, EPA estimated separately the cost of the improved A/C systems required to generate the 11 g/mi credit. This is consistent with our final A/C credit procedures, which will grant manufacturers A/C credits based on their total use of improved A/C systems, and not on the increased use of such systems relative to some base model year fleet. Some manufacturers may already be using improved A/C technology. However, this represents a small fraction of current vehicle sales. To the degree that such systems are already being used, EPA is over-estimating both the cost and benefit of the addition of improved A/C technology relative to the true reference fleet to a small degree.

The model then works with one manufacturer at a time to add technologies until that manufacturer meets its applicable standard. The OMEGA model can utilize several approaches to determining the order in which vehicles receive technologies. For this analysis, EPA used a "manufacturer-based net cost-effectiveness factor" to rank the technology packages in the order in which a manufacturer is likely to apply them. Conceptually, this approach estimates the cost of adding the technology from the manufacturer's perspective and divides it by the mass of CO_2 the technology will reduce. One component of the cost of adding a technology is its production cost, as discussed above. However, it is expected that new vehicle purchasers value improved fuel economy since it reduces the cost of operating the vehicle. Typical vehicle purchasers are assumed to value the fuel savings accrued over the period of time which they will own the vehicle, which is estimated to be roughly five years. It is also assumed that consumers discount these savings at the same rate as that used in the rest of the analysis (3 or 7 percent). Any residual value of the additional technology which might remain when the vehicle is sold is not considered. The CO_2 emission reduction is the change in CO_2 emissions multiplied by the percentage of vehicles surviving after each year of use multiplied by the annual miles travelled by age, again discounted to the year of vehicle purchase.

Given this definition, the higher priority technologies are those with the lowest manufacturer-based net cost-effectiveness value (relatively low technology cost or high fuel savings leads to lower values). Because the order of technology application is set for each vehicle, the model uses the manufacturer-based net cost-effectiveness primarily to decide which vehicle receives the next technology addition. Initially, technology package #1 is the only one available to any particular vehicle. However, as soon as a vehicle receives technology package #1, the model considers the manufacturer-based net cost-effectiveness of technology package #2 for that vehicle and so on. In general terms, the equation describing the calculation of manufacturer-based cost effectiveness is as follows:

$$ManufCostEff = \frac{TechCost - \sum_{i=1}^{PP}\left[dFS_i \times VMT_i\right] \times \frac{1}{(1-Gap)}}{\sum_{i}^{i+35}\left[[dCO2] \times VMT_i\right] \times \frac{1}{(1-Gap)}}$$

Where

ManufCostEff = Manufacturer-Based Cost Effectiveness (in dollars per kilogram CO_2),

TechCost = Marked up cost of the technology (dollars),

PP = Payback period, or the number of years of vehicle use over which consumers value fuel savings when evaluating the value of a new vehicle at time of purchase,

dFS_i = Difference in fuel consumption due to the addition of technology times fuel price in year i,

dCO_2 = Difference in CO_2 emissions due to the addition of technology,

VMTi = product of annual VMT for a vehicle of age i and the percentage of vehicles of age i still on the road, and

1- Gap = Ratio of onroad fuel economy to two-cycle (FTP/HFET) fuel economy.

The OMEGA model does not currently allow for the VMT used in determining the various technology ranking factors to be a function of the rebound factor. If the user believed that the consideration of rebound VMT was important, they could increase their estimate of the payback period to simulate the impact of the rebound VMT.

EPA describes the technology ranking methodology and manufacturer-based cost effectiveness metric in greater detail in a technical memo to the Docket for this final rule (Docket EPA–HQ–OAR–2009–0472).

When calculating the fuel savings, the full retail price of fuel, including taxes is used. While taxes are not generally included when calculating the cost or benefits of a regulation, the net cost component of the manufacturer-based net cost-effectiveness equation is not a measure of the social cost of this final rule, but a measure of the private cost, (*i.e.,* a measure of the vehicle purchaser's willingness to pay more for a vehicle with higher fuel efficiency). Since vehicle operators pay the full price of fuel, including taxes, they value fuel costs or savings at this level, and the manufacturers will consider this when choosing among the technology options.

This definition of manufacturer-based net cost-effectiveness ignores any change in the residual value of the vehicle due to the additional technology when the vehicle is five years old. As discussed in Chapter 1 of the RIA, based on historic used car pricing, applicable sales taxes, and insurance, vehicles are worth roughly 23% of their original cost after five years, discounted to year of vehicle purchase at 7% per annum. It is reasonable to estimate that the added technology to improve CO_2 level and fuel economy will retain this same percentage of value when the vehicle is five years old. However, it is less clear whether first purchasers, and thus, manufacturers consider this residual value when ranking technologies and making vehicle purchases, respectively. For this final rule, this factor was not included in our determination of manufacturer-based net cost-effectiveness in the analyses performed in support of this final rule.

The values of manufacturer-based net cost-effectiveness for specific technologies will vary from vehicle to vehicle, often substantially. This occurs for three reasons. First, both the cost and fuel-saving component cost, ownership fuel-savings, and lifetime CO_2 effectiveness of a specific technology all vary by the type of vehicle or engine to which it is being applied (*e.g.,* small car versus large truck, or 4-cylinder versus 8-cylinder engine). Second, the effectiveness of a specific technology often depends on the presence of other technologies already being used on the vehicle (*i.e.,* the dis-synergies). Third, the absolute fuel savings and CO_2 reduction of a percentage on incremental reduction in fuel consumption depends on the CO_2 level of the vehicle prior to adding the technology. Chapter 1 of the RIA of this final rule contains further detail on the values of manufacturer-based net cost-effectiveness for the various technology packages.

6. Why are the final CO_2 standards feasible?

The finding that the final standards are technically feasible is based primarily on two factors. One is the level of technology needed to meet the final standards. The other is the cost of this technology. The focus is on the final standards for 2016, as this is the most stringent standard and requires the most extensive use of technology.

With respect to the level of technology required to meet the standards, EPA established technology penetration caps. As described in Section III.D.4, EPA used two constraints to limit the model's application of technology by manufacturer. The first was the application of common fuel economy enablers such as low rolling resistance tires and transmission logic changes. These were allowed to be used on all vehicles and hence had no penetration cap. The second constraint was applied to most other technologies and limited their application to 85% with the exception of the most advanced technologies (*e.g.,* power-split hybrid and 2-mode hybrid) and diesel,[255] whose application was limited to 15%.

EPA used the OMEGA model to project the technology (and resultant cost) required for manufacturers to meet the current 2011 MY CAFE standards and the final 2016 MY CO_2 emission standards. Both sets of standards were evaluated using the OMEGA model. The 2011 MY CAFE standards were applied to cars and trucks separately with the transfer of credits from one category to the other allowed up to an increase in fuel economy of 1.0 mpg as allowed under the applicable MY 2011 CAFE regulations. Chrysler, Ford and General Motors are assumed to utilize FFV credits up to the maximum of 1.2 mpg for both their car and truck sales. Nissan is assumed to utilize FFV credits up to the maximum of 1.2 mpg for only their truck sales. The use of any banked credits from previous model years was not considered. The modification of the reference fleet to comply with the 2011 CAFE standards through the application of technology by the OMEGA model is the final step in creating the final reference fleet. This final reference fleet forms the basis for comparison for the model year 2016 standards.

Table III.D.6–1 shows the usage level of selected technologies in the 2008 vehicles coupled with 2016 sales prior to projecting their compliance with the 2011 MY CAFE standards. These technologies include converting port fuel-injected gasoline engines to direct injection (GDI), adding the ability to deactivate certain engine cylinders during low load operation to overhead cam engines (OHC–DEAC), adding a turbocharger and downsizing the engine (Turbo), diesel engine technology, increasing the number of transmission speeds to 6, or converting automatic transmissions to dual-clutch automated manual transmissions (Dual-Clutch Trans), adding 42 volt start-stop capability (Start-Stop), and converting a vehicle to an intermediate or strong hybrid design. This last category includes three current hybrid designs: Integrated motor assist (IMA), power-split (PS), 2-mode hybrids and electric vehicles.[256]

[255] While diesel engines are not an "advanced technology" per se, diesel engines that can meet EPA's light duty Tier 2 Bin 5 NO_X standards have advanced (and somewhat costly) aftertreatment systems on them that make this technology penetration cap appropriate in addition to their relatively high incremental costs.

[256] EPA did not project reliance on the use of any plug-in hybrid or battery electric vehicles when projecting manufacturers' compliance with the 2016 standards. However, BMW did sell a battery electric vehicle in the 2008 model year, so these sales are included in the technology penetration estimates for the reference case and the final and alternative standards evaluated for 2016.

TABLE III.D.6–1—PENETRATION OF TECHNOLOGY IN 2008 VEHICLES WITH 2016 SALES: CARS AND TRUCKS

[Percent of sales]

	GDI	OHC–DEAC	Turbo	Diesel	6 Speed auto trans	Dual clutch trans	Start-stop	Hybrid
BMW	7.5	0.0	6.1	0.0	86	0.9	0	0.1
Chrysler	0.0	0.0	0.5	0.1	14	0.0	0	0.0
Daimler	0.0	0.0	6.5	5.6	76	7.5	0	0.0
Ford	0.4	0.0	2.2	0.0	29	0.0	0	0.0
General Motors	3.1	0.0	1.4	0.0	15	0.0	0	0.3
Honda	1.4	7.1	1.4	0.0	0	0.0	0	2.1
Hyundai	0.0	0.0	0.0	0.0	3	0.0	0	0.0
Kia	0.0	0.0	0.0	0.0	0	0.0	0	0.0
Mazda	13.6	0.0	13.6	0.0	26	0.0	0	0.0
Mitsubishi	0.0	0.0	0.0	0.0	10	0.0	0	0.0
Nissan	0.0	0.0	0.0	0.0	0	0.0	0	0.8
Porsche	58.6	0.0	14.9	0.0	49	0.0	0	0.0
Subaru	0.0	0.0	9.8	0.0	0	0.0	0	0.0
Suzuki	0.0	0.0	0.0	0.0	0	0.0	0	0.0
Tata	0.0	0.0	17.3	0.0	99	0.0	0	0.0
Toyota	6.8	0.0	0.0	0.0	21	0.0	0	11.6
Volkswagen	50.6	0.0	39.5	0.0	69	13.1	0	0.0
Overall	3.8	0.8	2.6	0.1	19.1	0.5	0.0	2.2

As can be seen, all of these technologies were already being used on some 2008 MY vehicles, with the exception of direct injection gasoline engines with either cylinder deactivation or turbocharging and downsizing. Transmissions with more gearsets were the most prevalent, with some manufacturers (*e.g.,* BMW, Suzuki) using them on essentially all of their vehicles. Both Daimler and VW equip many of their vehicles with automated manual transmissions, while VW makes extensive use of direct injection gasoline engine technology. Toyota has converted a significant percentage of its 2008 vehicles to strong hybrid design.

Table III.D.6–2 shows the usage level of the same technologies in the reference case fleet after projecting their compliance with the 2011 MY CAFE standards. Except for mass reduction, the figures shown represent the percentages of each manufacturer's sales which are projected to be equipped with the indicated technology. For mass reduction, the overall mass reduction projected for that manufacturer's sales is also shown. The last row in Table III.D.6–2 shows the increase in projected technology penetration due to compliance with the 2011 MY CAFE standards. The results of DOT's Volpe modeling were used to project that all manufacturers would comply with the 2011 MY standards in 2016 without the need to pay fines, with one exception. This exception was Porsche in the case of their car fleet. When projecting Porsche's compliance with the 2011 MY CAFE standard for cars, NHTSA projected that Porsche would achieve a CO_2 emission level of 304.3 g/mi instead of the required 284.8 g/mi level (29.2 mpg instead of 31.2 mpg), and pay fines in lieu of further control.

TABLE III.D.6–2—PENETRATION OF TECHNOLOGY UNDER 2011 MY CAFE STANDARDS IN 2016 SALES: CARS AND TRUCKS

[Percent of sales]

	GDI	OHC–DEAC	Turbo	6 Speed auto trans	Dual clutch trans	Start-stop	Mass reduction
BMW	44	12	30	53	37	13	2
Chrysler	0	0	0	18	0	0	0
Daimler	23	22	8	52	34	26	2
Ford	0	0	3	27	0	0	0
General Motors	3	0	1	15	0	0	0
Honda	2	6	2	0	0	0	0
Hyundai	0	0	0	3	0	0	0
Kia	0	0	0	0	0	0	0
Mazda	13	0	13	20	0	0	0
Mitsubishi	32	0	2	25	35	0	1
Nissan	0	0	0	0	0	0	0
Porsche	92	0	75	5	55	38	4
Subaru	0	0	9	0	0	0	0
Suzuki	70	0	0	3	67	67	3
Tata	85	54	20	27	73	73	6
Toyota	7	0	0	19	0	0	0
Volkswagen	89	5	81	14	78	18	3
Overall	10	2	7	16	7	3	0
Increase over 2008 MY	6	1	4	−3	6	3	0

As can be seen, the 2011 MY CAFE standards, when evaluated on an industry wide basis, require only a modest increase in the use of these technologies. The projected MY 2016 fraction of automatic transmission with more gearsets actually decreases slightly due to conversion of these units to more efficient designs such as automated manual transmissions and hybrids. However, the impact of the 2011 MY CAFE standards is much greater on selected manufacturers, particularly BMW, Daimler, Porsche, Tata (Jaguar/Land Rover) and VW. All of these manufacturers are projected to increase their use of direct injection gasoline engine technology, advanced transmission technology, and start-stop technology. It should be noted that these manufacturers have traditionally paid fines under the CAFE program. However, with higher fuel prices and the lower cost mature technology projected to be available by 2016, these manufacturers would likely find it in their best interest to improve their fuel economy levels instead of continuing to pay fines (again with the exception of Porsche cars). While not shown, no gasoline engines were projected to be converted to diesel technology and no hybrid vehicles were projected. Most manufacturers do not require the level of CO_2 emission control associated with either of these technologies. The few manufacturers that would were projected to choose to pay CAFE fines in 2011 in lieu of adding diesel or hybrid technologies.

This 2008 baseline fleet, modified to meet 2011 standards, becomes our "reference" case. See Section II.B above. This is the fleet against which the final 2016 standards are compared. Thus, it is also the fleet that is assumed to exist in the absence of this rule. No air conditioning improvements are assumed for model year 2011 vehicles. The average CO_2 emission levels of this reference fleet vary slightly from 2012–2016 due to small changes in the vehicle sales by market segments and manufacturer. CO_2 emissions from cars range from 282–284 g/mi, while those from trucks range from 382–384 g/mi. CO_2 emissions from the combined fleet range from 316–320. These estimates are described in greater detail in Section 5.3.2.2 of the EPA RIA.

Conceptually, both EPA and NHTSA perform the same projection in order to develop their respective reference fleets. However, because the two agencies use two different models to modify the baseline fleet to meet the 2011 CAFE standards, the projected technology that could be added will be slightly different. The differences, however, are relatively small since most manufacturers only require modest addition of technology to meet the 2011 CAFE standards.

EPA then used the OMEGA model once again to project the level of technology needed to meet the final 2016 CO_2 emission standards. Using the results of the OMEGA model, every manufacturer was projected to be able to meet the final 2016 standards with the technology described above except for four: BMW, VW, Porsche and Tata (which is comprised of Jaguar and Land Rover vehicles in the U.S. fleet). For these manufacturers, the results presented below are those with the fully allowable application of technology available in EPA's OMEGA modeling analysis and not for the technology projected to enable compliance with the final standards. Described below are a number of potential feasible solutions for how these companies can achieve compliance. The overall level of technology needed to meet the final 2016 standards is shown in Table III.D.6–3. As discussed above, all manufacturers are projected to improve the air conditioning systems on 85% of their 2016 sales.[257]

TABLE III.D.6–3—FINAL PENETRATION OF TECHNOLOGY FOR 2016 CO_2 STANDARDS: CARS AND TRUCKS

[Percent of sales]

	GDI	OHC–DEAC	Turbo	Diesel	6 Speed auto trans	Dual clutch trans	Start-stop	Hybrid	Mass Reduction
BMW	80	21	61	6	13	63	65	14	5
Chrysler	79	13	17	0	31	52	54	0	6
Daimler	76	30	53	5	12	72	67	14	5
Ford	84	21	19	0	27	60	61	0	6
General Motors	67	25	14	0	8	61	61	0	6
Honda	43	6	2	0	0	49	18	2	3
Hyundai	59	0	1	0	8	52	32	0	3
Kia	33	0	1	0	0	52	4	0	2
Mazda	60	0	14	1	17	47	41	0	4
Mitsubishi	74	0	33	0	14	74	74	0	6
Nissan	66	7	11	0	2	62	58	1	5
Porsche	83	15	62	8	5	45	62	15	4
Subaru	60	0	9	0	0	58	44	0	3
Suzuki	77	0	0	0	10	67	67	0	4
Tata	85	55	27	0	14	70	70	15	5
Toyota	26	7	3	0	13	40	7	12	2
Volkswagen	82	18	71	11	10	68	60	15	4
Overall	60	13	15	1	12	55	42	4	4
Increase over 2011 CAFE	49	11	9	1	−4	48	39	2	4

[257] Many of the technologies shown in this table are mutually exclusive. Thus, 85% penetration might not be possible. For example, any use of hybrids will reduce the DEAC, Turbo, 6SPD, DCT, and 42V S–S technologies. Additionally, not every technology is available to be used on every vehicle type.

Table III.D.6–4 shows the 2016 standards, as well as the achieved CO_2 emission levels for the five manufacturers which are not able to meet these standards under the premises of our modeling. It should be noted that the two sets of combined emission levels shown in Table III.D.6–4 are based on sales weighting car and truck emission levels.

TABLE III.D.6–4—EMISSIONS OF MANUFACTURERS UNABLE TO MEET FINAL 2016 STANDARDS (G/MI CO_2)

Manufacturer	Achieved emissions			2016 Standards			Shortfall
	Car	Truck	Combined	Car	Truck	Combined	Combined
BMW	236.3	278.7	248.5	228.4	282.5	243.9	4.6
Tata	258.6	323.6	284.2	249.9	272.5	258.8	25.4
Daimler	246.3	297.8	262.6	238.3	294.3	256.1	6.5
Porsche	244.1	332.0	273.4	206.1	286.9	233.0	40.4
Volkswagen	223.5	326.6	241.6	218.6	292.7	231.6	10.0

As can be seen, BMW and Daimler have the smallest shortfalls, 5–6 g/mi, while Porsche has the largest, 40 g/mi.

On an industry average basis, the technology penetrations are very similar to those projected in the proposal. There is a slight shift from the use of cylinder deactivation to the two advanced transmission technologies. This is due to the fact that the estimated costs for these three technologies have been updated, and thus, their relative cost effectiveness when applied to specific vehicles have also shifted. The reader is referred to Section II.E of this preamble as well as Chapter 3 of the Joint TSD for a detailed description of the cost estimates supporting this final rule and to the RIA for a description of the selection of technology packages for specific vehicle types. The other technologies shown in Table III.D.6–4 changed by 2 percent or less between the proposal and this final rule.

As can be seen, the overall average reduction in vehicle weight is projected to be 4 percent. This reduction varies across the two vehicle classes and vehicle base weight. For cars below 2,950 pounds curb weight, the average reduction is 2.8 percent (75 pounds), while the average was 4.3 percent (153 pounds) for cars above 2,950 curb weight. For trucks below 3,850 pounds curb weight, the average reduction is 4.7 percent (163 pounds), while it was 5.1 percent (240 pounds) for trucks above 3,850 curb weight. Splitting trucks at a higher weight, for trucks below 5,000 pounds curb weight, the average reduction is 4.4 percent (186 pounds), while it was 7.0 percent (376 pounds) for trucks above 5,000 curb weight.

The levels of requisite technologies differ significantly across the various manufacturers. Therefore, several analyses were performed to ascertain the cause. Because the baseline case fleet consists of 2008 MY vehicle designs, these analyses were focused on these vehicles, their technology and their CO_2 emission levels.

Comparing CO_2 emissions across manufacturers is not a simple task. In addition to widely varying vehicle styles, designs, and sizes, manufacturers have implemented fuel efficient technologies to varying degrees, as indicated in Table III.D.6–1. The projected levels of requisite technology to enable compliance with the final 2016 standards shown in Table III.D.6–3 account for two of the major factors which can affect CO_2 emissions (1) Level of technology already being utilized and (2) vehicle size, as represented by footprint.

For example, the fuel economy of a manufacturer's 2008 vehicles may be relatively high because of the use of advanced technologies. This is the case with Toyota's high sales of their Prius hybrid. However, the presence of this technology in a 2008 vehicle eliminates the ability to significantly reduce CO_2 further through the use of this technology. In the extreme, if a manufacturer were to hybridize a high level of its sales in 2016, it does not matter whether this technology was present in 2008 or whether it would be added in order to comply with the standards. The final level of hybrid technology would be the same. Thus, the level at which technology is present in 2008 vehicles does not explain the difference in requisite technology levels shown in Table III.D.6–3.

Similarly, the final CO_2 emission standards adjust the required CO_2 level according to a vehicle's footprint, requiring lower absolute emission levels from smaller vehicles. Thus, just because a manufacturer produces larger vehicles than another manufacturer does not explain the differences seen in Table III.D.6–3.

In order to remove these two factors from our comparison, the EPA lumped parameter model described above was used to estimate the degree to which technology present on each 2008 MY vehicle in our reference fleet was improving fuel efficiency. The effect of this technology was removed and each vehicle's CO_2 emissions were estimated as if it utilized no additional fuel efficiency technology beyond the baseline. The differences in vehicle size were accounted for by determining the difference between the sales-weighted average of each manufacturer's "no technology" CO_2 levels to their required CO_2 emission level under the final 2016 standards. The industry-wide difference was subtracted from each manufacturer's value to highlight which manufacturers had lower and higher than average "no technology" emissions. The results are shown in Figure III.D.6–1.

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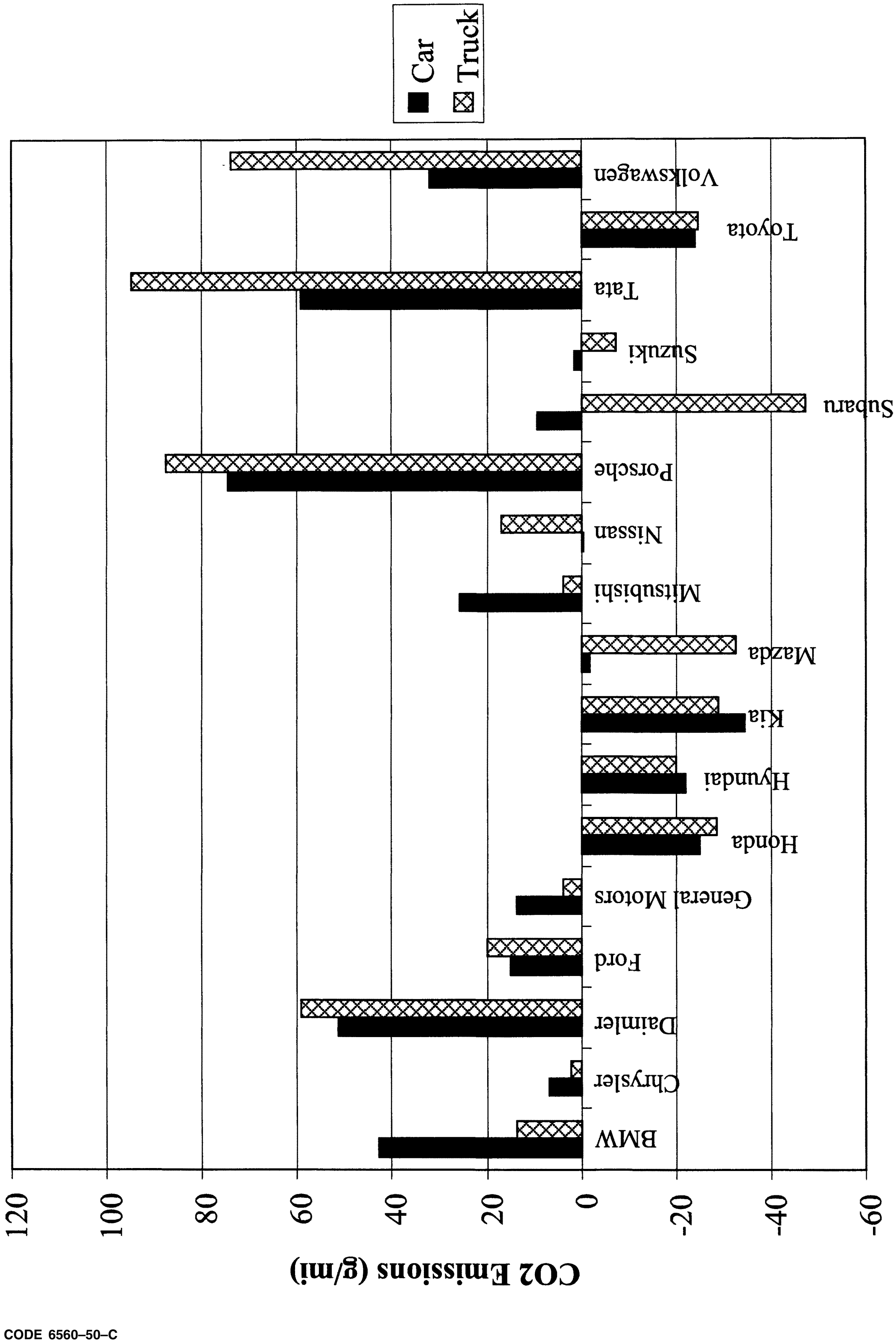

Figure III.D.6-1 CO_2 Emission Reduction Required in 2016 from 2008 Vehicles After Removing the Benefit of Technology Already Present, Relative to That for the Fleet as a Whole

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As can be seen in Table III.D.6–3 the manufacturers projected to require the greatest levels of technology also show the highest offsets relative to the industry. The greatest offset shown in Figure III.D.6–1 is for Tata's trucks (Land Rover). These vehicles are estimated to have 100 g/mi greater CO_2 emissions than the average 2008 MY truck after accounting for differences in the use of fuel saving technology and footprint. The lowest adjustment is for Subaru's trucks, which have 50 g/mi CO_2 lower emissions than the average truck.

While this comparison confirms the differences in the technology penetrations shown in Table III.D.6–3, it does not yet explain why these differences exist. Two well-known factors affecting vehicle fuel efficiency are vehicle weight and acceleration performance (henceforth referred to as "performance"). The footprint-based form of the final CO_2 standard accounts for most of the difference in vehicle weight seen in the 2008 MY fleet. However, even at the same footprint, vehicles can have varying weights. Higher performing vehicles also tend to have higher CO_2 emissions over the two-cycle fuel economy test procedure. So manufacturers with higher average performance levels will tend to have higher average CO_2 emissions for any given footprint. This variability at any given footprint contributes to much of the scatter in the data (shown for example on plots like Figures II.C.1–3 through II.C.1–6).

We developed a methodology to assess the impact of these two factors on each manufacturer's projected compliance with the 2016 standards. First, we had to remove (or isolate) the effect of CO_2 control technology already being employed on 2008 vehicles. As described above, 2008 vehicles exhibit a wide range of control technology and leaving these impacts in place would confound the assessment of performance and weight on CO_2 emissions. Thus, the first step was to estimate each vehicle's "no technology" CO_2 emissions. To do this, we used the EPA lumped parameter model (described in the TSD) to estimate the overall percentage reduction in CO_2 emissions associated with technology already on the vehicle and then backed out this effect mathematically. Second, we performed a least-square linear regression of these no technology CO_2 levels against curb weight and the ratio of rated engine horsepower to curb weight simultaneously. The ratio of rated engine horsepower to curb weight is a good surrogate for acceleration performance and the data is available for all vehicles, whereas the zero to sixty time is not. Both factors were found to be statistically significant at the 95% confidence level. Together, they explained over 80% of the variability in vehicles' CO_2 emissions for cars and over 70% for trucks. Third, we determined the sales-weighted average curb weight per footprint for cars and trucks, respectively, for the fleet as a whole. We also determined the sales-weighted average of the ratio of rated engine horsepower to curb weight for cars and trucks, respectively, for the fleet as a whole. Fourth, we adjusted each vehicle's "no technology" CO_2 emissions to eliminate the degree to which the vehicle had higher or lower acceleration performance or curb weight per footprint relative to the car or truck fleet as a whole. For example, if a car's ratio of horsepower to weight was 0.007 and the average ratio for all cars was 0.006, then the vehicle's "no technology" CO_2 emission level was reduced by the difference between these two values (0.001) times the impact of the ratio of horsepower to weight on car CO_2 emissions from the above linear regression. Finally, we substituted these performance and weight adjusted CO_2 emission levels for the original, "no technology" CO_2 emission levels shown in Figure III.D.6–1. The results are shown in Figure III.D.6–2.

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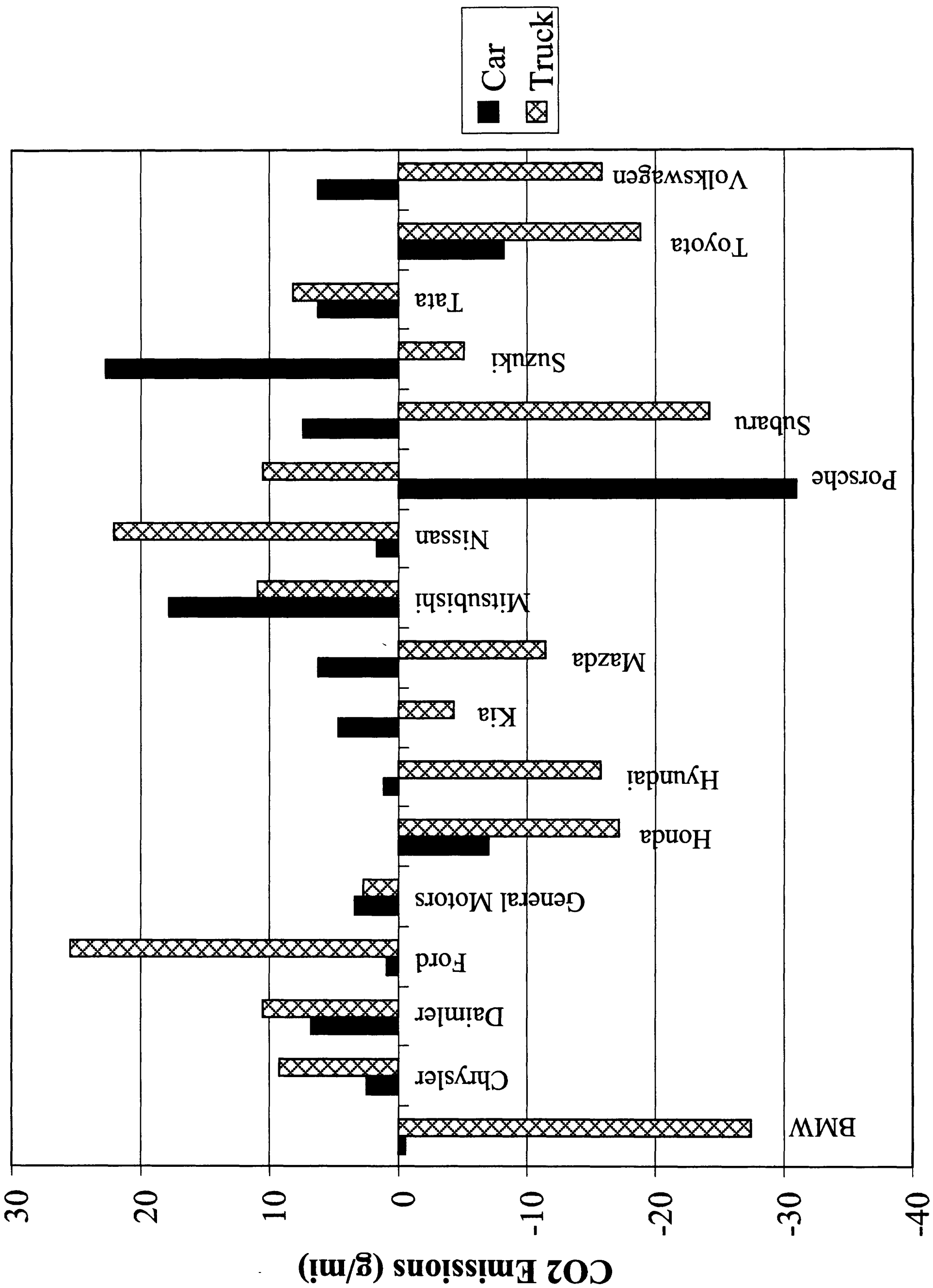

Figure III.D.6-2 CO_2 Emission Reduction Required in 2016 From 2008 Vehicles After 1) Removing the Benefit of Technology Already Present, and 2) Adjusting for Differences in Weight per Footprint. and Performance. Relative to That for the Fleet as a as a Whole

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First, note that the scale in Figure III.D.6–2 is much smaller by a factor of 3 than that in Figure III.D.6–1. In other words, accounting for differences in vehicle weight (at constant footprint) and performance dramatically reduces the variability among the manufacturers' CO_2 emissions. Most of the manufacturers with high positive offsets in Figure III.D.6–1 now show low or negative offsets. For example, BMW's and VW's trucks show very low CO_2 emissions. Tata's emissions are very close to the industry average. Daimler's vehicles are no more than 10 g/mi above the average for the industry. This analysis indicates that the primary reasons for the differences in technology penetrations shown for the various manufacturers in Table III.D.6–3 are weight and acceleration performance. EPA has not determined why some manufacturers' vehicle weight is relatively high for its footprint value, or whether this weight provides additional utility for the consumer. Performance is more straightforward. Some consumers desire high-acceleration performance and some manufacturers orient their sales towards these consumers. However, the cost in terms of CO_2 emissions is clear. Manufacturers producing relatively heavy or high performance vehicles presently (with concomitant increased CO_2 emissions) will require greater levels of technology in order to meet the final CO_2 standards in 2016.

As can be seen from Table III.D.6–3 above, widespread use of several technologies is projected due to the final standards. The vast majority of engines are projected to be converted to direct injection, with some of these engines including cylinder deactivation or turbocharging and downsizing. More than 60 percent of all transmissions are projected to be either 6+ speed automatic transmissions or dual-clutch automated manual transmissions. More than one-third of the fleet is projected to be equipped with 42 volt start-stop capability. This technology was not utilized in 2008 vehicles, but as discussed above, promises significant fuel efficiency improvement at a moderate cost.

In their comments, Porsche stated that their vehicles have twice the power-to-weight ratio as the fleet average and that their vehicles presently have a high degree of technology penetration, which allows them to meet the 2009 CAFE standards. Porsche also commented that the 2016 standards are not feasible for their firm, in part due to the high level of technologies already present in their vehicles and due to their "very long production life cycles". BMW in their comments stated that their vehicles are "feature-dense" thus "requiring additional efforts to comply" with future standards.[258] Ferrari, in their comments, states that the standards are not feasible for high-performance sports cars without compromising on their "distinctiveness". They also state that because they already have many technologies on the vehicles, "there are limited possibilities for further improvements." Finally Ferrari states that smaller volume manufacturers have higher costs "because they can be distributed over very limited production volumes", and they have longer product lifecycles. The latter view was also shared by Lotus. These comments will be addressed below, but are cited here as supporting the conclusions from the above analysis that high-performance and feature-dense vehicles have a greater challenge meeting the 2016 standards. In general, other manufacturers covering the rest of the fleet and other commenters agreed with EPA's analysis in the proposal of projected technology usage, and supported the view that the 2016 model year standards were feasible in the lead-time provided.

In response to the comments above, EPA foresees no significant technical or engineering issues with the projected deployment of these technologies across the fleet by MY 2016, with their incorporation being folded into the vehicle redesign process (with the exception of some of the small volume manufacturers). All of these technologies are commercially available now. The automotive industry has already begun to convert its port fuel-injected gasoline engines to direct injection. Cylinder deactivation and turbocharging technologies are already commercially available. As indicated in Table III.D.6–1, high-speed transmissions are already widely used. However, while more common in Europe, automated manual transmissions are not currently used extensively in the U.S. Widespread use of this technology would require significant capital investment but does not present any significant technical or engineering issues. Start-stop systems based on a 42-volt architecture also represent a challenge because of the complications involved in a changeover to a higher voltage electrical architecture. However, with appropriate capital investments (which are captured in the EPA estimated costs), these technology penetration rates are achievable within the timeframe of this rule. While most manufacturers have some plans for these systems, our projections indicate that their use may exceed 35% of sales, with some manufacturers projected to use higher levels.

Most manufacturers are not projected to hybridize any vehicles to comply with the final standards. The hybrids shown for Toyota are projected to be sold even in the absence of the final standards. However the relatively high hybrid penetrations (14–15%) projected for BMW, Daimler, Porsche, Tata and Volkswagen deserve further discussion. These manufacturers are all projected by the OMEGA model to utilize the maximum application of full hybrids allowed by our model in this timeframe, which is 15 percent.

As discussed in the EPA RIA, a maximum 2016 technology penetration rate of 85% is projected for the vast majority of available technologies, however, for full hybrid systems the projection shows that given the available lead-time full hybrids can only be applied to approximately 15% of a manufacturer's fleet. This number of course can vary by manufacturer. Hybrids are a relatively costly technology option which requires significant changes to a vehicle's powertrain design, and EPA estimates that manufacturers will require a significant amount of lead time and capital investment to introduce this technology into the market in very large numbers. Thus the EPA captures this significant change in production facilities with a lower penetration cap. A more thorough discussion of lead time limitations can be found below and in Section III.B.5.

While the hybridization levels of BMW, Daimler, Porsche, Tata and Volkswagen are relatively high, the sales levels of these five manufacturers are relatively low. Thus, industry-wide, hybridization reaches only 4 percent, compared with 3 percent in the reference case. This 4 percent level is believed to be well within the capability of the hybrid component industry by 2016. Thus, the primary challenge for these five companies would be at the manufacturer level, redesigning a relatively large percentage of sales to include hybrid technology. The final TLAAS provisions will provide significant needed lead time to these manufacturers for pre-2016 compliance, since all qualified companies are able to take advantage of these provisions.

By 2016, it is likely that these manufacturers would also be able to

[258] As a side note, one of the benefits for the off-cycle technology credits allowed in this final rule is the opportunity this flexibility provides for some of these 'feature-dense' vehicles to generate such credits to assist, to some extent, in the companies' ability to comply.

change vehicle characteristics which currently cause their vehicles to emit much more CO_2 than similar sized vehicles produced by other manufacturers. These factors may include changes in model mix, further mass reduction, electric and/or plug-in hybrid vehicles as well as technologies that may not be included in our packages. Also, companies may have technology penetration rates of less costly technologies (listed in the above tables) greater than 85%, and they may also be able to apply hybrid technology to more than 15 percent of their fleet (while the 15% cap on the application of hybrid technology is reasonable for the industry as a whole, higher percentages are certainly possible for individual manufacturers, particularly those with small volumes). For example, a switch to a low GWP alternative refrigerant in a large fraction of a fleet can replace many other much more costly technologies, but this option is not captured in the modeling. In addition, these manufacturers can also take advantage of flexibilities, such as early credits for air conditioning and trading with other manufacturers.

EPA believes it is likely that there will be certain high volume manufacturers that will earn a significant amount of early GHG credits starting in 2010 that would expire 5 years later, by 2015, unused. It is possible that these manufacturers may be willing to sell these credits to manufacturers with whom there is little or no direct competition.[259] Furthermore, a large number of manufacturers have also stated publicly that they support the 2016 standards. The following companies have all submitted letters in support of the national program, including the 2016 MY levels discussed above: BMW, Chrysler, Daimler, Ford, GM, Nissan, Honda, Mazda, Toyota, and Volkswagen. This supports the view that the emissions reductions needed to achieve the standards are technically and economically feasible for all these companies, and that EPA's projection of model year 2016 non-compliance for BMW, Daimler, and Volkswagen is based on an inability of our model at this time to fully account for the full flexibilities of the EPA program as well as the potentially unique technology approaches or new product offerings which these manufacturers are likely to employ.

In addition, manufacturers do not need to apply technology exactly according to our projections. Our projections simply indicate one path which would achieve compliance. Those manufacturers whose vehicles are heavier (feature dense) and higher performing than average in particular have additional options to facilitate compliance and reduce their technological burden closer to the industry average. These options include decreasing the mass of the vehicles and/or decreasing the power output of the engines. Finally, EPA allows compliance to be shown through the use of emission credits obtained from other manufacturers. Especially for the lower volume sales of some manufacturers that could be one component of an effective compliance strategy, reducing the technology that needs to be employed on their vehicles.

For light-duty cars and trucks, manufacturers have available to them a range of technologies that are currently commercially available and can feasibly be employed in their vehicles by MY 2016. Our modeling projects widespread use of these technologies as a technologically feasible approach to complying with the final standards. Comments from the manufacturers provided broad support for this conclusion. A limited number of commenters presented specific concerns about their technology opportunities, and EPA has described above (and elsewhere in the rule) the paths available for them to comply.

In sum, EPA believes that the emissions reductions called for by the final standards are technologically feasible, based on projections of widespread use of commercially available technology, as well as use by some manufacturers of other technology approaches and compliance flexibilities not fully reflected in our modeling.

EPA also projected the cost associated with these projections of technology penetration. Table III.D.6–4 shows the cost of technology in order for manufacturers to comply with the 2011 MY CAFE standards, as well as those associated with the final 2016 CO_2 emission standards. The latter costs are incremental to those associated with the 2011 MY standards and also include $60 per vehicle, on average, for the cost of projected use of improved air-conditioning systems.[260]

TABLE III.D.6–4—COST OF TECHNOLOGY PER VEHICLE IN 2016 ($2007)

	2011 MY CAFE standards, relative to 2008 MY			Final 2016 CO_2 standards, relative to 2011 MY CAFE standards		
	Cars	Trucks	All	Cars	Trucks	All
BMW	$346	$423	$368	$1,558	$1,195	$1,453
Chrysler	33	116	77	1,129	1,501	1,329
Daimler	468	683	536	1,536	931	1,343
Ford	73	161	106	1,108	1,442	1,231
General Motors	31	181	102	899	1,581	1,219
Honda	0	0	0	635	473	575
Hyundai	0	69	10	802	425	745
Kia	0	42	7	667	247	594
Mazda	0	0	0	855	537	808
Mitsubishi	328	246	295	817	1,218	978
Nissan	0	61	18	686	1,119	810
Porsche	473	706	550	1,506	759	1,257
Subaru	68	62	66	962	790	899
Suzuki	49	232	79	1,015	537	937
Tata	611	1,205	845	1,181	680	984
Toyota	0	0	0	381	609	455
Volkswagen	228	482	272	1,848	972	1,694

[259] For example, a manufacturer that only sells electric vehicles may very well sell the credits they earn to another manufacturer that does not sell any electric vehicles.

[260] Note that the actual cost of the A/C technology is estimated at $71 per vehicle as shown in Table III.D.2–3. However, we expect only 85 percent of the fleet to add that technology. Therefore, the cost of the technology when spread across the entire fleet is $60 per vehicle ($71 × 85% = $60).

TABLE III.D.6–4—COST OF TECHNOLOGY PER VEHICLE IN 2016 ($2007)—Continued

	2011 MY CAFE standards, relative to 2008 MY			Final 2016 CO_2 standards, relative to 2011 MY CAFE standards		
	Cars	Trucks	All	Cars	Trucks	All
Overall	63	138	89	870	1,099	948

As can be seen, the industry average cost of complying with the 2011 MY CAFE standards is quite low, $89 per vehicle. This cost is $11 per vehicle higher than that projected in the NPRM. This change is very small and is due to several factors, mainly changes in the projected sales of each manufacturer's specific vehicles, and changes in estimated technology costs. Similar to the costs projected in the NPRM, the range of costs across manufacturers is quite large. Honda, Mazda and Toyota are projected to face no cost. In contrast, Mitsubishi, Porsche, Tata and Volkswagen face costs of at least $272 per vehicle. As described above, three of these last four manufacturers (all but Mitsubishi) face high costs to meet even the 2011 MY CAFE standards due to either their vehicles' weight per unit footprint or performance. Porsche would have been projected to face lower costs in 2016 if they were not expected to pay CAFE fines in 2011.

As shown in the last row of Table III.D.6–4, the average cost of technology to meet the final 2016 standards for cars and trucks combined relative to the 2011 MY CAFE standards is $948 per vehicle. This is $103 lower than that projected in the NPRM, due primarily to lower technology cost projections for the final rule compared to the NPRM for certain technologies. (See Chapter 1 of the Joint TSD for a detailed description of how our technology costs for the final rule differ from those used in the NPRM). As was the case in the NPRM, Table III.D.6–4 shows that the average cost for cars would be slightly lower than that for trucks. Toyota and Honda show projected costs significantly below the average, while BMW, Porsche, Tata and Volkswagen show significantly higher costs. On average, the $948 per vehicle cost is significant, representing 3.4 percent of the total cost of a new vehicle. However, as discussed below, the fuel savings associated with the final standards exceed this cost significantly. In general, commenters supported EPA's cost projections, as discussed in Section II.

While the CO_2 emission compliance modeling using the OMEGA model focused on the final 2016 MY standards, the final standards for 2012–2015 are also feasible. As discussed above, manufacturers develop their future vehicle designs with several model years in view. Generally, the technology estimated above for 2016 MY vehicles represents the technology which would be added to those vehicles which are being redesigned in 2012–2015. The final CO_2 standards for 2012–2016 reduce CO_2 emissions at a fairly steady rate. Thus, manufacturers which redesign their vehicles at a fairly steady rate will automatically comply with the interim standard as they plan for compliance in 2016.

Manufacturers which redesign much fewer than 20% of their sales in the early years of the final program would face a more difficult challenge, as simply implementing the "2016 MY" technology as vehicles are redesigned may not enable compliance in the early years. However, even in this case, manufacturers would have several options to enable compliance. One, they could utilize the debit carry-forward provisions described above. This may be sufficient alone to enable compliance through the 2012–2016 MY time period, if their redesign schedule exceeds 20% per year prior to 2016. If not, at some point, the manufacturer might need to increase their use of technology beyond that projected above in order to generate the credits necessary to balance the accrued debits. For most manufacturers representing the vast majority of U.S. sales, this would simply mean extending the same technology to a greater percentage of sales. The added cost of this in the later years of the program would be balanced by lower costs in the earlier years. Two, the manufacture could take advantage of the many optional credit generation provisions contained in this final rule, including early-credit generation for model years 2009–2011, credits for advanced technology vehicles, and credits for the application of technology which result in off-cycle GHG reductions. Finally, the manufacturer could buy credits from another manufacturer. As indicated above, several manufacturers are projected to require less stringent technology than the average. These manufacturers would be in a position to provide credits at a reasonable technology cost. Thus, EPA believes the final standards for 2012–2016 would be feasible. Further discussion of the technical feasibility of the interim year standards, including for smaller volume manufacturers can be found in Section III.B, in the discussion on the Temporary Leadtime Allowance Alternative Standards.

7. What other fleet-wide CO_2 levels were considered?

Two alternative sets of CO_2 standards were considered. One set would reduce CO_2 emissions at a rate of 4 percent per year. The second set would reduce CO_2 emissions at a rate of 6 percent per year. The analysis of these standards followed the exact same process as described above for the final standards. The only difference was the level of CO_2 emission standards. The footprint-based standard coefficients of the car and truck curves for these two alternative control scenarios were discussed above. The resultant projected CO_2 standards in 2016 for each manufacturer under these two alternative scenarios and under the final rule are shown in Table III.D.7–1.

TABLE III.D.7–1—OVERALL AVERAGE CO_2 EMISSION STANDARDS BY MANUFACTURER IN 2016

	4% per year	Final Rule	6% per year
BMW	248	244	224
Chrysler	270	266	245
Daimler	260	256	236
Ford	261	257	237
General Motors	275	271	250
Honda	248	244	224

TABLE III.D.7–1—OVERALL AVERAGE CO_2 EMISSION STANDARDS BY MANUFACTURER IN 2016—Continued

	4% per year	Final Rule	6% per year
Hyundai	234	231	212
Kia	239	236	217
Mazda	232	228	210
Mitsubishi	244	239	219
Nissan	250	245	226
Porsche	237	233	213
Subaru	238	234	214
Suzuki	222	218	199
Tata	263	259	239
Toyota	249	245	225
Volkswagen	236	232	213
Overall	254	250	230

Tables III.D.7–2 and III.D.7–3 show the technology penetration levels for the 4 percent per year and 6 percent per year standards in 2016.

TABLE III.D.7–2—TECHNOLOGY PENETRATION—4% PER YEAR CO_2 STANDARDS IN 2016: CARS AND TRUCKS COMBINED

[In percent]

	GDI	OHC–DEAC	Turbo	Diesel	6 Speed auto trans	Dual clutch trans	Start-stop	Hybrid	Mass reduction (%)
BMW	80	21	61	6	13	63	65	14	5
Chrysler	67	13	17	0	26	52	54	0	6
Daimler *	76	30	53	5	12	72	67	14	5
Ford	77	18	16	0	25	58	59	0	5
General Motors	62	24	11	0	7	57	57	0	5
Honda	44	6	2	0	0	49	15	2	2
Hyundai	52	0	1	0	3	52	28	0	3
Kia	37	0	1	0	0	57	0	0	2
Mazda	79	0	14	1	17	66	60	0	5
Mitsubishi	85	0	31	0	16	72	72	0	6
Nissan	69	7	11	0	2	64	61	1	6
Porsche *	83	15	62	8	5	45	62	15	4
Subaru	72	0	9	0	0	70	37	0	3
Suzuki	70	0	0	0	3	67	67	0	3
Tata *	85	55	27	0	14	70	70	15	5
Toyota	15	7	0	0	13	30	7	12	1
Volkswagen *	82	18	71	11	10	68	60	15	4
Overall	56	13	14	1	11	53	41	4	4
Increase over 2011 CAFE	46	11	7	1	−5	46	38	2	4

* These manufacturers were unable to meet the final 2016 standards with the imposed caps on technology.

TABLE III.D.7–3—TECHNOLOGY PENETRATION—6% PER YEAR ALTERNATIVE STANDARDS IN 2016: CARS AND TRUCKS COMBINED

[In percent]

	GDI	OHC–DEAC	Turbo	Diesel	6 Speed auto trans	Dual clutch trans	Start-stop	Hybrid	Mass reduction (%)
BMW *	80	21	61	6	13	63	65	14	5
Chrysler	85	13	50	0	3	82	83	2	8
Daimler *	76	30	53	5	12	72	67	14	5
Ford*	85	13	57	0	4	74	75	10	7
General Motors	85	25	43	0	2	83	83	2	8
Honda	68	6	10	0	1	65	65	2	6
Hyundai	73	1	12	0	9	64	64	0	5
Kia	62	0	1	0	0	62	61	0	5
Mazda	85	0	19	1	4	80	82	0	7
Mitsubishi *	85	4	42	0	4	75	75	10	7
Nissan	85	8	38	0	0	78	81	4	8
Porsche *	83	15	62	8	5	45	62	15	4
Subaru	84	0	18	1	3	79	80	0	6
Suzuki	85	0	85	0	0	85	85	0	8
Tata *	85	55	27	0	14	70	70	15	5
Toyota	71	7	5	0	20	49	47	12	4

TABLE III.D.7–3—TECHNOLOGY PENETRATION—6% PER YEAR ALTERNATIVE STANDARDS IN 2016: CARS AND TRUCKS COMBINED—Continued

[In percent]

	GDI	OHC–DEAC	Turbo	Diesel	6 Speed auto trans	Dual clutch trans	Start-stop	Hybrid	Mass reduction (%)
Volkswagen *	82	18	71	11	10	68	60	15	4
Overall	79	12	33	1	7	69	69	6	6
Increase over 2011 CAFE	69	10	26	1	−9	62	66	4	6

* These manufacturers were unable to meet the final 2016 standards with the imposed caps on technology.

With respect to the 4 percent per year standards, the levels of requisite control technology are lower than those under the final standards, as would be expected. Industry-wide, the largest decreases were a 7 percent decrease in use of gasoline direct injection engines, a 4 percent decrease in the use of dual clutch transmissions, and a 2 percent decrease in the application of start-stop technology. On a manufacturer specific basis, the most significant decreases were a 10 percent or larger decrease in the use of stop-start technology for Honda, Kia, Mitsubishi and Suzuki and a 12 percent drop in turbocharger use for Mitsubishi. These are relatively small changes and are due to the fact that the 4 percent per year standards only require 4 g/mi CO_2 less control than the final standards in 2016. Porsche, Tata and Volkswagen continue to be unable to comply with the CO_2 standards in 2016, even under the 4 percent per year standard scenario. BMW just complied under this scenario, so its costs and technology penetrations are the same as under the final standards.

With respect to the 6 percent per year standards, the levels of requisite control technology increased substantially relative to those under the final standards, as again would be expected. Industry-wide, the largest increase was a 25 percent increase in the application of start-stop technology and 13–17 percent increases in the use of gasoline direct injection engines, turbocharging and dual clutch transmissions. On a manufacturer specific basis, the most significant increases were a 10 percent increase in hybrid penetration for Ford and Mitsubishi. These are more significant changes and are due to the fact that the 6 percent per year standards require 20 g/mi CO_2 more control than the final standards in 2016. Our projections for BMW, Porsche, Tata and Volkswagen continue to show they are unable to comply with the CO_2 standards in 2016, so our projections for these manufacturers do not differ relative to the final standards, though the amount of short-fall for each firm increases significantly, by an additional 20 g/mi CO_2 per firm. However, Ford and Mitsubishi join this list as can be seen from Figure III.D.6–2. The CO_2 emissions from Ford's cars are very similar to those of the industry when adjusted for technology, weight and performance. However, their trucks emit more than 25% more CO_2 per mile than the industry average. It is possible that addressing this issue would resolve their difficulty in complying with the 6 percent per year scenario. Both Mitsubishi's cars and truck emit roughly 10% more than the industry average vehicles after adjusting for technology, weight and performance. Again, addressing this issue could resolve their difficulty in complying with the 6 percent per year scenario. Five manufacturers are projected to need to increase their use of start-stop technology by at least 30 percent.

Table III.D.7–4 shows the projected cost of the two alternative sets of standards.

TABLE III.D.7–4—TECHNOLOGY COST PER VEHICLE IN 2016—ALTERNATIVE STANDARDS ($2007)

	4 Percent per year standards, relative to 2011 MY CAFE standards			6 Percent per year standards, relative to 2011 MY CAFE standards		
	Cars	Trucks	All	Cars	Trucks	All
BMW	$1,558	$1,195	$1,453	$1,558	$1,195	$1,453
Chrysler	1,111	1,236	1,178	1,447	2,156	1,827
Daimler	1,536	931	1,343	1,536	931	1,343
Ford	1,013	1,358	1,140	1,839	2,090	1,932
General Motors	834	1,501	1,148	1,728	2,030	1,870
Honda	598	411	529	894	891	893
Hyundai	769	202	684	1,052	1,251	1,082
Kia	588	238	527	1,132	247	979
Mazda	766	537	733	1,093	1,083	1,092
Mitsubishi	733	1,164	906	1,224	1,840	1,471
Nissan	572	1,119	729	1,151	1,693	1,306
Porsche	1,506	759	1,257	1,506	759	1,257
Subaru	962	616	836	1,173	1,316	1,225
Suzuki	1,015	179	879	1,426	1,352	1,414
Tata	1,181	680	984	1,181	680	984
Toyota	323	560	400	747	906	799
Volkswagen	1,848	972	1,694	1,848	972	1,694
Overall	811	1,020	883	1,296	1,538	1,379

As can be seen, the average cost of the 4 percent per year standards is only $65 per vehicle less than that for the final standards. This incremental cost is very similar to that projected in the NPRM. In contrast, the average cost of the 6 percent per year standards is over $430 per vehicle more than that for the final standards, which is $80 less than that projected in the NPRM (again due to lower technology costs). Compliance costs are entering the region of non-linearity. The $65 cost savings of the 4 percent per year standards relative to the final rule represents $19 per g/mi CO_2 increase. The $430 cost increase of the 6 percent per year standards relative to the final rule represents a 25 per g/mi CO_2 increase. More importantly, two additional manufacturers, Ford and Mitsubishi, are projected to be unable to comply with the 6% per year standards. In addition, under the 6% per year standards, four manufacturers (Chrysler, General Motors, Suzuki and Nissan) are within 2 g/mi CO_2 of the minimum achievable levels projected by EPA's OMEGA model analysis for 2016.

EPA does not believe the 4% per year alternative is an appropriate standard for the MY 2012–2016 time frame. As discussed above, the 250 g/mi final rule is technologically feasible in this time frame at reasonable costs, and provides higher GHG emission reductions at a modest cost increase over the 4% per year alternative (less than $100 per vehicle). In addition, the 4% per year alternative does not result in a harmonized National Program for the country. Based on California's letter of May 18, 2009, the emission standards under this alternative would not result in the State of California revising its regulations such that compliance with EPA's GHG standards would be deemed to be in compliance with California's GHG standards for these model years. Thus, the consequence of promulgating a 4% per year standard would be to require manufacturers to produce two vehicle fleets: A fleet meeting the 4% per year Federal standard, and a separate fleet meeting the more stringent California standard for sale in California and the section 177 states. This further increases the costs of the 4% per year standard and could lead to additional difficulties for the already stressed automotive industry.

EPA also does not believe the 6% per year alternative is an appropriate standard for the MY 2012–2016 time frame. As shown in Tables III.D.7–3 and III.D.7–4, the 6% per year alternative represents a significant increase in both the technology required and the overall costs compared to the final standards. In absolute percent increases in the technology penetration, compared to the final standards the 6% per year alternative requires for the industry as a whole: An 18% increase in GDI fuel systems, an 11% increase in turbo-downsize systems, a 6% increase in dual-clutch automated manual transmissions (DCT), and a 9% increase in start-stop systems. For a number of manufacturers the expected increase in technology is greater: For GM, a 15% increase in both DCTs and start-stop systems, for Nissan a 9% increase in full hybrid systems, for Ford an 11% increase in full hybrid systems, for Chrysler a 34% increase in both DCT and start-stop systems and for Hyundai a 23% increase in the overall penetration of DCT and start-stop systems. For the industry as a whole, the per-vehicle cost increase for the 6% per year alternative is nearly $500. On average this is a 50% increase in costs compared to the final standards. At the same time, CO_2 emissions would be reduced by about 8%, compared to the 250 g/mi target level.

As noted above, EPA's OMEGA model predicts that for model year 2016, Ford, Mitsubishi, Mercedes, BMW, Volkswagen, Jaguar-Land Rover, and Porsche do not meet their target under the 6 percent per year scenario. In addition, Chrysler, General Motors, Suzuki and Nissan all are within 2 grams/mi CO_2 of maximizing the applicable technology allowed under EPA's OMEGA model—that is, these companies have almost no head-room for compliance. In total, these 11 companies represent more than 58 percent of total 2016 projected U.S. light-duty vehicle sales. This provides a strong indication that the 6 percent per year standard is much more stringent than the final standards, and presents a significant risk of non-compliance for many firms, including four of the seven largest firms by U.S. sales.

These technology and cost increases are significant, given the amount of lead-time between now and model years 2012–2016. In order to achieve the levels of technology penetration for the final standards, the industry needs to invest significant capital and product development resources right away, in particular for the 2012 and 2013 model year, which is only 2–3 years from now. For the 2014–2016 time frame, significant product development and capital investments will need to occur over the next 2–3 years in order to be ready for launching these new products for those model years. Thus a major part of the required capital and resource investment will need to occur now and over the next few years, under the final standards. EPA believes that the final rule (a target of 250 gram/mile in 2016) already requires significant investment and product development costs for the industry, focused on the next few years.

It is important to note, and as discussed later in this preamble, as well as in the Joint Technical Support Document and the EPA Regulatory Impact Analysis document, the average model year 2016 per-vehicle cost increase of nearly $500 includes an estimate of both the increase in capital investments by the auto companies and the suppliers as well as the increase in product development costs. These costs can be significant, especially as they must occur over the next 2–3 years. Both the domestic and transplant auto firms, as well as the domestic and world-wide automotive supplier base, is experiencing one of the most difficult markets in the U.S. and internationally that has been seen in the past 30 years. One major impact of the global downturn in the automotive industry and certainly in the U.S. is the significant reduction in product development engineers and staffs, as well as a tightening of the credit markets which allow auto firms and suppliers to make the near-term capital investments necessary to bring new technology into production. The 6% per year alternative standard would impose significantly increased pressure on capital and other resources, indicating it is too stringent for this time frame, given both the relatively limited amount of lead-time between now and model years 2012–2016, the need for much of these resources over the next few years, as well the current financial and related circumstances of the automotive industry. EPA is not concluding that the 6% per year alternative standards are technologically infeasible, but EPA believes such standards for this time frame would be overly stringent given the significant strain it would place on the resources of the industry under current conditions. EPA believes this degree of stringency is not warranted at this time. Therefore EPA does not believe the 6% per year alternative would be an appropriate balance of various relevant factors for model years 2012–1016.

Jaguar/Land Rover, in their comments, agreed that the more stringent standards would not be economically practicable, and several automotive firms indicated that the proposed standards, while feasible, would be overly challenging.[261] On the other hand, the Center for Biological Diversity (henceforth referred to here as CBD), strongly urged EPA to adopt more

[261] *See* comments from Toyota, General Motors.

stringent standards. CBD gives examples of higher standards in other nations to support their contention that the standards should be more stringent. CBD also claims that the agencies are "setting standards that deliberately delay implementation of technology that is available now" by setting lead time for the rule greater than 18 months. CBD also accuses the agencies of arbitrarily "adhering to strict five-year manufacturer 'redesign cycles.' " CBD notes that the agencies have stated that all of the "technologies are already available today," and EPA and NHTSA's assessment is that manufacturers "would be able to meet the proposed standards through more widespread use of these technologies across the fleet." Based on the agencies' previous statements, CBD concludes that the fleet can meet the 250 g/mi target in 2010. EPA believes that in all cases, CBD's analysis for feasibility and necessary lead time is flawed.

Other countries' absolute fleetwide standards are not a reliable or directly relevant comparison. The fleet make-up in other nations is quite different than that of the United States. CBD primarily cites the European Union and Japan as examples. Both of these regions have a large fraction of small vehicles (with lower average weight, and footprint size) when compared to vehicles in the U.S. Also the U.S. has a much greater fraction of light-duty trucks. In particular in Europe, there is a much higher fraction of diesel vehicles in the existing fleet, which leads to lower CO_2 emissions in the baseline fleet as compared to the U.S. This is in large part due to the significantly different fuel prices seen in Europe as compared to the U.S. The European fleet also has a much higher penetration of manual transmission than the U.S., which also results in lower CO_2 emissions. Moreover, these countries use different test cycles, which bias CO_2 emissions relative to the EPA 2 cycle test cycles. When looked at from a technology-basis, with the exception of the existing large penetration of diesels and manual transmissions in the European fleet—there is no "magic" in the European and Japanese markets which leads to lower fleet-wide CO_2 emissions. In fact, from a technology perspective, the standards contained in this final rule are premised to a large degree on the same technologies which the European and Japanese governments have relied upon to establish their CO_2 and fuel economy limits for this same time frame and for the fleet mixes in their countries. That is for example, large increases in the use of 6+ speed transmissions, automated manual transmissions, gasoline direct injection, engine downsizing and turbocharging, and start-stop systems. CBD has not provided any detailed analysis of what technologies are available in Europe which EPA is not considering—and there are no such "magic" technologies. The vast majority of the differences between the current and future CO_2 performance of the Japanese and European light-duty vehicle fleets are due to differences in the size and current composition of the vehicle fleets in those two regions—not because EPA has ignored technologies which are available for application to the U.S. market in the 2012–2016 time frame.

If CBD is advocating a radical reshifting of domestic fleet composition, (such as requiring U.S. consumers to purchase much smaller vehicles and requiring U.S. consumers to purchase vehicles with manual transmissions), it is sufficient to say that standards forcing such a result are not compelled under section 202(a), where reasonable preservation of consumer choice remains a pertinent factor for EPA to consider in balancing the relevant statutory factors. *See* also *International Harvester* (478 F. 2d at 640 (Administrator required to consider issues of basic demand for new passenger vehicles in making technical feasibility and lead time determinations). Thus EPA believes that the standard is at the proper level of stringency for the projected domestic fleet in the 2012–2016 model years taking into account the wide variety of consumer choice that is reflected in this projection of the domestic fleet.

As mentioned earlier (in III.D.4), CBD's comments on available lead time also are inaccurate. Under section 202(a), standards are to take effect only "after providing such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period." Having sufficient lead time includes among other things, the time required to certify vehicles. For example, model year 2012 vehicles will be tested and certified for the EPA within a short time after the rule is finalized, and this can start as early as calendar year 2010, for MY 2012 vehicles that can be produced in calendar year 2011. In addition, these 2012 MY vehicles have already been fully designed, with prototypes built several years earlier. It takes several years to redesign a vehicle, and several more to design an entirely new vehicle not based on an existing platform. Thus, redesign cycles are an inextricable component of adequate lead time under the Act. A full line manufacturer only has limited staffing and financial resources to redesign vehicles, therefore the redesigns are staggered throughout a multi-year period to optimize human capital.[262] Furthermore, redesigns require a significant outlay of capital from the manufacturer. This includes research and development, material and equipment purchasing, overhead, benefits, etc. These costs are significant and are included in the cost estimates for the technologies in this rule. Because of the manpower and financial capital constraints, it would only be possible to redesign all the vehicles across a manufacturer's line simultaneously if the manufacturer has access to tremendous amounts of ready capital and an unrealistically large engineering staff. However no major automotive firm in the world has the capability to undertake such an effort, and it is unlikely that the supplier basis could support such an effort if it was required by all major automotive firms. Even if this unlikely condition were possible, the large engineering staff would then have to be downsized or work on the next redesign of the entire line another few years later. This would have the effect of increasing the cost of the vehicles.

There is much evidence to indicate that the average redesign cycle in the industry is about 5 years.[263] There are some manufacturers who have longer cycles (such as smaller manufacturers described above), and there are others who have shorter cycles for some of their products. EPA believes that there are no full line manufacturers who can maintain significant redesigns of vehicles (with relative large sales) in 1 or 2 years, and CBD has provided no evidence indicating this is technically feasible. A complete redesign of the entire U.S. light-duty fleet by model year 2012 is clearly infeasible, and EPA believes that several model years additional lead time is necessary in order for the manufacturers to meet the standards. The graduated increase in the stringency of the standards from MYs 2012 through 2016 accounts for this needed lead time.

There are other reasons that the fleet cannot meet the 250g/mi CO_2 target in 2012 (much less in 2010). The commenter reasons that if technology is in use now—even if limited use—it can

[262] *See* for example "How Automakers Plan Their Products", Center for Automotive Research, July 2007.

[263] *See* for example "Car Wars 2010–2013, The U.S. automotive product pipeline", John Murphy, Research Analyst, Bank of America/Merrill Lynch research paper, July 15, 2009.

be utilized across the fleet nearly immediately. This is not the case. An immediate demand from original equipment manufacturers (OEMs) to supply 100% of the fleet with these technologies in 2012 would cause their suppliers to encounter the same lead time issues discussed above. Suppliers have limited capacity to change their current production over to the newer technologies quickly. Part of this reason is due to engineering, cost and manpower constraints as described above, but additionally, the suppliers face an issue of "stranded capital". This is when the basic tooling and machines that produce the technologies in question need to be replaced. If these tools and machines are replaced before they near the end of their useful life, the suppliers are left with "stranded capital" *i.e.,* a significant financial loss because they are replacing perfectly good equipment with newer equipment. This situation can also occur for the OEMs. In an extreme example, a plant that switches over from building port fuel injected gasoline engines to building batteries and motors, will require a nearly complete retooling of the plant. In a less extreme example, a plant that builds that same engine and switches over to suddenly building smaller turbocharged direct injection engines with starter alternators might have significant retooling costs as well as stranded capital. Finally, it takes a significant amount of time to retool a factory and smoothly validate the tooling and processes to mass produce a replacement technology. This is why most manufacturers do this process over time, replacing equipment as they wear out. CBD has not accounted for any of these considerations. EPA believes that attempting to force the types of massive technology penetration needed in the early model years of the standard to achieve the 2016 standards would be physically and cost prohibitive.

A number of automotive firms and associations (including the Alliance of Automobile Manufacturers, Mercedes, and Toyota) commented that the standards during the early model years, in particular MY 2012, are too stringent, and that a more linear phase-in of the standards beginning with the MY 2011 CAFE standards and ending with the 250 gram/mi proposed EPA projected fleet-wide level in MY 2016 is more appropriate. In the May 19, 2009 Joint Notice of Intent, EPA and NHTSA stated that the standards would have "* * * *a generally linear phase-in from MY 2012 through to model year 2016*." (74 FR 24008). The Alliance of Automobile Manufacturers stated that the phase-in of the standards is not linear, and they proposed a methodology for the CAFE standards to be a linear progression from MY 2011 to MY 2016. The California Air Resources Board commented that the proposed level of stringency, including the EPA proposed standards for MY 2012–2015, were appropriate and urged EPA to finalize the standards as proposed and not reduce the stringency in the early model years as this would result in a large loss of the GHG reductions from the National Program. EPA agrees with the comments from CARB, and we have not reduced the stringency of the program for the early model years. While some automotive firms indicated a desire to see a linear transition from the Model Year 2011 CAFE standards, our technology and cost analysis indicates that our standards are appropriate for these interim years. As shown in Section III.H of this final rule, the final standards result in significant GHG reductions, including the reductions from MY 2012–2015, and at reasonable costs, providing appropriate lead time. The automotive industry commenters did not point to a specific technical issue with the standards, but rather their desire for a linear phase-in from the existing 2011 CAFE standards.

In summary, the EPA believes that the MY 2012–2016 standards finalized are feasible and that there are compelling reasons not to adopt more stringent standards, based on a reasonable weighing of the statutory factors, including available technology, its cost, and the lead time necessary to permit its development and application. For further discussion of these issues, see Chapter 4 of the RIA as well as the response to comments.

E. Certification, Compliance, and Enforcement

1. Compliance Program Overview

This section describes EPA's comprehensive program to ensure compliance with emission standards for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), as described in Section III.B. An effective compliance program is essential to achieving the environmental and public health benefits promised by these mobile source GHG standards. EPA's GHG compliance program is designed around two overarching priorities: (1) To address Clean Air Act (CAA) requirements and policy objectives; and (2) to streamline the compliance process for both manufacturers and EPA by building on existing practice wherever possible, and by structuring the program such that manufacturers can use a single data set to satisfy both the new GHG and Corporate Average Fuel Economy (CAFE) testing and reporting requirements. The EPA and NHTSA programs recognize, and replicate as closely as possible, the compliance protocols associated with the existing CAA Tier 2 vehicle emission standards, and with CAFE standards. The certification, testing, reporting, and associated compliance activities closely track current practices and are thus familiar to manufacturers. EPA already oversees testing, collects and processes test data, and performs calculations to determine compliance with both CAFE and CAA standards. Under this coordinated approach, the compliance mechanisms for both programs are consistent and non-duplicative.

Vehicle emission standards established under the CAA apply throughout a vehicle's full useful life. Today's rule establishes fleet average greenhouse gas standards where compliance with the fleet average is determined based on the testing performed at time of production, as with the current CAFE fleet average. EPA is also establishing in-use standards that apply throughout a vehicle's useful life, with the in-use standard determined by adding an adjustment factor to the emission results used to calculate the fleet average. EPA's program will thus not only assess compliance with the fleet average standards described in Section III.B, but will also assess compliance with the in-use standards. As it does now, EPA will use a variety of compliance mechanisms to conduct these assessments, including pre-production certification and post-production, in-use monitoring once vehicles enter customer service. Specifically, EPA is establishing a compliance program for the fleet average that utilizes CAFE program protocols with respect to testing, a certification procedure that operates in conjunction with the existing CAA Tier 2 certification procedures, and an assessment of compliance with the in-use standards concurrent with existing EPA and manufacturer Tier 2 emission compliance testing programs. Under this compliance program manufacturers will also be afforded numerous flexibilities to help achieve compliance, both stemming from the program design itself in the form of a manufacturer-specific CO_2 fleet average standard, as well as in various credit banking and trading opportunities, as described in Section III.C. EPA received broad comment from regulated industry and from the public interest community supporting this overall compliance program structure.

The compliance program is outlined in further detail below.

2. Compliance With Fleet-Average CO_2 Standards

Fleet average emission levels can only be determined when a complete fleet profile becomes available at the close of the model year. Therefore, EPA will determine compliance with the fleet average CO_2 standards when the model year closes out, as is currently the protocol under EPA's Tier 2 program as well as under the current CAFE program. The compliance determination will be based on actual production figures for each model and on model-level emissions data collected through testing over the course of the model year. Manufacturers will submit this information to EPA in an end-of-year report which is discussed in detail in Section III.E.5.h below.

Manufacturers currently conduct their CAFE testing over an entire model year to maximize efficient use of testing and engineering resources. Manufacturers submit their CAFE test results to EPA and EPA conducts confirmatory fuel economy testing at its laboratory on a subset of these vehicles under EPA's Part 600 regulations. EPA's proposal to extend this approach to the GHG program received overwhelming support from vehicle manufacturers. EPA is finalizing GHG requirements under which manufacturers will continue to perform the model-level testing currently required for CAFE fuel economy performance and measure and report the CO_2 values for all tests conducted.[264] Manufacturers will submit one data set in satisfaction of both CAFE and GHG requirements such that EPA's program will not impose additional timing or testing requirements on manufacturers beyond that required by the CAFE program. For example, manufacturers currently submit fuel economy test results at the subconfiguration and configuration levels to satisfy CAFE requirements. Now manufacturers will also submit CO_2 values for the same vehicles. Section III.E.3 discusses how this will be implemented in the certification process.

a. Compliance Determinations

As described in Section III.B above, the fleet average standards will be determined on a manufacturer by manufacturer basis, separately for cars and trucks, using the footprint attribute curves. EPA will calculate the fleet average emission level using actual production figures and, for each model type, CO_2 emission test values generated at the time of a manufacturer's CAFE testing. EPA will then compare the actual fleet average to the manufacturer's footprint standard to determine compliance, taking into consideration use of averaging and credits.

Final determination of compliance with fleet average CO_2 standards may not occur until several years after the close of the model year due to the flexibilities of carry-forward and carry-back credits and the remediation of deficits (see Section III.C). A failure to meet the fleet average standard after credit opportunities have been exhausted could ultimately result in penalties and injunctive orders under the CAA as described in Section III.E.6 below.

EPA received considerable comment about the need for transparency in its implementation of the greenhouse gas program and specifically about the need for public access to information about Agency compliance determinations. Many comments emphasized the importance of making greenhouse gas compliance information publicly available to ensure such transparency. EPA also received comment from industry about the need to protect confidential business information. Both transparency and protection of confidential information are longstanding EPA practices, and both will remain priorities in EPA's implementation of the greenhouse gas program. EPA periodically provides mobile source emissions and fuel economy information to the public, for example through the annual Compliance Report[265] and Fuel Economy Trends Report.[266] As proposed, EPA plans to expand these reports to include GHG performance and compliance trends information, such as annual status of credit balances or debits, use of various credit programs, attained fleet average emission levels compared with standards, and final compliance status for a model year after credit reconciliation occurs. EPA intends to regularly disseminate non-confidential, model-level and fleet information for each manufacturer after the close of the model year. EPA will reassess data release needs and opportunities once the program is underway.

Beyond transparency in reporting emissions data and compliance status, EPA is concerned, as a matter of principle moving into a new era of greenhouse gas control, that greenhouse gas reductions reported for purposes of compliance with the standards adopted in this rule will be reflected in the real world and not just as calculated fleet average emission levels or measured certification test results. Therefore EPA will pay close attention to technical details behind manufacturer reports. For example, EPA intends to look closely at each manufacturer's certification testing procedures, GHG calculation procedures, and laboratory correlation with EPA's laboratory, and to carefully review manufacturer pre-production, production, and in-use testing programs. In addition, EPA plans to monitor GHG performance through its own in-use surveillance program in the coming years. This will ensure that the environmental benefits of the rule are achieved as well as ensure a level playing field for all.

b. Required Minimum Testing for Fleet Average CO_2

EPA received no public comment on provisions that would extend current CAFE testing requirements and flexibilities to the GHG program, and is finalizing as proposed minimum testing requirements for fleet average CO_2 determination. EPA will require and use the same test data to determine a manufacturer's compliance with both the CAFE standard and the fleet average CO_2 emissions standard. CAFE requires manufacturers to submit test data representing at least 90% of the manufacturer's model year production, by configuration.[267] The CAFE testing covers the vast majority of models in a manufacturer's fleet. Manufacturers industry-wide currently test more than 1,000 vehicles each year to meet this requirement. EPA believes this minimum testing requirement is necessary and applicable for calculating accurate CO_2 fleet average emissions. Manufacturers may test additional

[264] As discussed in Section III.B.1, vehicle and fleet average compliance will be based on a combination of CO_2, HC, and CO emissions. This is consistent with the carbon balance methodology used to determine fuel consumption for the labeling and CAFE programs. The final regulations account for these total carbon emissions appropriately and refer to the sum of these emissions as the "carbon-related exhaust emissions" (CREE). Although regulatory text uses the more accurate term "CREE" to represent the CO_2-equivalent sum of carbon emissions, the term CO_2 is used as shorthand throughout Section III.E as a more familiar term for most readers.

[265] 2007 Progress Report Vehicle and Engine Compliance Activities; EPA–420–R–08–011; October 2008. This document is available electronically at *http://www.epa.gov/otaq/about/420r08011.pdf.*

[266] Light-Duty Automotive Technology and Fuel-Economy Trends: 1975 Through 2008; EPA–420–S–08–003; September 2008. This document is available electronically at *http://www.epa.gov/otaq/fetrends.htm.*

[267] *See* 40 CFR 600.010–08(d).

vehicles, at their option. As described above, EPA will use the emissions results from the model-level testing to calculate a manufacturer's fleet average CO_2 emissions and to determine compliance with the CO_2 fleet average standard.

EPA will continue to allow certain testing flexibilities that exist under the CAFE program. EPA has always permitted manufacturers some ability to reduce their test burden in tradeoff for lower fuel economy numbers. Specifically the practice of "data substitution" enables manufacturers to apply fuel economy test values from a "worst case" configuration to other configurations in lieu of testing them. The substituted values may only be applied to configurations that would be expected to have better fuel economy and for which no actual test data exist. EPA will continue to accept use of substituted data in the GHG program, but only when the substituted data are also used for CAFE purposes.

EPA regulations for CAFE testing permit the use of analytically derived fuel economy data in lieu of conducting actual fuel economy tests in certain situations.[268] Analytically derived data are generated mathematically using expressions determined by EPA and are allowed on a limited basis when a manufacturer has not tested a specific vehicle configuration. This has been done as a way to reduce some of the testing burden on manufacturers without sacrificing accuracy in fuel economy measurement. EPA has issued guidance that provides details on analytically derived data and that specifies the conditions when analytically derived fuel economy data may be used. EPA will apply the same guidance to the GHG program and will allow any analytically derived data used for CAFE to also satisfy the GHG data reporting requirements. EPA will revise the terms in the current equations for analytically derived fuel economy to specify them in terms of CO_2. Analytically derived CO_2 data will not be permitted for the Emission Data Vehicle representing a test group for pre-production certification, only for the determination of the model level test results used to determine actual fleet-average CO_2 levels.

EPA is retaining the definitions needed to determine CO_2 levels of each model type (such as "subconfiguration," "configuration," "base level," etc.) as they are currently defined in EPA's fuel economy regulations.

[268] 40 CFR 600.006–08(e).

3. Vehicle Certification

CAA section 203(a)(1) prohibits manufacturers from introducing a new motor vehicle into commerce unless the vehicle is covered by an EPA-issued certificate of conformity. Section 206(a)(1) of the CAA describes the requirements for EPA issuance of a certificate of conformity, based on a demonstration of compliance with the emission standards established by EPA under section 202 of the Act. The certification demonstration requires emission testing, and must be done for each model year.[269]

Under Tier 2 and other EPA emission standard programs, vehicle manufacturers certify a group of vehicles called a test group. A test group typically includes multiple vehicle car lines and model types that share critical emissions-related features.[270] The manufacturer generally selects and tests one vehicle to represent the entire test group for certification purposes. The test vehicle is the one expected to be the worst case for the emission standard at issue. Emission results from the test vehicle are used to assign the test group to one of several specified bins of emissions levels, identified in the Tier 2 rule, and this bin level becomes the in-use emissions standard for that test group.[271]

Since compliance with the Tier 2 fleet average depends on actual test group sales volumes and bin levels, it is not possible to determine compliance with the fleet average at the time the manufacturer applies for and receives a certificate of conformity for a test group. Instead, EPA requires the manufacturer to make a good faith demonstration in the certification application that vehicles in the test group will both (1) comply throughout their useful life with the emissions bin assigned, and (2) contribute to fleet-wide compliance with the Tier 2 average when the year is over. EPA issues a certificate for the vehicles included in the test group based on this demonstration, and includes a condition in the certificate that if the manufacturer does not comply with the fleet average, then production vehicles from that test group will be treated as not covered by the certificate to the extent needed to bring the manufacturer's fleet average into compliance with Tier 2.

[269] CAA section 206(a)(1).

[270] The specific test group criteria are described in 40 CFR 86.1827–01, car lines and model types have the meaning given in 40 CFR 86.1803–01.

[271] Initially in-use standards were different from the bin level determined at certification as the useful life level. The current in-use standards, however, are the same as the bin levels. In all cases, the bin level, reflecting useful life levels, has been used for determining compliance with the fleet average.

The certification process often occurs several months prior to production and manufacturer testing may occur months before the certificate is issued. The certification process for the Tier 2 program is an efficient way for manufacturers to conduct the needed testing well in advance of certification, and to receive the needed certificates in a time frame which allows for the orderly production of vehicles. The use of a condition on the certificate has been an effective way to ensure compliance with the Tier 2 fleet average.

EPA will similarly condition each certificate of conformity for the GHG program upon a manufacturer's demonstration of compliance with the manufacturer's fleet-wide average CO_2 standard. The following discussion explains how EPA will integrate the new GHG vehicle certification program into the existing certification program.

a. Compliance Plans

In an effort to expedite the Tier 2 program certification process and facilitate early resolution of any compliance related concerns, EPA conducts annual reviews of each manufacturer's certification, in-use compliance and fuel economy plans for upcoming model year vehicles. EPA meets with each manufacturer individually, typically before the manufacturer begins to submit applications for certification for the new model year. Discussion topics include compliance plans for the upcoming model year, any new product offerings/new technologies, certification and/or testing issues, phase-in and/or ABT plans, and a projection of potential EPA confirmatory test vehicles. EPA has been conducting these compliance preview meetings for more than 10 years and has found them to be very useful for both EPA and manufacturers. Besides helping to expedite the certification process, certification preview meetings provide an opportunity to resolve potential issues before the process begins. The meetings give EPA an early opportunity to assess a manufacturer's compliance strategy, which in turn enables EPA to address any potential concerns before plans are finalized. The early interaction reduces the likelihood of unforeseen issues occurring during the actual certification of a test group which can result in the delay or even termination of the certification process.

For the reasons discussed above, along with additional factors, EPA believes it is appropriate for manufacturers to include their GHG compliance plan information as part of the new model year compliance preview process. This requirement is both consistent with existing practice under Tier 2 and very similar to the pre-model year report required under existing and new CAFE regulation. Furthermore, in light of the production weighted fleet average program design in which the final compliance determination cannot be made until after the end of the model year, EPA believes it is especially important for manufacturers to demonstrate that they have a credible compliance plan prior to the beginning of certification.

Several commenters raised concerns about EPA's proposal for requiring manufacturers to submit GHG compliance plans. AIAM stated that EPA did not identify a clear purpose for the review of the plans, criteria for evaluating the plans, or consequences if EPA found the plans to be unacceptable. AIAM also expressed concern over the appropriateness of requiring manufacturers to prepare regulatory compliance plans in advance, since vicissitudes of the market and other factors beyond a manufacturer's direct control may change over the course of the year and affect the model year outcome. Finally, AIAM commented that EPA should not attempt to take any enforcement action based on an asserted inadequacy of a plan. The comments stated that compliance should be determined only after the end of a model year and the subsequent credit earning period. The Alliance commented that there was an inconsistency between the proposed preamble language and the regulatory language in 600.514–12(a)(2)(i). The preamble language indicated that the compliance report should be submitted prior to the beginning of the model year and prior to the certification of any test group, while the regulatory language stated that the pre-model year report must be submitted during the month of December. The Alliance pointed out that if EPA wanted GHG compliance plan information before the certification of any test groups, the regulatory language would need to be corrected.

EPA understands that a manufacturer's plan may change over the course of a model year and that compliance information manufacturers present prior to the beginning of a new model year may not represent the final compliance outcome. Rather, EPA views the compliance plan as a manufacturer's good-faith projection of strategy for achieving compliance with the greenhouse gas standard. It is not EPA's intent to base compliance action solely on differences between projections in the compliance plan and end of year results. EPA understands that compliance with the GHG program will be determined at the end of the model year after all appropriate credits have been taken into consideration.

As stated earlier, a requirement to include GHG compliance information in the new model year compliance preview meetings is consistent with long standing EPA policy. The information will provide EPA with an early overview of the manufacturer's GHG compliance plan and allow EPA to make an early assessment as to possible issues, questions, or concerns with the program in order to expedite the certification process and help manufacturers better understand overall compliance provisions of the GHG program. Therefore, EPA is finalizing revisions to 40 CFR 600.514–12 which will require manufacturers to submit a compliance plan to EPA prior to the beginning of the model year and prior to the certification of any test group. The compliance plan must, at a minimum, include a manufacturer's projected footprint profile, projected total and model-level production volumes, projected fleet average and model-level CO_2 emission values, projected fleet average CO_2 standards and projected fleet average CO_2 credit status. In addition, EPA will expect the compliance plan to explain the various credit, transfer and trading options that will be used to comply with the standard, including the amount of credit the manufacturer intends to generate for air conditioning leakage, air conditioning efficiency, off-cycle technology, and various early credit programs. The compliance plan should also indicate how and when any deficits will be paid off through accrual of future credits.

EPA has corrected the inconsistency between the proposed preamble and regulatory language with respect to when the compliance report must be submitted and what level of information detail it must contain. EPA is finalizing revisions to 40 CFR 600.514–12 which require the compliance plan to be submitted to EPA prior to the beginning of the model year and prior to the certification of any test group. Today's action will also finalize simplified reporting requirements as discussed above.

b. Certification Test Groups and Test Vehicle Selection

Manufacturers currently divide their fleet into "test groups" for certification purposes. The test group is EPA's unit of certification; one certificate is issued per test group. These groupings cover vehicles with similar emission control system designs expected to have similar emissions performance.[272] The factors considered for determining test groups include combustion cycle, engine type, engine displacement, number of cylinders and cylinder arrangement, fuel type, fuel metering system, catalyst construction and precious metal composition, among others. Vehicles having these features in common are generally placed in the same test group.[273] Cars and trucks may be included in the same test group as long as they have similar emissions performance (manufacturers frequently produce cars and trucks that have identical engine designs and emission controls).

EPA recognizes that the Tier 2 test group criteria do not necessarily relate to CO_2 emission levels. For instance, while some of the criteria, such as combustion cycle, engine type and displacement, and fuel metering, may have a relationship to CO_2 emissions, others, such as those pertaining to the catalyst, may not. In fact, there are many vehicle design factors that affect CO_2 generation and emissions but are not included in EPA's test group criteria.[274] Most important among these may be vehicle weight, horsepower, aerodynamics, vehicle size, and performance features.

As described in the proposal, EPA considered but did not propose a requirement for separate CO_2 test groups established around criteria more directly related to CO_2 emissions. Although CO_2-specific test groups might more consistently predict CO_2 emissions of all vehicles in the test group, the addition of a CO_2 test group requirement would greatly increase the pre-production certification burden for both manufacturers and EPA. For example, a current Tier 2 test group would need to be split into two groups if automatic and manual transmissions models had been included in the same group. Two- and four-wheel drive vehicles in a current test group would similarly require separation, as would weight differences among vehicles. This would at least triple the number of test groups. EPA believes that the added burden of creating separate CO_2 test groups is not warranted or necessary to maintain an appropriately rigorous certification

[272] 40 CFR 86.1827–01.

[273] EPA provides for other groupings in certain circumstances, and can establish its own test groups in cases where the criteria do not apply. 40 CFR 86.1827–01(b), (c) and (d).

[274] EPA noted this potential lack of connection between fuel economy testing and testing for emissions standard purposes when it first adopted fuel economy test procedures. *See* 41 FR at 38677 (Sept. 10, 1976).

program because the test group data are later replaced by model specific data which are used as the basis for determining compliance with a manufacturer's fleet average standard.

For these reasons, EPA will retain the current Tier 2 test group structure for cars and light trucks in the certification requirements for CO_2. EPA believes that the current test group concept is also appropriate for N_20 and CH_4 because the technologies that are employed to control N_2O and CH_4 emissions will generally be the same as those used to control the criteria pollutants. Vehicle manufacturers agreed with this assessment and universally supported the use of current Tier 2 test groups in lieu of developing separate CO_2 test groups.

At the time of certification, manufacturers may use the CO_2 emission level from the Tier 2 Emission Data Vehicle as a surrogate to represent all of the models in the test group. However, following certification further testing will generally be required for compliance with the fleet average CO_2 standard as described below. EPA's issuance of a certificate will be conditioned upon the manufacturer's subsequent model level testing and attainment of the actual fleet average. Further discussion of these requirements is presented in Section III.E.6.

As just discussed, the "worst case" Emissions Data Vehicle selected to represent a test group under Tier 2 (40 CFR 86.1828–01) may not have the highest levels of CO_2 in that group. For instance, there may be a heavier, more powerful configuration that emits higher CO_2, but may, due to the way the catalytic converter has been matched to the engine, actually have lower NO_X, CO, PM or HC.

Therefore, in lieu of a separate CO_2 specific test group, EPA considered requiring manufacturers to select a CO_2 test vehicle from within the Tier 2 test group that would be expected, based on good engineering judgment, to have the highest CO_2 emissions within that test group. The CO_2 emissions results from this vehicle would be used to establish an in-use CO_2 emission standard for the test group. The requirement for a separate, worst case CO_2 vehicle would provide EPA with some assurance that all vehicles within the test group would have CO_2 emission levels at or below those of the selected vehicle, even if there is some variation in the CO_2 control strategies within the test group (such as different transmission types). Under this approach, the test vehicle might or might not be the same one that would be selected as worst case for criteria pollutants. Vehicle manufacturers expressed concern with this approach as well, and EPA ultimately rejected this approach because it could have required manufacturers to test two vehicles in each test group, rather than a single vehicle. This would represent an added timing burden to manufacturers because they might need to build additional test vehicles at the time of certification that previously weren't required to be tested.

Instead, EPA proposed and will adopt provisions that allow a single Emission Data Vehicle to represent the test group for both Tier 2 and CO_2 certification. The manufacturer will be allowed to initially apply the Emission Data Vehicle's CO_2 emissions value to all models in the test group, even if other models in the test group are expected to have higher CO_2 emissions. However, as a condition of the certificate, this surrogate CO_2 emissions value will generally be replaced with actual, model-level CO_2 values based on results from CAFE testing that occurs later in the model year. This model-level data will become the official certification test results (as per the conditioned certificate) and will be used to determine compliance with the fleet average. Only if the test vehicle is in fact the worst case CO_2 vehicle for the test group could the manufacturer elect to apply the Emission Data Vehicle emission levels to all models in the test group for purposes of calculating fleet average emissions. Manufacturers would be unlikely to make this choice, because doing so would ignore the emissions performance of vehicle models in their fleet with lower CO_2 emissions and would unnecessarily inflate their CO_2 fleet average. Testing at the model level already occurs and data are already being submitted to EPA for CAFE and labeling purposes, so it would be an unusual situation that would cause a manufacturer to ignore these data and choose to accept a higher CO_2 fleet average.

Manufacturers will be subject to two standards, the fleet average standard and the in-use standard for the useful life of the vehicle. Compliance with the fleet average standard is based on production-weighted averaging of the test data applied to each model. For each model, the in-use standard will generally be set at 10% higher than the level used for that model in calculating the fleet average (*see* Section III.E.4).[275] The certificate will cover both of these standards, and the manufacturer will have to demonstrate compliance with both of these standards for purposes of receiving a certificate of conformity. The certification process for the in-use standard is discussed below in Section III.E.4.

[275] In cases where configuration or sub-configuration level data exist, the in-use standard will be set at 10% higher than those emissions test results. See Section III.E.4.

c. Certification Testing Protocols and Procedures

To be consistent with CAFE, EPA will combine the CO_2 emissions results from the FTP and HFET tests using the same calculation method used to determine fuel economy for CAFE purposes. This approach is appropriate for CO_2 because CO_2 and fuel economy are so closely related. Other than the fact that fuel economy is calculated using a harmonic average and CO_2 emissions can be calculated using a conventional average, the calculation methods are very similar. The FTP CO_2 data will be weighted at 55%, and the highway CO_2 data at 45%, and then averaged to determine the combined number. See Section III.B.1 for more detailed information on CO_2 test procedures, Section III.C.1 on Air Conditioning Emissions, and Section III.B.7 for N_2O and CH_4 test procedures.

For the purposes of compliance with the fleet average and in-use standards, the emissions measured from each test vehicle will include hydrocarbons (HC) and carbon monoxide (CO), in addition to CO_2. All three of these exhaust constituents are currently measured and used to determine the amount of fuel burned over a given test cycle using a "carbon balance equation" defined in the regulations, and thus measurement of these is an integral part of current fuel economy testing. As explained in Section III.C, it is important to account for the total carbon content of the fuel. Therefore the carbon-related combustion products HC and CO must be included in the calculations along with CO_2, and any other carbon-containing exhaust components such as aldehyde emissions from alcohol-fueled vehicles. CO emissions are adjusted by a coefficient that reflects the carbon weight fraction (CWF) of the CO molecule, and HC emissions are adjusted by a coefficient that reflects the CWF of the fuel being burned (the molecular weight approach doesn't work since there are many different hydrocarbon compounds being accounted for). Thus, EPA will calculate the carbon-related exhaust emissions, also known as "CREE," of each test vehicle according to the following formula, where HC, CO, and CO_2 are in units of grams per mile:

carbon-related exhaust emissions (grams/mile) = CWF*HC + 1.571*CO + CO_2

Where:

CWF = the carbon weight fraction of the test fuel.

As part of the current CAFE and Tier 2 compliance programs, EPA selects a subset of vehicles for confirmatory testing at its National Vehicle and Fuel Emissions Laboratory. The purpose of confirmatory testing is to validate the manufacturer's emissions and/or fuel economy data. Under this rule, EPA will add CO_2, N_2O, and CH_4 to the emissions measured in the course of Tier 2 and CAFE confirmatory testing. The N_2O and methane measurement requirements will begin for model year 2015, when requirements for manufacturer measurement to comply with the standard also take effect. The emission values measured at the EPA laboratory will continue to stand as official, as under existing regulatory programs.

Under current practice, if during EPA's confirmatory fuel economy testing, the EPA fuel economy value differs from the manufacturer's value by more than 3%, manufacturers can request a re-test. The re-test results stand as official, even if they differ by more than 3% from the manufacturer's value. EPA proposed extending this practice to CO_2 results, but manufacturers commented that this could lead to duplicative testing and increased test burden. EPA agrees that the close relationship between CO_2 and fuel economy precludes the need to conduct additional confirmatory tests for both fuel economy and CO_2 to resolve potential discrepancies. Therefore EPA will continue to allow a re-test request based on a 3% or greater disparity in manufacturer and EPA confirmatory fuel economy test values, since a manufacturer's fleet average emissions level would be established on the basis of model-level testing only (unlike Tier 2 for which a fixed bin standard structure provides the opportunity for a compliance buffer).

4. Useful Life Compliance

Section 202(a)(1) of the CAA requires emission standards to apply to vehicles throughout their statutory useful life, as further described in Section III.A. For emission programs that have fleet average standards, such as Tier 2 NO_X fleet average standards and the new CO_2 standards, the useful life requirement applies to individual vehicles rather than to the fleet average standard. For example, in Tier 2 the useful life requirements apply to the individual emission standard levels or "bins" that the vehicles are certified to, not the fleet average standard. For Tier 2, the useful life requirement is 10 years [276] or 120,000 miles with an optional 15 year or 150,000 mile provision. A similar approach is used for heavy-duty engines, however a specific Family Emissions Level is assigned to the engine family at certification, as compared to a pre-defined bin emissions level as in Tier 2.

As noted above, the in-use CO_2 standard under the greenhouse gas program, like Tier 2, will apply to individual vehicles and is separate from the fleet-average standard. However, unlike the Tier 2 program and other EPA fleet average standards, the model-level CO_2 test results are themselves used to calculate the fleet average standard for compliance purposes. This is consistent with the current CAFE practice, but it means the fleet average standard and the emission test results used to calculate compliance with the fleet average standard do not take into account test-to-test variability and production variability that can affect in-use levels. Since the CO_2 fleet average uses the model level emissions test results themselves for purposes of calculating the fleet average, EPA proposed an adjustment factor for the in-use standard to provide some margin for production and test-to-test variability that could result in differences between the initial emission test results used to calculate the fleet average and emission results obtained during subsequent in-use testing. EPA proposed that each model's in-use CO_2 standard would be the model specific level used in calculating the fleet average, adjusted to be 10% higher.

EPA received significant comment from industry expressing concern with the in-use standard. The comments focused on concerns about manufacturer liability for in-use CO_2 performance and for the most part did not address the proposed 10% adjustment level or even the need for an adjustment to account for variability. Some comments suggested that an in-use standard is not necessary because in-use testing is not mandated in the CAA. Others stated that since there is no evidence that CO_2 emission levels increase over time, there is no need for an in-use standard. Finally, there was a general concern that failure to meet the in-use standard would result in recall liability and that recall can only be used in cases where it can be demonstrated that a "repair" can remedy the nonconformity. One manufacturer provided comments supporting the use of a 10% adjustment factor for the in-use standard. These comments also recommended that the 10% adjustment factor be applied to configuration or subconfiguration data rather than to model-level data unless the lower-level data were not available. Finally, the manufacturer expressed concern that a straight 10% adjustment would result in inequity between high- and low-emitting vehicles.

Section 202(a)(1) specifies that emissions standards are to be applicable for the useful life of the vehicle. The in-use emissions standard for CO_2 implements this provision. While EPA agrees that the CAA does not require the Agency to perform in-use testing to monitor compliance with in-use standards, the Act clearly authorizes in-use testing. EPA has a long tradition of performing in-use testing and has found it to be an effective tool in the overall light-duty vehicle compliance program. EPA continues to believe that it is appropriate to perform in-use testing and that the evaluation of individual vehicle performance for all regulated emission constituents, including CO_2, N_2O and CH_4, is necessary to ensure compliance with all light-duty requirements. EPA also believes that the CAA clearly mandates that all emission standards apply for a vehicle's useful life and that an in-use standard is therefore necessary.

EPA agrees with industry commenters that there is little evidence to indicate that CO_2 emission levels from current-technology vehicles increase over time. However, as stated above, the CAA mandates that all emission standards apply for a vehicle's useful life regardless of whether the emissions increase over time. In addition, there are factors other than emission deterioration over time that can cause in-use emissions to be greater than emission standards. The most obvious are component defects, production mistakes, and the stacking of component production and design tolerances. Any one of these can cause an exceedance of emission standards for individual vehicles or whole model lines. Finally EPA believes that it is essential to monitor in-use GHG emissions performance of new technologies, for which there is currently no in-use experience, as they enter the market. Thus EPA believes that the value in establishing an in-use standard extends beyond just addressing emission deterioration over time from current technology vehicles.

The concern over recall liability in cases where there is no effective repair remedy has some legitimate basis. For

[276] 11 years for heavy-light-duty trucks, ref. 40 CFR 86.1805–12.

example, EPA agrees there would be a concern if a number of vehicles for a particular model were to have in-use emissions that exceed the in-use standard, with no effective repair available to remedy the noncompliance. However, EPA does not anticipate a scenario involving exceedance of the in-use standard that would cause the Agency to pursue a recall unless there is a repairable cause of the exceedance. At the same time, failures to emission-related components, systems, software, and calibrations do occur that could result in a failure of the in-use CO_2 standard. For example, a defective oxygen sensor that causes a vehicle to burn excessive fuel could result in higher CO_2 levels that would exceed the in-use standard. While it is likely that such a problem would affect other emissions as well, there would still be a demonstratable, repairable problem such that a recall might be valid. Therefore, EPA believes that a CO_2 in-use standard is statutorily required and can serve as a useful tool for determining compliance with the GHG program.

EPA agrees with the industry comment that it is appropriate where possible to apply the 10% adjustment factor to the vehicle-level emission test results, rather than to a model-type value that includes production weighting factors. If no subconfiguration test data are available, then the adjustment factor will be applied to the model-type value. Therefore, EPA is finalizing an in-use standard based on a 10% multiplicative adjustment factor but the adjustment will be applied to emissions test results for the vehicle subconfiguration if such data exist, or to the model-type emissions level used to calculate the fleet average if subconfiguration test data are not available.

EPA believes that the useful life period established for criteria pollutants under Tier 2 is also appropriate for CO_2. Data from EPA's current in-use compliance test program indicate that CO_2 emissions from current technology vehicles increase very little with age and in some cases may actually improve slightly. The stable CO_2 levels are expected because unlike criteria pollutants, CO_2 emissions in current technology vehicles are not controlled by after treatment systems that may fail with age. Rather, vehicle CO_2 emission levels depend primarily on fundamental vehicle design characteristics that do not change over time. Therefore, vehicles designed for a given CO_2 emissions level will be expected to sustain the same emissions profile over their full useful life.

The CAA requires emission standards to be applicable for the vehicle's full useful life. Under Tier 2 and other vehicle emission standard programs, EPA requires manufacturers to demonstrate at the time of certification that the new vehicles being certified will continue to meet emission standards throughout their useful life. EPA allows manufacturers several options for predicting in-use deterioration, including full vehicle testing, bench-aging specific components, and application of a deterioration factor based on data and/or engineering judgment.

In the specific case of CO_2, EPA does not currently anticipate notable deterioration and has therefore determined that an assigned deterioration factor be applied at the time of certification. At this time EPA will use an additive assigned deterioration factor of zero, or a multiplicative factor of one. EPA anticipates that the deterioration factor will be updated from time to time, as new data regarding emissions deterioration for CO_2 are obtained and analyzed. Additionally, EPA may consider technology-specific deterioration factors, should data indicate that certain CO_2 control technologies deteriorate differently than others.

During compliance plan discussions prior to the beginning of the certification process, EPA will explore with each manufacturer any new technologies that could warrant use of a different deterioration factor. For any vehicle model determined likely to experience increases in CO_2 emissions over the vehicle's useful life, manufacturers will not be allowed to use the assigned deterioration factor but rather will be required to establish an appropriate factor. If such an instance were to occur, EPA would allow manufacturers to use the whole-vehicle mileage accumulation method currently offered in EPA's regulations.[277]

N_2O and CH_4 emissions are directly affected by vehicle emission control systems. Any of the durability options offered under EPA's current compliance program can be used to determine how emissions of N_2O and CH_4 change over time. EPA recognizes that manufacturers have not been required to account for durability effects of N_2O and CH_4 prior to now. EPA also realizes that industry will need sufficient time to explore durability options and become familiar with procedures for determining deterioration of N_2O and CH_4. Therefore, until the 2015 model year, rather than requiring manufacturers to establish a durability program for N_2O and CH_4, EPA will allow manufacturers to attest that vehicles meet the deteriorated, full useful life standard. If manufacturers choose to comply with the optional CO_2 equivalent standard, EPA will allow the use of the manufacturer's existing NO_X deterioration factor for N_2O and the existing NMOG deterioration factor for CH_4.

a. Ensuring Useful Life Compliance

The CAA requires a vehicle to comply with emission standards over its regulatory useful life and affords EPA broad authority for the implementation of this requirement. As such, EPA has authority to require a manufacturer to remedy any noncompliance issues. The remedy can range from adjusting a manufacturer's credit balance to the voluntary or mandatory recall of noncompliant vehicles. These potential remedies provide manufacturers with a strong incentive to design and build complying vehicles.

Currently, EPA regulations require manufacturers to conduct in-use testing as a condition of certification. Specifically, manufacturers must commit to later procure and test privately-owned vehicles that have been normally used and maintained. The vehicles are tested to determine the in-use levels of criteria pollutants when they are in their first and fourth years of service. This testing is referred to as the In-Use Verification Program (IUVP) testing, which was first implemented as part of EPA's CAP 2000 certification program.[278] The emissions data collected from IUVP serve several purposes. IUVP results provide EPA with annual real-world in-use data representing the majority of certified vehicles. EPA uses IUVP data to identify in-use problems, validate the accuracy of the certification program, verify manufacturer durability processes, and support emission modeling efforts. Manufacturers are required to test low mileage and high mileage vehicles over the FTP and US06 test cycles. They are also required to provide evaporative emissions, onboard refueling vapory recovery (ORVR) emissions and on-board diagnostics (OBD) data.

Manufacturers are required to provide data for all regulated criteria pollutants. Some manufacturers have voluntarily submitted CO_2 data as part of IUVP. EPA proposed that manufacturers provide CO_2, N_2O, and CH_4 data as part of the IUVP. EPA also proposed that in order to adequately analyze and assess

[277] 40 CFR 86.1823–08.

[278] 64 FR 23906, May 4, 1999.

in-use CO_2 results, which are based on the combination of FTP and highway cycle test results, the highway fuel economy test would also need to be part of IUVP. The University of California, Santa Barbara expressed support for including N_2O and CH_4 emissions as part of the IUVP. Manufacturer comments were almost unanimously opposed to including any GHG as part of the IUVP. Specifically, industry commented that CO_2 emissions do not deteriorate over time and in some cases actually improve. Ford provided data for several 2004 through 2007 model year vehicles that indicate CO_2 emissions improved an average of 1.42% when vehicles were tested over 5,000 miles. Manufacturers commented that the inclusion of a greenhouse gas emissions requirement and the highway test cycle as part of the IUVP would unnecessarily increase burden on manufacturers and provide no benefit, since CO_2 emissions do not deteriorate over time. Manufacturers also commented that N_2O and CH_4 emissions are very low and by EPA's own account only represent about 1% of total light-duty vehicle GHG emissions. They also expressed concern over the cost and burden of measuring N_2O for IUVP, since many manufacturers use contractor laboratories to assist in their IUVP testing and many of these facilities do not have the necessary equipment to measure N_2O. They stated that since it was unnecessary to include CO_2 emissions as part of IUVP and since N_2O and CH_4 were such small contributors to GHG emissions, it did not make sense to include N_2O and CH_4 as part of the IUVP either. They felt that N_2O and CH_4 could be more appropriately handled through attestation or an annual unregulated emissions report.

As discussed above, although EPA shares the view expressed in manufacturer comments that historical data demonstrate little CO_2 deterioration, in-use emissions can increase for a number of reasons other than deterioration over time. For example, production or design errors can result in increased GHG emissions. Components that aren't built as they were designed or vehicles inadvertently assembled improperly or with the wrong parts or with parts improperly designed can result in GHG emissions greater than those demonstrated to EPA during the certification process and used in calculating the manufacturer's fleet average. The "stacking" of component design and production tolerances can also result in in-use emissions that are greater than those used in calculating a manufacturer's fleet average.

EPA believes IUVP testing is also important to monitor in-use versus certification emission levels. Because the emphasis of the GHG program is on a manufacturer's fleet average standard, it is difficult for EPA to make an assessment as to whether manufacturer's vehicles are actually producing the GHG levels claimed in their fleet average without some in-use data for comparison. For example, EPA has expressed concern that with the in-use standard based on a 10% adjustment factor, there would be an incentive for manufacturers to develop their fleet average utilizing the full range of the 10% in-use standard. The only way for EPA to assess whether manufacturers are designing and producing vehicles that meet their respective fleet average standards is for EPA to be able to review in-use GHG emissions from the IUVP.

Finally EPA does have some concern about potential CO_2 emissions deterioration in advanced technologies for which we currently have no in-use experience or data. Since CAFE has never had an in-use requirement and today's final regulations are the first ever GHG standards, there has been no need to focus on GHG emissions in-use as there will be with the new GHG standards. Many of the advanced technologies that EPA expects manufacturers to use to meet the GHG standards have been introduced in production vehicles, but until now not for the purpose of controlling greenhouse gas emissions. For example, advanced dual-clutch or seven-speed automatic transmissions, and start-stop technologies have not been broadly tested in the field for their long-term CO_2 performance. In-use GHG performance information for vehicles using these technologies is needed for many reasons, including evaluation of whether allowing use of assigned deterioration factors for CO_2 in lieu of actual deterioration factors will continue to be appropriate.

Therefore, EPA is finalizing the requirement that all manufacturers must provide IUVP emissions data for CO_2. EPA will also require manufacturers to perform the highway test cycle as part of IUVP. Since the CO_2 standard reflects a combined value of FTP and highway results, it is necessary to include the highway emission test in IUVP to enable EPA to compare an in-use CO_2 level with a vehicle's in-use standard. EPA understands that requiring manufacturers to also measure N_2O and CH_4 will be initially challenging, since many manufacturer facilities do not currently have the proper analytical equipment. To be consistent with timing of the N_2O and CH_4 emissions standards for this rule, N_2O and CH_4 will not be required for IUVP until the 2015 model year.

Another component of the CAP 2000 certification program is the In-Use Confirmatory Program (IUCP). This is a manufacturer-conducted recall quality in-use test program that can be used as the basis for EPA to order an emission recall. In order for vehicles tested in the IUVP to qualify for IUCP, there is a threshold of 1.30 times the certification emission standard and an additional requirement that at least 50% of the test vehicles for the test group fail for the same substance. EPA proposed to exclude IUVP data for CO_2, N_2O, and CH_4 emissions from the IUCP thresholds. EPA felt that there was not sufficient data to determine if the existing IUCP thresholds were appropriate or even applicable to those emissions. The University of California, Santa Barbara disagreed with EPA's concerns and recommended that CO_2, N_2O, and CH_4 emissions all be subject to the IUVP threshold criteria. Manufacturers commented that since CO_2 performance is a function of vehicle design and cannot be remedied in the field with the addition or replacement of emissions control devices like traditional criteria pollutants, it would not be appropriate or necessary to include IUCP threshold criteria for GHG emissions.

EPA continues to believe that the IUCP is an important part of EPA's in-use compliance program for traditional criteria pollutants. For GHG emissions, EPA believes the IUCP will also be a valuable future tool for achieving compliance. However, there are insufficient data today to determine whether the current IUCP threshold criteria are appropriate for GHG emissions. Once EPA can gather more data from the IUVP program and from EPA's internal surveillance program described below, EPA will reassess the need to exclude IUCP thresholds, and if warranted, propose a separate rulemaking establishing IUCP threshold criteria which may include CO_2, N_2O, and CH_4 emissions. Therefore, for today's final action, EPA will exclude IUVP data for CO_2, N_2O, and CH_4 emissions from the IUCP thresholds.

EPA has also administered its own in-use testing program for light-duty vehicles under authority of section 207(c) of the CAA for more than 30 years. In this program, EPA procures and tests representative privately owned vehicles to determine whether they are complying with emission standards.

When testing indicates noncompliance, EPA works with the manufacturer to determine the cause of the problem and to conduct appropriate additional testing to determine its extent or the effectiveness of identified remedies. This program operates in conjunction with the IUVP program and other sources of information to provide a comprehensive picture of the compliance profile for the entire fleet and address compliance problems that are identified. EPA will add CO_2, N_2O, and CH_4 to the emissions measurements it collects during surveillance testing.

b. In-Use Compliance Standard

For Tier 2, the in-use standard and the standard used for fleet average calculation are the same. In-use compliance for an individual vehicle is determined by comparing the vehicle's in-use emission results with the emission standard levels or "bin" to which the vehicle is certified rather than to the Tier 2 fleet average standard for the manufacturer. This is because as part of a fleet average standard, individual vehicles can be certified to various emission standard levels, which could be higher or lower than the fleet average standard. Thus, it would be inappropriate to compare an individual vehicle to the fleet average, since that vehicle could have been certified to an emission level that is different than the fleet average level.

This will also be true for the CO_2 fleet average standard. Therefore, to ensure that an individual vehicle complies with the CO_2 standards in-use, it is necessary to compare the vehicle's in-use CO_2 emission result with the appropriate model-level certification CO_2 level used in determining the manufacturer's fleet average result.

There is a fundamental difference between the CO_2 standards and Tier 2 standards. For Tier 2, the standard level used for the fleet average calculation is one of eight different emission levels, or "bins," whereas for the CO_2 fleet average standard, the standard level used for the fleet average calculation is the model-level certification CO_2 result. The Tier 2 fleet average standard is calculated using the "bin" emission level or standard, not the actual certification emission level of the certification test vehicle. So no matter how low a manufacturer's actual certification emission results are, the fleet average is still calculated based on the "bin" level rather than the lower certification result.[279] In contrast, the CO_2 fleet average standard will be calculated using the actual vehicle model-level CO_2 values from the certification test vehicles. With a specified certification emission standard, such as the Tier 2 "bins," manufacturers typically attempt to over-comply with the standard to give themselves some cushion for potentially higher in-use testing results due to emissions performance deterioration and/or variability that could result in higher emission levels during subsequent in-use testing. For our CO_2 standards, the emission level used to calculate the fleet average is the actual certification vehicle test result, thus manufacturers cannot over comply since the certification test vehicle result will always be the value used in determining the CO_2 fleet average. If the manufacturer attempted to design the vehicle to achieve a lower CO_2 value, similar to Tier 2 for in-use purposes, the new lower CO_2 value would simply become the new value used for calculating the fleet average.

The CO_2 fleet average standard is based on the performance of pre-production technology that is representative of the point of production, and while there is expected to be limited if any deterioration in effectiveness for any vehicle during the useful life, the fleet average standard does not take into account the test-to-test variability or production variability that can affect in-use levels. Therefore, EPA believes that unlike Tier 2, it is necessary to have a different in-use standard for CO_2 to account for these variabilities. EPA proposed an in-use standard that was 10% higher than the appropriate model-level certification CO_2 level used in determining the manufacturer's fleet average result.

As described above, manufacturers typically design their vehicles to emit at emission levels considerably below the certification standards. This intentional difference between the actual emission level and the emission standard is referred to as "certification margin," since it is typically the difference between the certification emission level and the emission standard. The certification margin can provide manufacturers with some protection from exceeding emission standards in-use, since the in-use standards are typically the levels used to calculate the fleet average. For Tier 2, the certification margin is the delta between the specific emission standard level, or "bin," to which the vehicle is certified, and the vehicle's certification emission level.

Since the level of the fleet average standard does not reflect this kind of variability, EPA believes it is appropriate to set an in-use standard that provides a reasonable cushion for in-use variability that is beyond a manufacturer's control. EPA proposed a factor of 10% that would act as a surrogate for a certification margin. The factor would only be applicable to CO_2 emissions, and would be applied to the model-level test results that are used to establish the model-level in-use standard.

EPA selected a value of 10% for the in-use standard based on a review of EPA's fuel economy labeling and CAFE confirmatory test results for the past several vehicle model years. The EPA data indicate that it is common for test variability to range between three to six percent and only on rare occasions to exceed 10%. EPA believes that a value of 10% should be sufficient to account for testing variability and any production variability that a manufacturer may encounter. EPA considered both higher and lower values. The Tier 2 fleet as a whole, for example, has a certification margin approaching 50%.[280] However, there are some fundamental differences between CO_2 emissions and other criteria pollutants in the magnitude of the compounds. Tier 2 NMOG and NO_X emission standards are hundredths of a gram per mile (*e.g.,* 0.07 g/mi NO_X & 0.09 g/mi NMOG), whereas the CO_2 standards are four orders of magnitude greater (*e.g.,* 250 g/mi). Thus EPA does not believe it is appropriate to consider a value on the order of 50 percent. In addition, little deterioration in emissions control is expected in-use. The adjustment factor addresses only one element of what is usually built into a compliance margin.

The intent of the separate in-use standard, based on a 10% compliance factor adjustment, is to provide a reasonable margin such that vehicles are not automatically deemed as exceeding standards simply because of normal variability in test results. EPA has some concerns however that this in-use compliance factor could be perceived as providing manufacturers with the ability to design their fleets to generate CO_2 emissions up to 10% higher than the actual values they use to certify and to calculate the year end fleet average value that determines compliance with the fleet average standard. This concern provides additional rationale for

[279] In a similar fashion, the fleet average for heavy-duty engines is calculated using a Family Emission Level, determined by the manufacturer, which is different from the emission level of the test engine.

[280] *See* pages 39–41 of EPA's Vehicle and Engine Compliance Activities 2007 Progress Report (EPA–420–R–08–011) published in October, 2008. This document is available electronically at *http://epa.gov/otaq/about/420r08011.pdf.*

requiring FTP and HFET IUVP data for CO_2 emissions to ensure that in-use values are not regularly 10% higher than the values used in the fleet average calculation. If in the course of reviewing a manufacturer's IUVP data it becomes apparent that a manufacturer's CO_2 results are consistently higher than the values used for calculation of the fleet average, EPA will discuss the matter with the manufacturer and consider possible resolutions such as changes to ensure that the emissions test data more accurately reflect the emissions level of vehicles at the time of production, increased EPA confirmatory testing, and other similar measures.

Commenters generally did not comment on whether 10% was the appropriate level for the adjustment factor. Honda did support use of the proposed 10% adjustment factor for the in-use standard. But Honda also recommended that the 10% adjustment factor be applied to subconfiguration data rather than the model-level data unless there was no subconfiguration data available. Honda also expressed some concern over the inequity a straight 10% adjustment would incur between high- and low-emitting vehicles. They suggested that rather than using an across-the-board 10% multiplicative adjustment factor applied to the model-level CO_2 value for all vehicles, it would be more equitable to take the sum of a 5% multiplicative factor applied to the model-level CO_2 value and a 5% factor applied to the manufacturer's fleet CO_2 target.

EPA understands that use of a multiplicative adjustment factor would result in a higher absolute in-use value for a vehicle that has higher CO_2 than for a vehicle with a lower CO_2. However, this difference is not relevant to the purpose of the adjustment factor, which is to provide some cushion for test and production variability. EPA does not believe the difference would be great enough to confer the higher-emitting vehicles with an unfair advantage with respect to emissions variability.

Given that the purpose of the in-use standard is to enable a fair comparison between certification and in-use emission levels, EPA agrees that it is appropriate to apply the 10% adjustment factor to actual emission test results rather than to model-type emission levels which are production weighted. Therefore, EPA is finalizing an in-use standard that applies a multiplicative 10% adjustment factor to the subconfiguration emissions values, if such are available. (For flexible-fuel and dual-fuel vehicles the multiplicative factor will be applied to the test results on each fuel. In other words, these vehicles will have two applicable in-use emission standards; one for operation on the conventional fuel and one for operation on the alternative fuel.) If no emissions data exist at the subconfiguration level the adjustment will be applied to the model-type value as originally proposed. If the in-use emission result for a vehicle exceeds the emissions level, as applicable, adjusted as just described by 10%, then the vehicle will have exceeded the in-use emission standard. The in-use standard will apply to all in-use compliance testing including IUVP, selective enforcement audits, and EPA's internal test program.

5. Credit Program Implementation

As described in Section III.E.2 above, for each manufacturer's model year production, the manufacturer will average the CO_2 emissions within each of the two averaging sets (passenger cars and trucks) and compare that with its respective fleet average standards (which in turn will have been determined from the appropriate footprint curve applicable to that model year). In addition to this within-company averaging, when a manufacturer's fleet average CO_2 values of vehicles produced in an averaging set over-complies compared to the applicable fleet average standard, the manufacturer could generate credits that it could save for later use (banking) or could sell or otherwise distribute to another manufacturer (trading). Section III.C discusses opportunities for manufacturers to improve their fleet average, beyond the credits that are simply calculated by over-achieving their applicable fleet average standard. Implementation of the credit program generally involves two steps: calculation of the credit amount and reporting the amount and the associated data and calculations to EPA.

EPA is promulgating two broad types of credit programs under this rulemaking. One type of credit directly lowers a manufacturer's actual fleet average by virtue of being applied within the methodology for calculating the fleet average emissions. Examples of this type of credit include the credits available for alternative fuel vehicles and the advanced technology vehicle provisions. The second type of credit is independent of the calculation of a manufacturer's fleet average. Rather than giving credit by lowering a manufacturer's fleet average via a credit mechanism, these credits (in megagrams) are calculated separately and are simply added to the manufacturer's overall "bank" of credits (or debits). Using a fictional example, the remainder of this section reviews the different types of credits and shows where and how they are calculated and how they impact a manufacturer's available credits.

a. Basic Credits: Fleet Average Emissions Are Below the Standard

As just noted, basic credits are earned by a manufacturer's fleet that performs better than the applicable fleet average standard. Manufacturers will calculate their fleet average standards (separate standards are calculated for cars and trucks) using the footprint-based equations described in Section III.B. A manufacturer's actual end-of-year fleet average is calculated similarly to the way in which CAFE values are currently calculated; in fact, the regulations are essentially identical. The current CAFE calculation methods are in 40 CFR Part 600. As part of this rulemaking, EPA has amended key subparts and sections of Part 600 to require that fleet average CO_2 emissions be calculated in a manner parallel to the way CAFE values are calculated. First, manufacturers will determine a CO_2-equivalent value for each model type. The CO_2-equivalent value is a summation of the carbon-containing constituents of the exhaust emissions on a CO_2-equivalent basis. For gasoline and diesel vehicles this simply involves measurement of total hydrocarbons and carbon monoxide in addition to CO_2. The calculation becomes somewhat more complex for alternative fuel vehicles due to the different nature of their exhaust emissions. For example, for ethanol-fueled vehicles, the emission tests must measure ethanol, methanol, formaldehyde, and acetaldehyde in addition to CO_2. However, all these measurements are currently necessary to determine fuel economy for the labeling and CAFE programs, and thus no new testing or data collection will be required.[281] Second, manufacturers will calculate a fleet average by weighting the CO_2 value for each model type by the production of that model type, as they currently do for the CAFE program. Again, this will be done separately for cars and trucks. Finally, the manufacturer will compare the calculated standard with the fleet average that is actually achieved to determine the credits (or debits) that are generated. Both the determination of the applicable standard and the actual fleet average will be done after the model

[281] Note that the final rule also provides an option for manufacturers to incorporate N_2O and CH_4 in this calculation at their CO_2-equivalent values.

year is complete and using final model year vehicle production data.

Consider a basic hypothetical example where Manufacturer "A" has calculated a car fleet average standard of 300 grams/mile and a car fleet average of 290 grams/mile (Table III.E.5–1). Further assume that the manufacturer produced 500,000 cars. The credit is calculated by taking the difference between the standard and the fleet average (300 − 290=10) and multiplying it by the manufacturer's production of 500,000. This result is then multiplied by the assigned lifetime vehicle miles travelled (for cars this is 195,264 miles, as discussed in Joint TSD Chapter 4), then finally divided by 1,000,000 to convert from grams to total megagrams. The result is the total number of megagrams of credit generated by the manufacturer's car fleet. The same methodology is used to calculate the total number of megagrams of deficit, if the manufacturer was not able to comply with the fleet average standard. In this example, the result is 976,320 megagrams of credits, as shown in Table III.E.5–1.

TABLE III.E.5–1—SUMMARY FOR MANUFACTURER A: EARNING BASIC CREDITS

		CO_2	Totals
Total production	Conventional: 500,000	290 g/mi	500,000
Fleet average standard		300 g/mi	
Fleet average		290 g/mi	
Credits	[(300 − 290) × 500,000 × 195,264] 1,000,000		= 954,855 Mg

b. Interim Advanced Technology Vehicle Provisions

The lower exhaust greenhouse gas emissions of some advanced technology vehicles can directly benefit a manufacturer's fleet average, thus increasing the amount of fleet average-based credits they earn (or reducing the amount of debits that would otherwise accrue). Manufacturers that produce electric vehicles, plug-in hybrid electric vehicles, or fuel cell electric vehicles will include these vehicles in the fleet average calculation with their model type emission values. As described in detail in Section III.C.3, the emissions from electric vehicles and plug-in hybrid electric vehicles when operating on electricity will be accounted for by assuming zero emissions (0 g/mi CO_2) for a limited number of vehicles through the 2016 model year. This interim limited use of 0 g/mi will be allowed for the technologies specifically noted above and as defined in the regulations, with the limitation that the vehicles must be certified to Tier 2 Bin 5 emission standards or cleaner (*i.e.,* advanced technology vehicles must contribute to criteria pollutant reductions as well as to greenhouse gas emission reductions).

EPA proposed specific definitions for the vehicle technologies eligible for these provisions. One manufacturer suggested the following changes in their comments:

Insert an additional criterion for electric vehicles that specifically states that an electric vehicle may not have an onboard combustion engine/generator system.

A minor deletion of text from the definition for "Fuel cell."

The deletion of the requirement that a PHEV have an equivalent all-electric range of more than 10 miles.

EPA agrees with the first comment. As written in the proposal, a vehicle with an onboard combustion engine that serves as a generator would not have been excluded from the definition of electric vehicle. However, EPA believes it should be. Although such a vehicle might be propelled by an electric motor directly, if the indirect source of electricity is an onboard combustion engine then the vehicle is fundamentally not an electric vehicle. EPA is also adopting the commenter's proposed rephrasing of the definition for "Fuel cell," which is simpler and clearer. Finally, in the context of the advanced technology incentive provisions in this final rule, EPA concurs with the commenter that the requirement that a PHEV have an equivalent all-electric range of at least ten miles is unnecessary. In the context of the proposed credit multiplier EPA was concerned that some vehicles could install a charging system on a limited battery and gain credit beyond what the limited technology would deserve simply by virtue of being defined as a PHEV. However, because EPA is not finalizing the proposed multiplier provisions (*see* Section III.C.3) and is instead using as the sole incentive the zero emission tailpipe level as the compliance value for a manufacturer's fleetwide average, this concern is no longer valid. Since EPA is not promulgating multipliers, the concern expressed at proposal no longer applies, and each PHEV will get a benefit from electricity commensurate with its measured use of grid electricity, thus EPA is no longer concerned about the multiplier effect. Thus, EPA is finalizing the following definitions in the regulations:

Electric vehicle means a motor vehicle that is powered solely by an electric motor drawing current from a rechargeable energy storage system, such as from storage batteries or other portable electrical energy storage devices, including hydrogen fuel cells, provided that:

○ Recharge energy must be drawn from a source off the vehicle, such as residential electric service;

○ The vehicle must be certified to the emission standards of Bin #1 of Table S04–1 in paragraph (c)(6) of § 86.1811; and

○ The vehicle does not have an onboard combustion engine/generator system as a means of providing electrical energy.

Fuel cell electric vehicle means a motor vehicle propelled solely by an electric motor where energy for the motor is supplied by a fuel cell.

Fuel cell means an electrochemical cell that produces electricity via the non-combustion reaction of a consumable fuel, typically hydrogen.

Plug-in hybrid electric vehicle (PHEV) means a hybrid electric vehicle that has the capability to charge the battery from an off-vehicle electric source, such that the off-vehicle source cannot be connected to the vehicle while the vehicle is in motion.

With some simplifying assumptions, assume that 25,000 of Manufacturer A's fleet are now plug-in hybrid electric vehicles with a calculated CO_2 value of 80 g/mi, and the remaining 475,000 are conventional technology vehicles with an average CO_2 value of 290 grams/mile. By including the advanced technology PHEVs in their fleet, Manufacturer A now has more than 2.9 million credits (Table III.E.5–2).

TABLE III.E.5–2—SUMMARY FOR MANUFACTURER A: EARNING BASIC AND INTERIM ADVANCED TECHNOLOGY CREDITS

		CO_2	Totals
Total production	Conventional: 475,000	290 g/mi	500,000
	PHEV: 25,000	80 g/mi	
Fleet average standard		300 g/mi	
Fleet average	[(475,000 × 290) + (25,000 × 80)] [500,000]	280 g/mi	
Credits	[(300 − 280) × 500,000 × 195,264] 1,000,000		= 1,952,640 Mg

c. Flexible-Fuel Vehicle Credits

As noted in Section III.C, treatment of flexible-fuel vehicle (FFV) credits differs between model years 2012–2015 and 2016 and later. For the 2012 through 2015 model years the FFV credits will be calculated as they are in the CAFE program for the same model years, except that formulae in the final regulations have been modified as needed to do the calculations in terms of grams per mile of CO_2 values rather than miles per gallon. These credits are integral to the fleet average calculation and allow the vehicles to be represented by artificially reduced emissions. To use this credit program, the CO_2 values of FFVs will be represented by the average of two things: the CO_2 value while operating on gasoline and the CO_2 value while operating on the alternative fuel multiplied by 0.15.

For MY 2012 to 2015 for example, Manufacturer A makes 30,000 FFVs with CO_2 values of 280 g/mi using gasoline and 260 g/mi using E85. The CO_2 value that would represent the FFVs in the fleet average calculation would be calculated as follows:

FFV emissions = [280 + (260 × 0.15)] 2 = 160 g/mi

Including these FFVs with the applicable credit in Manufacturer A's fleet average, as shown below in Table III.E.5–3, further reduces the fleet average to 256 grams/mile and increases the manufacturer's credits to about 4.2 million megagrams.

TABLE III.E.5–3 SUMMARY FOR MANUFACTURER A: EARNING BASIC, INTERIM ADVANCED TECHNOLOGY, AND FLEXIBLE FUEL VEHICLE CREDITS

		CO_2	Totals
Total production	Conventional: 445,000	290 g/mi	500,000
	PHEV: 25,000	80 g/mi	
	FFV: 30,000	160 g/mi	
Fleet average standard		300 g/mi	
Fleet average	[(445,000 × 290) + (25,000 × 80) + 30,000 × 160] [500,000]	272 g/mi	
Credits	[(300 − 272) × 500,000 × 195,264] 1,000,000		= 2,733,696 Mg

In the 2016 and later model years, the calculation of FFV emissions differ substantially from prior years in that the determination of the CO_2 value to represent an FFV model type will be based upon the actual use of the alternative fuel and on actual emissions while operating on that fuel. EPA's default assumption in the regulations is that the alternative fuel is used negligibly, and the CO_2 value that will apply to an FFV by default would be the value determined for operation on conventional fuel. However, if the manufacturer believes that the alternative fuel is used in real-world driving and that accounting for this use could improve the fleet average, the manufacturer has two options. First, the regulations allow a manufacturer to request that EPA determine an appropriate weighting value for an alternative fuel to reflect the degree of use of that fuel in FFVs relative to real-world use of the conventional fuel. Section III.C describes how EPA might make this determination. Any value determined by EPA will be published by EPA, and that weighting value would be available for all manufacturers to use for that fuel. The second option allows a manufacturer to determine the degree of alternative fuel use for their own vehicle(s), using a variety of potential methods. Both the method and the use of the final results must be approved by EPA before their use is allowed. In either case, whether EPA supplies the weighting factors or EPA approves a manufacturer's alternative fuel weighting factors, the CO_2 emissions of an FFV in 2016 and later would be as follows (assuming non-zero use of the alternative fuel):

(W1 × CO2conv) + (W2 × CO2alt),

Where W1 and W2 are the proportion of miles driven using conventional fuel and alternative fuel, respectively, CO2conv is the CO_2 value while using conventional fuel, and CO2alt is the CO_2 value while using the alternative fuel. In the example above, for instance, the default CO_2 value for the fictional FFV described above would be the gasoline value of 280 g/mi, and the resulting fleet average and total credits would be 279 g/mi and 2,050,272 megagrams, respectively. However, if the EPA determines that real-world ethanol use amounts to 40 percent of driving, then using the equation above the FFV would be included in the fleet average calculation with a CO_2 value of 272 g/mi, resulting in an overall fleet average of 278 g/mi and total credit accumulation of 2,147,904 megagrams.

d. Dedicated Alternative Fuel Vehicle Credits

Like the FFV credit program described above, these credits will be treated differently in the first years of the program than in the 2016 and later model years. In fact, these credits are essentially identical to the FFV credits except for two things: (1) There is no need to average CO_2 values for gasoline and alternative fuel, and (2) in 2016 and later there is no demonstration needed to get a benefit from the alternative fuel. The CO_2 values are essentially determined the same way they are for FFVs operating on the alternative fuel. For the 2012 through 2015 model years the CO_2 test results are multiplied by the credit adjustment factor of 0.15, and the result is production-weighted in the fleet average calculation. For example, assume that Manufacturer A now produces 20,000 dedicated CNG vehicles with CO_2 emissions of 220 grams/mile, in addition to the FFVs and PHEVs already included in their fleet (Table III.E.5–4). Prior to the 2016 model year the CO_2 emissions representing these CNG vehicles will be 33 grams/mile (220×0.15).

TABLE III.E.5–4—SUMMARY FOR MANUFACTURER A: EARNING BASIC, ADVANCED TECHNOLOGY, FLEXIBLE FUEL VEHICLE, AND DEDICATED ALTERNATIVE FUEL VEHICLE CREDITS

		CO_2	Totals
Total production	Conventional: 425,000	290 g/mi	500,000
	PHEV: 25,000	80 g/mi	
	FFV: 30,000	160 g/mi	
	CNG: 20,000	33 g/mi	
Fleet average standard		300 g/mi	
Fleet average	$[(425{,}000 \times 290) + (25{,}000 \times 80) + (30{,}000 \times 160) + (20{,}000 \times 33)]$ [500,000].	261 g/mi	
Credits	$[(300 - 261) \times 500{,}000 \times 195{,}264]$ 1,000,000		= 3,807,648 Mg

The calculation for 2016 and later will be the same except the 0.15 credit adjustment factor is removed from the equation, and the CNG vehicles in this example would simply be production-weighted in the equation using their actual emissions value of 220 grams/mile instead of the "credited" value of 33 grams/mile.

e. Air Conditioning Leakage Credits

Unlike the credit programs described above, air conditioning-related credits do not affect the overall calculation of the fleet average or fleet average standard. Whether a manufacturer generates zero air conditioning credits or many, the calculated fleet average remains the same. Air conditioning credits are calculated and added to any credits (or deficit) that results from the fleet average calculations shown above. Thus, these credits can increase a manufacturer's credit balance or offset a deficit, but their calculation is external to the fleet average calculation. As noted in Section III.C, manufacturers can generate credits for reducing the leakage of refrigerant from their air conditioning systems. To do this the manufacturer will identify an air conditioning system improvement, indicate that they intend to use the improvement to generate credits, and then calculate an annual leakage rate (grams/year) for that system based on the method defined by the regulations. Air conditioning credits will be determined separately for cars and trucks using the car and truck-specific equations described in Section III.C.

In order to put these credits on the same basis as the basic and other credits described above, the air conditioning leakage credits will need to be calculated separately for cars and trucks. Thus, the resulting grams per mile credit determined from the appropriate car or truck equation will be multiplied by the lifetime VMT assigned by EPA (195,264 for cars; 225,865 for trucks), and then divided by 1,000,000 to get the total megagrams of CO_2 credits generated by the improved air conditioning system. Although the calculations are done separately for cars and trucks, the total megagrams will be summed and then added to the overall credit balance maintained by the manufacturer.

For example, assume that Manufacturer A has improved an air conditioning system that is installed in 250,000 cars and that the calculated leakage rate is 12 grams/year. Assume that the manufacturer has also implemented a new refrigerant with a Global Warming Potential of 850. In this case the credit per air conditioning unit, rounded to the nearest gram per mile would be:

$[13.8 \times [1 - (12/16.6 \times 850/1{,}430)] = 7.9$ g/mi.

Total megagrams of credits would then be:

$[7.9 \times 250{,}000 \times 195{,}264]$ $1{,}000{,}000 = 385{,}646$ Mg.

These credits would be added directly to a manufacturer's total balance; thus in this example Manufacturer A would now have, after consideration of all the above credits, a total of 4,193,294 megagrams of credits.

f. Air Conditioning Efficiency Credits

As noted in Section III.C.1.b, manufacturers may earn credits for improvements in air conditioning efficiency that reduce the impact of the air conditioning system on fuel consumption. These credits are similar to the air conditioning leakage credits described above, in that these credits are determined independently from the manufacturer's fleet average calculation, and the resulting credits are added to the manufacturer's overall balance for the respective model year. Like the air conditioning leakage credits, these credits can increase a manufacturer's credit balance or offset a deficit, but their calculation is external to the fleet average calculation.

In order to put these credits on the same basis as the basic and other credits describe above, the air conditioning efficiency credits are calculated separately for cars and trucks. Thus, the resulting grams per mile credit determined in the above equation is multiplied by the lifetime VMT, and then divided by 1,000,000 to get the total megagrams of efficiency credits generated by the improved air conditioning system. Although the calculations are done separately for cars and trucks, the total megagrams can be summed and then added to the overall credit balance maintained by the manufacturer.

As described in Section III.C, manufacturers will determine their credit based on selections from a menu of technologies, each of which provides a gram per mile credit amount. The credits will be summed for all the technologies implemented by the manufacturer, but cannot exceed 5.7 grams per mile. Once this is done, the calculation is a straightforward translation of a gram per mile credit to total car or truck megagrams, using the same methodology described above. For example, if Manufacturer A implements enough technologies to get the maximum 5.7 grams per mile for an air conditioning system that sells 250,000 units in cars, the calculation of total credits would be as follows:

$[5.7 \times 250{,}000 \times 195{,}264]$ $1{,}000{,}000 = 278{,}251$ Mg.

These credits would be added directly to a manufacturer's total balance; thus in this example Manufacturer A would now have, after consideration of all the above credits, a total of 4,471,545 megagrams of credits.

g. Off-Cycle Technology Credits

As described in Section III.C, these credits will be available for certain new or innovative technologies that achieve real-world CO_2 reductions that aren't adequately captured on the city or highway test cycles used to determine compliance with the fleet average standards. Like the air conditioning credits, these credits are independent of the fleet average calculation. Section III.C.4 describes two options for generating these credits: Either using EPA's 5-cycle fuel economy labeling methodology, or if that method fails to capture the CO_2-reducing impact of the technology, the manufacturer could propose and use, with EPA approval, a different analytical approach to determining the credit amount. Like the air conditioning credits above, these credits will have to be determined separately for cars and trucks because of the differing lifetime mileage assumptions between cars and trucks.

Using the 5-cycle approach is relatively straightforward, and because the 5-cycle formulae account for nationwide variations in driving conditions, no additional adjustments to the test results would be necessary. The manufacturer would simply calculate a 5-cycle CO_2 value with the technology installed and operating and compare it with a 5-cycle CO_2 value determined without the technology installed and/or operating. Existing regulations describe how to calculate 5-cycle fuel economy values, and the GHG regulations contain provisions that describe how to calculate 5-cycle CO_2 values (see 40 CFR 600.114–08). The manufacturer will have to design a test program that accounts for vehicle differences if the technology is installed in different vehicle types, and enough data will have to be collected to address data uncertainty issues. Manufacturers seeking to generate off-cycle credits based on a 5-cycle analysis will be required to submit a description of their test program and the results to EPA for approval.

As noted in Section III.C.4, a manufacturer-developed testing, data collection, and analysis program will require additional EPA approval and oversight. EPA received considerable comment from environmental and public interest organizations suggesting that EPA's decisions about which technologies merit off-cycle credit should be open and public. EPA agrees that a public process will help ensure a fair review and alleviate concerns about potential misuse of the off-cycle credit flexibility. Therefore EPA intends to seek public comment on manufacturer proposals for off-cycle credit that do not use the 5-cycle approach to quantify emission reductions. EPA will consider any comments it receives in determining whether and how much credit is appropriate. Manufacturers should submit proposals well in advance of their desired decision date to allow time for these public and EPA reviews.

Once the demonstration of the CO_2 reduction of an off-cycle technology is complete, and the resulting value accounts for variations in driving, climate and other conditions across the country, the two approaches are treated fundamentally the same way and in a way that parallels the approach for determining the air conditioning credits described above. Once a gram per mile value is approved by the EPA, the manufacturer will determine the total credit value by multiplying the gram per mile per vehicle credit by the production volume of vehicles with that technology and approved for use of the credit. This would then be multiplied by the lifetime vehicle miles for cars or trucks, whichever applies, and divided by 1,000,000 to obtain total megagrams of CO_2 credits. These credits would then be added to the manufacturer's total balance for the given model year. Just like the above air conditioning case, an off-cycle technology that is demonstrated to achieve an average CO_2 reduction of 4.4 grams/mile and that is installed in 175,000 cars would generate credits as follows:

$[4.4 \times 175{,}000 \times 195{,}264] \quad 1{,}000{,}000 = 150{,}353$ Mg.

h. End-of-Year Reporting

In general, implementation of the averaging, banking, and trading (ABT) program, including the calculation of credits and deficits, will be accomplished via existing reporting mechanisms. EPA's existing regulations define how manufacturers calculate fleet average miles per gallon for CAFE compliance purposes. Today's action modifies these regulations to also require the parallel calculation of fleet average CO_2 levels for car and light truck compliance categories. These regulations already require an end-of-year report for each model year, submitted to EPA, which details the test results and calculations that determine each manufacturer's CAFE levels. EPA will now require a similar report that includes fleet average CO_2 levels and related information. That can be integrated with the CAFE report at the manufacturer's option. In addition to requiring reporting of the actual fleet average achieved, this end-of-year report will also contain the calculations and data determining the manufacturer's applicable fleet average standard for that model year. As under the existing Tier 2 program, the report will be required to contain the fleet average standard, all values required to calculate the fleet average standard, the actual fleet average CO_2 that was achieved, all values required to calculate the actual fleet average, the number of credits generated or debits incurred, all the values required to calculate the credits or debits, the number of credits bought or sold, and the resulting balance of credits or debits.

Because of the multitude of credit programs that are available under the greenhouse gas program, the end-of-year report will be required to have more data and a more defined and specific structure than the CAFE end-of-year report does today. Although requiring "all the data required" to calculate a given value should be inclusive, the report will contain some requirements specific to certain types of credits. For advanced technology credits that apply to vehicles like electric vehicles and plug-in hybrid electric vehicles, manufacturers will be required to identify the number and type of these vehicles and the effect of these credits on their fleet average. The same will be true for credits due to flexible-fuel and alternative-fuel vehicles, although for 2016 and later flexible-fuel credits manufacturers may also have to provide a demonstration of the actual use of the alternative fuel in-use and the resulting calculations of CO_2 values for such vehicles. For air conditioning leakage credits manufacturers will have to include a summary of their use of such credits that will include which air conditioning systems were subject to such credits, information regarding the vehicle models which were equipped with credit-earning air conditioning systems, the production volume of these air conditioning systems, the leakage score of each air conditioning system generating credits, and the resulting calculation of leakage credits. Air conditioning efficiency reporting will be somewhat more complicated given the phase-in of the efficiency test procedure, and reporting will have to detail compliance with the phase-in as well as the test results and the resulting efficiency credits generated. Similar reporting requirements will also apply to the variety of possible off-cycle credit options, where manufacturers will have to report the applicable technology, the amount of credit per unit, the production volume of the technology, and the total credits from that technology.

Although it is the final end-of-year report, when final production numbers are known, that will determine the degree of compliance and the actual values of any credits being generated by manufacturers, EPA will expect manufacturers to be prepared to discuss their compliance approach and their potential use of the variety of credit options in pre-certification meetings that EPA routinely has with manufacturers. In addition, and in conjunction with a pre-model year report required under the CAFE program, the manufacturer will be required to submit projections of all of the elements described above, plus any projected credit trading transactions (described below).

Finally, to the extent that there are any credit transactions, the manufacturer will have to detail in the end-of-year report documentation on all credit transactions that the manufacturer has engaged in. Information for each transaction will include: the name of the credit provider, the name of the credit recipient, the date the transfer occurred, the quantity of credits transferred, and the model year in which the credits were earned. The final report is due to EPA within 90 days of the end of the model year, or no later than March 31 in the calendar year after the calendar year named for the model year. For example, the final GHG report for the 2012 model year is due no later than March 31, 2013. Failure by the manufacturer to submit the annual report in the specified time period will be considered to be a violation of section 203(a)(1) of the Clean Air Act.

6. Enforcement

As discussed above in Section III.E.5, manufacturers will report to EPA their fleet average and fleet average standard for a given model year (reporting separately for each of the car and truck averaging sets), the credits or deficits generated in the current year, the balance of credit balances or deficits (taking into account banked credits, deficit carry-forward, etc. see Section III.E.5), and whether they were in compliance with the fleet average standard under the terms of the regulations. EPA will review the annual reports, figures, and calculations submitted by the manufacturer to determine any nonconformance.

Each certificate, required prior to introduction into commerce, will be conditioned upon the manufacturer attaining the CO_2 fleet average standard. If a manufacturer fails to meet this condition and has not generated or purchased enough credits to cover the fleet average exceedance following the three year deficit carry-forward (Section III.B.4, then EPA will review the manufacturer's production for the model year in which the deficit originated and designate which vehicles caused the fleet average standard to be exceeded.

EPA proposed that the vehicles that would be identified as nonconforming would come from the most recent model year, and some comments pointed out that this was inconsistent with how the NLEV and Tier 2 programs were structured. EPA agrees with these comments and is finalizing an enforcement structure that is essentially identical to the one in place for existing programs. EPA would designate as nonconforming those vehicles with the highest emission values first, continuing until a number of vehicles equal to the calculated number of non-complying vehicles as determined above is reached. Those vehicles would be considered to be not covered by the certificates of conformity covering those model types. In a test group where only a portion of vehicles would be deemed nonconforming, EPA would determine the actual nonconforming vehicles by counting backwards from the last vehicle produced in that model type. A manufacturer would be subject to penalties and injunctive orders on an individual vehicle basis for sale of vehicles not covered by a certificate. This is the same general mechanism used for the National LEV and Tier 2 corporate average standards.

Section 205 of the CAA authorizes EPA to assess penalties of up to $37,500 per vehicle for violations of the requirements or prohibitions of this rule.[282] This section of the CAA provides that the agency shall take the following penalty factors into consideration in determining the appropriate penalty for any specific case: the gravity of the violation, the economic benefit or savings (if any) resulting from the violation, the size of the violator's business, the violator's history of compliance with this title, action taken to remedy the violation, the effect of the penalty on the violator's ability to continue in business, and such other matters as justice may require.

Manufacturer comments expressed concern about potential enforcement action for violations of the greenhouse gas standards, and the circumstances under which EPA would impose penalties. Manufacturers also suggested that EPA should adopt a penalty structure similar to the one in place under CAFE.

The CAA specifies different civil penalty provisions for noncompliance than EPCA does, and EPA cannot therefore adopt the CAFE penalty structure. However, EPA recognizes that it may be appropriate, should a manufacturer fail to comply with the NHTSA fuel economy standards as well as the CO_2 standard in a case arising out of the same facts and circumstances, to take into account the civil penalties that NHTSA has assessed for violations of the CAFE standards when determining the appropriate penalty amount for violations of the CO_2 emissions standards. This approach is consistent with EPA's broad discretion to consider "such other matters as justice may require," and will allow EPA to exercise its discretion to prevent injustice and ensure that penalties for violations of the CO_2 rule are assessed in a fair and reasonable manner.

The statutory penalty factor that allows EPA to consider "such other matters as justice may require" vests EPA with broad discretion to reduce the penalty when other adjustment factors prove insufficient or inappropriate to achieve justice.[283] The underlying principle of this penalty factor is to operate as a safety mechanism when necessary to prevent injustice.[284]

In other environmental statutes, Congress has specifically required EPA to consider penalties assessed by other government agencies where violations arise from the same set of facts. For instance, section 311(b)(8) of the Clean Water Act, 33 U.S.C. 1321(b)(8) authorizes EPA to consider any other penalty for the same incident when determining the appropriate Clean Water Act penalty. Likewise, section 113(e) of the CAA authorizes EPA to consider "payment by the violator of penalties previously assessed for the same violation" when assessing penalties for certain violations of Title I of the Act.

7. Prohibited Acts in the CAA

Section 203 of the Clean Air Act describes acts that are prohibited by law. This section and associated regulations apply equally to the greenhouse gas standards as to any other regulated emission. Acts that are prohibited by section 203 of the Clean Air Act include the introduction into commerce or the sale of a vehicle without a certificate of conformity, removing or otherwise defeating emission control equipment, the sale or installation of devices designed to defeat emission controls, and other actions. EPA proposed to include in the

[282] 42 U.S.C. 7524(a), Civil Monetary Penalty Inflation Adjustment, 69 FR 7121 (Feb. 13, 2004) and Civil Monetary Penalty Inflation Adjustment Rule, 73 FR 75340 (Dec. 11, 2008).

[283] *In re Spang & Co.,* 6 E.A.D. 226, 249 (EAB 1995).

[284] *B.J. Carney Industries,* 7 E.A.D. 171, 232, n. 82 (EAB 1997).

regulations a new section that details these prohibited acts. Prior regulations, such as the NLEV program, had included such a section, and although there is no burden associated with the regulations or any specific need to repeat what is in the Clean Air Act, EPA believes that including this language in the regulations provides clarity and improves the ease of use and completeness of the regulations. No comments were received on the proposal, and EPA is finalizing the section on prohibited acts (see 40 CFR 86.1854–12).

8. Other Certification Issues

a. Carryover/Carry Across Certification Test Data

EPA's certification program for vehicles allows manufacturers to carry certification test data over and across certification testing from one model year to the next, when no significant changes to models are made. EPA will also apply this policy to CO_2, N_2O and CH_4 certification test data. A manufacturer may also be eligible to use carryover and carry across data to demonstrate CO_2 fleet average compliance if they have done so for CAFE purposes.

b. Compliance Fees

The CAA allows EPA to collect fees to cover the costs of issuing certificates of conformity for the classes of vehicles and engines covered by this rule. On May 11, 2004, EPA updated its fees regulation based on a study of the costs associated with its motor vehicle and engine compliance program (69 FR 51402). At the time that cost study was conducted the current rulemaking was not considered.

At this time the extent of any added costs to EPA as a result of this rule is not known. EPA will assess its compliance testing and other activities associated with the rule and may amend its fees regulations in the future to include any warranted new costs.

c. Small Entity Exemption

EPA is exempting small entities, and these entities (necessarily) would not be subject to the certification requirements of this rule.

As discussed in Section III.B.8, businesses meeting the Small Business Administration (SBA) criterion of a small business as described in 13 CFR 121.201 would not be subject to the GHG requirements, pending future regulatory action. EPA proposed that such entities instead be required to submit a declaration to EPA containing a detailed written description of how that manufacturer qualifies as a small entity under the provisions of 13 CFR 121.201. EPA has reconsidered the need for this additional submission under the regulations and is deleting it as not necessary. We already have information on the limited number of small entities that we expect would receive the benefits of the exemption, and do not need the proposed regulatory requirement to be able to effectively implement this exemption for those parties who in fact meet its terms. Small entities are currently covered by a number of EPA motor vehicle emission regulations, and they routinely submit information and data on an annual basis as part of their compliance responsibilities.

As discussed in detail in Section III.B.6, small volume manufacturers with annual sales volumes of less than 5,000 vehicles will also be deferred from the CO_2 standards, pending future regulatory action. These manufacturers would still be required to meet N_2O and CH_4 standards, however. To qualify for CO_2 standard deferral, manufacturers would need to submit a declaration to EPA, and would also be required to demonstrate due diligence in having attempted to first secure credits from other manufacturers. This declaration would have to be signed by a chief officer of the company, and would have to be made at least 30 days prior to the introduction into commerce of any vehicles for each model year for which the small volume manufacturer status is requested, but not later than December of the calendar year prior to the model year for which deferral is requested. For example, if a manufacturer will be introducing model year 2012 vehicles in October of 2011, then the small volume manufacturer declaration would be due in September, 2011. If 2012 model year vehicles are not planned for introduction until March, 2012, then the declaration would have to be submitted in December, 2011. Such manufacturers are not automatically exempted from other EPA regulations for light-duty vehicles and light-duty trucks; therefore, absent this annual declaration EPA would assume that each manufacturer was not deferred from compliance with the greenhouse gas standards.

d. Onboard Diagnostics (OBD) and CO_2 Regulations

The light-duty on-board diagnostics (OBD) regulations require manufacturers to detect and identify malfunctions in all monitored emission-related powertrain systems or components.[285] Specifically, the OBD system is required to monitor catalysts, oxygen sensors, engine misfire, evaporative system leaks, and any other emission control systems directly intended to control emissions, such as exhaust gas recirculation (EGR), secondary air, and fuel control systems. The monitoring threshold for all of these systems or components is 1.5 times the applicable standards, which typically include NMHC, CO, NO_X, and PM. EPA did not propose that CO_2 emissions would become one of the applicable standards required to be monitored by the OBD system. EPA did not propose CO_2 become an applicable standard for OBD because it was confident that many of the emission-related systems and components currently monitored would effectively catch any malfunctions related to CO_2 emissions. For example, malfunctions resulting from engine misfire, oxygen sensors, the EGR system, the secondary air system, and the fuel control system would all have an impact on CO_2 emissions. Thus, repairs made to any of these systems or components should also result in an improvement in CO_2 emissions. In addition, EPA did not have data on the feasibility or effectiveness of monitoring various emission systems and components for CO_2 emissions and did not believe that it would be prudent to include CO_2 emissions without such information.

EPA did not address whether N_2O or CH_4 emissions should become applicable standards for OBD monitoring in the proposal. Several manufacturers felt that EPA's silence on this issue implied that EPA was proposing that N_2O and CH_4 emissions become applicable OBD standards. They commented that EPA should not include them as part of OBD. They felt that adding N_2O and CH_4 would significantly increase OBD development burden, without significant benefit, since any malfunctions that increase N_2O and CH_4 would likely be caught by current OBD system designs. EPA agrees with the manufacturer's comments on including N_2O and CH_4 as applicable standards. Therefore, at this time, EPA is not requiring CO_2, N_2O, and CH_4 emissions as one of the applicable standards required for the OBD monitoring threshold. EPA plans to evaluate OBD monitoring technology, with regard to monitoring these GHG emissions-related systems and components, and may choose to propose to include CO_2, N_2O, and CH_4 emissions as part of the OBD requirements in a future regulatory action.

[285] 40 CFR 86.1806–04.

e. Applicability of Current High Altitude Provisions to Greenhouse Gases

Vehicles covered by this rule must meet the CO_2, N_2O and CH_4 standard at altitude. The CAA requires emission standards under section 202 for light-duty vehicles and trucks to apply at all altitudes.[286] EPA does not expect vehicle CO_2, CH_4, or N_2O emissions to be significantly different at high altitudes based on vehicle calibrations commonly used at all altitudes. Therefore, EPA will retain its current high altitude regulations so manufacturers will not normally be required to submit vehicle CO_2 test data for high altitude. Instead, they must submit an engineering evaluation indicating that common calibration approaches will be utilized at high altitude. Any deviation in emission control practices employed only at altitude will need to be included in the auxiliary emission control device (AECD) descriptions submitted by manufacturers at certification. In addition, any AECD specific to high altitude will be required to include emissions data to allow EPA evaluate and quantify any emission impact and validity of the AECD.

f. Applicability of Standards to Aftermarket Conversions

With the exception of the small entity and small volume exemptions, EPA's emission standards, including greenhouse gas standards, will continue to apply as stated in the applicability sections of the relevant regulations. The greenhouse gas standards are being incorporated into 40 CFR part 86, subpart S, which includes exhaust and evaporative emission standards for criteria pollutants. Subpart S includes requirements for new light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, Otto-cycle complete heavy-duty vehicles, and some incomplete light-duty trucks. Subpart S is currently specifically applicable to aftermarket conversion systems, aftermarket conversion installers, and aftermarket conversion certifiers, as those terms are defined in 40 CFR 85.502. EPA expects that some aftermarket conversion companies will qualify for and seek the small entity and/or small volume exemption, but those that do not qualify will be required to meet the applicable emission standards, including the greenhouse gas standards.

[286] *See* CAA 206(f).

g. Geographical Location of Greenhouse Gas Fleet Vehicles

One manufacturer commented that the CAFE sales area location defined by Department of Transportation regulations is different than the EPA sales area location defined by the CAA. DOT regulations require CAFE compliance[287] in the 50 states, the District of Columbia, and Puerto Rico. However, EPA emission certification regulations require emission compliance[288] in the 50 states, the District of Columbia, the Puerto Rico, the Virgin Islands, Guam, American Samoa and the Commonwealth of the Northern Mariana Islands.

The comment stated that EPA has the discretion under the CAA to align the sales area location of production vehicles for the greenhouse gas fleet with the sales area location for the CAFE fleet and recommended that EPA amend the definitions in 40 CFR 86.1803 accordingly. This would exclude from greenhouse gas requirements production vehicles that are introduced into commerce in the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana.

Although EPA has tried to harmonize greenhouse gas and CAFE requirements in this rule to the extent possible, EPA believes that the approach suggested in comment would be contrary to the requirements of the Act. EPA does not believe that the Agency has discretion under the CAA to exclude from greenhouse gas requirements production vehicles introduced into commerce in the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. In addition, this change would introduce an undesirable level of complexity into the certification process and result in confusion due to vehicles intended for commerce in separate geographical locations being covered under a single certificate. For these reasons, EPA will retain the proposed greenhouse gas production vehicle sales area location as defined in the CAA.

[287] DOT regulations at 49 CFR 525.4(a)(5) read "The term *customs territory of the United States* is used as defined in 19 U.S.C. 1202." Section 19 U.S.C. 1202 has been replaced by the Harmonized Tariff Schedule of the United States. The Harmonized Tariff Schedule reads in part that "The term 'customs territory of the United States' * * * includes only the States, the District of Columbia, and Puerto Rico."

[288] Section 216 of the Clean Air Act defines the term commerce to mean "(A) commerce between any place in any State and any place outside thereof; and (B) commerce wholly within the District of Columbia."

Section 302(d) of the Clean Air Act reads "The term 'State' means a State, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, and American Samoa and includes the Commonwealth of the Northern Mariana Islands." In addition, 40 CFR 85.1502(14) regarding the importation of motor vehicles and motor vehicle engines defines the United States to include "the States, the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, Guam, American Samoa, and the U.S. Virgin Islands."

9. Miscellaneous Revisions to Existing Regulations

a. Revisions and Additions to Definitions

EPA has amended its definitions of "engine code," "transmission class," and "transmission configuration" in its vehicle certification regulations (part 86) to conform to the definitions for those terms in its fuel economy regulations (part 600). The exact terms in part 86 are used for reporting purposes and are not used for any compliance purpose (*e.g.,* an engine code will not determine which vehicle is selected for emission testing). However, the terms are used for this purpose in part 600 (*e.g.,* engine codes, transmission class, and transmission configurations are all criteria used to determine which vehicles are to be tested for the purposes of establishing corporate average fuel economy). Since the same vehicles tested to determine corporate average fuel economy will also be tested to determine fleet average CO_2, the same definitions will apply. Thus EPA has amended its part 86 definitions of the above terms to conform to the definitions in part 600.

Two provisions have been amended to bring EPA's fuel economy regulations in Part 600 into conformity with the fleet average CO_2 requirement contained in this rulemaking and with NHTSA's reform truck regulations. First, the definition of "footprint" in this rule is also being added to EPA's part 86 and 600 regulations. This definition is based on the definition promulgated by NHTSA at 49 CFR 523.2. Second, EPA is amending its model year CAFE reporting regulations to include the footprint information necessary for EPA to determine the reformed truck standards and the corporate average fuel economy. This same information is included in this rule for fleet average CO_2 and fuel economy compliance.

b. Addition of Ethanol Fuel Economy Calculation Procedures

EPA has amended part 600 to add calculation procedures for determining the carbon-related exhaust emissions and calculating the fuel economy of vehicles operating on ethanol fuel. Manufacturers have been using these procedures as needed, but the regulatory language—which specifies how to determine the fuel economy of gasoline, diesel, compressed natural gas, and methanol fueled vehicles—has not previously been updated to specify procedures for vehicles operating on ethanol. Under today's rule EPA is requiring use of a carbon balance approach for ethanol-fueled vehicles that is similar to the way carbon-related exhaust emissions are calculated for vehicles operating on other fuels for the purpose of determining fuel economy and for compliance with the fleet average CO_2 standards. The carbon balance formula is similar to the one in place for methanol, except that ethanol and acetaldehyde emissions must also be measured for ethanol-fueled vehicles. The carbon balance equation for determining fuel economy is as follows, where CWF is the carbon weight fraction of the fuel and CWF_{exHC} is the carbon weight fraction of the exhaust hydrocarbons:

$$mpg = (CWF \times SG \times 3781.8)/((CWF_{exHC} \times HC) + (0.429 \times CO) + (0.273 \times CO_2) + (0.375 \times CH_3OH) + (0.400 \times HCHO) + (0.521 \times C_2H_5OH) + (0.545 \times C_2H_4O)).$$

The equation for determining the total carbon-related exhaust emissions for compliance with the CO_2 fleet average standards is the following, where CWF_{exHC} is the carbon weight fraction of the exhaust hydrocarbons:

$$CO_2\text{-eq} = (CWF_{exHC} \times HC) + (0.429 \times CO) + (0.375 \times CH_3OH) + (0.400 \times HCHO) + (0.521 \times C_2H_5OH) + (0.545 \times C_2H_4O) + CO_2.$$

c. Revision of Electric Vehicle Applicability Provisions

In 1980, EPA issued a rule that provided for the inclusion of electric vehicles in the CAFE program.[289] EPA now believes that certain provisions of the regulations should be updated to reflect the current state of motor vehicle emission and fuel economy regulations. In particular, EPA believes that the exemption of electric vehicles in certain cases from fuel economy labeling and CAFE requirements should be reevaluated and revised.

The 1980 rule created an exemption for electric vehicles from fuel economy labeling in the following cases: (1) If the electric vehicles are produced by a company that produces only electric vehicles; and (2) if the electric vehicles are produced by a company that produces fewer than 10,000 vehicles of all kinds worldwide. EPA believes that this exemption language is no longer appropriate and is deleting it from the affected regulations. First, since 1980 many regulatory provisions have been put in place to address the concerns of small manufacturers and enable them to comply with fuel economy and emission programs with reduced burden. EPA believes that all small volume manufacturers should compete on a fair and level regulatory playing field and that there is no longer a need to treat small volume electric vehicles any differently than small volume manufacturers of other types of vehicles. Current regulations contain streamlined certification procedures for small companies, and because electric vehicles emit no direct pollution there is effectively no certification emission testing burden. For example, the greenhouse gas regulations contain a provision allowing the exemption of certain small entities. Meeting the requirements for fuel economy labeling and CAFE will entail a testing, reporting, and labeling burden, but these burdens are not extraordinary and should be applied equally to all small volume manufacturers, regardless of the fuel that moves their vehicles. EPA has been working with existing electric vehicle manufacturers on fuel economy labeling, and EPA believes it is important for the consumer to have impartial, accurate, and useful label information regarding the energy consumption of these vehicles. Second, EPCA does not provide for an exemption of electric vehicles from NHTSA's CAFE program, and NHTSA regulations regarding the applicability of the CAFE program do not provide an exemption for electric vehicles. Third, the blanket exemption for any manufacturer of only electric vehicles assumed at the time that these companies would all be small, but the exemption language inappropriately did not account for size and would allow large manufacturers to be exempt as well. Finally, because of growth expected in the electric vehicle market in the future, EPA believes that the labeling and CAFE regulations need to be designed to more specifically accommodate electric vehicles and to require that consumers be provided with appropriate information regarding these vehicles. For these reasons EPA has revised 40 CFR Part 600 applicability regulations such that these electric vehicle exemptions are deleted starting with the 2012 model year.

d. Miscellaneous Conforming Regulatory Amendments

EPA has made a number of minor amendments to update the regulations as needed or to ensure that the regulations are consistent with changes discussed in this preamble. For example, for consistency with the ethanol fuel economy calculation procedures discussed above, EPA has amended regulations where necessary to require the collection of emissions of ethanol and acetaldehyde. Other changes are made to applicable sections to remove obsolete regulatory requirements such as phase-ins related to EPA's Tier 2 emission standards program, and still other changes are made to better accommodate electric vehicles in EPA emission control regulations. Not all of these minor amendments are noted in this preamble, thus the reader should carefully evaluate regulatory text to ensure a complete understanding of the regulatory changes being promulgated by EPA.

In the process of amending regulations that vary in applicability by model year, EPA has several approaches that can be taken. The first option is to amend an existing section of the regulations. For example, EPA did this in the final regulations with § 86.111–94. In this case EPA chose to directly amend this section—which applies to 1994 and later model years as indicated by the suffix after the hyphen—but ensure that the model year of applicability of the amendments (2015 and later for N_2O measurement) is stated clearly in the regulatory text. A second option is to create a new section with specific applicability to the 2012 and later model years; *i.e.,* a section number with a "12" following the hyphen. This approach typically involves pulling forward all the language from an earlier model year section, then amending as needed (but it could also involve a wholesale revision and replacement with entirely new language). For example, EPA took this approach with § 86.1809–12. Although only paragraphs (d) and (e) contain revisions pertaining to this greenhouse gas rule, the remainder of the section is "pulled forward" from a prior model year section (in this case, § 86.1809–10) for completeness. Thus paragraphs (a) through (c) are unchanged relative to the prior model year section. Readers should therefore be aware that sections that are indicated as taking effect in the 2012 model year may differ in only subtle ways from the prior model year section being superseded. A third approach (not used in this regulation) is to use the "Reserved. For guidance see * * *" technique. For example, in the § 86.1809–12, rather than bring forward the existing language from paragraphs (a) through (c), EPA could have simply put a statement in the regulations

[289] 45 FR 49256, July 24, 1980.

directing the reader to refer back to § 86.1809–10 for those requirements. This method has been used in the past, but is not being used in this regulation.

10. Warranty, Defect Reporting, and Other Emission-Related Components Provisions

As outlined in the proposal, Section 207(a) of the Clean Air Act (CAA) requires manufacturers to provide a defect warranty that warrants a vehicle is designed to comply with emission standards and will be free from defects that may cause noncompliance over the specified warranty period which is 2 years/24,000 miles (whichever is first) or, for major emission control components, 8 years/80,000 miles. The warranty covers parts which must function properly to assure continued compliance with emission standards. The proposal explained that under the greenhouse gas rule, this coverage would include compliance with the proposed CO_2, CH_4, and N_2O standards. The proposal did not discuss the CAA Section 207(b) performance warranty.

EPA proposed to include air conditioning system components under the CAA section 207(a) emission warranty in cases where manufacturers use air conditioning leakage and efficiency credits to comply with the proposed fleet average CO_2 standards. The warranty period of 2 years/24,000 miles would apply. EPA requested comments as to whether any other parts or components should be designated as "emission related parts" and thus subject to warranty and defect reporting provisions under this rule.

The Alliance of Automobile Manufacturers (Alliance), Toyota and the State of New Jersey provided comments. The State of New Jersey supported EPA's proposal to include motor vehicle air conditioning system components under the emission warranty provisions. Both the Alliance and Toyota commented that emission warranty requirements are not appropriate for mobile air conditioners because (1) in-use performance of the air conditioning system at levels comparable to a new vehicle is not needed to achieve the emission levels targeted by EPA and (2) manufacturer general warranties already cover air conditioning systems and are typically longer than the two-year/24,000 mile proposed emissions warranty period.

Regarding direct emissions (refrigerant leakage), the Alliance and Toyota commented that warranty requirements are unnecessary for refrigerants with a global warming potential (GWP) below 150 because the environmental impact is negligible even if refrigerants are released from the system. Regarding indirect emissions (fuel consumed to power the air conditioning system), the Alliance commented that EPA should not require warranty coverage of the air conditioning system because in the vast majority of air conditioning failure modes, the system stops cooling and ceases operation—either because the critical moving parts stop moving or because the system is switched off—thereby actually reducing the indirect CO_2 emissions.

EPA received no comments regarding (1) other parts or components which should be designated as "emission related parts" subject to warranty requirements, (2) defect reporting requirements, or (3) other requirements associated with warranty and defect reporting requirements (*e.g.,* voluntary emission-related recall reporting requirements, performance warranty requirements, voluntary aftermarket parts certification requirements or tampering requirements.

Defect Warranty. EPA's current policy for defect warranty requirements is provided in Section 207 of the Act. There are currently no defect warranty regulations. Congress provided under Section 207(a) and (b) of the CAA that emission-related components shall be covered under the 207(a) defect warranty and the 207(b) performance warranty for the warranty period outlined in section 207(i) of the CAA. For example, section 207(a) reads in part:

"* * * the manufacturer of each new motor vehicle and new motor vehicle engine shall warrant to the ultimate purchaser and each subsequent purchaser that such vehicle or engine is (A) designed, built and equipped so as to conform at the time of sale with applicable regulations under section 202, and (B) free from defects in materials and workmanship which cause such vehicle or engine to fail to conform with applicable regulations for its useful life (as determined under sec. 202(d)). In the case of vehicles and engines manufactured in the model year 1995 and thereafter such warranty shall require that the vehicle or engine is free from any such defects for the warranty period provided under subsection (i)."

Section 207(i) reads in part:

"(i) Warranty Period.—

(1) In General.—For purposes of subsection (a)(1) and subsection (b), the warranty period, effective with respect to new light-duty trucks and new light-duty vehicles and engines, manufactured in model year 1995 and thereafter, shall be the first 2 years or 24,000 miles of use (whichever first occurs), except as provided in paragraph (2). For the purposes of subsection (a)(1) and subsection (b), for other vehicles and engines the warranty period shall be the period established by the Administrator by regulation (promulgated prior to the enactment of the Clean Air Act Amendments of 1990) for such purposes unless the Administrator subsequently modifies such regulation.

(2) In the case of a specified major emission control component, the warranty period for new light-duty trucks and new light-duty vehicles manufactured in the model year 1995 and thereafter for purposes of subsection (a)(1) and subsection (b) shall be 8 years or 80,000 miles of use (whichever first occurs). As used in this paragraph, the term 'specified major emission control component' means only a catalytic converter, an electronic emissions control unit, and an onboard emissions diagnostic device, except that the Administrator may designate any other pollution control device or component as a specified major emission control component if—(A) the device or component was not in general use on vehicles and engines manufactured prior to the model year 1990; and (B) the Administrator determines that the retail cost (exclusive of installation costs) of such device or component exceeds $200 (in 1989 dollars, adjusted for inflation or deflation) as calculated by the Administrator at the time of such determination * * *"

Thus, the CAA provides the basis of the warranty requirements contained in today's final rule, which will cover "emission related parts" necessary to provide compliance with CO_2, CH_4, and N_2O standards. Emission related parts would include those parts, systems, components and software installed for the specific purpose of controlling emissions or those components, systems, or elements of design which must function properly to assure continued vehicle emission compliance, including compliance with CO_2, CH_4, and N_2O standards; (similar to the current definition of "emission related parts" provided in 40 CFR 85.2102(14) for performance warranty requirements). For example, today's action will extend defect warranty requirements to emission-related components on advanced technology vehicles such as cylinder deactivation components or batteries used in hybrid-electric vehicles.

Under today's rule, EPA will extend the defect warranty requirement to emission-related components necessary to meet CO_2, CH_4, and N_2O standards, including emission-related components which are used to obtain optional credits for (1) certification of advanced technology vehicles, (2) credits for reduction of air conditioning refrigerant leakage, (3) credits for improving air conditioning system efficiency, (4) credits for off-cycle CO_2 reducing technologies, and (5) optional early credits for 2009–2011 model year vehicles outlined in the provisions of 40

CFR 86.1867–12 (which are required to be reported to EPA after the 2011 model year).

Regarding the comments received by the Alliance and Toyota, that warranty coverage is not needed for air conditioning components, EPA believes that the Clean Air Act requires warranty coverage on components used to demonstrate compliance with the emission standards, including components used in the optional credit programs for reduction of air conditioning refrigerant leakage and air conditioning efficiency improvements. EPA does not have the discretion to forgo warranty requirements by regulation in today's final rule. Thus, the Agency is adopting defect warranty requirements for air conditioning components as proposed.

Effective date of Warranty for Components used to Obtain Early Credits. Regarding the defect warranty for emission-related components used to obtain optional early credits for 2009–2011 vehicles, the defect warranty should provide coverage for these components at the time the early credits report is submitted to EPA (*e.g.,* no later than 90 days after the end of the 2011 model year). For example, the defect warranty for early credit components does not have to apply retroactively (before the manufacturer declares the credits to EPA). The Agency believes this approach is reasonable, because (1) manufacturer's early credit plans may not be finalized until after vehicles have been produced; (2) manufacturers will be provided satisfactory lead time to provide warranty requirements to customers; and (3) the manufacturer's basic (bumper-to-bumper) warranty for air conditioning and other early credit components are typically longer than the two-year/24,000 mile proposed warranty period which will be applicable to most early credit components.

Performance Warranty. EPA did not propose any changes to the current performance warranty requirements, because the performance warranty preconditions outlined in section 207(b) of the CAA have not been satisfied. For example, section 207(b) of the CAA comes into play if EPA issues performance warranty short test regulations and determines that there are inspection facilities available in the field to determine when vehicles do not comply with greenhouse gas emission standards. Once EPA issues performance warranty short test regulations, then the CAA performance warranty provisions require the manufacturer to pay for emission-related repairs if a vehicle is properly maintained and used, and fails the short test and is required to repair the vehicle. Currently the provisions of 85.2207 and 85.2222 provide performance warranty short test (commonly called an inspection and maintenance or I/M test). The provisions of 85.2207 and 85.2222 provide an I/M test procedure and failure criteria based on an inspection of the onboard diagnostic (OBD) system of the vehicle. The OBD inspection procedure in 85.2222 is currently used in most areas of the country where I/M tests are required. For example, a vehicle fails the OBD test procedure outlined in 85.2222 if the vehicle's MIL is commanded to be "on" during the I/M test procedure.

Although most areas of the country which require I/M testing use the OBD test procedure outlined in 40 CFR 85.2207 and 85.2222, the NPRM did not propose that the OBD system would be required to monitor CO_2, CH_4 or N_2O emission performance, ref 74 FR 49574 and 74 FR 49755. Therefore, the performance warranty preconditions in 201(b) of the CAA are not currently in effect for greenhouse gas CO_2 emissions. The performance warranty continues to apply for criteria pollutants but not for greenhouse emissions.

Defect Reporting and Voluntary Emission-related Recall Reporting Requirements. EPA did not propose any changes to the current defect reporting and voluntary emission-related recall reporting requirements outlined in the provisions of 40 CFR 85.1901–1909. Although EPA requested comments, we did not receive any comments on defect reporting and voluntary emission-related recall reporting requirements. Current regulations require manufacturers to submit a defect report to EPA whenever an emission-related defect exists in 25 or more in-use vehicles or engines of the same model year. The defect report is required to be submitted to EPA within 15 working days of the time the manufacturer becomes aware of a defect that affects 25 or more vehicles. Current regulations require manufacturers to submit to EPA voluntary emission-related recall reports within 15 working days of the date when owner notification begins.

Similar to the performance warranty requirements outlined above, the Agency believes that as proposed, defect reporting and voluntary emission-related recall reporting requirements would apply to emission-related components necessary to meet CO_2, CH_4, and N_2O standards for the useful life of the vehicle, including emission-related components that are used to obtain optional credits for (1) certification of advanced technology vehicles, (2) credits for reduction of air conditioning refrigerant leakage, (3) credits for improving air conditioning system efficiency, and (4) credits for off-cycle CO_2 reducing technologies, and (5) optional early credits for 2009–2011 model year vehicles outlined in the provisions of 40 CFR 86.1867–12 (which are required to be reported to EPA after the 2011 model year). For early credit components, defect reporting requirements and voluntary emission-related recall reporting requirements become effective at the time the early credits report is submitted to EPA (*e.g.,* no later than 90 days after the end of the 2011 model year).

The final rule includes a minor clarification to the provisions of 40 CFR 85.1902 (b) and (d) to clarify that beginning with the 2012 model year, manufacturers are required to report emission-related defects and voluntary emission recalls to EPA, including emission-related defects and voluntary emission recalls related to greenhouse gas emissions (CH_4, N_2O and CO_2).

11. Light Duty Vehicles and Fuel Economy Labeling

American consumers need accurate and meaningful information about the environmental and fuel economy performance of new light duty vehicles. EPA believes it is important that the fuel-economy label affixed to the new vehicles provide consumers with the critical information they need to make smart purchase decisions, especially in light of the expected increase in market share of electric and other advanced technology vehicles. Consumers may need new and different information than today's vehicle labels provide in order to help them understand the energy use and associated cost of owning these electric and advanced technology vehicles.

Therefore, in proposing this greenhouse gas action, EPA sought comment on issues surrounding consumer vehicle labeling in general, and labeling of advanced technology vehicles in particular. EPA specifically asked for input as to whether today's miles per gallon fuel economy metric provides adequate information to consumers.

EPA received considerable public input in response to the request for comment in the proposal. Since the greenhouse gas rule was proposed in September, 2009, EPA has initiated a separate rulemaking to explore in detail the information displayed on the fuel economy label and the methodology for deriving that information. The purpose of the vehicle labeling rulemaking is to ensure that American consumers continue to have the most accurate, meaningful, and useful information available to them when purchasing new vehicles, and that the information is presented to them in clear and understandable terms.

EPA will consider all vehicle labeling comments received in response to the greenhouse gas proposal in its development of the new labeling rule in coming months. We encourage the interested public to stay engaged and continue to provide input on this issue in the context of the vehicle labeling rulemaking.

F. How will this final rule reduce GHG emissions and their associated effects?

This action is an important step towards curbing steady growth of GHG emissions from cars and light trucks. In the absence of control, GHG emissions worldwide and in the U.S. are projected to continue steady growth. Table III.F–1 shows emissions of CO_2, methane, nitrous oxide and air conditioning refrigerants on a CO_2-equivalent basis for calendar years 2010, 2020, 2030, 2040 and 2050. As shown below, U.S. GHGs are estimated to make up roughly 17 percent of total worldwide emissions in 2010, and the contribution of direct emissions from cars and light-trucks to this U.S. share is growing over time, reaching an estimated 19 percent of U.S. emissions by 2030 in the absence of control. As discussed later in this section, this steady rise in GHG emissions is associated with numerous adverse impacts on human health, food and agriculture, air quality, and water and forestry resources.

TABLE III.F–1—REFERENCE CASE GHG EMISSIONS BY CALENDAR YEAR

[$MMTCO_2eq$]

	2010	2020	2030	2040	2050
All Sectors (Worldwide) [a]	41,016	48,059	52,870	56,940	60,209
All Sectors (U.S. Only) [a]	7,118	7,390	7,765	8,101	8,379
U.S. Cars/Light Truck Only [b]	1,243	1,293	1,449	1,769	2,219

[a] ADAGE model projections, U.S. EPA.[290]
[b] MOVES2010 (2010), OMEGA Model (2020–50) U.S. EPA. See RIA Chapter 5.3 for modeling details.

EPA's GHG rule will result in significant reductions as newer, cleaner vehicles come into the fleet, and the rule is estimated to have a measurable impact on world global temperatures. As discussed in Section I, this GHG rule is part of a joint National Program such that a large majority of the projected benefits would be achieved jointly with NHTSA's CAFE standards, which are described in detail in Section IV. EPA estimates the reductions attributable to the GHG program over time assuming the model year 2016 standards continue indefinitely post-2016,[291] compared to a reference scenario in which the 2011 model year fuel economy standards continue beyond 2011.

Using this approach EPA estimates these standards would cut annual fleetwide car and light truck tailpipe CO_2-eq emissions by 21 percent by 2030, when 90 percent of car and light truck miles will be travelled by vehicles meeting the new standards. Roughly 20 percent of these reductions are due to "upstream" emission reductions from gasoline extraction, production and distribution processes as a result of reduced gasoline demand associated with this rule. Some of the overall emission reductions also come from projected improvements in the efficiency of vehicle air conditioning systems, which will substantially reduce direct emissions of HFCs, one of the most potent greenhouse gases, as well as indirect emissions of tailpipe CO_2 emissions attributable to reduced engine load from air conditioning. In total, EPA estimates that compared to a baseline of indefinite 2011 model year standards, net GHG emission reductions from the program would be 307 million metric tons CO_2-equivalent ($MMTCO_2eq$) annually by 2030, which represents a reduction of 4 percent of total U.S. GHG emissions and 0.6 percent of total worldwide GHG emissions projected in that year. This estimate accounts for all upstream fuel production and distribution emission reductions, vehicle tailpipe emission reductions including air conditioning benefits, as well as increased vehicle miles travelled (VMT) due to the "rebound" effect discussed in Section III.H. EPA estimates this would be the equivalent of removing approximately 50 million cars and light trucks from the road in this timeframe.[292]

EPA projects the total reduction of the program over the full life of model year 2012–2016 vehicles to be about 960 $MMTCO_2eq$, with fuel savings of 78 billion gallons (1.8 billion barrels) of gasoline over the life of these vehicles, assuming that some manufacturers take advantage of low-cost HFC reduction strategies to help meet these standards.

The impacts on global mean temperature and global mean sea level rise resulting from these emission reductions are discussed in Section III.F.3.

1. Impact on GHG Emissions

This action will reduce GHG emissions emitted directly from vehicles due to reduced fuel use and more efficient air conditioning systems. In addition to these "downstream" emissions, reducing CO_2 emissions translates directly to reductions in the emissions associated with the processes involved in getting petroleum to the pump, including the extraction and transportation of crude oil, and the production and distribution of finished gasoline (termed "upstream" emissions). Reductions from tailpipe GHG standards grow over time as the fleet turns over to vehicles subject to the standards, meaning the benefit of the program will continue as long as the oldest vehicles in the fleet are replaced by newer, lower CO_2 emitting vehicles.

EPA is not projecting any reductions in tailpipe CH_4 or N_2O emissions as a result of the emission caps set forth in this rule, which are meant to prevent emission backsliding and to bring diesel vehicles equipped with advanced technology aftertreatment, and other advanced technology vehicles such as lean-burn gasoline vehicles, into

[290] U.S. EPA (2009). "EPA Analysis of the American Clean Energy and Security Act of 2009: H.R. 2454 in the 111th Congress." U.S. Environmental Protection Agency, Washington, DC USA (*http://www.epa.gov/climatechange/economics/economicanalyses.html*). ADAGE model projections of worldwide and U.S. totals include EISA, and are provided for context.

[291] This analysis does not include the EISA requirement for 35 MPG through 2020 or California's Pavley 1 GHG standards. The standards are intended to supersede these requirements, and the baseline case for comparison are the emissions that would result without further action above the currently promulgated fuel economy standards.

[292] Estimated using MOVES2010, the average vehicle in the light duty fleet emitted 5.1 tons of CO_2 during calendar year 2008.

alignment with current gasoline vehicle emissions.[293]

No substantive comments were received on the emissions modeling methods or on the greenhouse gas inventories presented in the proposal. These analyses are updated here to include model revisions and more recent economic analysis, including revised estimates of future vehicle sales, fuel prices, and vehicle miles traveled. The primary source for these data is the AEO 2010 preliminary release.[294] For more details, please see the TSD and RIA Chapter 5.

As detailed in the RIA, EPA estimated calendar year tailpipe CO_2 reductions based on pre- and post-control CO_2 gram per mile levels from EPA's OMEGA model and assumed to continue indefinitely into the future, coupled with VMT projections derived from AEO 2010 Early Release. These estimates reflect the real-world CO_2 emissions reductions projected for the entire U.S. vehicle fleet in a specified calendar year, including the projected effect of air conditioning credits, the TLAAS program and FFV credits. EPA also estimated full lifetime reductions for model years 2012–2016 using pre- and post-control CO_2 levels projected by the OMEGA model, coupled with projected vehicle sales and lifetime mileage estimates. These estimates reflect the real-world CO_2 emissions reductions projected for model years 2012 through 2016 vehicles over their entire life.

This rule allows manufacturers to earn credits for improved vehicle air conditioning efficiency. Since these improvements are relatively low cost, EPA projects that manufacturers will take advantage of this flexibility, leading to reductions from emissions associated with vehicle air conditioning systems. As explained above, these reductions will come from both direct emissions of air conditioning refrigerant over the life of the vehicle and tailpipe CO_2 emissions produced by the increased load of the A/C system on the engine. In particular, EPA estimates that direct emissions of HFCs, one of the most potent greenhouse gases, would be reduced 50 percent from light-duty vehicles when the fleet has turned over to more efficient vehicles. The fuel savings derived from lower tailpipe CO_2 would also lead to reductions in upstream emissions. Our estimated reductions from the A/C credits program are based on our analysis of how manufacturers are expected to take advantage of this credit opportunity in complying with the CO_2 fleetwide average tailpipe standards.

Upstream emission reductions associated with the production and distribution of fuel were estimated using emission factors from DOE's GREET1.8 model, with some modifications as detailed in Chapter 5 of the RIA. These estimates include both international and domestic emission reductions, since reductions in foreign exports of finished gasoline and/or crude would make up a significant share of the fuel savings resulting from the GHG standards. Thus, significant portions of the upstream GHG emission reductions will occur outside of the U.S.; a breakdown of projected international versus domestic reductions is included in the RIA.

a. Calendar Year Reductions for Future Years

Table III.F.1–1 shows reductions estimated from these GHG standards assuming a pre-control case of 2011 MY standards continuing indefinitely beyond 2011, and a post-control case in which 2016 MY GHG standards continue indefinitely beyond 2016.[295] These reductions are broken down by upstream and downstream components, including air conditioning improvements, and also account for the offset from a 10 percent VMT "rebound" effect as discussed in Section III.H. Including the reductions from upstream emissions, total reductions are estimated to reach 307 $MMTCO_2eq$ annually by 2030 (a 21 percent reduction in U.S. car and light truck emissions), and grow to over 500 $MMTCO_2eq$ in 2050 as cleaner vehicles continue to come into the fleet (a 23 percent reduction in U.S. car and light truck emissions).

TABLE III.F.1–1—PROJECTED GHG REDUCTIONS

[$MMTCO_2eq$ per year]

	Calendar year			
	2020	2030	2040	2050
Net Reduction *	156.4	307.0	401.5	505.9
Net CO_2	*139.1*	*273.3*	*360.4*	*458.7*
Net other GHG	*17.3*	*33.7*	*41.1*	*47.2*
Downstream Reduction	125.2	245.7	320.7	403.0
CO_2 (excluding A/C)	*101.2*	*199.5*	*263.2*	*335.1*
A/C—indirect CO_2	*10.6*	*20.2*	*26.5*	*33.8*
A/C—direct HFCs	*13.3*	*26.0*	*30.9*	*34.2*
CH_4 (rebound effect)	*0.0*	*0.0*	*0.0*	*0.0*
N_2O (rebound effect)	*0.0*	*−0.1*	*−0.1*	*−0.1*
Upstream Reduction	31.2	61.3	80.8	102.9
CO_2	*27.2*	*53.5*	*70.6*	*89.9*
CH_4	*3.9*	*7.6*	*10.0*	*12.7*
N_4O	*0.1*	*0.3*	*0.3*	*0.4*
Percent reduction relative to U.S. reference (cars + light trucks)	12.1%	21.2%	22.7%	22.8%
Percent reduction relative to U.S. reference (all sectors)	2.1%	4.0%	5.0%	6.0%
Percent reduction relative to worldwide reference	0.3%	0.6%	0.7%	0.8%

* Includes impacts of 10% VMT rebound rate presented in Table III.F.1–3.

[293] EPA is adopting a compliance option whereby manufacturers can comply with a CO_2 equivalent standard in lieu of meeting the CH_4 and N_2O standards. This should have no effect on the estimated GHG reductions attributable to the rule since a condition of meeting that alternative standard is that the fleetwide CO_2 target remains in place.

[294] Energy Information Administration. Annual Energy Outlook 2010 Early Release. *http://www.eia.doe.gov/oiaf/aeo/.*

[295] Legally, the 2011 CAFE standards only apply to the 2011 model year and no standards apply to future model years. However, we do not believe that it would be appropriate to assume that no CAFE standards would apply beyond the 2011 model year when projecting the impacts of this rule.

b. Lifetime Reductions for 2012–2016 Model Years

EPA also analyzed the emission reductions over the full life of the 2012–2016 model year cars and trucks affected by this program.[296] These results, including both upstream and downstream GHG contributions, are presented in Table III.F.1–2, showing lifetime reductions of about 960 $MMTCO_2eq$, with fuel savings of 78 billion gallons (1.8 billion barrels) of gasoline.

TABLE III.F.1–2—PROJECTED NET GHG REDUCTIONS

[$MMTCO_2eq$ per year]

Model year	Lifetime GHG reduction ($MMT\ CO_2$ EQ)	Lifetime Fuel savings (billion gallons)
2012	88.9	7.3
2013	130.2	10.5
2014	174.2	13.9
2015	244.2	19.5
2016	324.6	26.5
Total Program Benefit	962.0	77.7

c. Impacts of VMT Rebound Effect

As noted above and discussed more fully in Section III.H., the effect of fuel cost on VMT ("rebound") was accounted for in our assessment of economic and environmental impacts of this rule. A 10 percent rebound case was used for this analysis, meaning that VMT for affected model years is modeled as increasing by 10 percent as much as the increase in fuel economy; *i.e.,* a 10 percent increase in fuel economy would yield a 1.0 percent increase in VMT. Results are shown in Table III.F.1–3; using the 10 percent rebound rate results in an overall emission increase of 25.0 $MMTCO_2eq$ annually in 2030 (this increase is accounted for in the reductions presented in Tables III.F.1–1 and III.F.1–2). Our estimated changes in CH_4 or N_2O emissions as a result of these vehicle GHG standards are attributed solely to this rebound effect.

TABLE III.F.1–3—GHG IMPACT OF 10% VMT REBOUND [a]

[$MMTCO_2eq$ per year]

	2020	2030	2040	2050
Total GHG Increase	13.0	25.0	32.9	41.9
Tailpipe & Indirect A/C CO_2	*10.2*	*19.6*	*25.8*	*32.8*
Upstream GHGs [b]	*2.8*	*5.4*	*7.1*	*9.1*
Tailpipe CH_4	*0.0*	*0.0*	*0.0*	*0.0*
Tailpipe N_2O	*0.0*	*0.1*	*0.1*	*0.1*

[a] These impacts are included in the reductions shown in Table III.F.1–1 and III.F.1–2.

[b] Upstream rebound impact calculated as upstream total CO_2 effect times ratio of downstream tailpipe rebound CO_2 effect to downstream tailpipe total CO_2 effect.

d. Analysis of Alternatives

EPA analyzed two alternative scenarios, including 4% and 6% annual increases in GHG emission standards. In addition to this annual increase, EPA assumed that manufacturers would use air conditioning improvements in identical penetrations as in the primary scenario. Under these assumptions, EPA expects achieved fleetwide average emission levels of 253 g/mile CO_2eq (4%), and 230 g/mile CO_2eq (6%) in 2016.

As in the primary scenario, EPA assumed that the fleet complied with the standards. For full details on modeling assumptions, please refer to RIA Chapter 5. EPA's assessment of these alternative standards, including our response to public comments, is discussed in Section III.D.

TABLE III.F.1–4—CALENDAR YEAR IMPACTS OF ALTERNATIVE SCENARIOS

	Scenario	Calendar year			
		CY 2020	CY 2030	CY 2040	CY 2050
Total GHG Reductions ($MMT\ CO_2$ eq)	Primary	−156.4	−307.0	−401.5	−505.8
	4%	−141.9	−286.2	−375.4	−472.9
	6%	−202.6	−403.4	−529.3	−668.7
Fuel Savings (Billion Gallons Gasoline Equivalent)	Primary	−12.6	−24.7	−32.6	−41.5
	4%	−11.3	−22.9	−30.3	−38.6
	6%	−16.7	−33.2	−43.9	−55.9

[296] As detailed in the RIA Chapter 5 and TSD Chapter 4, for this analysis the full life of the vehicle is represented by average lifetime mileages for cars (195,000 miles) and trucks (226,000 miles) averaged over calendar years 2012 through 2030, a function of how far vehicles drive per year and scrappage rates.

TABLE III.F.1–5—MODEL YEAR IMPACTS OF ALTERNATIVE SCENARIOS

	Scenario	Model year lifetime					
		MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Total GHG Reductions (MMT CO_2 eq)	Primary	−88.8	−130.2	−174.2	−244.2	−324.6	−962.0
	4%	−39.9	−96.6	−155.4	−226.5	−303.6	−822.0
	6%	−61.7	−146.5	−237.0	−332.2	−427.6	−1,204.9
Fuel Savings (Billion Gallons Gasoline Equivalent).	Primary	−7.3	−10.5	−13.9	−19.5	−26.5	−77.7
	4%	−2.9	−7.1	−12.2	−18.0	−24.6	−64.8
	6%	−4.9	−12.0	−19.4	−27.3	−35.6	−99.1

2. Overview of Climate Change Impacts From GHG Emissions

Once emitted, GHGs that are the subject of this regulation can remain in the atmosphere for decades to centuries, meaning that (1) their concentrations become well-mixed throughout the global atmosphere regardless of emission origin, and (2) their effects on climate are long lasting. GHG emissions come mainly from the combustion of fossil fuels (coal, oil, and gas), with additional contributions from the clearing of forests and agricultural activities. The transportation sector represents a significant portion, 28%, of U.S. GHG emissions.[297]

This section provides a summary of observed and projected changes in GHG emissions and associated climate change impacts. The source document for the section below is the Technical Support Document (TSD)[298] for EPA's Endangerment and Cause or Contribute Findings Under the Clean Air Act.[299] Below is the Executive Summary of the TSD which provides technical support for the endangerment and cause or contribute analyses concerning GHG emissions under section 202(a) of the Clean Air Act. The TSD reviews observed and projected changes in climate based on current and projected atmospheric GHG concentrations and emissions, as well as the related impacts and risks from climate change that are projected in the absence of GHG mitigation actions, including this action and other U.S. and global actions. The TSD was updated and revised based on expert technical review and public comment as part of EPA's rulemaking process for the final Endangerment Findings. The key findings synthesized here and the information throughout the TSD are primarily drawn from the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), the U.S. Climate Change Science Program (CCSP), the U.S. Global Change Research Program (USGCRP), and the National Research Council (NRC).[300]

a. Observed Trends in Greenhouse Gas Emissions and Concentrations

The primary long-lived GHGs directly emitted by human activities include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Greenhouse gases have a warming effect by trapping heat in the atmosphere that would otherwise escape to space. In 2007, U.S. GHG emissions were 7,150 teragrams[301] of CO_2 equivalent[302] ($TgCO_2eq$). The dominant gas emitted is CO_2, mostly from fossil fuel combustion. Methane is the second largest component of U.S. emissions, followed by N_2O and the fluorinated gases (HFCs, PFCs, and SF_6). Electricity generation is the largest emitting sector (34% of total U.S. GHG emissions), followed by transportation (28%) and industry (19%).

Transportation sources under Section 202(a)[303] of the Clean Air Act (passenger cars, light duty trucks, other trucks and buses, motorcycles, and passenger cooling) emitted 1,649 $TgCO_2eq$ in 2007, representing 23% of total U.S. GHG emissions. U.S. transportation sources under Section 202(a) made up 4.3% of total global GHG emissions in 2005,[304] which, in addition to the United States as a whole, ranked only behind total GHG emissions from China, Russia, and India but ahead of Japan, Brazil, Germany, and the rest of the world's countries. In 2005, total U.S. GHG emissions were responsible for 18% of global emissions, ranking only behind China, which was responsible for 19% of global GHG emissions. The scope of this action focuses on GHG emissions under Section 202(a) from passenger cars and light duty trucks source categories (see Section III.F.1).

The global atmospheric CO_2 concentration has increased about 38% from pre-industrial levels to 2009, and almost all of the increase is due to anthropogenic emissions. The global atmospheric concentration of CH_4 has increased by 149% since pre-industrial levels (through 2007); and the N_2O concentration has increased by 23% (through 2007). The observed concentration increase in these gases can also be attributed primarily to anthropogenic emissions. The industrial fluorinated gases, HFCs, PFCs, and SF_6, have relatively low atmospheric concentrations but the total radiative forcing due to these gases is increasing rapidly; these gases are almost entirely anthropogenic in origin.

Historic data show that current atmospheric concentrations of the two most important directly emitted, long-lived GHGs (CO_2 and CH_4) are well above the natural range of atmospheric concentrations compared to at least the last 650,000 years. Atmospheric GHG concentrations have been increasing because anthropogenic emissions have been outpacing the rate at which GHGs are removed from the atmosphere by

[297] U.S. EPA (2009) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007.* EPA–430–R–09–004, Washington, DC.

[298] "Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act." Docket: EPA–HQ–OAR–2009–0472–11292.

[299] *See* 74 FR 66496 (Dec. 15, 2009).

[300] For a complete list of core references from IPCC, USGCRP/CCSP, NRC and others relied upon for development of the TSD for EPA's Endangerment and Cause or Contribute Findings *see* section 1(b), specifically, Table 1.1 of the TSD.

[301] One teragram (Tg) = 1 million metric tons. 1 metric ton = 1,000 kilograms = 1.102 short tons = 2,205 pounds.

[302] Long-lived GHGs are compared and summed together on a CO_2-equivalent basis by multiplying each gas by its global warming potential (GWP), as estimated by IPCC. In accordance with United Nations Framework Convention on Climate Change (UNFCCC) reporting procedures, the U.S. quantifies GHG emissions using the 100-year timeframe values for GWPs established in the IPCC Second Assessment Report.

[303] Source categories under Section 202(a) of the Clean Air Act are a subset of source categories considered in the transportation sector and do not include emissions from non-highway sources such as boats, rail, aircraft, agricultural equipment, construction/mining equipment, and other off-road equipment.

[304] More recent emission data are available for the United States and other individual countries, but 2005 is the most recent year for which data for all countries and all gases are available.

natural processes over timescales of decades to centuries.

b. Observed Effects Associated With Global Elevated Concentrations of GHGs

Current ambient air concentrations of CO_2 and other GHGs remain well below published exposure thresholds for any direct adverse health effects, such as respiratory or toxic effects.

The global average net effect of the increase in atmospheric GHG concentrations, plus other human activities (*e.g.,* land-use change and aerosol emissions), on the global energy balance since 1750 has been one of warming. This total net heating effect, referred to as forcing, is estimated to be +1.6 (+0.6 to +2.4) watts per square meter (W/m^2), with much of the range surrounding this estimate due to uncertainties about the cooling and warming effects of aerosols. However, as aerosol forcing has more regional variability than the well-mixed, long-lived GHGs, the global average might not capture some regional effects. The combined radiative forcing due to the cumulative (*i.e.,* 1750 to 2005) increase in atmospheric concentrations of CO_2, CH_4, and N_2O is estimated to be +2.30 (+2.07 to +2.53) W/m^2. The rate of increase in positive radiative forcing due to these three GHGs during the industrial era is very likely to have been unprecedented in more than 10,000 years.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Global mean surface temperatures have risen by 1.3 ± 0.32 F (0.74 C ± 0.18 C) over the last 100 years. Eight of the 10 warmest years on record have occurred since 2001. Global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries.

Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. Climate model simulations suggest natural forcing alone (*i.e.,* changes in solar irradiance) cannot explain the observed warming.

U.S. temperatures also warmed during the 20th and into the 21st century; temperatures are now approximately 1.3 F (0.7 C) warmer than at the start of the 20th century, with an increased rate of warming over the past 30 years. Both the IPCC [305] and the CCSP reports attributed recent North American warming to elevated GHG concentrations. In the CCSP (2008) report,[306] the authors find that for North America, "more than half of this warming [for the period 1951–2006] is likely the result of human-caused greenhouse gas forcing of climate change."

Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. Over the contiguous United States, total annual precipitation increased by 6.1% from 1901 to 2008. It is likely that there have been increases in the number of heavy precipitation events within many land regions, even in those where there has been a reduction in total precipitation amount, consistent with a warming climate.

There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate. It is not clear whether the increasing rate of sea level rise is a reflection of short-term variability or an increase in the longer-term trend. Nearly all of the Atlantic Ocean shows sea level rise during the last 50 years with the rate of rise reaching a maximum (over 2 millimeters [mm] per year) in a band along the U.S. east coast running east-northeast.

Satellite data since 1979 show that annual average Arctic sea ice extent has shrunk by 4.1% per decade. The size and speed of recent Arctic summer sea ice loss is highly anomalous relative to the previous few thousands of years.

Widespread changes in extreme temperatures have been observed in the last 50 years across all world regions, including the United States. Cold days, cold nights, and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent.

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. However, directly attributing specific regional changes in climate to emissions of GHGs from human activities is difficult, especially for precipitation.

Ocean CO_2 uptake has lowered the average ocean pH (increased acidity) level by approximately 0.1 since 1750. Consequences for marine ecosystems can include reduced calcification by shell-forming organisms, and in the longer term, the dissolution of carbonate sediments.

Observations show that climate change is currently affecting U.S. physical and biological systems in significant ways. The consistency of these observed changes in physical and biological systems and the observed significant warming likely cannot be explained entirely due to natural variability or other confounding non-climate factors.

c. Projections of Future Climate Change With Continued Increases in Elevated GHG Concentrations

Most future scenarios that assume no explicit GHG mitigation actions (beyond those already enacted) project increasing global GHG emissions over the century, with climbing GHG concentrations. Carbon dioxide is expected to remain the dominant anthropogenic GHG over the course of the 21st century. The radiative forcing associated with the non-CO_2 GHGs is still significant and increasing over time.

Future warming over the course of the 21st century, even under scenarios of low-emission growth, is very likely to be greater than observed warming over the past century. According to climate model simulations summarized by the IPCC,[307] through about 2030, the global warming rate is affected little by the choice of different future emissions scenarios. By the end of the 21st century, projected average global warming (compared to average temperature around 1990) varies significantly depending on the emission scenario and climate sensitivity assumptions, ranging from 3.2 to 7.2 F (1.8 to 4.0 C), with an uncertainty range of 2.0 to 11.5 F (1.1 to 6.4 C).

All of the United States is very likely to warm during this century, and most areas of the United States are expected to warm by more than the global

[305] Hegerl, G.C. et al. (2007) Understanding and Attributing Climate Change. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[306] CCSP (2008) *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Randall Dole, Martin Hoerling, and Siegfried Schubert (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 156 pp.

[307] Meehl, G.A. *et al.* (2007) Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

average. The largest warming is projected to occur in winter over northern parts of Alaska. In western, central and eastern regions of North America, the projected warming has less seasonal variation and is not as large, especially near the coast, consistent with less warming over the oceans.

It is very likely that heat waves will become more intense, more frequent, and longer lasting in a future warm climate, whereas cold episodes are projected to decrease significantly.

Increases in the amount of precipitation are very likely in higher latitudes, while decreases are likely in most subtropical latitudes and the southwestern United States, continuing observed patterns. The mid-continental area is expected to experience drying during summer, indicating a greater risk of drought.

Intensity of precipitation events is projected to increase in the United States and other regions of the world. More intense precipitation is expected to increase the risk of flooding and result in greater runoff and erosion that has the potential for adverse water quality effects.

It is likely that hurricanes will become more intense, with stronger peak winds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures. Frequency changes in hurricanes are currently too uncertain for confident projections.

By the end of the century, global average sea level is projected by IPCC [308] to rise between 7.1 and 23 inches (18 and 59 centimeter [cm]), relative to around 1990, in the absence of increased dynamic ice sheet loss. Recent rapid changes at the edges of the Greenland and West Antarctic ice sheets show acceleration of flow and thinning. While an understanding of these ice sheet processes is incomplete, their inclusion in models would likely lead to increased sea level projections for the end of the 21st century.

Sea ice extent is projected to shrink in the Arctic under all IPCC emissions scenarios.

d. Projected Risks and Impacts Associated With Future Climate Change

Risk to society, ecosystems, and many natural Earth processes increase with increases in both the rate and magnitude of climate change. Climate warming may increase the possibility of large, abrupt regional or global climatic events (*e.g.,* disintegration of the Greenland Ice Sheet or collapse of the West Antarctic Ice Sheet). The partial deglaciation of Greenland (and possibly West Antarctica) could be triggered by a sustained temperature increase of 2 to 7 F (1 to 4 C) above 1990 levels. Such warming would cause a 13 to 20 feet (4 to 6 meter) rise in sea level, which would occur over a time period of centuries to millennia.

The CCSP [309] reports that climate change has the potential to accentuate the disparities already evident in the American health care system, as many of the expected health effects are likely to fall disproportionately on the poor, the elderly, the disabled, and the uninsured. The IPCC [310] states with very high confidence that climate change impacts on human health in U.S. cities will be compounded by population growth and an aging population.

Severe heat waves are projected to intensify in magnitude and duration over the portions of the United States where these events already occur, with potential increases in mortality and morbidity, especially among the elderly, young, and frail.

Some reduction in the risk of death related to extreme cold is expected. It is not clear whether reduced mortality from cold will be greater or less than increased heat-related mortality in the United States due to climate change.

Increases in regional ozone pollution relative to ozone levels without climate change are expected due to higher temperatures and weaker circulation in the United States and other world cities relative to air quality levels without climate change. Climate change is expected to increase regional ozone pollution, with associated risks in respiratory illnesses and premature death. In addition to human health effects, tropospheric ozone has significant adverse effects on crop yields, pasture and forest growth, and species composition. The directional effect of climate change on ambient particulate matter levels remains uncertain.

Within settlements experiencing climate change, certain parts of the population may be especially vulnerable; these include the poor, the elderly, those already in poor health, the disabled, those living alone, and/or indigenous populations dependent on one or a few resources. Thus, the potential impacts of climate change raise environmental justice issues.

The CCSP [311] concludes that, with increased CO_2 and temperature, the life cycle of grain and oilseed crops will likely progress more rapidly. But, as temperature rises, these crops will increasingly begin to experience failure, especially if climate variability increases and precipitation lessens or becomes more variable. Furthermore, the marketable yield of many horticultural crops (*e.g.,* tomatoes, onions, fruits) is very likely to be more sensitive to climate change than grain and oilseed crops.

Higher temperatures will very likely reduce livestock production during the summer season in some areas, but these losses will very likely be partially offset by warmer temperatures during the winter season.

Cold-water fisheries will likely be negatively affected; warm-water fisheries will generally benefit; and the results for cool-water fisheries will be mixed, with gains in the northern and losses in the southern portions of ranges.

Climate change has very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior West, the Southwest, and Alaska, and will continue to do so. Over North America, forest growth and productivity have been observed to increase since the middle of the 20th century, in part due to observed climate change. Rising CO_2 will very likely increase photosynthesis for forests, but the increased photosynthesis will likely only increase wood production in young forests on fertile soils. The combined effects of expected increased temperature, CO_2, nitrogen deposition, ozone, and forest

[308] IPCC (2007) Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[309] Ebi, K.L., J. Balbus, P.L. Kinney, E. Lipp, D. Mills, M.S. O'Neill, and M. Wilson (2008) Effects of Global Change on Human Health. In: *Analyses of the effects of global change on human health and welfare and human systems.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, pp. 2–1 to 2–78.

[310] Field, C.B. et al. (2007) North America. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[311] Backlund, P., A. Janetos, D.S. Schimel, J. Hatfield, M.G. Ryan, S.R. Archer, and D. Lettenmaier (2008) Executive Summary. In: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC., USA, 362 pp.

disturbance on soil processes and soil carbon storage remain unclear.

Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. Sea level is rising along much of the U.S. coast, and the rate of change will very likely increase in the future, exacerbating the impacts of progressive inundation, storm-surge flooding, and shoreline erosion. Storm impacts are likely to be more severe, especially along the Gulf and Atlantic coasts. Salt marshes, other coastal habitats, and dependent species are threatened by sea level rise, fixed structures blocking landward migration, and changes in vegetation. Population growth and rising value of infrastructure in coastal areas increases vulnerability to climate variability and future climate change.

Climate change will likely further constrain already overallocated water resources in some regions of the United States, increasing competition among agricultural, municipal, industrial, and ecological uses. Although water management practices in the United States are generally advanced, particularly in the West, the reliance on past conditions as the basis for current and future planning may no longer be appropriate, as climate change increasingly creates conditions well outside of historical observations. Rising temperatures will diminish snowpack and increase evaporation, affecting seasonal availability of water. In the Great Lakes and major river systems, lower water levels are likely to exacerbate challenges relating to water quality, navigation, recreation, hydropower generation, water transfers, and binational relationships. Decreased water supply and lower water levels are likely to exacerbate challenges relating to aquatic navigation in the United States.

Higher water temperatures, increased precipitation intensity, and longer periods of low flows will exacerbate many forms of water pollution, potentially making attainment of water quality goals more difficult. As waters become warmer, the aquatic life they now support will be replaced by other species better adapted to warmer water. In the long term, warmer water and changing flow may result in deterioration of aquatic ecosystems.

Ocean acidification is projected to continue, resulting in the reduced biological production of marine calcifiers, including corals.

Climate change is likely to affect U.S. energy use and energy production and physical and institutional infrastructures. It will also likely interact with and possibly exacerbate ongoing environmental change and environmental pressures in settlements, particularly in Alaska where indigenous communities are facing major environmental and cultural impacts. The U.S. energy sector, which relies heavily on water for hydropower and cooling capacity, may be adversely impacted by changes to water supply and quality in reservoirs and other water bodies. Water infrastructure, including drinking water and wastewater treatment plants, and sewer and stormwater management systems, will be at greater risk of flooding, sea level rise and storm surge, low flows, and other factors that could impair performance.

Disturbances such as wildfires and insect outbreaks are increasing in the United States and are likely to intensify in a warmer future with warmer winters, drier soils, and longer growing seasons. Although recent climate trends have increased vegetation growth, continuing increases in disturbances are likely to limit carbon storage, facilitate invasive species, and disrupt ecosystem services.

Over the 21st century, changes in climate will cause species to shift north and to higher elevations and fundamentally rearrange U.S. ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter ecosystem structure, function, and services.

Climate change impacts will vary in nature and magnitude across different regions of the United States.

Sustained high summer temperatures, heat waves, and declining air quality are projected in the Northeast,[312] Southeast,[313] Southwest,[314] and Midwest.[315] Projected climate change would continue to cause loss of sea ice, glacier retreat, permafrost thawing, and coastal erosion in Alaska.

Reduced snowpack, earlier spring snowmelt, and increased likelihood of seasonal summer droughts are projected in the Northeast, Northwest,[316] and Alaska. More severe, sustained droughts and water scarcity are projected in the Southeast, Great Plains,[317] and Southwest.

The Southeast, Midwest, and Northwest in particular are expected to be impacted by an increased frequency of heavy downpours and greater flood risk.

Ecosystems of the Southeast, Midwest, Great Plains, Southwest, Northwest, and Alaska are expected to experience altered distribution of native species (including local extinctions), more frequent and intense wildfires, and an increase in insect pest outbreaks and invasive species.

Sea level rise is expected to increase storm surge height and strength, flooding, erosion, and wetland loss along the coasts, particularly in the Northeast, Southeast, and islands.

Warmer water temperatures and ocean acidification are expected to degrade important aquatic resources of islands and coasts such as coral reefs and fisheries.

A longer growing season, low levels of warming, and fertilization effects of carbon dioxide may benefit certain crop species and forests, particularly in the Northeast and Alaska. Projected summer rainfall increases in the Pacific islands may augment limited freshwater supplies. Cold-related mortality is projected to decrease, especially in the Southeast. In the Midwest in particular, heating oil demand and snow-related traffic accidents are expected to decrease.

Climate change impacts in certain regions of the world may exacerbate problems that raise humanitarian, trade, and national security issues for the United States. The IPCC[318] identifies the most vulnerable world regions as the Arctic, because of the effects of high rates of projected warming on natural systems; Africa, especially the sub-Saharan region, because of current low adaptive capacity as well as climate change; small islands, due to high exposure of population and infrastructure to risk of sea level rise

[312] Northeast includes West Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine.

[313] Southeast includes Kentucky, Virginia, Arkansas, Tennessee, North Carolina, South Carolina, southeast Texas, Louisiana, Mississippi, Alabama, Georgia, and Florida.

[314] Southwest includes California, Nevada, Utah, western Colorado, Arizona, New Mexico (except the extreme eastern section), and southwest Texas.

[315] The Midwest includes Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, Ohio, and Missouri.

[316] The Northwest includes Washington, Idaho, western Montana, and Oregon.

[317] The Great Plains includes central and eastern Montana, North Dakota, South Dakota, Wyoming, Nebraska, eastern Colorado, Nebraska, Kansas, extreme eastern New Mexico, central Texas, and Oklahoma.

[318] Parry, M.L. *et al.* (2007) Technical Summary. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)], Cambridge University Press, Cambridge, United Kingdom, pp. 23–78.

and increased storm surge; and Asian mega-deltas, such as the Ganges-Brahmaputra and the Zhujiang, due to large populations and high exposure to sea level rise, storm surge and river flooding. Climate change has been described as a potential threat multiplier with regard to national security issues.

3. Changes in Global Climate Indicators Associated With the Rule's GHG Emissions Reductions

EPA examined [319] the reductions in CO_2 and other GHGs associated with this action and analyzed the projected effects on global mean surface temperature and sea level, two common indicators of climate change. The analysis projects that this action will reduce climate warming and sea level rise. Although the projected reductions are small in overall magnitude by themselves, they are quantifiable and would contribute to reducing climate change risks. A commenter agreed that the modeling results showed small, but quantifiable, reductions in the global atmospheric CO_2 concentration, as well as a reduction in projected global mean surface temperature and sea level rise, from implementation of this action, across all climate sensitivities. As such, the commenter encourages the agencies to move forward with this action while continuing to develop additional, more stringent vehicle standards beyond 2016.

Another commenter indicated that the projected changes in climate impacts resulting from this action are small and therefore not meaningful. EPA disagrees with this view as the reductions may be small in overall magnitude, but in the global climate change context, they are quantifiable showing a clear directional signal across a range of climate sensitivities.[320] [321] EPA therefore determines that the projected reductions in atmospheric CO_2, global mean temperature and sea level rise are meaningful in the context of this rule. EPA addresses this point further in the Response to Comments document. For the final rule, EPA provides an additional climate change impact analysis for projected changes in ocean pH in the context of this action. In addition, EPA updated the modeling analysis based on the revised GHG emission reductions provided in Section III.F.1; however, the change in modeling results was very small in magnitude. Based on the reanalysis the results for projected atmospheric CO_2 concentrations are estimated to be reduced by an average of 2.9 ppm (previously 3.0 ppm), global mean temperature is estimated to be reduced by 0.006 to 0.015 °C by 2100 (previously 0.007 to 0.016 °C) and sea-level rise is projected to be reduced by approximately 0.06–0.14cm by 2100 (previously 0.06–0.15cm).

a. Estimated Projected Reductions in Atmospheric CO_2 Concentration, Global Mean Surface Temperatures Sea Level Rise and Ocean pH

EPA estimated changes in the atmospheric CO_2 concentration, global mean surface temperature and sea level to 2100 resulting from the emissions reductions in this action using the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC, version 5.3). This widely-used, peer reviewed modeling tool was also used to project temperature and sea level rise under different emissions scenarios in the Third and Fourth Assessments of the Intergovernmental Panel on Climate Change (IPCC).

GHG emissions reductions from Section III.F.1 were applied as net reductions to a peer reviewed global reference case (or baseline) emissions scenario to generate an emissions scenario specific to this action. For the scenario related to this action, all emissions reductions were assumed to begin in 2012, with zero emissions change in 2011 (from the reference case) followed by emissions linearly increasing to equal the value supplied in Section III.F.1 for 2020 and then continuing to 2100. Details about the reference case scenario and how the emissions reductions were applied to generate the scenario can be found in the RIA Chapter 7.

Changes in atmospheric CO_2 concentration, temperature, and sea-level for both the reference case and the emissions scenarios associated with this action were computed using MAGICC. To compute the reductions in the atmospheric CO_2 concentrations as well as in temperature and sea level resulting from this action, the output from the scenario associated with this final rule was subtracted from an existing Global Change Assessment Model (GCAM, formerly MiniCAM) reference emission scenario. To capture some key uncertainties in the climate system with the MAGICC model, changes in temperature and sea-level rise were projected across the most current IPCC range for climate sensitivities which ranges from 1.5 °C to 6.0 °C (representing the 90% confidence interval).[322] This wide range reflects the uncertainty in this measure of how much the global mean temperature would rise if the concentration of carbon dioxide in the atmosphere were to double. Details about this modeling analysis can be found in the RIA Chapter 7.4.

The results of this modeling, summarized in Table III.F.3–1, show small, but quantifiable, reductions in atmospheric CO_2 concentrations, projected global mean surface temperature and sea level resulting from this action, across all climate sensitivities. As a result of the emission reductions from this action, the atmospheric CO_2 concentration is projected to be reduced by an average of 2.9 parts per million (ppm), the global mean temperature is projected to be reduced by approximately 0.006–0.015 °C by 2100, and global mean sea level rise is projected to be reduced by approximately 0.06–0.14cm by 2100. The reductions are small relative to the IPCC's 2100 "best estimates" for global mean temperature increases (1.8–4.0 °C) and sea level rise (0.20–0.59m) for all global GHG emissions sources for a range of emissions scenarios. EPA used a peer reviewed model, the MAGICC model, to do this analysis. This analysis is specific to this rule and therefore does not come from previously published work. Further discussion of EPA's modeling analysis is found in the final RIA.

[319] Using the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC, *http://www.cgd.ucar.edu/cas/wigley/magicc/*), EPA estimated the effects of this action's greenhouse gas emissions reductions on global mean temperature and sea level. Please refer to Chapter 7.4 of the RIA for additional information.

[320] The National Research Council (NRC) 2001 study, *Climate Change Science: An Analysis of Some Key Questions,* defines climate sensitivity as the sensitivity of the climate system to a forcing is commonly expressed in terms of the global mean temperature change that would be expected after a time sufficiently long enough for both the atmosphere and ocean to come to equilibrium with the change in climate forcing.

[321] To capture some of the uncertainty in the climate system, the changes in atmospheric CO_2, projected temperatures and sea level were estimated across the most current Intergovernmental Panel on Climate Change (IPCC) range of climate sensitivities, 1.5 °C to 6.0 °C.

[322] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The IPCC states that climate sensitivity is "likely" to be in the range of 2 °C to 4.5 °C, "very unlikely" to be less than 1.5 °C, and "values substantially higher than 4.5 °C cannot be excluded." IPCC WGI, 2007, *Climate Change 2007—The Physical Science Basis,* Contribution of Working Group I to the Fourth Assessment Report of the IPCC, *http://www.ipcc.ch/.*

TABLE III.F.3–1—EFFECT OF GHG EMISSIONS REDUCTIONS ON PROJECTED CHANGES IN GLOBAL CLIMATE FOR THE FINAL VEHICLES RULEMAKING

[For climate sensitivities ranging from 1.5–6 C]

Measure	Units	Year	Projected change
Atmospheric CO_2 Concentration	ppm	2100	−2.7–3.1
Global Mean Surface Temperature	C	2100	−0.006–0.015
Sea Level Rise	Cm	2100	−0.06–0.14
Ocean pH	pH units	2100	0.0014

As a substantial portion of CO_2 emitted into the atmosphere is not removed by natural processes for millennia, each unit of CO_2 not emitted into the atmosphere avoids essentially permanent climate change on centennial time scales. Though the magnitude of the avoided climate change projected here is small, these reductions would represent a reduction in the adverse risks associated with climate change (though these risks were not formally estimated for this action) across all climate sensitivities.

The IPCC [323] has noted that ocean acidification due to the direct effects of elevated CO_2 concentrations will impair a wide range of planktonic and other marine organisms that use aragonite to make their shells or skeletons. EPA used the Program CO2SYS,[324] version 1.05 to estimate projected changes in tropical ocean pH based on the atmospheric CO_2 concentration reductions resulting from this action and other specified input conditions (*e.g.,* sea surface temperature characteristic of tropical waters). The program performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. EPA used the program to calculate ocean pH as a function of atmospheric CO_2, among other specified input conditions. Based on the projected atmospheric CO_2 concentration reductions (average of 2.9 ppm by 2100) that would result from this rule, the program calculates an increase in ocean pH of about 0.0014 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from today's rule would result in an increase in ocean pH.

EPA's analysis of the rule's effect on global climate conditions is intended to quantify these potential reductions using the best available science. While EPA's modeling results of the effect of this rule alone show small differences in climate effects (CO_2 concentration, temperature, sea-level rise, ocean pH), when expressed in terms of global climate endpoints and global GHG emissions, they yield results that are repeatable and consistent within the modeling frameworks used.

G. How will the standards impact non-GHG emissions and their associated effects?

In addition to reducing the emissions of greenhouse gases, this rule will influence the emissions of "criteria" air pollutants and air toxics (*i.e.,* hazardous air pollutants). The criteria air pollutants include carbon monoxide (CO), fine particulate matter (PM2.5), sulfur dioxide (SO_X) and the ozone precursors hydrocarbons (VOC) and oxides of nitrogen (NO_X); the air toxics include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Our estimates of these non-GHG emission impacts from the GHG program are shown by pollutant in Table III.G–1 and Table III.G–2 in total, and broken down by the two drivers of these changes: (a) "Upstream" emission reductions due to decreased extraction, production and distribution of motor gasoline; and (b) "downstream" emission increases, reflecting the effects of VMT rebound (discussed in Sections III.F and III.H) and the effects of our assumptions about ethanol-blended fuel (E10), as discussed below. Total program impacts on criteria and toxics emissions are discussed below, followed by individual discussions of the upstream and downstream impacts. Those are followed by discussions of the effects on air quality, health, and other environmental concerns.

As in the proposal, for this analysis we attribute decreased fuel consumption from this program to gasoline only, while assuming no effect on volumes of ethanol and other renewable fuels because they are mandated under the Renewable Fuel Standard (RFS2). However, because this rule does not assume RFS2 volumes of ethanol in the baseline, the result is a greater projected market share of E10 in the control case.[325] In fact, the GHG standards will not be affecting the market share of E10, because EPA's analysis for the RFS2 rule predicts 100% E10 penetration by 2014.[326]

The amount of E10 affects downstream non-GHG emissions. In the proposal, EPA stated these same fuel assumptions and qualitatively noted that there were likely unquantified impacts on non-GHG emissions between the two cases. In DRIA Chapter 5, EPA indicated its plans to quantify these impacts in the air quality modeling and in the final rule inventories. Upstream emission impacts depend only on fuel volumes, so the impacts presented here reflect only the reduced gasoline consumption.

The inventories presented in this rulemaking include an analysis of these fuel effects which was conducted using EPA's Motor Vehicle Emission Simulator (MOVES2010). The most notable impact, although still relatively slight, is a 2.2 percent increase in 2030 in national acetaldehyde emissions over the baseline scenario. It should be noted that these emission impacts are not due to the new GHG vehicle standards. These impacts are instead a consequence of the assumed ethanol volumes. This program does not mandate an increase in E10, nor any particular fuel blend. The emission impact of this shift was also modeled in the RFS2 rule.

As shown in Table III.G–1, EPA estimates that this program would result in reductions of NO_X, VOC, PM and

[323] Fischlin, A. *et al.* (2007) Ecosystems, their Properties, Goods, and Services. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[324] Lewis, E., and D. W. R. Wallace. 1998. Program Developed for CO_2 System Calculations. ORNL/CDIAC–105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

[325] When this rule's analysis was initiated, the RFS2 rule was not yet final. Therefore, it assumes the ethanol volumes in Annual Energy Outlook 2007 (U.S. Energy Information Administration, Annual Energy Outlook 2007, Transportation Demand Sector Supplemental Table. *http://www.eia.doe.gov/oiaf/archive/aeo07/supplement/index.html*)

[326] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA–420–R–10–006. February 2010. Docket EPA–HQ–OAR–2009–0472–11332. *See* also 75 FR 14670, March 26, 2010.

SO_X, but would increase CO emissions. For NO_X, VOC, and PM we estimate net reductions because the emissions reductions from upstream sources are larger than the emission increases due to downstream sources. In the case of CO, we estimate slight emission increases, because there are relatively small reductions in upstream emissions, and thus the projected downstream emission increases are greater than the projected emission decreases due to reduced fuel production. For SO_X, downstream emissions are roughly proportional to fuel consumption, therefore a decrease is seen in both upstream and downstream sources.

For all criteria pollutants the overall impact of the program would be relatively small compared to total U.S. inventories across all sectors. In 2030, EPA estimates the program would reduce total NO_X, PM and SO_X inventories by 0.1 to 0.8 percent and reduce the VOC inventory by 1.0 percent, while increasing the total national CO inventory by 0.6 percent.

As shown in Table III.G–2, EPA estimates that the GHG program would result in small changes for air toxic emissions compared to total U.S. inventories across all sectors. In 2030, EPA estimates the program would reduce total benzene and 1,3 butadiene emissions by 0.1 to 0.3 percent. Total acrolein and formaldehyde emissions would increase by 0.1 percent. Acetaldehyde emissions would increase by 2.2 percent.

One commenter requested that EPA present emission inventories for additional air toxics. EPA is presenting inventories for certain air toxic emissions which were identified as key national and regional-scale cancer and noncancer risk drivers in past National Air Toxics Assessments (NATA). For additional details, please refer to the Response to Comments document.[327]

Other factors which may impact non-GHG emissions, but are not estimated in this analysis, include:

Vehicle technologies used to reduce tailpipe CO_2 emissions; because the regulatory standards for non-GHG emissions are the primary driver for these emissions, EPA expects the impact of this program to be negligible on non-GHG emission rates per mile.

The potential for increased market penetration of diesel vehicles; because these vehicles would be held to the same certification and in-use standards for criteria pollutants as their gasoline counterparts, EPA expects their impact to be negligible on criteria pollutants and other non-GHG emissions. EPA does not project increased penetration of diesels as necessary to meet the GHG standards.

Early introduction of electric vehicles and plug-in hybrid electric vehicles, which would reduce criteria emissions in cases where those vehicles are able to be certified to lower certification standards. This would also likely reduce gaseous air toxics.

Reduced refueling emissions due to less frequent refueling events and reduced annual refueling volumes resulting from the GHG standards.

Increased hot soak evaporative emissions due to the likely increase in number of trips associated with VMT rebound modeled in this rule.

TABLE III.G–1—ANNUAL CRITERIA EMISSION IMPACTS OF PROGRAM

[Short tons]

	Total impacts		*Upstream impacts*		*Downstream impacts*	
	2020	2030	*2020*	*2030*	*2020*	*2030*
VOC	−60,187	−115,542	*−64,506*	*−126,749*	*4,318*	*11,207*
% of total inventory	−0.51%	−1.01%	*−0.55%*	*−1.11%*	*0.04%*	*0.01%*
CO	3,992	170,675	*−6,165*	*−12,113*	*10,156*	*182,788*
% of total inventory	0.01%	0.56%	*−0.02%*	*−0.04%*	*0.01%*	*0.6%*
NO_X	−5,881	−21,763	*−19,291*	*−37,905*	*13,410*	*16,143*
% of total inventory	−0.02	−0.07%	*−0.06%*	*−0.12%*	*0.04%*	*0.05%*
$PM_{2.5}$	−2,398	−4,564	*−2,629*	*−5,165*	*231.0*	*602.3*
% of total inventory	−0.03%	−0.05%	*−0.03%*	*−0.06%*	*0.00%*	*0.01%*
SO_X	−13,832	−27,443	*−11,804*	*−23,194*	*−2,027*	*−4,249*
% of total inventory	−0.41%	−0.82%	*−0.35%*	*−0.69%*	*−0.06%*	*−0.13%*

TABLE III.G–2—ANNUAL AIR TOXIC EMISSION IMPACTS OF PROGRAM

[Short tons]

	Total impacts		Upstream impacts		Downstream impacts	
	2020	2030	2020	2030	2020	2030
1,3-Butadiene	−95	−21	−1.5	−3.0	−93.6	−18.1
% of total inventory	−0.38%	−0.10%	−0.01%	−0.01%	−0.37%	−0.09%
Acetaldehyde	760	668	−6.8	−13.4	766.9	681.5
% of total inventory	2.26%	2.18%	−0.02%	−0.04%	2.28%	2.22%
Acrolein	1	5	−0.9	−1.8	1.7	6.5
% of total inventory	0.01%	0.07%	−0.01%	−0.03%	0.03%	0.10%
Benzene	−890	−523	−139.6	−274.3	−750.0	−248.3
% of total inventory	−0.48%	−0.29%	−0.08%	−0.15%	−0.40%	−0.14%
Formaldehyde	−49	15	−51.4	−101.0	2.1	116.3
% of total inventory	−0.06%	0.02%	−0.06%	−0.12%	0.00%	0.14%

[327] U.S. EPA. National Air Toxics Assessment. 2002, 1999, and 1996. Available at: *http://www.epa.gov/nata/*.

1. Upstream Impacts of Program

No substantive comments were received on the upstream inventory modeling used in the proposal. The rulemaking inventories were updated with the revised estimates of fuel savings as detailed in Section III.F.

Reducing tailpipe CO_2 emissions from light-duty cars and trucks through tailpipe standards and improved A/C efficiency will result in reduced fuel demand and reductions in the emissions associated with all of the processes involved in getting petroleum to the pump. These upstream emission impacts on criteria pollutants are summarized in Table III.G–1. The upstream reductions grow over time as the fleet turns over to cleaner CO_2 vehicles, so that by 2030 VOC would decrease by 127,000 tons, NO_X by 38,000 tons, and $PM_{2.5}$ by 5,000 tons. Table III.G–2 shows the corresponding impacts on upstream air toxic emissions in 2030. Formaldehyde decreases by 101 tons, benzene by 274 tons, acetaldehyde by 13 tons, acrolein by 2 tons, and 1,3-butadiene by 3 tons.

To determine these impacts, EPA estimated the impact of reduced petroleum volumes on the extraction and transportation of crude oil as well as the production and distribution of finished gasoline. For the purpose of assessing domestic-only emission reductions it was necessary to estimate the fraction of fuel savings attributable to domestic finished gasoline, and of this gasoline what fraction is produced from domestic crude. For this analysis EPA estimated that 50 percent of fuel savings is attributable to domestic finished gasoline and that 90 percent of this gasoline originated from imported crude. Emission factors for most upstream emission sources are based on the GREET1.8 model, developed by DOE's Argonne National Laboratory,[328] but in some cases the GREET values were modified or updated by EPA to be consistent with the National Emission Inventory (NEI).[329] The primary updates for this analysis were to incorporate newer information on gasoline distribution emissions for VOC from the NEI, which were significantly higher than GREET estimates; and the incorporation of upstream emission factors for the air toxics estimated in this analysis: benzene, 1,3-butadiene, acetaldehyde, acrolein, and formaldehyde. The development of these emission factors is detailed in RIA Chapter 5.

2. Downstream Impacts of Program

No substantive comments were received on the emission modeling or emission inventories presented in this section. However, two changes in modeling differentiate the analysis presented here from that presented in the proposal. Economic inputs such as fuel prices and vehicle sales were updated from AEO 2009 to AEO 2010 Early Release, and as described above, the effects of ethanol volume assumptions were explicitly modeled. Thus, the primary differences in non-GHG emissions between the proposed rule and final rule are attributed more to these changes in analytic inputs, and less to changes in the GHG standards program.

Downstream emission impacts attributable to this program are due to the VMT rebound effect and the ethanol volume assumptions. As discussed in more detail in Section III.H, the effect of fuel cost on VMT ("rebound") was accounted for in our assessment of economic and environmental impacts of this rule. A 10 percent rebound case was used for this analysis, meaning that VMT for affected model years is modeled as increasing by 10 percent as much as the increase in fuel economy; *i.e.,* a 10 percent increase in fuel economy would yield approximately a 1 percent increase in VMT.

As detailed in the introduction to this section, fuel composition also has effects on vehicle emissions and particularly air toxics. The relationship between fuel composition and emission impacts used in MOVES2010 and applied in this analysis match those developed for the recent Renewable Fuels Standard (RFS2) requirement, and are extensively documented in the RFS2 RIA and supporting documents.[330]

Downstream emission impacts of the rebound effect are summarized in Table III.G–1 for criteria pollutants and precursors and Table III.G–2 for air toxics. The emission impacts from the rebound effect and the change in fuel supply grow over time as the fleet turns over to cleaner CO_2 vehicles, so that by 2030 VOC would increase by 11,000 tons, NO_X by 16,000 tons, and $PM_{2.5}$ by 600 tons. Table III.G–2 shows the corresponding impacts on air toxic emissions. These impacts in 2030 include 18 fewer tons of 1,3-butadiene, 668 additional tons of acetaldehyde, 248 fewer tons of benzene, 116 additional tons of formaldehyde, and 6.5 additional tons of acrolein.

For this analysis, MOVES2010 was used to estimate base VOC, CO, NO_X, PM and air toxics emissions for both control and reference cases. Rebound emissions from light duty cars and trucks were then calculated using the OMEGA model post-processor and added to the control case. A more complete discussion of the inputs, methodology, and results is contained in RIA Chapter 5.

3. Health Effects of Non-GHG Pollutants

In this section we discuss health effects associated with exposure to some of the criteria and air toxics impacted by the vehicle standards; PM, ozone, NO_X and SO_X, CO and air toxics. No substantive comments were received on the health effects of non-GHG pollutants.

a. Particulate Matter

i. Background

Particulate matter is a generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. Since 1987, EPA has delineated that subset of inhalable particles small enough to penetrate to the thoracic region (including the tracheobronchial and alveolar regions) of the respiratory tract (referred to as thoracic particles). Current NAAQS use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 m), and use PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 m and less than or equal to 10 m, or $PM_{10\text{-}2.5}$). Ultrafine particles are a subset of fine particles, generally less than 100 nanometers (0.1 m) in aerodynamic diameter.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (*e.g.,* SO_X, NO_X and VOC) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology, and source category. Thus, $PM_{2.5}$ may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon

[328] Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation model (GREET), U.S. Department of Energy, Argonne National Laboratory, *http://www.transportation.anl.gov/modeling_simulation/GREET/.*

[329] U.S. EPA. 2002 National Emissions Inventory (NEI) Data and Documentation, *http://www.epa.gov/ttn/chief/net/2002inventory.html.*

[330] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA–420–R–10–006. February 2010. Docket EPA–HQ–OAR–2009–0472–11332. *See* also 75 FR 14670, March 26, 2010.

and metal compounds. These particles can remain in the atmosphere for days to weeks and travel hundreds to thousands of kilometers.

ii. Health Effects of PM

Scientific studies show ambient PM is associated with a series of adverse health effects. These health effects are discussed in detail in EPA's Integrated Science Assessment for Particulate Matter (ISA).[331] Further discussion of health effects associated with PM can also be found in the RIA for this rule. The ISA summarizes evidence associated with $PM_{2.5}$, $PM_{10\text{-}2.5}$, and ultrafine particles (UFPs).

The ISA concludes that health effects associated with short-term exposures (hours to days) to ambient $PM_{2.5}$ include non-fatal cardiovascular effects, mortality, and respiratory effects, such as exacerbation of asthma symptoms in children and hospital admissions and emergency department visits for chronic obstructive pulmonary disease (COPD) and respiratory infections.[332] The ISA notes that long-term exposure to $PM_{2.5}$ (months to years) is associated with the development/progression of cardiovascular disease, premature mortality, and respiratory effects, including reduced lung function growth, increased respiratory symptoms, and asthma development.[333] The ISA concludes that that the currently available scientific evidence from epidemiologic, controlled human exposure studies, and toxicological studies supports that a causal association exists between short- and long-term exposures to $PM_{2.5}$ and cardiovascular effects and mortality. Furthermore, the ISA concludes that the collective evidence supports likely causal associations between short- and long-term $PM_{2.5}$ exposures and respiratory effects. The ISA also concludes that the evidence is suggestive of a causal association for reproductive and developmental effects and cancer, mutagenicity, and genotoxicity and long-term exposure to $PM_{2.5}$.[334]

For $PM_{10\text{-}2.5}$, the ISA concludes that the current evidence is suggestive of a causal relationship between short-term exposures and cardiovascular effects, such as hospitalization for ischemic heart disease. There is also suggestive evidence of a causal relationship between short-term $PM_{10\text{-}2.5}$ exposure and mortality and respiratory effects. Data are inadequate to draw conclusions regarding the health effects associated with long-term exposure to $PM_{10\text{-}2.5}$.[335]

For UFPs, the ISA concludes that there is suggestive evidence of a causal relationship between short-term exposures and cardiovascular effects, such as changes in heart rhythm and blood vessel function. It also concludes that there is suggestive evidence of association between short-term exposure to UFPs and respiratory effects. Data are inadequate to draw conclusions regarding the health effects associated with long-term exposure to UFP's.[336]

b. Ozone

i. Background

Ground-level ozone pollution is typically formed by the reaction of VOC and NO_X in the lower atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources, such as highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex.[337] Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone can be transported hundreds of miles downwind from precursor emissions, resulting in elevated ozone levels even in areas with low local VOC or NO_X emissions.

ii. Health Effects of Ozone

The health and welfare effects of ozone are well documented and are assessed in EPA's 2006 Air Quality Criteria Document (ozone AQCD) and 2007 Staff Paper.[338] [339] Ozone can irritate the respiratory system, causing coughing, throat irritation, and/or uncomfortable sensation in the chest. Ozone can reduce lung function and make it more difficult to breathe deeply; breathing may also become more rapid and shallow than normal, thereby limiting a person's activity. Ozone can also aggravate asthma, leading to more asthma attacks that require medical attention and/or the use of additional medication. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[340] Animal toxicological evidence indicates that with repeated exposure, ozone can inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue and irreversible reductions in lung function. People who are more susceptible to effects associated with exposure to ozone can include children, the elderly, and individuals with respiratory disease such as asthma. Those with greater exposures to ozone, for instance due to

[331] U.S. EPA (2009) Integrated Science Assessment for Particulate Matter. EPA 600/R–08/139F, Docket EPA–HQ–OAR–2009–0472–11295.

[332] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. Section 2.3.1.1.

[333] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. page 2–12, Sections 7.3.1.1 and 7.3.2.1.

[334] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. Section 2.3.2.

[335] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. Section 2.3.4, Table 2–6.

[336] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. Section 2.3.5, Table 2–6.

[337] U.S. EPA (2006). Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). EPA/600/R–05/004aF–cF. Washington, DC: U.S. EPA. Docket EPA–HQ–OAR–2009–0472–0099 through –0101.

[338] U.S. EPA. (2006). Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). EPA/600/R–05/004aF–cF. Washington, DC: U.S. EPA.

[339] U.S. EPA (2007). Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. EPA–452/R–07–003. Washington, DC, U.S. EPA. Docket EPA–HQ–OAR–2009–0472–0105 through –0106.

[340] National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution.* The National Academies Press: Washington, DC Docket EPA–HQ–OAR–2009–0472–0322.

time spent outdoors (*e.g.,* children and outdoor workers), are of particular concern.

The 2006 ozone AQCD also examined relevant new scientific information that has emerged in the past decade, including the impact of ozone exposure on such health effects as changes in lung structure and biochemistry, inflammation of the lungs, exacerbation and causation of asthma, respiratory illness-related school absence, hospital admissions and premature mortality. Animal toxicological studies have suggested potential interactions between ozone and PM with increased responses observed to mixtures of the two pollutants compared to either ozone or PM alone. The respiratory morbidity observed in animal studies along with the evidence from epidemiologic studies supports a causal relationship between acute ambient ozone exposures and increased respiratory-related emergency room visits and hospitalizations in the warm season. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and non-accidental and cardiopulmonary mortality.

c. NO_X and SO_X

i. Background

Nitrogen dioxide (NO_2) is a member of the NO_X family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. SO_2, a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (*e.g.,* coal or oil derived), extracting gasoline from oil, or extracting metals from ore.

SO_2 and NO_2 can dissolve in water vapor and further oxidize to form sulfuric and nitric acid which react with ammonia to form sulfates and nitrates, both of which are important components of ambient PM. The health effects of ambient PM are discussed in Section III.G.3.a of this preamble. NO_X along with non-methane hydrocarbon (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section III.G.3.b.

ii. Health Effects of NO_2

Information on the health effects of NO_2 can be found in the EPA Integrated Science Assessment (ISA) for Nitrogen Oxides.[341] The EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. In addition, small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of asthmatic subjects. Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

Although the weight of evidence supporting a causal relationship is somewhat less certain than that associated with respiratory morbidity, NO_2 has also been linked to other health endpoints. These include all-cause (nonaccidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

iii. Health Effects of SO_2

Information on the health effects of SO_2 can be found in the EPA Integrated Science Assessment for Sulfur Oxides.[342] SO_2 has long been known to cause adverse respiratory health effects, particularly among individuals with asthma. Other potentially sensitive groups include children and the elderly. During periods of elevated ventilation, asthmatics may experience symptomatic bronchoconstriction within minutes of exposure. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. Separately, based on an evaluation of the epidemiologic evidence of associations between short-term exposure to SO_2 and mortality, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

d. Carbon Monoxide

Information on the health effects of carbon monoxide (CO) can be found in the EPA Integrated Science Assessment (ISA) for Carbon Monoxide.[343] The ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[344] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[345]

Human clinical studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The ISA concludes that a causal relationship is likely between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal

[341] U.S. EPA (2008). *Integrated Science Assessment for Oxides of Nitrogen—Health Criteria (Final Report).* EPA/600/R–08/071. Washington, DC: U.S.EPA. Docket EPA–HQ–OAR–2009–0472–0350.

[342] U.S. EPA. (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides—Health Criteria (Final Report).* EPA/600/R–08/047F. Washington, DC: U.S. Environmental Protection Agency. Docket EPA–HQ–OAR–2009–0472–0335.

[343] U.S. EPA, 2010. Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–09/019F, 2010. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.*

[344] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determination: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[345] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and nonambient components; and both components may contribute to adverse health effects.

relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report inconsistent neural and behavioral effects following low-level CO exposures. The ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of epidemiologic and animal toxicological studies cited in the ISA have evaluated associations between preterm birth and cardiac birth defects and CO exposure. The epidemiologic studies provide limited evidence of a CO-induced effect on pre-term births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found associations between perinatal CO exposure and decrements in birth weight, as well as other developmental outcomes. The ISA concludes these studies are suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of effects on respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions associated with ambient CO concentrations. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50–100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term exposures to CO and mortality. Epidemiologic studies provide evidence of an association between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in copollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

e. Air Toxics

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to the class of pollutants known collectively as "air toxics".[346] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. These compounds, except acetaldehyde, were identified as national or regional risk drivers in the 2002 National-scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources.[347] Emissions and ambient concentrations of compounds are discussed in the RIA chapters on emission inventories and air quality (Chapters 5 and 7, respectively).

i. Benzene

The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[348] [349] [350] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[351] [352]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[353] [354] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[355] [356] In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[357] [358] [359] [360] EPA's

[346] U.S. EPA. 2002 National-Scale Air Toxics Assessment. *http://www.epa.gov/ttn/atw/nata12002/risksum.html.* Docket EPA–HQ–OAR–2009–0472–11322.

[347] U.S. EPA. 2009. National-Scale Air Toxics Assessment for 2002. *http://www.epa.gov/ttn/atw/nata2002/.* Docket EPA–HQ–OAR–2009–0472–11321.

[348] U.S. EPA. 2000. Integrated Risk Information System File for Benzene. This material is available electronically at *http://www.epa.gov/iris/subst/0276.htm.* Docket EPA–HQ–OAR–2009–0472–1659.

[349] International Agency for Research on Cancer (IARC). 1982. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29. Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France, p. 345–389. Docket EPA–HQ–OAR–2009–0472–0366.

[350] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. 1992. Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691–3695. Docket EPA–HQ–OAR–2009–0472–0370.

[351] International Agency for Research on Cancer (IARC). 1982. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29. Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2009–0472–0366.

[352] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: *http://ntp.niehs.nih.gov/go/16183.*

[353] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193–197. Docket EPA–HQ–OAR–2009–0472–0368.

[354] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541–554. Docket EPA–HQ–OAR–2009–0472–0325.

[355] Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes (1996) Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236–246. Docket EPA–HQ–OAR–2009–0472–0326.

[356] U.S. EPA (2002) Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at *http://www.epa.gov/iris/subst/0276.htm.* Docket EPA–HQ–OAR–2009–0472–0327.

[357] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003) HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China. Docket EPA–HQ–OAR–2009–0472–0328.

[358] Qu, Q., R. Shore, G. Li, X. Jin, L.C. Chen, B. Cohen, *et al.* (2002) Hematological changes among Chinese workers with a broad range of benzene exposures. Am. J. Industr. Med. 42: 275–285. Docket EPA–HQ–OAR–2009–0472–0329.

[359] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004) Hematotoxically in Workers Exposed to

Continued

IRIS program has not yet evaluated these new data.

ii. 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[361] [362] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[363] [364] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[365]

iii. Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[366] EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[367] [368] In an analysis of the lymphohematopoietic cancer mortality from an extended follow-up of these workers, NCI confirmed an association between lymphohematopoietic cancer risk and peak exposures.[369] A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[370] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[371] Recently, the IARC re-classified formaldehyde as a human carcinogen (Group 1).[372]

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation—including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma—particularly in the young.[373] [374]

iv. Acetaldehyde

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[375] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[376] [377] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[378] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of

Low Levels of Benzene. Science 306: 1774–1776. Docket EPA–HQ–OAR–2009–0472–0330.

[360] Turtletaub, K.W. and Mani, C. (2003) Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No.113. Docket EPA–HQ–OAR–2009–0472–0385.

[361] U.S. EPA (2002) Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600–P–98–001F. This document is available electronically at *http://www.epa.gov/iris/supdocs/buta-sup.pdf.* Docket EPA–HQ–OAR–2009–0472–0386.

[362] U.S. EPA (2002) Full IRIS Summary for 1,3-butadiene (CASRN 106–99–0). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC. *http://www.epa.gov/iris/subst/0139.htm.* Docket EPA–HQ–OAR–2009–0472–1660

[363] International Agency for Research on Cancer (IARC) (1999) Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide and Volume 97 (in preparation), World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2009–0472–0387.

[364] U.S. Department of Health and Human Services (2005) National Toxicology Program 11th Report on Carcinogens available at: *ntp.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932.*

[365] Bevan, C.; Stadler, J.C.; Elliot, G.S.; *et al.* (1996) Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1–10. Docket EPA–HQ–OAR–2009–0472–0388.

[366] U.S. EPA (1987) Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde, Office of Pesticides and Toxic Substances, April 1987. Docket EPA–HQ–OAR–2009–0472–0389.

[367] Hauptmann, M.; Lubin, J.H.; Stewart, P.A.; Hayes, R.B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615–1623. Docket EPA–HQ–OAR–2009–0472–0336.

[368] Hauptmann, M..; Lubin, J.H.; Stewart, P.A.; Hayes, R.B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117–1130. Docket EPA–HQ–OAR–2009–0472–0337.

[369] Beane Freeman, L.E.; Blair, A.; Lubin, J.H.; Stewart, P.A.; Hayes, R.B.; Hoover, R.N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751–761. Docket EPA–HQ–OAR–2009–0472–0338.

[370] Pinkerton, L.E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193–200. Docket EPA–HQ–OAR–2009–0472–0339.

[371] Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608–1615. Docket EPA–HQ–OAR–2009–0472–0340.

[372] International Agency for Research on Cancer (IARC). 2006. Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Volume 88. (in preparation), World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2009–0472–1164.

[373] Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. *http://www.atsdr.cdc.gov/toxprofiles/tp111.html* Docket EPA–HQ–OAR–2009–0472–1191.

[374] WHO (2002) Concise International Chemical Assessment Document 40: Formaldehyde. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva. Docket EPA–HQ–OAR–2009–0472–1199.

[375] U.S. EPA. 1991. Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/iris/subst/0290.htm.* Docket EPA–HQ–OAR–2009–0472–0390.

[376] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: *ntp.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932.*

[377] International Agency for Research on Cancer (IARC). 1999. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France. Docket EPA–HQ–OAR–2009–0472–0387.

[378] U.S. EPA. 1991. Integrated Risk Information System File of Acetaldehyde. This material is available electronically at *http://www.epa.gov/iris/subst/0290.htm.*

acetaldehyde exposure.[379] [380] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[381] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

v. Acrolein

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[382] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[383] Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms.[384] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[385] Acute exposure effects in animal studies report bronchial hyper-responsiveness.[386] In a recent study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease by comparison to non-diseased mice which also showed decreases in respiratory rate.[387] Based on these animal data and demonstration of similar effects in humans (*e.g.,* reduction in respiratory rate), individuals with compromised respiratory function (*e.g.,* emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[388] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[389]

vi. Polycyclic Organic Matter (POM)

POM is generally defined as a large class of organic compounds which have multiple benzene rings and a boiling point greater than 100 degrees Celsius. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. One of these compounds, naphthalene, is discussed separately below. Polycyclic aromatic hydrocarbons (PAHs) are a subset of POM that contain only hydrogen and carbon atoms. A number of PAHs are known or suspected carcinogens. Recent studies have found that maternal exposures to PAHs (a subclass of POM) in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development at age three.[390] [391] EPA has not yet evaluated these recent studies.

vii. Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[392] The draft reassessment completed external peer review.[393] Based on external peer review comments received, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[394] California EPA has released a new risk assessment for naphthalene, and the

[379] Appleman, L. M., R. A. Woutersen, V. J. Feron, R. N. Hooftman, and W. R. F. Notten. 1986. Effects of the variable versus fixed exposure levels on the toxicity of acetaldehyde in rats. *J. Appl. Toxicol.* 6: 331–336.

[380] Appleman, L.M., R.A. Woutersen, and V.J. Feron. 1982. Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. *Toxicology.* 23: 293–297. Docket EPA–HQ–OAR–2009–0472–0392.

[381] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. 1993. Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. *Am. Rev. Respir.Dis.*148(4 Pt 1): 940–3. Docket EPA–HQ–OAR–2009–0472–0408.

[382] Sim VM, Pattle RE. Effect of possible smog irritants on human subjects JAMA165: 1980–2010, 1957. Docket EPA–HQ–OAR–2009–0472–0395.

[383] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R–03/003. Available online at: *http://www.epa.gov/ncea/iris.*

[384] Weber-Tschopp, A; Fischer, T; Gierer, R; *et al.* (1977) Experimentelle reizwirkungen von Acrolein auf den Menschen. Int Arch Occup Environ Hlth 40(2):117–130. In German Docket EPA–HQ–OAR–2009–0472–0394.

[385] Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *http://www.epa.gov/iris/subst/0364.htm.* Docket EPA–HQ–OAR–2009–0472–0391.

[386] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R–03/003. Available online at: *http://www.epa.gov/ncea/iris.*

[387] Morris JB, Symanowicz PT, Olsen JE, *et al.* 2003. Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563–1571. Docket EPA–HQ–OAR–2009–0472–0396.

[388] U.S. EPA 2003. Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at *http://www.epa.gov/iris/subst/0364.htm.*

[389] International Agency for Research on Cancer (IARC). 1995. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 63. Dry cleaning, some chlorinated solvents and other industrial chemicals, World Health Organization, Lyon, France. Docket EPA–HQ–OAR–2009–0472–0393.

[390] Perera, F.P.; Rauh, V.; Tsai, W–Y.; *et al.* (2002) Effect of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. *Environ Health Perspect.* 111: 201–205. Docket EPA–HQ–OAR–2009–0472–0372.

[391] Perera, F.P.; Rauh, V.; Whyatt, R.M.; Tsai, W.Y.; Tang, D.; Diaz, D.; Hoepner, L.; Barr, D.; Tu, Y.H.; Camann, D.; Kinney, P. (2006) Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ Health Perspect 114: 1287–1292. Docket EPA–HQ–OAR–2009–0472–0373.

[392] U.S. EPA 2004. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/iris/subst/0436.htm.* Docket EPA–HQ–OAR–2009–0472–0272.

[393] Oak Ridge Institute for Science and Education. (2004). External Peer Review for the IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene. August 2004. *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=84403.* Docket EPA–HQ–OAR–2009–0472–0273.

[394] National Toxicology Program (NTP). (2004). 11th Report on Carcinogens. Public Health Service, U.S. Department of Health and Human Services, Research Triangle Park, NC. Available from: *http://ntp-server.niehs.nih.gov.*

IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[395] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[396]

viii. Other Air Toxics

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles will be affected by this final rule. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[397]

f. Exposure and Health Effects Associated With Traffic

Populations who live, work, or attend school near major roads experience elevated exposure concentrations to a wide range of air pollutants, as well as higher risks for a number of adverse health effects. While the previous sections of this preamble have focused on the health effects associated with individual criteria pollutants or air toxics, this section discusses the mixture of different exposures near major roadways, rather than the effects of any single pollutant. As such, this section emphasizes traffic-related air pollution, in general, as the relevant indicator of exposure rather than any particular pollutant.

Concentrations of many traffic-generated air pollutants are elevated for up to 300–500 meters downwind of roads with high traffic volumes.[398] Numerous sources on roads contribute to elevated roadside concentrations, including exhaust and evaporative emissions, and resuspension of road dust and tire and brake wear. Concentrations of several criteria and hazardous air pollutants are elevated near major roads. Furthermore, different semi-volatile organic compounds and chemical components of particulate matter, including elemental carbon, organic material, and trace metals, have been reported at higher concentrations near major roads.

Populations near major roads experience greater risk of certain adverse health effects. The Health Effects Institute published a report on the health effects of traffic-related air pollution.[399] It concluded that evidence is "sufficient to infer the presence of a causal association" between traffic exposure and exacerbation of childhood asthma symptoms. The HEI report also concludes that the evidence is either "sufficient" or "suggestive but not sufficient" for a causal association between traffic exposure and new childhood asthma cases. A review of asthma studies by Salam et al. (2008) reaches similar conclusions.[400] The HEI report also concludes that there is "suggestive" evidence for pulmonary function deficits associated with traffic exposure, but concluded that there is "inadequate and insufficient" evidence for causal associations with respiratory health care utilization, adult-onset asthma, COPD symptoms, and allergy. A review by Holguin (2008) notes that the effects of traffic on asthma may be modified by nutrition status, medication use, and genetic factors.[401]

The HEI report also concludes that evidence is "suggestive" of a causal association between traffic exposure and all-cause and cardiovascular mortality. There is also evidence of an association between traffic-related air pollutants and cardiovascular effects such as changes in heart rhythm, heart attack, and cardiovascular disease. The HEI report characterizes this evidence as "suggestive" of a causal association, and an independent epidemiological literature review by Adar and Kaufman (2007) concludes that there is "consistent evidence" linking traffic-related pollution and adverse cardiovascular health outcomes.[402]

Some studies have reported associations between traffic exposure and other health effects, such as birth outcomes (*e.g.,* low birth weight) and childhood cancer. The HEI report concludes that there is currently "inadequate and insufficient" evidence for a causal association between these effects and traffic exposure. A review by Raaschou-Nielsen and Reynolds (2006) concluded that evidence of an association between childhood cancer and traffic-related air pollutants is weak, but noted the inability to draw firm conclusions based on limited evidence.[403]

There is a large population in the U.S. living in close proximity of major roads. According to the Census Bureau's American Housing Survey for 2007, approximately 20 million residences in the U.S., 15.6% of all homes, are located within 300 feet (91 m) of a highway with 4+ lanes, a railroad, or an airport.[404] Therefore, at current population of approximately 309 million, assuming that population and housing similarly distributed, there are over 48 million people in the U.S. living near such sources. The HEI report also notes that in two North American cities, Los Angeles and Toronto, over 40% of each city's population live within 500 meters of a highway or 100 meters of a major road. It also notes that about 33% of each city's population resides within 50 meters of major roads. Together, the evidence suggests that a large U.S. population lives in areas with elevated traffic-related air pollution.

People living near roads are often socioeconomically disadvantaged. According to the 2007 American Housing Survey, a renter-occupied property is over twice as likely as an owner-occupied property to be located near a highway with 4+ lanes, railroad or airport. In the same survey, the median household income of rental housing occupants was less than half that of owner-occupants ($28,921/ $59,886). Numerous studies in individual urban areas report higher levels of traffic-related air pollutants in areas with high minority or poor populations.[405][406][407]

[395] International Agency for Research on Cancer (IARC). (2002). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France. Docket EPA–HQ–OAR–2009–0472–0274.

[396] U.S. EPA. 1998. Toxicological Review of Naphthalene, Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at *http://www.epa.gov/iris/subst/0436.htm.*

[397] U.S. EPA Integrated Risk Information System (IRIS) database is available at: *http://www.epa.gov/iris.*

[398] Zhou, Y.; Levy, J.I. (2007) Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. BMC Public Health 7: 89. doi:10.1186/1471–2458–7–89.

[399] HEI Panel on the Health Effects of Air Pollution. (2010) Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. [Online at *http://www.healtheffects.org*].

[400] Salam, M.T.; Islam, T.; Gilliland, F.D. (2008) Recent evidence for adverse effects of residential proximity to traffic sources on asthma. Current Opin Pulm Med 14: 3–8.

[401] Holguin, F. (2008) Traffic, outdoor air pollution, and asthma. Immunol Allergy Clinics North Am 28: 577–588.

[402] Adar, S.D.; Kaufman, J.D. (2007) Cardiovascular disease and air pollutants: evaluating and improving epidemiological data implicating traffic exposure. Inhal Toxicol 19: 135–149.

[403] Raaschou-Nielsen, O.; Reynolds, P. (2006) Air pollution and childhood cancer: A review of the epidemiological literature. Int J Cancer 118: 2920–2929.

[404] U.S. Census Bureau (2008) American Housing Survey for the United States in 2007. Series H–150 (National Data), Table 1A–6. [Accessed at *http://www.census.gov/hhes/www/housing/ahs/ahs07/ahs07.html* on January 22, 2009]

[405] Lena, T.S.; Ochieng, V.; Carter, M.; Holguín-Veras, J.; Kinney, P.L. (2002) Elemental carbon and $PM_{2.5}$ levels in an urban community heavily impacted by truck traffic. Environ Health Perspect 110: 1009–1015.

[406] Wier, M.; Sciammas, C.; Seto, E.; Bhatia, R.; Rivard, T. (2009) Health, traffic, and environmental

Students may also be exposed in situations where schools are located near major roads. In a study of nine metropolitan areas across the U.S., Appatova et al. (2008) found that on average greater than 33% of schools were located within 400 m of an Interstate, U.S., or State highway, while 12% were located within 100 m.[408] The study also found that among the metropolitan areas studied, schools in the Eastern U.S. were more often sited near major roadways than schools in the Western U.S.

Demographic studies of students in schools near major roadways suggest that this population is more likely than the general student population to be of non-white race or Hispanic ethnicity, and more often live in low socioeconomic status locations.[409] [410] [411] There is some inconsistency in the evidence, which may be due to different local development patterns and measures of traffic and geographic scale used in the studies.[408]

4. Environmental Effects of Non-GHG Pollutants

In this section we discuss some of the environmental effects of PM and its precursors such as visibility impairment, atmospheric deposition, and materials damage and soiling, as well as environmental effects associated with the presence of ozone in the ambient air, such as impacts on plants, including trees, agronomic crops and urban ornamentals, and environmental effects associated with air toxics. No substantive comments were received on the environmental effects of non-GHG pollutants.

a. Visibility

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[412] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2009 PM ISA.[413]

EPA is pursuing a two-part strategy to address visibility. First, EPA has concluded that $PM_{2.5}$ causes adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity, and has set secondary $PM_{2.5}$ standards.[414] The secondary $PM_{2.5}$ standards act in conjunction with the regional haze program. The regional haze rule (64 FR 35714) was put in place in July 1999 to protect the visibility in mandatory class I Federal areas. There are 156 national parks, forests and wilderness areas categorized as mandatory class I Federal areas (62 FR 38680–81, July 18, 1997).[415] Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I Federal areas.

b. Plant and Ecosystem Effects of Ozone

Elevated ozone levels contribute to environmental effects, with impacts to plants and ecosystems being of most concern. Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation. Ozone damage to plants includes visible injury to leaves and impaired photosynthesis, both of which can lead to reduced plant growth and reproduction, resulting in reduced crop yields, forestry production, and use of sensitive ornamentals in landscaping. In addition, the impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to a subsequent reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.

These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on forest and other natural vegetation can potentially lead to species shifts and loss from the affected ecosystems, resulting in a loss or reduction in associated ecosystem goods and services. Lastly, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas. The final 2006 Ozone Air Quality Criteria Document presents more detailed information on ozone effects on vegetation and ecosystems.

c. Atmospheric Deposition

Wet and dry deposition of ambient particulate matter delivers a complex mixture of metals (*e.g.,* mercury, zinc, lead, nickel, aluminum, cadmium), organic compounds (*e.g.,* POM, dioxins, furans) and inorganic compounds (*e.g.,* nitrate, sulfate) to terrestrial and aquatic ecosystems. The chemical form of the compounds deposited depends on a variety of factors including ambient conditions (*e.g.,* temperature, humidity, oxidant levels) and the sources of the material. Chemical and physical transformations of the compounds occur in the atmosphere as well as the media onto which they deposit. These transformations in turn influence the fate, bioavailability and potential toxicity of these compounds. Atmospheric deposition has been identified as a key component of the environmental and human health hazard posed by several pollutants including mercury, dioxin and PCBs.[416]

Adverse impacts on water quality can occur when atmospheric contaminants deposit to the water surface or when

justice: collaborative research and community action in San Francisco, California. Am J Public Health 99: S499–S504.

[407] Forkenbrock, D.J. and L.A. Schweitzer, *Environmental Justice and Transportation Investment Policy.* Iowa City: University of Iowa, 1997.

[408] Appatova, A.S.; Ryan, P.H.; LeMasters, G.K.; Grinshpun, S.A. (2008) Proximal exposure of public schools and students to major roadways: a nationwide U.S. survey. J Environ Plan Mgmt

[409] Green, R.S.; Smorodinsky, S.; Kim, J.J.; McLaughlin, R.; Ostro, B. (2004) Proximity of California public schools to busy roads. Environ Health Perspect 112: 61–66.

[410] Houston, D.; Ong, P.; Wu, J.; Winer, A. (2006) Proximity of licensed child care facilities to near-roadway vehicle pollution. Am J Public Health 96: 1611–1617.

[411] Wu, Y.; Batterman, S. (2006) Proximity of schools in Detroit, Michigan to automobile and truck traffic. J Exposure Sci Environ Epidemiol 16: 457–470.

[412] National Research Council, 1993. Protecting Visibility in National Parks and Wilderness Areas. National Academy of Sciences Committee on Haze in National Parks and Wilderness Areas. National Academy Press, Washington, DC. Docket EPA–HQ–OAR–2005–0161. This book can be viewed on the National Academy Press Web site at *http://www.nap.edu/books/0309048443/html/.*

[413] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–08/139F, 2009. Docket EPA–HQ–OAR–2009–0472–11295.

[414] The existing annual primary and secondary $PM_{2.5}$ standards have been remanded and are being addressed in the currently ongoing PM NAAQS review.

[415] These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

[416] U.S. EPA (2000) Deposition of Air Pollutants to the Great Waters: Third Report to Congress. Office of Air Quality Planning and Standards. EPA–453/R–00–0005. Docket EPA–HQ–OAR–2009–0472–0091.

material deposited on the land enters a waterbody through runoff. Potential impacts of atmospheric deposition to waterbodies include those related to both nutrient and toxic inputs. Adverse effects to human health and welfare can occur from the addition of excess nitrogen via atmospheric deposition. The nitrogen-nutrient enrichment contributes to toxic algae blooms and zones of depleted oxygen, which can lead to fish kills, frequently in coastal waters. Deposition of heavy metals or other toxics may lead to the human ingestion of contaminated fish, impairment of drinking water, damage to the marine ecology, and limits to recreational uses. Several studies have been conducted in U.S. coastal waters and in the Great Lakes Region in which the role of ambient PM deposition and runoff is investigated.[417] [418] [419] [420] [421]

Atmospheric deposition of nitrogen and sulfur contributes to acidification, altering biogeochemistry and affecting animal and plant life in terrestrial and aquatic ecosystems across the U.S. The sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition is predominantly governed by geology. Prolonged exposure to excess nitrogen and sulfur deposition in sensitive areas acidifies lakes, rivers and soils. Increased acidity in surface waters creates inhospitable conditions for biota and affects the abundance and nutritional value of preferred prey species, threatening biodiversity and ecosystem function. Over time, acidifying deposition also removes essential nutrients from forest soils, depleting the capacity of soils to neutralize future acid loadings and negatively affecting forest sustainability. Major effects include a decline in sensitive forest tree species, such as red spruce (*Picea rubens*) and sugar maple (*Acer saccharum*), and a loss of biodiversity of fishes, zooplankton, and macro invertebrates.

In addition to the role nitrogen deposition plays in acidification, nitrogen deposition also leads to nutrient enrichment and altered biogeochemical cycling. In aquatic systems increased nitrogen can alter species assemblages and cause eutrophication. In terrestrial systems nitrogen loading can lead to loss of nitrogen sensitive lichen species, decreased biodiversity of grasslands, meadows and other sensitive habitats, and increased potential for invasive species. For a broader explanation of the topics treated here, refer to the description in Section 7.1.2 of the RIA.

Adverse impacts on soil chemistry and plant life have been observed for areas heavily influenced by atmospheric deposition of nutrients, metals and acid species, resulting in species shifts, loss of biodiversity, forest decline and damage to forest productivity. Potential impacts also include adverse effects to human health through ingestion of contaminated vegetation or livestock (as in the case for dioxin deposition), reduction in crop yield, and limited use of land due to contamination.

Atmospheric deposition of pollutants can reduce the aesthetic appeal of buildings and culturally important articles through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion. Atmospheric deposition may affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to adsorb corrosive gases (principally sulfur dioxide).

d. Environmental Effects of Air Toxics

Fuel combustion emissions contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds (VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[422] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[423] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (*e.g.,* acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[424]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[425] [426] [427] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

5. Air Quality Impacts of Non-GHG Pollutants

Air quality modeling was performed to assess the impact of the vehicle standards on criteria and air toxic pollutants. In this section, we present information on current modeled levels of pollution as well as projections for 2030, with respect to ambient $PM_{2.5}$, ozone, selected air toxics, visibility levels and nitrogen and sulfur deposition. The air quality modeling results indicate that the GHG standards have relatively small but measureable impacts on ambient concentrations of these pollutants. The results are discussed in more detail below and in Section 7.2 of the RIA. No substantive

[417] U.S. EPA (2004) National Coastal Condition Report II. Office of Research and Development/Office of Water. EPA–620/R–03/002. Docket EPA–HQ–OAR–2009–0472–0089.

[418] Gao, Y., E.D. Nelson, M.P. Field, et al. 2002. Characterization of atmospheric trace elements on $PM_{2.5}$ particulate matter over the New York-New Jersey harbor estuary. *Atmos. Environ.* 36: 1077–1086. Docket EPA–HQ–OAR–2009–0472–11297.

[419] Kim, G., N. Hussain, J.R. Scudlark, and T.M. Church. 2000. Factors influencing the atmospheric depositional fluxes of stable Pb, 210Pb, and 7Be into Chesapeake Bay. *J. Atmos. Chem.* 36: 65–79. Docket EPA–HQ–OAR–2009–0472–11299.

[420] Lu, R., R.P. Turco, K. Stolzenbach, *et al.* 2003. Dry deposition of airborne trace metals on the Los Angeles Basin and adjacent coastal waters. *J. Geophys. Res.* 108(D2, 4074): AAC 11–1 to 11–24. Docket EPA–HQ–OAR–2009–0472–11296.

[421] Marvin, C.H., M.N. Charlton, E.J. Reiner, et al. 2002. Surficial sediment contamination in Lakes Erie and Ontario: A comparative analysis. *J. Great Lakes Res.* 28(3): 437–450. Docket EPA–HQ–OAR–2009–0472–11300.

[422] U.S. EPA. 1991. Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3–91/001. Docket EPA–HQ–OAR–2009–0472–0401.

[423] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343. Docket EPA–HQ–OAR–2009–0472–0357.

[424] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341–343. Docket EPA–HQ–OAR–2009–0472–0357.

[425] Viskari E–L. 2000. Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327–337. Docket EPA–HQ–OAR–2009–0472–1128.

[426] Ugrekhelidze D, F Korte, G Kvesitadze. 1997. Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24–29. Docket EPA–HQ–OAR–2009–0472–1142.

[427] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. 1987. Toxic components of motor vehicle emissions for the spruce Picea abies. Environ. Pollut. 48:235–243. Docket EPA–HQ–OAR–2009–0472–0358.

comments were received on our plans for non-GHG air quality modeling that were detailed in the proposal for this rule.

We used the Community Multi-scale Air Quality (CMAQ) photochemical model, version 4.7.1, for our analysis. This version of CMAQ includes a number of improvements to previous versions of the model. These improvements are discussed in Section 7.2 of the RIA.

a. Particulate Matter

i. Current Levels

$PM_{2.5}$ concentrations exceeding the level of the $PM_{2.5}$ NAAQS occur in many parts of the country. In 2005, EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 943, January 5, 2005). These areas are composed of 208 full or partial counties with a total population exceeding 88 million. The 1997 $PM_{2.5}$ NAAQS was revised in 2006 and the 2006 24-hour $PM_{2.5}$ NAAQS became effective on December 18, 2006. On October 8, 2009, the EPA issued final nonattainment area designations for the 2006 24-hour $PM_{2.5}$ NAAQS (74 FR 58688, November 13, 2009). These designations include 31 areas composed of 120 full or partial counties with a population of over 70 million. In total, there are 54 $PM_{2.5}$ nonattainment areas composed of 243 counties with a population of almost 102 million people.

ii. Projected Levels Without This Rule

States with $PM_{2.5}$ nonattainment areas are required to take action to bring those areas into compliance in the future. Areas designated as not attaining the 1997 $PM_{2.5}$ NAAQS will need to attain the 1997 standards in the 2010 to 2015 time frame, and then maintain them thereafter. The 2006 24-hour $PM_{2.5}$ nonattainment areas will be required to attain the 2006 24-hour $PM_{2.5}$ NAAQS in the 2014 to 2019 time frame and then be required to maintain the 2006 24-hour $PM_{2.5}$ NAAQS thereafter. The vehicle standards finalized in this action become effective in 2012 and therefore may be useful to states in attaining or maintaining the $PM_{2.5}$ NAAQS.

EPA has already adopted many emission control programs that are expected to reduce ambient $PM_{2.5}$ levels and which will assist in reducing the number of areas that fail to achieve the $PM_{2.5}$ NAAQS. Even so, our air quality modeling projects that in 2030, with all current controls but excluding the impacts of the vehicle standards adopted here, at least 9 counties with a population of almost 28 million may not attain the 1997 annual $PM_{2.5}$ standard of 15 g/m^3 and 26 counties with a population of over 41 million may not attain the 2006 24-hour $PM_{2.5}$ standard of 35 g/m^3. These numbers do not account for those areas that are close to (*e.g.,* within 10 percent of) the $PM_{2.5}$ standards. These areas, although not violating the standards, will also benefit from any reductions in $PM_{2.5}$ ensuring long-term maintenance of the $PM_{2.5}$ NAAQS.

iii. Projected Levels With This Rule

Air quality modeling performed for this final rule shows that in 2030 the majority of the modeled counties will see decreases of less than 0.05 g/m^3 in their annual $PM_{2.5}$ design values. The decreases in annual $PM_{2.5}$ design values that we see in some counties are likely due to emission reductions related to lower gasoline production at existing oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. The maximum projected decrease in an annual $PM_{2.5}$ design value is 0.07 g/m^3 in Harris County, TX. There are also a few counties that are projected to see increases of no more than 0.01 g/m^3 in their annual $PM_{2.5}$ design values. These small increases in annual $PM_{2.5}$ design values are likely related to downstream emission increases. On a population-weighted basis, the average modeled 2030 annual $PM_{2.5}$ design value is projected to decrease by 0.01 g/m^3 due to this final rule. Those counties that are projected to be above the annual $PM_{2.5}$ standard in 2030 will see slightly larger population-weighted decreases of 0.03 g/m^3 in their design values due to this final rule.

In addition to looking at annual $PM_{2.5}$ design values, we also modeled the impact of the standards on 24-hour $PM_{2.5}$ design values. Air quality modeling performed for this final rule shows that in 2030 the majority of the modeled counties will see changes of between -0.05 g/m^3 and +0.05 g/m^3 in their 24-hour $PM_{2.5}$ design values. The decreases in 24-hour $PM_{2.5}$ design values that we see in some counties are likely due to emission reductions related to lower gasoline production at existing oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. The maximum projected decrease in a 24-hour $PM_{2.5}$ design value is 0.21 g/m^3 in Harris County, TX. There are also some counties that are projected to see increases of less than 0.05 g/m^3 in their 24-hour $PM_{2.5}$ design values. These small increases in 24-hour $PM_{2.5}$ design values are likely related to downstream emission increases. On a population-weighted basis, the average modeled 2030 24-hour $PM_{2.5}$ design value is projected to decrease by 0.01 g/m^3 due to this final rule. Those counties that are projected to be above the 24-hour $PM_{2.5}$ standard in 2030 will see slightly larger population-weighted decreases of 0.05 g/m^3 in their design values due to this final rule.

b. Ozone

i. Current Levels

8-hour ozone concentrations exceeding the level of the ozone NAAQS occur in many parts of the country. In 2008, the EPA amended the ozone NAAQS (73 FR 16436, March 27, 2008). The final 2008 ozone NAAQS rule set forth revisions to the previous 1997 NAAQS for ozone to provide increased protection of public health and welfare. EPA recently proposed to reconsider the 2008 ozone NAAQS (75 FR 2938, January 19, 2010). Because of the uncertainty the reconsideration proposal creates regarding the continued applicability of the 2008 ozone NAAQS, EPA has used its authority to extend by 1 year the deadline for promulgating designations for those NAAQS (75 FR 2936, January 19, 2010). The new deadline is March 12, 2011. EPA intends to complete the reconsideration by August 31, 2010. If EPA establishes new ozone NAAQS as a result of the reconsideration, they would replace the 2008 ozone NAAQS and requirements to designate areas and implement the 2008 NAAQS would no longer apply.

As of January 6, 2010 there are 51 areas designated as nonattainment for the 1997 8-hour ozone NAAQS, comprising 266 full or partial counties with a total population of over 122 million people. These numbers do not include the people living in areas where there is a future risk of failing to maintain or attain the 1997 8-hour ozone NAAQS. The numbers above likely underestimate the number of counties that are not meeting the ozone NAAQS because the nonattainment areas associated with the more stringent 2008 8-hour ozone NAAQS have not yet been designated. Table III.G.5–1 provides an estimate, based on 2005–07 air quality data, of the counties with design values greater than the 2008 8-hour ozone NAAQS of 0.075 ppm.

TABLE III.G.5–1—COUNTIES WITH DESIGN VALUES GREATER THAN THE OZONE NAAQS

	Number of counties	Population [a]
1997 Ozone Standard: Counties within the 54 areas currently designated as nonattainment (as of 1/6/10)	266	122,343,799
2008 Ozone Standard: Additional counties that would not meet the 2008 NAAQS (based on 2006–2008 air quality data) [b]	156	36,678,478
Total	422	159,022,277

NOTES:
[a] Population numbers are from 2000 census data.
[b] Area designations for the 2008 ozone NAAQS have not yet been made. Nonattainment for the 2008 Ozone NAAQS would be based on three years of air quality data from later years. Also, the county numbers in this row include only the counties with monitors violating the 2008 Ozone NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

ii. Projected Levels Without This Rule

States with 8-hour ozone nonattainment areas are required to take action to bring those areas into compliance in the future. Based on the final rule designating and classifying 8-hour ozone nonattainment areas for the 1997 standard (69 FR 23951, April 30, 2004), most 8-hour ozone nonattainment areas will be required to attain the ozone NAAQS in the 2007 to 2013 time frame and then maintain the NAAQS thereafter. As noted, EPA is reconsidering the 2008 ozone NAAQS. If EPA promulgates different ozone NAAQS in 2010 as a result of the reconsideration, these standards would replace the 2008 ozone NAAQS and there would no longer be a requirement to designate areas for the 2008 NAAQS. EPA would designate nonattainment areas for a potential new 2010 primary ozone NAAQS in 2011. The attainment dates for areas designated nonattainment for a potential new 2010 primary ozone NAAQS are likely to be in the 2014 to 2031 timeframe, depending on the severity of the problem.[428]

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels and assist in reducing the number of areas that fail to achieve the ozone NAAQS. Even so, our air quality modeling projects that in 2030, with all current controls but excluding the impacts of the vehicle standards, up to 16 counties with a population of almost 35 million may not attain the 2008 ozone standard of 0.075 ppm (75 ppb). These numbers do not account for those areas that are close to (*e.g.,* within 10 percent of) the 2008 ozone standard. These areas, although not violating the standards, will also be impacted by changes in ozone as they work to ensure long-term maintenance of the ozone NAAQS.

iii. Projected Levels With This Rule

We do not expect this rule to have a meaningful impact on ozone concentrations, given the small magnitude of the ozone impacts and the fact that much of the impact is due to ethanol assumptions that are independent of this rule. Our modeling projects increases in ozone design value concentrations in many areas of the country and decreases in ozone design value concentrations in a few areas. However, the increases in ozone design values are not due to the standards finalized in this rule, but are related to our assumptions about the volume of ethanol that will be blended into gasoline. The ethanol volumes will be occurring as a result of the recent Renewable Fuel Standards (RFS2) rule.[429]

The ethanol volume assumptions are discussed in the introduction to Section III.G of this preamble. We attribute decreased fuel consumption and production from this program to gasoline only, while assuming constant ethanol volumes in our reference and control cases. Holding ethanol volumes constant while decreasing gasoline volumes increases the market share of 10% ethanol (E10) in the control case. However, the increased E10 market share is projected to occur regardless of this rule; in the RFS2 analysis we project 100% E10 by 2014. The air quality impacts of this effect are included in our analyses for the recent RFS2 rule. As the RFS2 analyses indicate, increasing usage of E10 fuels (when compared with E0 fuels) can increase NO_X emissions and thereby increase ozone concentrations, especially in NO_X-limited areas where relatively small amounts of NO_X enable ozone to form rapidly.[430]

The majority of the ozone design value increases are less than 0.1 ppb. The maximum projected increase in an 8-hour ozone design value is 0.25 ppb in Richland County, South Carolina. As mentioned above there are some areas which see decreases in their ozone design values. The decreases in ambient ozone concentration are likely due to projected upstream emissions decreases in NO_X and VOCs from reduced gasoline production. The maximum decrease projected in an 8-hour ozone design value is 0.22 ppb in Riverside County, California. On a population-weighted basis, the average modeled 8-hour ozone design values are projected to increase by 0.01 ppb in 2030 and the design values for those counties that are projected to be above the 2008 ozone standard in 2030 will see population-weighted decreases of 0.10 ppb.

c. Air Toxics

i. Current Levels

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[431] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in U.S. EPA's most recent Mobile Source Air Toxics Rule.[432] According to the National Air Toxic Assessment

[428] U.S. EPA 2010, Fact Sheet Revisions to Ozone Standards. *http://www.epa.gov/groundlevelozone/pdfs/fs20100106std.pdf.*

[429] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA–420–R–10–006, February 2010. Docket EPA–HQ–OAR–2009–0472–11332. *See also* 75 FR 14670, March 26, 2010.

[430] Sections 3.4.2.1.2 and 3.4.3.3 of the Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis, EPA–420–R–10–006, February 2010. Docket EPA–HQ–OAR–2009–0472–11332.

[431] U.S. EPA (2009) 2002 National-Scale Air Toxics Assessment. *http://www.epa.gov/ttn/atw/nata2002/.* Docket EPA–HQ–OAR–2009–0472–11321.

[432] U.S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007. Docket EPA–HQ–OAR–2009–0472–0271, 0271.1 and 0271.2.

(NATA) for 2002,[433] mobile sources were responsible for 47 percent of outdoor toxic emissions, over 50 percent of the cancer risk, and over 80 percent of the noncancer hazard. Benzene is the largest contributor to cancer risk of all 124 pollutants quantitatively assessed in the 2002 NATA and mobile sources were responsible for 59 percent of benzene emissions in 2002. Over the years, EPA has implemented a number of mobile source and fuel controls resulting in VOC reductions, which also reduce benzene and other air toxic emissions.

ii. Projected Levels

Our modeling indicates that the GHG standards have relatively little impact on national average ambient concentrations of the modeled air toxics. Additional detail on the air toxics results can be found in Section 7.2.2.3 of the RIA.

d. Nitrogen and Sulfur Deposition

i. Current Levels

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 17 years although many areas continue to be negatively impacted by deposition. Deposition of inorganic nitrogen and sulfur species routinely measured in the U.S. between 2004 and 2006 were as high as 9.6 kilograms of nitrogen per hectare per year (kg N/ha/yr) and 21.3 kilograms of sulfur per hectare per year (kg S/ha/yr). The data show that reductions were more substantial for sulfur compounds than for nitrogen compounds. These numbers are generated by the U.S. national monitoring network and they likely underestimate nitrogen deposition because neither ammonia nor organic nitrogen is measured. In the eastern U.S., where data are most abundant, total sulfur deposition decreased by about 44% between 1990 and 2007, while total nitrogen deposition decreased by 25% over the same time frame.[434]

ii. Projected Levels

Our air quality modeling does not show substantial overall nationwide impacts on the annual total sulfur and nitrogen deposition occurring across the U.S. as a result of the vehicle standards required by this rule. For sulfur deposition the vehicle standards will result in annual percent decreases of 0.5% to more than 2% in locations with refineries as a result of the lower output from refineries due to less gasoline usage. These locations include the Texas and Louisiana portions of the Gulf Coast; the Washington DC area; Chicago, IL; portions of Oklahoma and northern Texas; Bismarck, North Dakota; Billings, Montana; Casper, Wyoming; Salt Lake City, Utah; Seattle, Washington; and San Francisco, Los Angeles, and San Luis Obispo, California. The remainder of the country will see only minimal changes in sulfur deposition, ranging from decreases of less than 0.5% to increases of less than 0.5%. For a map of 2030 sulfur deposition impacts and additional information on these impacts, *see* Section 7.2.2.5 of the RIA. The impacts of the vehicle standards on nitrogen deposition are minimal, ranging from decreases of up to 0.5% to increases of up to 0.5%.

e. Visibility

i. Current Levels

As mentioned in Section III.G.5.a, millions of people live in nonattainment areas for the $PM_{2.5}$ NAAQS. These populations, as well as large numbers of individuals who travel to these areas, are likely to experience visibility impairment. In addition, while visibility trends have improved in mandatory class I Federal areas, the most recent data show that these areas continue to suffer from visibility impairment. In summary, visibility impairment is experienced throughout the U.S., in multi-State regions, urban areas, and remote mandatory class I Federal areas.

ii. Projected Levels

Air quality modeling conducted for this final rule was used to project visibility conditions in 138 mandatory class I Federal areas across the U.S. in 2030. The results show that all the modeled areas will continue to have annual average deciview levels above background in 2030.[435] The results also indicate that the majority of the modeled mandatory class I Federal areas will see no change in their visibility, but some mandatory class I Federal areas will see improvements in visibility due to the vehicle standards and a few mandatory class I Federal areas will see visibility decreases. The average visibility at all modeled mandatory class I Federal areas on the 20% worst days is projected to improve by 0.002 deciviews, or 0.01%, in 2030. Section 7.2.2.6.2 of the RIA contains more detail on the visibility portion of the air quality modeling.

H. What are the estimated cost, economic, and other impacts of the program?

In this section, EPA presents the costs and impacts of EPA's GHG program. It is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to average fuel economy increases and CO_2 emissions reductions. The two agencies' standards comprise the National Program, and this discussion of costs and benefits of EPA's GHG standard does not change the fact that both the CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program. These costs and benefits are appropriately analyzed separately by each agency and should not be added together.

This section outlines the basis for assessing the benefits and costs of the GHG standards and provides estimates of these costs and benefits. Some of these effects are private, meaning that they affect consumers and producers directly in their sales, purchases, and use of vehicles. These private effects include the upfront costs of the technology, fuel savings, and the benefits of additional driving and reduced refueling. Other costs and benefits affect people outside the markets for vehicles and their use; these effects are termed external, because they affect people in ways other than the effect on the market for and use of new vehicles and are generally not taken into account by the purchaser of the vehicle. The external effects include the climate impacts, the effects on non-GHG pollutants, energy security impacts, and the effects on traffic, accidents, and noise due to additional driving. The sum of the private and external benefits and costs is the net social benefits of the program. There is some debate about the

[433] U.S. EPA (2009) 2002 National-Scale Air Toxics Assessment. *http://www.epa.gov/ttn/atw/nata2002/.* Docket EPA–HQ–OAR–2009–0472–11321.

[434] U.S. EPA. U.S. EPA's 2008 Report on the Environment (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R–07/045F (NTIS PB2008–112484). Docket EPA–HQ–OAR–2009–0472–11298. Updated data available online at: *http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&ch=46&subtop=341&lv=list.listByChapter&r=201744.*

[435] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a "deciview", which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

role of private benefits in assessing the benefits and costs of the program: If consumers optimize their purchases of fuel economy, with full information and perfect foresight, in perfectly efficient markets, it is possible that they have already considered these benefits in their vehicle purchase decisions. If so, then no net private benefits would result from the program, because consumers would already buy vehicles with the amount of fuel economy that is optimal for them; requiring additional fuel economy would alter both the purchase prices of new cars and their lifetime streams of operating costs in ways that will inevitably reduce consumers' well-being. If these conditions do not hold, then the private benefits and costs would both count toward the program's benefits. Section III.H.1 discusses this issue more fully.

The net benefits of EPA's final program consist of the effects of the program on:

The vehicle program costs (costs of complying with the vehicle CO_2 standards, taking into account FFV credits through 2015, the temporary lead-time alternative allowance standard program (TLAASP), full car/truck trading, and the A/C credit program, and other flexibilities built into the final program),

Fuel savings associated with reduced fuel usage resulting from the program,

Greenhouse gas emissions,

Other pollutants,

Noise, congestion, accidents,

Energy security impacts,

Reduced refueling events

Increased driving due to the "rebound" effect.

EPA also presents the cost-effectiveness of the standards.

The total monetized benefits (excluding fuel savings) under the program are projected to be $17.5 to $41.8 billion in 2030, using a 3 percent discount rate applied to the valuation of $PM_{2.5}$-related premature mortality and depending on the value used for the social cost of carbon. The total monetized benefits (excluding fuel savings) under the program are projected to be $17.4 to $41.7 billion in 2030, using a 7 percent discount rate applied to the valuation of $PM_{2.5}$-related premature mortality and depending on the value used for the social cost of carbon. These benefits are summarized below in Table III.H.10–2. The costs of the program in 2030 are estimated to be approximately $15.8 billion for new vehicle technology less $79.8 billion in savings realized by consumers through fewer fuel expenditures (calculated using pre-tax fuel prices). These costs are summarized below in Table III.H.10–1. The estimates developed here use as a baseline for comparison the fuel economy associated with MY 2011 vehicles. To the extent that greater fuel economy improvements than those assumed to occur under the baseline may have occurred due to market forces alone (absent the rule), the analysis overestimates private and social net benefits.

EPA has undertaken an analysis of the economy-wide impacts of the GHG tailpipe standards as an exploratory exercise that EPA believes could provide additional insights into the potential impacts of the program.[436] These results were not a factor regarding the appropriateness of the GHG tailpipe standards. It is important to note that the results of this modeling exercise are dependent on the assumptions associated with how producers will make fuel economy improvements and how consumers will respond to increases in higher vehicle costs and improved vehicle fuel economy as a result of the program. Section III.H.1 discusses the underlying distinctions and implications of the role of consumer response in economic impacts.

Further information on these and other aspects of the economic impacts of our rule are summarized in the following sections and are presented in more detail in the RIA for this rulemaking.

1. Conceptual Framework for Evaluating Consumer Impacts

For this rule, EPA projects significant private gains to consumers in three major areas: (1) Reductions in spending on fuel, (2) time saved due to less refueling, and (3) welfare gains from additional driving that results from the rebound effect. In combination, these private savings, mostly from fuel savings, appear to outweigh by a large margin the costs of the program, even without accounting for externalities.

Admittedly, these findings pose an economic conundrum. On the one hand, consumers are expected to gain significantly from the rules, as the increased cost of fuel efficient cars appears to be far smaller than the fuel savings. Yet these technologies are readily available; financially savvy consumers could have sought vehicles with improved fuel efficiency, and auto makers seeking those customers could have offered them. Assuming full information, perfect foresight, perfect competition, and financially rational consumers and producers, standard economic theory suggests that normal market operations would have provided the private net gains to consumers, and the only benefits of the rule would be due to external benefits. If our analysis projects net private benefits that consumers have not realized in this perfectly functioning market, then increased fuel economy should be accompanied by a corresponding loss in consumer welfare. This calculation assumes that consumers accurately predict and act on all the benefits they will get from a new vehicle, and that producers market products providing those benefits. The existence of large private net benefits from this rule, then, suggests either that the assumptions noted above do not hold, or that EPA's analysis has missed some factor(s) tied to improved fuel economy that reduce(s) consumer welfare.

With respect to the latter, EPA believes the costs of the technologies developed for this rule take into account the cost needed to ensure that all vehicle qualities (including performance, reliability, and size) stay constant, except for fuel economy and vehicle price. As a result, there would need to be some other changed qualities that would reduce the benefits consumers receive from their vehicles. Changing circumstances (*e.g.,* increased demand for horsepower in response to a drop in fuel prices), and any changes in vehicle attributes that manufacturers elect to make may result in additional private impacts to vehicle buyers from requiring increased fuel economy. Most comments generally supported the cost estimates and the maintenance of vehicle quality, though two comments expressed concern over unspecified losses to vehicle quality. Even if there is some such unidentified loss (which, given existing evidence and modeling capabilities, is very difficult to quantify), EPA believes that under realistic assumptions, the private gains from the rule, together with the social gains (in the form of reduction of externalities), will continue to substantially outweigh the costs.

The central conundrum has been referred to as the Energy Paradox in this setting (and in several others).[437] In short, the problem is that consumers appear not to purchase products that are in their economic self-interest. There are

[436] *See* Memorandum to Docket, "Economy-Wide Impacts of Proposed Greenhouse Gas Tailpipe Standards," March 4, 2010. Docket EPA–HQ–OAR–2009–0472.

[437] Jaffe, A.B., and Stavins, R.N. (1994). The Energy Paradox and the Diffusion of Conservation Technology. Resource and Energy Economics, 16(2), 91–122. Docket EPA–HQ–OAR–2009–0472–11415.

strong theoretical reasons why this might be so: [438]

Consumers might be myopic and hence undervalue the long-term.

Consumers might lack information or a full appreciation of information even when it is presented.

Consumers might be especially averse to the short-term losses associated with the higher prices of energy efficient products relative to the uncertain future fuel savings, even if the expected present value of those fuel savings exceeds the cost (the behavioral phenomenon of "loss aversion")

Even if consumers have relevant knowledge, the benefits of energy-efficient vehicles might not be sufficiently salient to them at the time of purchase, and the lack of salience might lead consumers to neglect an attribute that it would be in their economic interest to consider.

In the case of vehicle fuel efficiency, and perhaps as a result of one or more of the foregoing factors, consumers may have relatively few choices to purchase vehicles with greater fuel economy once other characteristics, such as vehicle class, are chosen.[439]

A great deal of work in behavioral economics identifies and elaborates factors of this sort, which help account for the Energy Paradox.[440] This point holds in the context of fuel savings (the main focus here), but it applies equally to the other private benefits, including reductions in refueling time and additional driving.[441] For example, it might well be questioned whether significant reductions in refueling time, and corresponding private savings, are fully internalized when consumers are making purchasing decisions.

Considerable research findings indicate that the Energy Paradox is real and significant but the literature has not reached a consensus about the reasons for its existence. Several researchers have found evidence suggesting that consumers do not give full or appropriate weight to fuel economy in purchasing decisions. For example, Sanstad and Howarth [442] argue that consumers optimize behavior without full information by resorting to imprecise but convenient rules of thumb. Some studies find that a substantial portion of this undervaluation can be explained by inaccurate assessments of energy savings, or by uncertainty and irreversibility of energy investments due to fluctuations in energy prices.[443] For a number of reasons, consumers may undervalue future energy savings due to routine mistakes in how they evaluate these trade-offs. For instance, the calculation of fuel savings is complex, and consumers may not make it correctly.[444] The attribute of fuel economy may be insufficiently salient, leading to a situation in which consumers pay less than $1 for an expected $1 benefit in terms of discounted gasoline costs.[445] Larrick and Soll (2008) find that consumers do not understand how to translate changes in miles-per-gallon into fuel savings (a concern that EPA is continuing to attempt to address).[446] In addition, future fuel price (a major component of fuel savings) is highly uncertain. Consumer fuel savings also vary across individuals, who travel different amounts and have different driving styles. Cost calculations based on the average do not distinguish between those that may gain or lose as a result of the policy.[447] Studies regularly show that fuel economy plays a role in consumers' vehicle purchases, but modeling that role is still in development, and there is no consensus that most consumers make fully informed tradeoffs.[448]

Some studies find that a substantial portion of the Energy Paradox can be explained in models of consumer behavior. For instance, one set of studies finds that accounting for uncertainty in fuel savings over time due to unanticipated changes in fuel prices goes a long way toward explaining this paradox. In this case, consumers give up some uncertain future fuel savings to avoid higher upfront costs.

A recent review commissioned by EPA supports the finding of great variability, by looking at one key parameter: The role of fuel economy in consumers' vehicle purchase decisions.[449] The review finds no

[438] For an overview, *see id.*

[439] For instance, the range of fuel economy (combined city and highway) available among all listed 2010 6-cylinder minivans is 18 to 20 miles per gallon. With a manual-transmission 4-cylinder minivan, it is possible to get 24 mpg. *See http://www.fueleconomy.gov,* which is jointly maintained by the U.S. Department of Energy and the EPA. For recent but unpublished evidence, see Allcott, Hunt, and Nathan Wozny, "Gasoline Prices, Fuel Economy, and the Energy Paradox" (2010), available at *http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf.*

[440] Jaffe, A.B., and Stavins, R.N. (1994). The Energy Paradox and the Diffusion of Conservation Technology. Resource and Energy Economics, 16(2), 91–122. Docket EPA–HQ–OAR–2009–0472–11415. *See* also Allcott and Wozny, supra note.

[441] For example, it might be maintained that, at the time of purchase, consumers take full account of the time spent refueling potentially saved by fuel-efficient cars, but it might also be questioned whether they have adequate information to do so, or whether that factor is sufficiently salient to play the proper role in purchasing decisions.

[442] Sanstad, A., and R. Howarth (1994). " 'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811–818 (Docket EPA–HQ–OAR–2009–0472–11416).

[443] Greene, D., J. German, and M. Delucchi (2009). "Fuel Economy: The Case for Market Failure" in Reducing Climate Impacts in the Transportation Sector, Sperling, D., and J. Cannon, eds. Springer Science (Docket EPA–HQ–OAR–2009–0472–11538); Dasgupta, S., S. Siddarth, and J. Silva-Risso (2007). "To Lease or to Buy? A Structural Model of a Consumer's Vehicle and Contract Choice Decisions." Journal of Marketing Research 44: 490–502 (Docket EPA–HQ–OAR–2009–0472–11539); Metcalf, G., and D. Rosenthal (1995). "The 'New' View of Investment Decisions and Public Policy Analysis: An Application to Green Lights and Cold Refrigerators," Journal of Policy Analysis and Management 14: 517–531 (Docket EPA–HQ–OAR–2009–0472–11540); Hassett, K., and G. Metcalf (1995), "Energy Tax Credits and Residential Conservation Investment: Evidence from Panel Data," *Journal of Public Economics* 57: 201–217 (Docket EPA–HQ–OAR–2009–0472–11543); Metcalf, G., and K. Hassett (1999), "Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data," *The Review of Economics and Statistics* 81(3): 516–528 (Docket EPA–HQ–OAR–2009–0472–0051); van Soest D., and E. Bulte (2001), "Does the Energy-Efficiency Paradox Exist? Technological Progress and Uncertainty." *Environmental and Resource Economics* 18: 101–12 (Docket EPA–HQ–OAR–2009–0472–11542).

[444] Turrentine, T. and K. Kurani (2007). "Car Buyers and Fuel Economy?" Energy Policy 35: 1213–1223 (Docket EPA–HQ–OAR–2009–0472); Larrick, R.P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593–1594 (Docket EPA–HQ–OAR–2009–0472–0041).

[445] Allcott, Hunt, and Nathan Wozny, "Gasoline Prices, Fuel Economy, and the Energy Paradox" (2010), available at *http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf* (Docket EPA–HQ–OAR–2009–0472–11554).

[446] Sanstad, A., and R. Howarth (1994). " 'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811–818 (Docket EPA–HQ–OAR–2009–0472–11415); Larrick, R. P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593–1594 (Docket EPA–HQ–OAR–2009–0472–0043).

[447] Hausman J., Joskow P. (1982). "Evaluating the Costs and Benefits of Appliance Efficiency Standards." *American Economic Review* 72: 220–25 (Docket EPA–HQ–OAR–2009–0472–11541).

[448] *E.g.,* Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry," *Econometrica* 63(4) (July 1995): 891–951 (Docket EPA–HQ–OAR–2009–0472–0021); Goldberg, Pinelopi Koujianou, "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," *Journal of Industrial Economics* 46(1) (March 1998): 1–33 (Docket EPA–HQ–OAR–2009–0472–0017); Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer (2009). "Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets," Working paper (accessed 6/30/09), available at *http://www.econ.ucdavis.edu/faculty/knittel/papers/gaspaper_latest.pdf.* (Docket EPA–HQ–OAR–2009–0472–0044).

[449] Greene, David L. "How Consumers Value Fuel Economy: A Literature Review." EPA Report EPA–420–R–10–008, March 2010 (Docket EPA–HQ–OAR–2009–0472–11575).

consensus on the role of fuel economy in consumer purchase decisions. Of 27 studies, significant numbers of them find that consumers undervalue, overvalue, or value approximately correctly the fuel savings that they will receive from improved fuel economy. The variation in the value of fuel economy in these studies is so high that it appears to be inappropriate to identify one central estimate from the literature. Thus, estimating consumer response to higher vehicle fuel economy is still unsettled science.

If there is a difference between fuel savings and consumers' willingness to pay for fuel savings, the next question is, which is the appropriate measure of consumer benefit? Fuel savings measure the actual monetary value that consumers will receive after purchasing a vehicle; the willingness to pay for fuel economy measures the value that, before a purchase, consumers place on additional fuel economy. As noted, there are a number of reasons that consumers may incorrectly estimate the benefits that they get from improved fuel economy, including risk or loss aversion, and poor ability to calculate savings. Also as noted, fuel economy may not be as salient as other vehicle characteristics when a consumer is considering vehicles. If these arguments are valid, then there will be significant gains to consumers of the government mandating additional fuel economy.

EPA requested and received a number of comments discussing the role of the Energy Paradox in consumer vehicle purchase decisions. Ten commenters, primarily from a number of academic and non-governmental organizations, argued that there is a gap between the fuel economy that consumers purchased and the cost-effective amount, due to a number of market and behavioral phenomena. These include consumers having inadequate information about future fuel savings relative to up-front costs; imperfect competition among auto manufacturers; lack of choice over fuel economy within classes; lack of salience of fuel economy relative to other vehicle features at the time of vehicle purchase; consumer use of heuristic decision-making processes or other rules of thumb, rather than analyzing fuel economy decisions; consumer risk and loss aversion leading to more attention to up-front costs than future fuel savings; and consumer emphasis on visible, status-providing features of vehicles more than on relatively invisible features such as fuel economy. The RIA, Chapter 8.1.2, includes further discussion of these phenomena.

Because of the gap between the fuel economy consumers purchase and the cost-effective amount, those and additional commenters support using the full value of fuel savings as a benefit of the rule. A few asserted, in addition, that auto companies would benefit from offering vehicles with improved fuel economy. Automakers might underprovide fuel economy because they believe consumers would not buy it, or that it is not as salient as price when consumers are buying a vehicle. The commenters who supported the existence of the gap cite these phenomena as a basis for regulation of fuel economy. In contrast, two commenters (the United Auto Workers and one nonprofit research organization) argued that the market for fuel economy works efficiently; consumers reveal through their purchase decisions that additional fuel economy is not important for them. These commenters expressed concern that regulation to promote more fuel economy would limit consumers' choices as well as the value of the vehicles to consumers. Yet other commenters (including some states) noted that the rule protects the existing variety and choice of vehicles in the market; for this reason, the value of vehicles to consumers should not suffer as a result of the rule.

While acknowledging the diversity of perspectives, EPA continues to include the full fuel savings as private benefits of the rule. Improved fuel economy will significantly reduce consumer expenditures on fuel, thus benefiting consumers. It is true that limitations in modeling affect our ability to estimate how much of these savings would have occurred in the absence of the rule. For example, some of the technologies predicted to be adopted in response to the rule may already be developing due to shifts in consumer demand for fuel economy. It is possible that some of these savings would have occurred in the absence of the rule. To the extent that greater fuel economy improvements than those assumed to occur under the baseline may have occurred due to market forces alone (absent the rule), the analysis overestimates private and social net benefits. In the absence of robust means to identify the changes in fuel economy that would have occurred without the rule, we estimate the benefits and costs under the assumption that the rule will lead to more fuel-efficient vehicles than would have occurred without the rule. As discussed below, limitations in modeling also affect our ability to estimate the effects of the rule on net benefits in the market for vehicles.

Consumer vehicle choice models estimate what vehicles consumers buy based on vehicle and consumer characteristics. In principle, such models could provide a means of understanding both the role of fuel economy in consumers' purchase decisions and the effects of this rule on the benefits that consumers will get from vehicles. The NPRM included a discussion of the wide variation in the structure and results of these models. Models or model results have not frequently been systematically compared to each other. When they have, the results show large variation over, for instance, the value that consumers place on additional fuel economy. As a result, EPA found that further assessment needed to be done before adopting a consumer vehicle choice model. In the NPRM, EPA asked for comment on the state of the art of consumer vehicle choice modeling and whether it is sufficiently developed for use in regulatory analysis.

The responses were varied. Of the six commenters on this issue, five supported EPA's performing consumer vehicle choice modeling, but only in general terms; they did not provide recommendations for how to evaluate the quality of different models or identify a model appropriate for EPA's purposes. One commenter argued that, if key differences across models were controlled, then different models would produce similar results, but there were no suggestions for what choices to make to control the key differences. One commenter specifically asked for estimates that quantify losses to consumer welfare. Two commenters mentioned the importance of taking into account any losses in vehicle attributes due to increasing fuel economy, but without specific guidance for how to do so. Some commenters, including some who supported the use of these models, highlighted some of the models' potential limitations. Two commenters noted the challenges of modeling for vehicles that are not yet in the market. Most consumer vehicle choice models are based on existing vehicle fleets. Future vehicles will present combinations of vehicle characteristics not previously seen in markets, such as higher fuel economy and higher price with other characteristics constant; the existing models may not do well in predicting consumer responses to these changes. One comment suggested that the models might be sufficient for predicting changes in consumer purchase patterns, but not for calculating the welfare gains and losses to consumers of the changes.

EPA has not used a consumer vehicle choice model for the final rule analysis, due to concerns we explained in the proposal (and discussed in Chapter 8.1 of the RIA), and because no new information became available to resolve those concerns. It is likely that variation exists in measuring consumer response to changes in fuel economy as well as other vehicle characteristics, such as performance. Thus, there does not appear to be evidence at this time to develop robust estimates of consumer welfare effects of changes in vehicle attributes. As noted earlier, EPA's and NHTSA's cost estimates are based on maintaining these other vehicle attributes. Comments generally supported the finding that our cost and technology estimates succeeded in maintaining these other attributes.

EPA will continue its efforts to review the literature, but, given the known difficulties, EPA has not conducted an analysis using these models for this program. These issues are discussed in detail in RIA Chapter 8.1.2.

The next issue is the potential for loss in consumer welfare due to the rule. As mentioned above (and discussed more thoroughly in Section III.D of this preamble), the technology cost estimates developed here take into account the costs to hold other vehicle attributes, such as size and performance, constant. In addition, the analysis assumes that the full technology costs are passed along to consumers. With these assumptions, because welfare losses are monetary estimates of how much consumers would have to be compensated to be made as well off as in the absence of the change,[450] the price increase measures the loss to the consumer.[451] Assuming that the full technology cost gets passed along to the consumer as an increase in price, the technology cost thus measures the welfare loss to the consumer. Increasing fuel economy would have to lead to other changes in the vehicles that consumers find undesirable for there to be additional losses not included in the technology costs.

At this time EPA has no available methods to estimate potential additional effects on consumers not included in the technology cost estimates, *e.g.,* due to changes in vehicles that consumers find undesirable, shifts in consumer demand for other attributes, and uncertainties about the long term reliability of new technologies. Comments on the rule generally supported EPA's analysis of the technology costs and the assumption that other vehicle characteristics were not adversely affected. Any consumer welfare loss cannot be quantified at this time. For reasons stated above, EPA believes that any such loss is likely far smaller than the private gains, including fuel savings and reduced refueling time.

Chapter 8.1 of the RIA discusses in more depth the research on the Energy Paradox and the state of the art of consumer vehicle choice modeling.

2. Costs Associated With the Vehicle Program

In this section, EPA presents our estimate of the costs associated with the final vehicle program. The presentation here summarizes the costs associated with the new vehicle technology expected to be added to meet the new GHG standards, including hardware costs to comply with the A/C credit program. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis and on an annual total basis.

The presentation here summarizes the outputs of the OMEGA model that was discussed in some detail in Section III.D of this preamble. For details behind the analysis such as the OMEGA model inputs and the estimates of costs associated with individual technologies, the reader is directed to Chapters 1 and 2 of the RIA, and Chapter 3 of the Joint TSD. For more detail on the outputs of the OMEGA model and the overall vehicle program costs summarized here, the reader is directed to Chapters 4 and 7 of the RIA.

With respect to the cost estimates for vehicle technologies, EPA notes that, because these estimates relate to technologies which are in most cases already available, these cost estimates are technically robust. Some comments were received that addressed the technology costs that served as inputs to the OMEGA model as was mentioned in Section II.E. While those comments did not result in changes to the technology cost inputs, the technology cost estimates for a select group of technologies have changed since the NPRM thus changing the vehicle program costs presented here. These changes, as summarized in Section II.E and in Chapter 3 of the Joint TSD, were made in response to updated cost estimates, from the FEV teardown study, available to the agencies shortly after publication of the NPRM, not in response to comments. Those cost changes are summarized in Section II.E and in Chapter 3 of the Joint TSD. EPA believes that we have been conservative in estimating the vehicle hardware costs associated with this rule.

With respect to the aggregate cost estimations presented in Section III.H.2.b, EPA notes that there are a number of areas where the results of our analysis may be conservative and, in general, EPA believes we have directionally overestimated the costs of compliance with these new standards, especially in not accounting for the full range of credit opportunities available to manufacturers. For example, some cost saving programs are considered in our analysis, such as full car/truck trading, while others are not, such as early credit generation and advanced vehicle technology credits.

a. Vehicle Compliance Costs Associated With the CO_2 Standards

For the technology and vehicle package costs associated with adding new CO_2-reducing technology to vehicles, EPA began with EPA's 2008 Staff Report and NHTSA's 2011 CAFE FRM both of which presented costs generated using existing literature, meetings with manufacturers and parts suppliers, and meetings with other experts in the field of automotive cost estimation.[452] EPA has updated some of those technology costs with new information from our contract with FEV, through further discussion with NHTSA, and by converting from 2006 dollars to 2007 dollars using the GDP price deflator. The estimated costs presented here represent the incremental costs associated with this rule relative to what the future vehicle fleet would be expected to look like absent this rule. A more detailed description of the factors considered in our reference case is presented in Section III.D.

The estimates of vehicle compliance costs cover the years of implementation of the program—2012 through 2016. EPA has also estimated compliance costs for the years following implementation so that we can shed

[450] This approach describes the economic concept of compensating variation, a payment of money after a change that would make a consumer as well off after the change as before it. A related concept, equivalent variation, estimates the income change that would be an alternative to the change taking place. The difference between them is whether the consumer's point of reference is her welfare before the change (compensating variation) or after the change (equivalent variation). In practice, these two measures are typically very close together.

[451] Indeed, it is likely to be an overestimate of the loss to the consumer, because the consumer has choices other than buying the same vehicle with a higher price; she could choose a different vehicle, or decide not to buy a new vehicle. The consumer would choose one of those options only if the alternative involves less loss than paying the higher price. Thus, the increase in price that the consumer faces would be the upper bound of loss of consumer welfare, unless there are other changes to the vehicle due to the fuel economy improvements that make the vehicle less desirable to consumers.

[452] "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions," EPA 420–R–08–008; NHTSA 2011 CAFE FRM is at 74 FR 14196; both documents are contained in Docket EPA–HQ–OAR–2009–0472.

light on the long term (2022 and later) cost impacts of the program.[453] EPA used the year 2022 here because our short-term and long-term markup factors described shortly below are applied in five year increments with the 2012 through 2016 implementation span and the 2017 through 2021 span both representing the short-term. Some of the individual technology cost estimates are presented in brief in Section III.D, and account for both the direct and indirect costs incurred in the automobile manufacturing and dealer industries (for a complete presentation of technology costs, please refer to Chapter 3 of the Joint TSD). To account for the indirect costs, EPA has applied an indirect cost markup (ICM) factor to all of our direct costs to arrive at the estimated technology cost.[454] The ICM factors used range from 1.11 to 1.64 in the short-term (2012 through 2021), depending on the complexity of the given technology, to account for differences in the levels of R&D, tooling, and other indirect costs that will be incurred. Once the program has been fully implemented, some of the indirect costs will no longer be attributable to these standards and, as such, a lower ICM factor is applied to direct costs in years following full implementation. The ICM factors used range from 1.07 to 1.39 in the long-term (2022 and later) depending on the complexity of the given technology.[455] Note that the short-term ICMs are used in the 2012 through 2016 years of implementation and continue through 2021. EPA does this since the standards are still being implemented during the 2012 through 2016 model years. Therefore, EPA considers the five year period following full implementation also to be short-term. Note that, in general the comments received were supportive of our use of ICMs as opposed to the more traditional Retail Price Equivalent (RPE).[456] However, we did receive some comment that we applied inappropriate ICM factors to some technologies. We have not changed our approach in response to those comments as explained in greater detail in our Response to Comments document.

EPA has also considered the impacts of manufacturer learning on the technology cost estimates. Consistent with past EPA rulemakings, EPA has estimated that some costs would decline by 20 percent with each of the first two doublings of production beginning with the first year of implementation. These volume-based cost declines, which EPA calls "volume" based learning, take place after manufacturers have had the opportunity to find ways to improve upon their manufacturing processes or otherwise manufacture these technologies in a more efficient way. After two 20 percent cost reduction steps, the cost reduction learning curve flattens out considerably as only minor improvements in manufacturing techniques and efficiencies remain to be had. By then, costs decline roughly three percent per year as manufacturers and suppliers continually strive to reduce costs. These time-based cost declines, which EPA calls "time" based learning, take place at a rate of three percent per year. EPA has considered learning impacts on most but not all of the technologies expected to be used because some of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. EPA has considered volume-based learning for only a handful of technologies that EPA considers to be new or emerging technologies such as the hybrids and electric vehicles. For most technologies, EPA has considered them to be more established given their current use in the fleet and, hence, we have applied the lower time based learning. We have more discussion of our learning approach and the technologies to which we have applied which type of learning in Chapter 3 of the Joint TSD.

The technology cost estimates discussed in Section III.D and detailed in Chapter 3 of the Joint TSD are used to build up technology package cost estimates which are then used as inputs to the OMEGA model. EPA discusses our technology packages and package costs in Chapter 1 of the RIA. The model determines what level of CO_2 improvement is required considering the reference case for each manufacturer's fleet. The vehicle compliance costs are the outputs of the model and take into account FFV credits through 2015, TLAAS, full car/truck trading, and the A/C credit program. Table III.H.2–1 presents the fleet average incremental vehicle compliance costs for this rule. As the table indicates, 2012–2016 costs increase every year as the standards become more stringent. Costs per car and per truck then remain stable through 2021 while cost per vehicle (car/truck combined) decline slightly as the fleet mix trends slowly to increasing car sales. In 2022, costs per car and per truck decline as the long-term ICM is applied because some indirect costs decrease or are no longer considered attributable to the program (*e.g.,* warranty costs go down). Costs per car and per truck remain constant thereafter while the cost per vehicle declines slightly as the fleet continues to trend toward cars. By 2030, projections of fleet mix changes become static and the cost per vehicle remains constant. EPA has a more detailed presentation of vehicle compliance costs on a manufacturer by manufacturer basis in Chapter 6 of the RIA.

TABLE III.H.2–1—INDUSTRY AVERAGE VEHICLE COMPLIANCE COSTS ASSOCIATED WITH THE TAILPIPE CO_2 STANDARDS

[$/vehicle in 2007 dollars]

Calendar year	$/car	$/truck	$/vehicle (car & truck combined)
2012	$342	$314	$331

[453] Note that the assumption made here is that the standards would continue to apply for years beyond 2016 so that new vehicles sold in model years 2017 and later would continue to incur costs as a result of this rule. Those costs are estimated to get lower in 2022 because some of the indirect costs attributable to this rule in the years prior to 2022 would be eliminated in 2022 and later.

[454] Need to add the recent reference for this study by RTI. Alex Rogozhin et al., *Automobile Industry Regail Price Equivalent and Indirect Cost Multipliers.* Prepared for EPA by RTI International and Transportation Research Institute, University of Michigan. EPA–420–R–09–003, February 2009 (Docket EPA–HQ–OAR–2009–0472).

[455] Gloria Helfand and Todd Sherwood, "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Office of Transportation and Air Quality, U.S. EPA, August 2009 (Docket EPA–HQ–OAR–2009–0472).

[456] The RPE is based on the historical relationship between direct costs and consumer prices; it is intended to reflect the average markup over time required to sustain the industry as a viable operation. Unlike the RPE approach, the ICM focuses more narrowly on the changes that are required in direct response to regulation-induced vehicle design changes which may not directly influence all of the indirect costs that are incurred in the normal course of business. For example, an RPE markup captures all indirect costs including costs such as the retirement benefits of retired employees. However, the retirement benefits for retired employees are not expected to change as a result of a new GHG regulation and, therefore, those indirect costs should not increase in relation to newly added hardware in response to a regulation.

TABLE III.H.2–1—INDUSTRY AVERAGE VEHICLE COMPLIANCE COSTS ASSOCIATED WITH THE TAILPIPE CO_2 STANDARDS—Continued

[$/vehicle in 2007 dollars]

Calendar year	$/car	$/truck	$/vehicle (car & truck combined)
2013	507	496	503
2014	631	652	639
2015	749	820	774
2016	869	1,098	948
2017	869	1,098	947
2018	869	1,098	945
2019	869	1,098	943
2020	869	1,098	940
2021	869	1,098	939
2022	817	1,032	882
2030	817	1,032	878
2040	817	1,032	875
2050	817	1,032	875

b. Annual Costs of the Vehicle Program

The costs presented here represent the incremental costs for newly added technology to comply with the final program. Together with the projected increases in car and light-truck sales, the increases in per-vehicle average costs shown in Table III.H.2–1 above result in the total annual costs reported in Table III.H.2–2 below. Note that the costs presented in Table III.H.2–2 do not include the savings that would occur as a result of the improvements to fuel consumption. Those impacts are presented in Section III.H.4.

TABLE III.H.2–2—QUANTIFIED ANNUAL COSTS ASSOCIATED WITH THE VEHICLE PROGRAM

[$Millions of 2007 dollars]

Year	Quantified annual costs
2012	$4,900
2013	8,000
2014	10,300
2015	12,700
2016	15,600
2020	15,600
2030	15,800
2040	17,400
2050	19,000
NPV, 3%	345,900
NPV, 7%	191,900

3. Cost per Ton of Emissions Reduced

EPA has calculated the cost per ton of GHG (CO_2-equivalent, or CO_2e) reductions associated with this rule using the above costs and the emissions reductions described in Section III.F. More detail on the costs, emission reductions, and the cost per ton can be found in the RIA and Joint TSD. EPA has calculated the cost per metric ton of GHG emissions reductions in the years 2020, 2030, 2040, and 2050 using the annual vehicle compliance costs and emission reductions for each of those years. The value in 2050 represents the long-term cost per ton of the emissions reduced. EPA has also calculated the cost per metric ton of GHG emission reductions including the savings associated with reduced fuel consumption (presented below in Section III.H.4). This latter calculation does not include the other benefits associated with this rule such as those associated with criteria pollutant reductions or energy security benefits as discussed later in sections III.H.4 through III.H.9. By including the fuel savings in the cost estimates, the cost per ton is less than $0, since the estimated value of fuel savings outweighs the vehicle program costs. With regard to the CH_4 and N_2O standards, since these standards will be emissions caps designed to ensure that manufacturers do not backslide from current levels, EPA has not estimated costs associated with the standards (since the standards will not require any change from current practices nor does EPA estimate they will result in emissions reductions).

The results for CO_2e costs per ton under the rule are shown in Table III.H.3–1.

TABLE III.H.3–1—ANNUAL COST PER METRIC TON OF CO_2e REDUCED, IN $2007 DOLLARS

Year	Vehicle program cost [a] ($millions)	Fuel savings [b] ($millions)	CO_2e reduced (million metric tons)	Cost per ton of the vehicle program only [a]	Cost per ton of the vehicle program with fuel savings [b]
2020	$15,600	−$35,700	160	$100	−$130
2030	15,800	−79,800	310	50	−210
2040	17,400	−119,300	400	40	−250
2050	19,000	−171,200	510	40	−300

[a] Costs here include vehicle compliance costs and do not include any fuel savings.
[b] Fuel savings calculated using pre-tax fuel prices.

4. Reduction in Fuel Consumption and Its Impacts

a. What are the projected changes in fuel consumption?

The new CO_2 standards will result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles will see corresponding savings associated with reduced fuel expenditures. EPA has estimated the impacts on fuel consumption for both the tailpipe CO_2 standards and the A/C credit program. To do this, fuel consumption is calculated using both current CO_2 emission levels and the new CO_2 standards. The difference between these estimates represents the net savings from the CO_2 standards. Note that the total number of miles that vehicles are driven each year is different under each of the control case scenarios than in the reference case due to the "rebound effect," which is discussed in Section III.H.4.c. EPA also notes that consumers who drive more than our average estimates for vehicle miles traveled (VMT) will experience more fuel savings; consumers who drive less than our average VMT estimates will experience less fuel savings.

The expected impacts on fuel consumption are shown in Table III.H.4–1. The gallons shown in the tables reflect impacts from the new CO_2 standards, including the A/C credit program, and include increased consumption resulting from the rebound effect.

TABLE III.H.4–1—FUEL CONSUMPTION IMPACTS OF THE VEHICLE STANDARDS AND A/C CREDIT PROGRAMS

[Million gallons]

Year	Total
2012	550
2013	1,320
2014	2,330
2015	3,750
2016	5,670
2020	12,590
2030	24,730
2040	32,620
2050	41,520

b. What are the monetized fuel savings?

Using the fuel consumption estimates presented in Section III.H.4.a, EPA can calculate the monetized fuel savings associated with the CO_2 standards. To do this, we multiply reduced fuel consumption in each year by the corresponding estimated average fuel price in that year, using the reference case taken from the AEO 2010 Early Release.[457] AEO is the government consensus estimate used by NHTSA and many other government agencies to estimate the projected price of fuel. EPA has done this calculation using both the pre-tax and post-tax fuel prices. Since the post-tax fuel prices are what consumers pay, the fuel savings calculated using these prices represent the savings consumers will see. The pre-tax fuel savings are those savings that society will see. These results are shown in Table III.H.4–2. Note that in Section III.H.10, EPA presents the benefit-cost of the rule and, for that reason, presents only the pre-tax fuel savings.

TABLE III.H.4–2—ESTIMATED MONETIZED FUEL SAVINGS

[Millions of 2007 dollars]

Calendar year	Fuel savings (pre-tax)	Fuel savings (post-tax)
2012	$1,137	$1,400
2013	2,923	3,800
2014	5,708	6,900
2015	9,612	11,300
2016	14,816	17,400
2020	35,739	41,100
2030	79,838	89,100
2040	119,324	131,700
2050	171,248	186,300
NPV, 3%	1,545,638	1,723,900
NPV, 7%	672,629	755,700

As shown in Table III.H.4–2, EPA is projecting that consumers would realize very large fuel savings as a result of the standards contained in this rule. As discussed further in Section III.H.1, it is a conundrum from an economic perspective that these large fuel savings have not been provided by automakers and purchased by consumers. A number of behavioral and market phenomena may lead to this disparity between the fuel economy that makes financial sense to consumers and the fuel economy they purchase. Regardless how consumers make their decisions on how much fuel economy to purchase, EPA expects that, in the aggregate, they will gain these fuel savings, which will provide actual money in consumers' pockets. We received considerable comment on this issue, as discussed in Section III.H.1, and the issue is discussed further in Chapter 8 of the RIA.

c. VMT Rebound Effect

The fuel economy rebound effect refers to the fraction of fuel savings expected to result from an increase in vehicle fuel economy, particularly one required by higher fuel efficiency standards, that is offset by additional vehicle use. The increase in vehicle use occurs because higher fuel economy reduces the fuel cost of driving, which is typically the largest single component of the monetary cost of operating a

[457] Energy Information Administration. Annual Energy Outlook 2010 Early Release. Supplemental Transportation Tables. December 2009. *http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls.*

vehicle, and vehicle owners respond to this reduction in operating costs by driving slightly more.

For this rule, EPA is using an estimate of 10% for the rebound effect. This value is based on the most recent time period analyzed in the Small and Van Dender 2007 paper,[458] and falls within the range of the larger body of historical work on the rebound effect.[459] Recent work by David Greene on the rebound effect for light-duty vehicles in the U.S. further supports the hypothesis that the rebound effect is decreasing over time.[460] If we were to use a dynamic estimate of the future rebound effect, our analysis shows that the rebound effect could be in the range of 5% or lower.[461] The rebound effect is also further discussed in Chapter 4 of the Joint TSD which reviews the relevant literature and discusses in more depth the reasoning for the rebound values used here.

We received several comments on the proposed value of the rebound effect. The California Air Resources Board (CARB) and the New Jersey Department of Environmental Protection supported the use of a 10% rebound effect, although CARB encouraged EPA to consider lowering the value to 5%. Other commenters, such as the Missouri Department of Natural Resources, the International Council on Clean Transportation (ICCT), the Center for Biological Diversity, and the Consumer Federation of America, recommended using a lower rebound effect. ICCT specifically recommended that the dynamic rebound effect methodology utilized by Small & Van Dender was the most appropriate methodology, which would support a rebound effect of 5% or lower. In contrast, the National Association of Dealerships asserted that the rebound effect should be higher (*e.g.,* in the lower range of the 15–30% historical range), but did not submit any data to support this claim.

While we appreciate the input provided by commenters, we did not receive any new data or analysis to justify revising our initial estimates of the rebound effect at this time. Based on the positive comments we received, we will continue using the dynamic rebound effect to help inform our estimate of the rebound effect in future rulemakings. However, given the relatively new nature of this analytical approach, we believe the larger body of historical studies should also be considered when determining the value of the rebound effect. As we described in the Technical Support Document, the more recent literature suggests that the rebound effect is 10% or lower, whereas the larger body of historical studies suggests a higher rebound effect. Therefore, we will continue to use the 10% rebound effect for this rulemaking. However, we plan to update our estimate of the rebound effect in future rulemakings as new data becomes available.

We also invited comments on whether we should also explore other alternatives for estimating the rebound effect, such as whether it would be appropriate to use the price elasticity of demand for gasoline to guide the choice of a value for the rebound effect. We received only one comment on this issue from ICCT. In their comments, ICCT stated that the short run elasticity can provide a useful point of comparison for rebound effect estimates, but it should not be used to guide the choice of a value for the rebound effect. Therefore, we have not incorporated this metric into our analysis.

5. Impacts on U.S. Vehicle Sales and Payback Period

a. Vehicle Sales Impacts

This analysis compares two effects. On the one hand, the vehicles will become more expensive, which would, by itself, discourage sales. On the other hand, the vehicles will have improved fuel economy and thus lower operating costs. If consumers do not accurately compare the value of fuel savings with the increased cost of fuel economy technology in their vehicle purchase decisions, as discussed in Preamble III.H.1, they will continue to behave in this way after this rule. If auto makers have accurately gauged how consumers consider fuel economy when purchasing vehicles and have provided the amount that consumers want in vehicles, then consumers should not be expected to want the more fuel-efficient vehicles. After all, auto makers would have provided as much fuel economy as consumers want. If, on the other hand, auto makers underestimated consumer demand for fuel economy, as suggested by some commenters and discussed in Preamble Section III.H.1 and RIA Section 8.1.2, then this rule may lead to production of more desirable vehicles, and vehicle sales may increase. This assumption implies that auto makers have missed some profit-making opportunities.

The methodology EPA used for estimating the impact on vehicle sales is relatively straightforward, but makes a number of simplifying assumptions. According to the literature, the price elasticity of demand for vehicles is commonly estimated to be -1.0.[462] In other words, a one percent increase in the price of a vehicle would be expected to decrease sales by one percent, holding all other factors constant. For our estimates, EPA calculated the effect of an increase in vehicle costs due to the GHG standards and assumes that consumers will face the full increase in costs, not an actual (estimated) change in vehicle price. (The estimated increases in vehicle cost due to the rule are discussed in Section III.H.2.) This is a conservative methodology, since an increase in cost may not pass fully into an increase in market price in an oligopolistic industry such as the automotive sector.[463] EPA also notes that we have not used these estimated sales impacts in the OMEGA Model.

Although EPA uses the one percent price elasticity of demand for vehicles as the basis for our vehicle sales impact estimates, we assumed that the consumer would take into account both the higher vehicle purchasing costs as well as some of the fuel savings benefits when deciding whether to purchase a new vehicle. Therefore, the incremental cost increase of a new vehicle would be offset by reduced fuel expenditures over a certain period of time (*i.e.,* the "payback period"). For the purposes of this rulemaking, EPA used a five-year payback period, which is consistent with the length of a typical new light-

[458] Small, K. and K. Van Dender, 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect", The Energy Journal, vol. 28, no. 1, pp. 25–51 (Docket EPA–HQ–OAR–2009–0472–0018).

[459] Sorrell, S. and J. Dimitropoulos, 2007. "UKERC Review of Evidence for the Rebound Effect, Technical Report 2: Econometric Studies", UKERC/WP/TPA/2007/010, UK Energy Research Centre, London, October (Docket EPA–HQ–OAR–2009–0472–0012).

[460] Report by Kenneth A. Small of University of California at Irvine to EPA, "The Rebound Effect from Fuel Efficiency Standards: Measurement and Projection to 2030", June 12, 2009 (Docket EPA–HQ–OAR–2009–0472–0002).

[461] Revised Report by David Greene of Oak Ridge National Laboratory to EPA, "Rebound 2007: Analysis of National Light-Duty Vehicle Travel Statistics," February 9, 2010 (Docket EPA–HQ–OAR–2009–0472–0220). This paper has been accepted for an upcoming special issue of Energy Policy, although the publication date has not yet been determined.

[462] Kleit A.N., 1990. "The Effect of Annual Changes in Automobile Fuel Economy Standards." Journal of Regulatory Economics 2: 151–172 (Docket EPA–HQ–OAR–2009–0472–0015); McCarthy, Patrick S., 1996. "Market Price and Income Elasticities of New Vehicle Demands." Review of Economics and Statistics 78: 543–547 (Docket EPA–HQ–OAR–2009–0472–0016); Goldberg, Pinelopi K., 1998. "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," Journal of Industrial Economics 46(1): 1–33 (Docket EPA–HQ–OAR–2009–0472–0017).

[463] See, for instance, Gron, Ann, and Deborah Swenson, 2000. "Cost Pass-Through in the U.S. Automobile Market," Review of Economics and Statistics 82: 316–324 (Docket EPA–HQ–OAR–2009–0472–0007).

duty vehicle loan.[464] The one commenter on this analysis stated that use of the five-year payback period was reasonable. This approach may not accurately reflect the role of fuel savings in consumers' purchase decisions, as the discussion in Section III.H.1 suggests. If consumers consider fuel savings in a different fashion than modeled here, then this approach will not accurately reflect the impact of this rule on vehicle sales.

This increase in costs has other effects on consumers as well: if vehicle prices increase, consumers will face higher insurance costs and sales tax, and additional finance costs if the vehicle is bought on credit. In addition, the resale value of the vehicles will increase. EPA received no comments on these adjustments. The only change to these adjustments between the NPRM and this discussion is an updating of the interest rate on auto loans. EPA estimates that, with corrections for these factors, the effect on consumer expenditures of the cost of the new technology should be 0.914 times the cost of the technology at a 3% discount rate, and 0.876 times the cost of the technology at a 7% discount rate. The details of this calculation are in the RIA, Chapter 8.1.

Once the cost estimates are adjusted for these additional factors, the fuel cost savings associated with the rule, discussed in Section III.H.4, are subtracted to get the net effect on consumer expenditures for a new vehicle. With the assumed elasticity of demand of −1, the percent change in this "effective price," estimated as the adjusted increase in cost, is equal to the negative of the percent change in vehicle purchases. The net effect of this calculation is in Table III.H.5–1 and Table III.H.5–2. The values have changed slightly from the NPRM, due to changes in fuel prices and fuel savings, technology costs, and baseline vehicle sales projections, in addition to the adjustment in financing costs.

The estimates provided in Table III.H.5–1 and Table III.H.5–2 are meant to be illustrative rather than a definitive prediction. When viewed at the industry-wide level, they give a general indication of the potential impact on vehicle sales. As shown below, the overall impact is positive and growing over time for both cars and trucks. Because the fuel savings associated with this rule are expected to exceed the technology costs, the effective prices of vehicles (the adjusted increase in technology cost less the fuel savings over five years) to consumers will fall, and consumers will buy more new vehicles. As a result, the lower net cost of the vehicles is projected to lead to an increase in sales for both cars and trucks.

As discussed above, this result depends on the assumption that more fuel efficient vehicles that yield net consumer benefits over five years would not otherwise be offered on the vehicle market due to market failures on the part of vehicle manufacturers. If vehicles that achieve the fuel economy standards prescribed by today's rulemaking would already be available, but consumers chose not to purchase them, then this rulemaking would not result in an increase in vehicle sales, because it does not alter how consumers make decisions about which vehicles to purchase. In addition, this analysis has not accounted for a number of factors that might affect consumer vehicle purchases, such as changing market conditions, changes in vehicle characteristics that might accompany improvements in fuel economy, or consumers considering a different "payback period" for their fuel economy purchases. If consumers use a shorter payback period, the sales impacts will be less positive, possibly negative; if consumers use a higher payback period, the impacts will be more positive. Also, this is an aggregate analysis; some individual consumers (those who drive less than estimated here) will face lower net benefits, while others (who drive more than estimated here) will have even greater savings. These complications add considerable uncertainty to our vehicle sales impact analysis.

TABLE III.H.5–1—VEHICLE SALES IMPACTS USING A 3% DISCOUNT RATE

	Change in car sales	% Change	Change in truck sales	% Change
2012	67,500	0.7	62,100	1.1
2013	76,000	0.8	190,200	3.2
2014	114,000	1.1	254,900	4.3
2015	222,200	2.1	352,800	6.1
2016	360,500	3.3	488,000	8.6

Table III.H.5–1 shows the impacts on new vehicle sales using a 3% discount rate. The fuel savings over five years are always higher than the technology costs. Although both cars and trucks show very small effects initially, over time vehicle sales become increasingly positive, as increased fuel prices make improved fuel economy more desirable. The increases in sales for trucks are larger than the increases for trucks (except in 2012) in both absolute numbers and percentage terms.

TABLE III.H.5–2—NEW VEHICLE SALES IMPACTS USING A 7% DISCOUNT RATE

	Change in car sales	% Change	Change in truck sales	% Change
2012	62,800	0.7	58,300	1
2013	70,500	0.7	92,300	1.5
2014	106,100	1	127,700	2.1

[464] As discussed further in Section III.H.1, there is not a consensus in the literature on how consumers consider fuel economy in their vehicle purchases. Results are inconsistent, possibly due to fuel economy not being a major focus of many of the studies, and possibly due to sensitivity of results to modeling and data used. A survey by Greene (Greene, David L. "How Consumers Value Fuel Economy: A Literature Review." EPA Report EPA–420–R–10–008, March 2010 (Docket EPA–HQ–OAR–2009–0472–11575)) finds that estimates in the literature of the value that consumers place on fuel economy when buying a vehicle range from negative—consumers would pay to *reduce* fuel economy—to more than 1000 times the value of fuel savings.

TABLE III.H.5–2—NEW VEHICLE SALES IMPACTS USING A 7% DISCOUNT RATE—Continued

	Change in car sales	% Change	Change in truck sales	% Change
2015	208,400	2	194,200	3.3
2016	339,400	3.1	280,000	4.9

Table III.H.5–2 shows the impacts on new vehicle sales using a 7% interest rate. While a 7% interest rate shows slightly lower impacts than using a 3% discount rate, the results are qualitatively similar to those using a 3% discount rate. Sales increase for every year. For both cars and trucks, sales become increasingly positive over time, as higher fuel prices make improved fuel economy more valuable. The car market grows more than the truck market in absolute numbers, but less on a percentage basis.

The effect of this rule on the use and scrappage of older vehicles will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, and the total sales of new vehicles. If the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' prices, sales of new vehicles will rise, while scrappage rates of used vehicles will increase slightly. This will cause the "turnover" of the vehicle fleet (*i.e.,* the retirement of used vehicles and their replacement by new models) to accelerate slightly, thus accentuating the anticipated effect of the rule on fleet-wide fuel consumption and CO_2 emissions. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles will decline, as will the rate at which used vehicles are retired from service. This effect will slow the replacement of used vehicles by new models, and thus partly offset the anticipated effects of this rule on fuel use and emissions.

Because the agencies are uncertain about how the value of projected fuel savings from this rule to potential buyers will compare to their estimates of increases in new vehicle prices, we have not attempted to estimate explicitly the effects of the rule on scrappage of older vehicles and the turnover of the vehicle fleet.

A detailed discussion of the vehicle sales impacts methodology is provided in the Chapter 8 of EPA's RIA.

b. Consumer Payback Period and Lifetime Savings on New Vehicle Purchases

Another factor of interest is the payback period on the purchase of a new vehicle that complies with the new standards. In other words, how long would it take for the expected fuel savings to outweigh the increased cost of a new vehicle? For example, a new 2016 MY vehicle is estimated to cost $948 more (on average, and relative to the reference case vehicle) due to the addition of new GHG reducing technology (see Section III.D.6 for details on this cost estimate). This new technology will result in lower fuel consumption and, therefore, savings in fuel expenditures (*see* Section III.H.10) for details on fuel savings). But how many months or years would pass before the fuel savings exceed the upfront cost of $948?

Table III.H.5–3 provides the answer to this question for a vehicle purchaser who pays for the new vehicle upfront in cash (we discuss later in this section the payback period for consumers who finance the new vehicle purchase with a loan). The table uses annual miles driven (vehicle miles traveled, or VMT) and survival rates consistent with the emission and benefits analyses presented in Chapter 4 of the Joint TSD. The control case includes rebound VMT but the reference case does not, consistent with other parts of the analysis. Also included are fuel savings associated with A/C controls (in the control case only). Not included here are the likely A/C-related maintenance savings as discussed in Chapter 2 of EPA's RIA. Further, this analysis does not include other societal impacts such as the value of increased driving, or noise, congestion and accidents since the focus is meant to be on those factors consumers think about most while in the showroom considering a new car purchase. Car/truck fleet weighting is handled as described in Chapter 1 of the Joint TSD. As can be seen in the table, it will take under 3 years (2 years and 7 months at a 3% discount rate, 2 years and 9 months at a 7% discount rate) for the cumulative discounted fuel savings to exceed the upfront increase in vehicle cost. More detail on this analysis can be found in Chapter 8 of EPA's RIA.

TABLE III.H.5–3—PAYBACK PERIOD ON A 2016 MY NEW VEHICLE PURCHASE VIA CASH

[2007 dollars]

Year of ownership	Increased vehicle cost [a]	Annual fuel savings [b]	Cumulative discounted fuel savings at 3%	Cumulative discounted fuel savings at 7%
1	$1,018	$424	$418	$410
2		$420	$820	$790
3		$414	$1,204	$1,139
4		$402	$1,567	$1,457

[a] Increased vehicle cost due to the rule is $948; the value here includes nationwide average sales tax of 5.3% and increased insurance premiums of 1.98%; both of these percentages are discussed in Section 8.1.1 of EPA's RIA.

[b] Calculated using AEO 2010 Early Release reference case fuel price including taxes.

However, most people purchase a new vehicle using credit rather than paying cash up front. The typical car loan today is a five year, 60 month loan. As of February 9, 2010, the national average interest rate for a 5 year new car loan was 6.54 percent. If the increased vehicle cost is spread out over 5 years at 6.54 percent, the analysis would look like that shown in Table III.H.5–4. As can be seen in this table, the fuel savings immediately outweigh the increased payments on the car loan, amounting to $177 in discounted net savings (3% discount rate) in the first year and similar savings for the next two years before reduced VMT starts to cause the fuel savings to fall. Results are similar using a 7% discount rate. This means that for every month that the average owner is making a payment for the financing of the average new vehicle their monthly fuel savings would be greater than the increase in the loan payments. This amounts to a savings on the order of $9 to $15 per month throughout the duration of the 5 year loan. Note that in year six when the car loan is paid off, the net savings equal the fuel savings (as would be the case for the remaining years of ownership).

TABLE III.H.5–4—PAYBACK PERIOD ON A 2016 MY NEW VEHICLE PURCHASE VIA CREDIT

[2007 dollars]

Year of ownership	Increased vehicle cost [a]	Annual fuel savings [b]	Annual discounted net savings at 3%	Annual discounted net savings at 7%
1	$245	$424	$177	$173
2	$245	$420	$167	$158
3	$245	$414	$157	$142
4	$245	$402	$142	$124
5	$245	$391	$127	$107
6	$0	$374	$318	$258

[a] This uses the same increased cost as Table III.H.4–3 but spreads it out over 5 years assuming a 5 year car loan at 6.54 percent.

[b] Calculated using AEO 2010 Early Release reference case fuel price including taxes.

The lifetime fuel savings and net savings can also be calculated for those who purchase the vehicle using cash and for those who purchase the vehicle with credit. This calculation applies to the vehicle owner who retains the vehicle for its entire life and drives the vehicle each year at the rate equal to the national projected average. The results are shown in Table III.H.5–5. In either case, the present value of the lifetime net savings is greater than $3,100 at a 3% discount rate, or $2,300 at a 7% discount rate.

TABLE III.H.5–5—LIFETIME DISCOUNTED NET SAVINGS ON A 2016 MY NEW VEHICLE PURCHASE

[2007 dollars]

Purchase option	Increased discounted vehicle cost	Lifetime discounted fuel savings [b]	Lifetime discounted net savings
3% discount rate			
Cash	$1,018	$4,306	$3,303
Credit [a]	1,140	4,306	3,166
7% discount rate			
Cash	1,018	3,381	2,396
Credit [a]	1,040	3,381	2,340

[a] Assumes a 5 year loan at 6.54 percent.

[b] Fuel savings here were calculated using AEO 2010 Early Release reference case fuel price including taxes.

Note that throughout this consumer payback discussion, the average number of vehicle miles traveled per year has been used. Drivers who drive more miles than the average would incur fuel related savings more quickly and, therefore, the payback would come sooner. Drivers who drive fewer miles than the average would incur fuel related savings more slowly and, therefore, the payback would come later.

6. Benefits of Reducing GHG Emissions

a. Social Cost of Carbon

In today's final rule, EPA and NHTSA assigned a dollar value to reductions in CO_2 emissions using the marginal dollar value of climate-related damages resulting from carbon emissions, also referred to as "social cost of carbon" (SCC). The SCC estimates used in today's rule were recently developed by an interagency process, in which EPA and NHTSA participated. As part of the interagency group, EPA and NHTSA have critically evaluated the new SCC estimates and endorse them for use in these regulatory analyses, for the reasons presented below. The SCC TSD, *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* presents a more detailed description of the methodology used to generate the new estimates, the underlying assumptions, and the limitations of the new SCC estimates.

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions from light-duty vehicles into a cost-benefit analysis of this final rule, which has a small, or "marginal," impact on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The interagency process that developed these SCC estimates involved a group of technical experts from numerous agencies, which met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in this rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses, which EPA and NHTSA have applied to this final rule. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

TABLE III.H.6–1—SOCIAL COST OF CO_2, 2010—2050[a]

[in 2007 dollars]

Year	Discount Rate			
	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	5	21	35	65
2015	6	24	38	73
2020	7	26	42	81
2025	8	30	46	90
2030	10	33	50	100
2035	11	36	54	110
2040	13	39	58	119
2045	14	42	62	128
2050	16	45	65	136

[a] The SCC estimates presented above have been rounded to nearest dollar for consistency with the benefits analysis. The SCC TSD presents estimates rounded to the nearest tenth of a cent.

i. Monetizing Carbon Dioxide Emissions

The "social cost of carbon" (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of carbon dioxide throughout this document.

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A 2009 report from the National Academies of Science points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages.[465] As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." EPA and NHTSA have used the SCC estimates to incorporate social benefits from reducing carbon dioxide emissions from light-duty vehicles into a cost-benefit analysis of this final rule, which has a small, or "marginal," impact on cumulative global emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions.

For policies that have marginal impacts on global emissions, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

As noted above, the interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. In addition to EPA and NHTSA, agencies that actively participated in the interagency process included the Departments of Agriculture, Commerce, Energy, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible

[465] National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use.* National Academies Press.

set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four global SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020. See the SCC TSD for the full range of annual SCC estimates from 2010 to 2050.

These new SCC estimates represent global measures and the center of our current attention because of the distinctive nature of the climate change problem. The climate change problem is highly unusual in at least two respects. First, it involves a global externality: Emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, the interagency group has set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, the interagency group will continue to explore the issues raised in the SCC TSD and consider public comments as part of the ongoing interagency process.

ii. Social Cost of Carbon Values Used in Past Regulatory Analyses

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of $2 per ton of CO_2 and a "global" SCC value of $33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0-$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: Global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2. The $33 and $5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models (DICE, PAGE, and FUND) at approximately 3 and 5 percent discount rates.[466] The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively.[467] The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. Government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules. In particular, EPA and NHTSA used the interim SCC estimates in the joint proposal leading to this final rule.

iii. Approach and Key Assumptions

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates, which EPA and NHTSA used in this final rule. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. The general approach to estimating SCC values was to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 C and a cumulative probability between 2 and 4.5 C of two-thirds.[468]

[466] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy, is now widely used to study climate impacts (*e.g.,* Tol 2002a, Tol 2002b, Anthoff *et al.* 2009, Tol 2009).

[467] Newell, R., and W. Pizer. 2003. Discounting the distant future: How much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46: 52–71.

[468] Roe, G., and M. Baker. 2007. "Why is climate sensitivity so unpredictable?" *Science* 318:629–632.

Five sets of GDP, population and carbon emissions trajectories based on the recent Stanford Energy Modeling Forum, EMF–22.

Constant annual discount rates of 2.5, 3, and 5 percent.

The SCC TSD presents a summary of the results and details, the modeling exercise and the choices and assumptions that underlie the resulting estimates of the SCC. The complete model results are available in the docket for this final rule [EPA–HQ–OAR–2009–0472].

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. The SCC TSD highlights a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

iv. Use of New SCC Estimates To Calculate GHG Benefits for This Final Rule

The table below summarizes the total GHG benefits for the lifetime of the rule, which are calculated by using the four new SCC values. Specifically, EPA calculated the total monetized benefits in each year by multiplying the marginal benefits estimates per metric ton of CO_2 (the SCC) by the reductions in CO_2 for that year.

TABLE III.H.6–2—MONETIZED CO_2 BENEFITS OF VEHICLE PROGRAM, CO_2 EMISSIONS [a b]

[Million 2007$]

Year	CO_2 emissions reduction (Million metric tons)	Benefits			
		Avg SCC at 5% ($5–$16) [c]	Avg SCC at 3% ($21–$45) [c]	Avg SCC at 2.5% ($35–$65) [c]	95th percentile SCC at 3% ($65–$136) [c]
2020	139	$900	$3,700	$5,800	$11,000
2030	273	2,700	8,900	14,000	27,000
2040	360	4,600	14,000	21,000	43,000
2050	459	7,200	21,000	30,000	62,000

[a] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[b] Numbers may not compute exactly from Tables III.H.6–1 and III.H.6–2 due to rounding.

[c] As noted above, SCC increases over time; tables lists ranges for years 2010 through 2050. See Table III.H.6–1 for the SCC estimates corresponding to the years in this table.

b. Summary of the Response to Comments

EPA and NHTSA received extensive public comments about the scientific, economic, and ethical issues involved in estimating the SCC, including the proposed rule's estimates of the value of emissions reductions from new cars and trucks.[469] In particular, the comments addressed the methodology used to derive the interim SCC estimates, limitations of integrated assessment models, discount rate selection, treatment of uncertainty and catastrophic impacts, use of global and domestic SCC, and the presentation and use of SCC estimates. The rest of this preamble section briefly summarizes EPA's response to the comments; the Response to Comments document provides the complete responses to all comments received.

EPA received extensive comments about the methodology and discount rates used to derive the interim SCC estimates. While one commenter from the auto industry noted that the interim methodology was acceptable given available data, many commenters (representing academic and environmental organizations) expressed concerns that the filters were too narrow, stated that model-weighting averaging was inappropriate, and recommended that EPA use lower discount rates. These commenters also discussed alternative approaches to select discount rates and generally recommended that EPA use lower rates to give more weight to climate damages experienced by future generations.

For the final rule, EPA conducted new analyses of SCC. EPA did not continue with its interim approach to derive estimates from the existing literature and instead conducted new model runs that produced a vast amount of SCC data at three separate certainty-equivalent discount rates (2.5, 3, and 5 percent). As discussed further in the SCC TSD, this modeling exercise resulted in a fuller distribution of SCC estimates and better accounted for uncertainty through a Monte Carlo analysis. Comments on specific issues are addressed in the Response to Comments document.

EPA received comments on the limitations of the integrated assessment models concluding that the selection of models and reliance on the model authors' datasets contributed to the downward bias of the interim SCC estimates. In this final rule, EPA relied on the default values in each model for the remaining parameter; research gaps

[469] EPA estimated GHG benefits in the proposed rule using a set of interim SCC values developed by an interagency group, in which EPA and NHTSA participated. As discussed in the SCC TSD, the interagency group selected the interim estimates from the existing literature and agreed to use those interim estimates in regulatory analyses until it could develop a more comprehensive characterization of the SCC.

and practical constraints required EPA to limit its modification of the models to socioeconomic and emissions scenarios, climate sensitivity, and discount rate. While EPA recognizes that the models' translations of physical impacts to economic values are incomplete, approximate, and highly uncertain, it regards them as the best currently available representations. EPA also considered, for each model, the treatment of uncertainty, catastrophic impacts, and omitted impacts, and as discussed in the SCC TSD and the Response to Comments document, used best available information and techniques to quantify such impacts as feasible and supplemented the SCC with qualitative assessments. Comments on specific issues are addressed in the Response to Comments document.

Six commenters, representing academia and environmental organizations, supported the proposed rule's preference for global SCC estimates while several industry groups stated that under the Clean Air Act, EPA is prohibited from using global estimates. EPA agrees that a global measure of GHG mitigation benefits is both appropriate and lawful for EPA to consider in evaluating the benefits of GHG emissions standards adopted under section 202(a). Global climate change represents a problem that the United States cannot solve alone without global action, and for a variety of reasons there is a value to the U.S. from domestic emissions reductions that reduce the harm occurring globally. This is not exercise of regulatory authority over conduct occurring overseas, but instead is a reasonable exercise of discretion in how to place a monetary value on a reduction in domestic emissions. See the Response to Comments document for a complete discussion of this issue.

Finally, EPA received various comments regarding the presentation of the SCC methodology and resulting estimates. EPA has responded to these concerns by presenting a detailed discussion about the methodology, including key model assumptions, as well as uncertainties and research gaps associated with the SCC estimates and the implications for the SCC estimates. Among these key assumptions and uncertainties are issues involving discount rates, climate sensitivity and socioeconomic scenario assumptions, incomplete treatment of potential catastrophic impacts, incomplete treatment of non-catastrophic impacts, uncertainty in extrapolation of damages to high temperatures, incomplete treatment of adaptation and technological change, and assumptions about risk aversion to high-impact outcomes (*see* SCC TSD).

7. Non-Greenhouse Gas Health and Environmental Impacts

This section presents EPA's analysis of the non-GHG health and environmental impacts that can be expected to occur as a result of the light-duty vehicle GHG rule. GHG emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutants. The vehicles that are subject to the standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The standards will affect exhaust emissions of these pollutants from vehicles. They will also affect emissions from upstream sources related to changes in fuel consumption. Changes in ambient ozone, $PM_{2.5}$, and air toxics that will result from the standards are expected to affect human health in the form of premature deaths and other serious human health effects, as well as other important public health and welfare effects.

As many commenters noted, it is important to quantify the health and environmental impacts associated with the final rule because a failure to adequately consider these ancillary co-pollutant impacts could lead to an incorrect assessment of their net costs and benefits. Moreover, co-pollutant impacts tend to accrue in the near term, while any effects from reduced climate change mostly accrue over a timeframe of several decades or longer.

This section is split into two sub-sections: The first presents the PM- and ozone-related health and environmental impacts associated with the final rule in calendar year (CY) 2030; the second presents the PM-related benefits-per-ton values used to monetize the PM-related co-benefits associated with the model year (MY) analysis of the final rule.[470]

a. Quantified and Monetized Non-GHG Human Health Benefits of the 2030 Calendar Year (CY) Analysis

This analysis reflects the impact of the final light-duty GHG rule in 2030 compared to a future-year reference scenario without the rule in place. Overall, we estimate that the final rule will lead to a net decrease in $PM_{2.5}$-related health impacts (see Section III.G.5 of this preamble for more information about the air quality modeling results). While the PM-related air quality impacts are relatively small, the decrease in population-weighted national average $PM_{2.5}$ exposure results in a net decrease in adverse PM-related human health impacts (the decrease in national population-weighted annual average $PM_{2.5}$ is 0.0036 g/m^3).

The air quality modeling (discussed in Section III.G.5) projects very small increases in ozone concentrations in many areas, but these are driven by the ethanol production volumes mandated by the recently finalized RFS2 rule and are not due to the standards finalized in this rule. While the ozone-related impacts are very small, the increase in population-weighted national average ozone exposure results in a small increase in ozone-related health impacts (population-weighted maximum 8-hour average ozone increases by 0.0104 ppb).

We base our analysis of the final rule's impact on human health in 2030 on peer-reviewed studies of air quality and human health effects.[471] [472] These methods are described in more detail in the RIA that accompanies this action. Our benefits methods are also consistent with recent rulemaking analyses such as the proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[473] the final NO_2 NAAQS,[474] and the final Category 3 Marine Engine rule.[475] To model the

[470] EPA typically analyzes rule impacts (emissions, air quality, costs and benefits) in the year in which they occur; for this analysis, we selected 2030 as a representative future year. We refer to this analysis as the "Calendar Year" (CY) analysis. EPA also conducted a separate analysis of the impacts over the model year lifetimes of the 2012 through 2016 model year vehicles. We refer to this analysis as the "Model Year" (MY) analysis. In contrast to the CY analysis, the MY lifetime analysis shows the lifetime impacts of the program on each of these MY fleets over the course of its lifetime.

[471] U.S. Environmental Protection Agency. (2006). *Final Regulatory Impact Analysis (RIA) for the National Ambient Air Quality Standards for Particulate Matter.* Prepared by: Office of Air and Radiation. Retrieved March 26, 2009 at *http://www.epa.gov/ttn/ecas/ria.html.* EPA–HQ–OAR–2009–0472–0240.

[472] U.S. Environmental Protection Agency. (2008). *Final Ozone NAAQS Regulatory Impact Analysis.* Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved March 26, 2009 at *http://www.epa.gov/ttn/ecas/ria.html.* EPA–HQ–OAR–2009–0472–0238.

[473] U.S. Environmental Protection Agency (U.S. EPA). 2009. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at *http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf.* Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0241.

[474] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final NO_2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at *http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf.* Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0237.

[475] U.S. Environmental Protection Agency. 2009. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel

ozone and PM air quality impacts of the final rule, we used the Community Multiscale Air Quality (CMAQ) model (see Section III.G.5). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[476] BenMAP is a computer program developed by the U.S. EPA that integrates a number of the modeling elements used in previous analyses (*e.g.,* interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

The range of total monetized ozone- and PM-related health impacts is presented in Table III.H.7–1. We present total benefits based on the PM- and ozone-related premature mortality function used. The benefits ranges therefore reflect the addition of each estimate of ozone-related premature mortality (each with its own row in Table III.H.7–1) to estimates of PM-related premature mortality. These estimates represent EPA's preferred approach to characterizing a best estimate of benefits. As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve to reflect the Agency's most current interpretation of the scientific and economic literature.

TABLE III.H.7–1—ESTIMATED 2030 MONETIZED PM- AND OZONE-RELATED HEALTH BENEFITS [a]

2030 Total Ozone and PM Benefits—PM Mortality Derived from American Cancer Society Analysis and Six-Cities Analysis [a]			
Premature Ozone Mortality Function	Reference	Total Benefits (Millions, 2007$, 3% Discount Rate) [b c d]	Total Benefits (Millions, 2007$, 7% Discount Rate) [b c d]
Multi-city analyses	Bell *et al.,* 2004	Total: $510–$1,300 PM: $550–$1,300 Ozone: −$40	Total: $460–$1,200 PM: $500–$1,200 Ozone: −$40
	Huang *et al.,* 2005	Total: $490–$1,300 PM: $550–$1,300 Ozone: −$64	Total: $440–$1,200 PM: $500–$1,200 Ozone: −$64
	Schwartz, 2005	Total: $490–$1,300 PM: $550–$1,300 Ozone: −$60	Total: $440–$1,200 PM: $500–$1,200 Ozone: −$60
Meta-analyses	Bell *et al.,* 2005	Total: $430–$1,200 PM: $550–$1,300 Ozone: −$120	Total: $380–$1,100 PM: $500–$1,200 Ozone: −$120
	Ito *et al.,* 2005	Total: $380–$1,200 PM: $550–$1,300 Ozone: −$170	Total: $330–$1,000 PM: $500–$1,200 Ozone: −$170
	Levy *et al.,* 2005	Total: $380–$1,200 PM: $550–$1,300 Ozone: −$170	Total: $330–$1,000 PM: $500–$1,200 Ozone: −$170

Notes:

[a] Total includes premature mortality-related and morbidity-related ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope *et al.,* 2002)[477] or the Six-Cities study (Laden et al., 2006).[478]

[b] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table III.H.7–2.

[c] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A–4. Results are rounded to two significant digits for ease of presentation and computation.

[d] Negatives indicate a disbenefit, or an increase in health effect incidence.

The benefits in Table III.H.7–1 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (*e.g.,* changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas. These are listed in Table III.H.7–2. As a result, the health benefits quantified in this section are likely underestimates of the total benefits attributable to the final rule.

Engines. EPA–420–R–09–019, December 2009. Prepared by Office of Air and Radiation. *http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf.* Accessed February 9, 2010. EPA–HQ–OAR–2009–0472–0283.

[476] Information on BenMAP, including downloads of the software, can be found at *http://www.epa.gov/ttn/ecas/benmodels.html.*

[477] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston (2002). "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132–1141. EPA–HQ–OAR–2009–0472–0263.

[478] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery (2006). Reduction in Fine Particulate Air Pollution and Mortality. American Journal of Respiratory and Critical Care Medicine. 173:667–672. EPA–HQ–OAR–2009–0472–1661.

TABLE III.H.7–2—UNQUANTIFIED AND NON-MONETIZED POTENTIAL EFFECTS

Pollutant/effects	Effects not included in analysis—changes in:
Ozone Health [a]	Chronic respiratory damage [b]. Premature aging of the lungs [b]. Non-asthma respiratory emergency room visits. Exposure to UVb (+/−) [e].
Ozone Welfare	Yields for —commercial forests. —some fruits and vegetables. —non-commercial crops. Damage to urban ornamental plants. Impacts on recreational demand from damaged forest aesthetics. Ecosystem functions. Exposure to UVb (+/−) [e].
PM Health [c]	Premature mortality—short term exposures [d]. Low birth weight. Pulmonary function. Chronic respiratory diseases other than chronic bronchitis. Non-asthma respiratory emergency room visits. Exposure to UVb (+/−) [e].
PM Welfare	Residential and recreational visibility in non-Class I areas. Soiling and materials damage. Damage to ecosystem functions. Exposure to UVb (+/−) [e].
Nitrogen and Sulfate Deposition Welfare	Commercial forests due to acidic sulfate and nitrate deposition. Commercial freshwater fishing due to acidic deposition. Recreation in terrestrial ecosystems due to acidic deposition. Existence values for currently healthy ecosystems. Commercial fishing, agriculture, and forests due to nitrogen deposition. Recreation in estuarine ecosystems due to nitrogen deposition. Ecosystem functions. Passive fertilization.
CO Health	Behavioral effects.
HC/Toxics Health [f]	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde). Anemia (benzene). Disruption of production of blood components (benzene). Reduction in the number of blood platelets (benzene). Excessive bone marrow formation (benzene). Depression of lymphocyte counts (benzene). Reproductive and developmental effects (1,3-butadiene). Irritation of eyes and mucus membranes (formaldehyde). Respiratory irritation (formaldehyde). Asthma attacks in asthmatics (formaldehyde). Asthma-like symptoms in non-asthmatics (formaldehyde). Irritation of the eyes, skin, and respiratory tract (acetaldehyde). Upper respiratory tract irritation and congestion (acrolein).
HC/Toxics Welfare	Direct toxic effects to animals. Bioaccumulation in the food chain. Damage to ecosystem function. Odor.

Notes:

[a] The public health impact of biological responses such as increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection are likely partially represented by our quantified endpoints.

[b] The public health impact of effects such as chronic respiratory damage and premature aging of the lungs may be partially represented by quantified endpoints such as hospital admissions or premature mortality, but a number of other related health impacts, such as doctor visits and decreased athletic performance, remain unquantified.

[c] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[d] While some of the effects of short-term exposures are likely to be captured in the estimates, there may be premature mortality due to short-term exposure to PM not captured in the cohort studies used in this analysis. However, the PM mortality results derived from the expert elicitation do take into account premature mortality effects of short term exposures.

[e] May result in benefits or disbenefits.

[f] Many of the key hydrocarbons related to this rule are also hazardous air pollutants listed in the CAA.

While there will be impacts associated with air toxic pollutant emission changes that result from the final rule, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[479] While EPA has since improved the tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics. EPA continues to work to address these limitations; however, we did not have the methods and tools available for national-scale application in time for the analysis of the final rule.[480]

EPA is also unaware of specific information identifying any effects on listed endangered species from the small fluctuations in pollutant concentrations associated with this rule (*see* Section III.G.5). Furthermore, our current modeling tools are not designed to trace fluctuations in ambient concentration levels to potential impacts on particular endangered species.

i. Quantified Human Health Impacts

Tables III.H.7–3 and III.H.7–4 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the final rule for 2030. For each endpoint presented in Tables III.H.7–3 and III.H.7–4, we provide both the mean estimate and the 90% confidence interval.

Using EPA's preferred estimates, based on the American Cancer Society (ACS) and Six-Cities studies and no threshold assumption in the model of mortality, we estimate that the final rule will result in between 60 and 150 cases of avoided $PM_{2.5}$-related premature deaths annually in 2030. As a sensitivity analysis, when the range of expert opinion is used, we estimate between 22 and 200 fewer premature mortalities in 2030 (*see* Table 7.7 in the RIA that accompanies this rule). For ozone-related premature mortality in 2030, we estimate a range of between 4 to 18 additional premature mortalities related to the ethanol production volumes mandated by the recently finalized RFS2 rule[481] (and reflected in the air quality modeling for this rule), but are not due to the final standards themselves.

TABLE III.H.7–3—ESTIMATED $PM_{2.5}$-RELATED HEALTH IMPACTS[a]

Health effect	2030 Annual reduction in incidence (5th%–95th%ile)
Premature Mortality—Derived from epidemiology literature:[b]	
Adult, age 30+, ACS Cohort Study (Pope *et al.,* 2002)	60 (23–96)
Adult, age 25+, Six-Cities Study (Laden *et al.,* 2006)	150 (83–220)
Infant, age <1 year (Woodruff *et al.,* 1997)	0 (0–1)
Chronic bronchitis (adult, age 26 and over)	42 (8–77)
Non-fatal myocardial infarction (adult, age 18 and over)	100 (38–170)
Hospital admissions—respiratory (all ages)[c]	13 (7–20)
Hospital admissions—cardiovascular (adults, age >18)[d]	32 (23–38)
Emergency room visits for asthma (age 18 years and younger)	42 (25–59)
Acute bronchitis (children, age 8–12)	95 (0–190)
Lower respiratory symptoms (children, age 7–14)	1,100 (540–1,700)
Upper respiratory symptoms (asthmatic children, age 9–18)	850 (270–1,400)
Asthma exacerbation (asthmatic children, age 6–18)	1,000 (120–2,900)
Work loss days	7,600 (6,600–8,500)
Minor restricted activity days (adults age 18–65)	45,000 (38,000–52,000)

Notes:

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope *et al.,* 2002) and the Six-Cities Study (Laden *et al.,* 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf (1997).[482]

[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

TABLE III.H.7–4—ESTIMATED OZONE-RELATED HEALTH IMPACTS[a]

Health effect	2030 Annual reduction in incidence (5th%–95th%ile)
Premature Mortality, All ages[b]	
Multi-City Analyses:	
Bell *et al.* (2004)—Non-accidental	−4 (−8–0)
Huang *et al.* (2005)—Cardiopulmonary	−7 (−14–1)

[479] Science Advisory Board. 2001. NATA—Evaluating the National-Scale Air Toxics Assessment for 1996—an SAB Advisory. *http://www.epa.gov/ttn/atw/sab/sabrev.html.* EPA–HQ–OAR–2009–0472–0244.

[480] In April 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit *http://epa.gov/air/toxicair/2009workshop.html.* for more information about the workshop and its associated materials.

[481] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA–420–R–10–006. February 2010. Docket EPA–HQ–OAR–2009–0472–11332. EPA–HQ–OAR–2009–0472–11332. *See also* 75 FR 14670, March 26, 2010.

[482] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. 1997. "The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States." *Environmental Health Perspectives* 105(6):608–612. EPA–HQ–OAR–2009–0472–0382.

TABLE III.H.7–4—ESTIMATED OZONE-RELATED HEALTH IMPACTS [a]—Continued

Health effect	2030 Annual reduction in incidence (5th%–95th%ile)
Schwartz (2005)—Non-accidental	−6 (−13–1)
Meta-analyses:	
Bell *et al.* (2005)—All cause	−13 (−24–−2)
Ito *et al.* (2005)—Non-accidental	−18 (−30–−6)
Levy *et al.* (2005)—All cause	−18 (−28–−9)
Hospital admissions—respiratory causes (adult, 65 and older) [c]	−38 (−86–−6)
Hospital admissions—respiratory causes (children, under 2)	−6 (−13–1)
Emergency room visit for asthma (all ages)	−16 (−51–8)
Minor restricted activity days (adults, age 18–65)	−18,000 (−40,000–3,700)
School absence days	−7,700 (−16,000–1,200)

Notes:

[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous U.S.

[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell *et al.* (2004); Huang *et al.* (2005); Schwartz (2005); Bell *et al.* (2005); Ito *et al.* (2005); Levy *et al.* (2005). The estimates of ozone-related premature mortality should therefore not be summed.

[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

ii. Monetized Benefits

Table III.H.7–5 presents the estimated monetary value of changes in the incidence of ozone and $PM_{2.5}$-related health effects. All monetized estimates are stated in 2007$. These estimates account for growth in real gross domestic product (GDP) per capita between the present and 2030. Our estimate of total monetized benefits in 2030 for the final rule, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between $380 and $1,300 million, assuming a 3 percent discount rate, or between $330 and $1,200 million, assuming a 7 percent discount rate. As the results indicate, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature fatalities each year.

TABLE III.H.7–5—ESTIMATED MONETARY VALUE OF CHANGES IN INCIDENCE OF HEALTH AND WELFARE EFFECTS

[In Millions of 2007$] [a b]

$PM_{2.5}$-related health effect		2030 (5th and 95th%ile)
Premature Mortality—Derived from Epidemiology Studies [c d].	Adult, age 30+—ACS study (Pope *et al.,* 2002)	
	3% discount rate	$510 ($70–$1,300)
	7% discount rate	$460 ($63–$1,200)
	Adult, age 25+—Six-Cities study (Laden *et al.,* 2006)	
	3% discount rate	$1,300 ($190–$3,300)
	7% discount rate	$1,200 ($180–$3,000)
	Infant Mortality, <1 year—(Woodruff *et al.* 1997)	$1.8 ($0–$7.0)
Chronic bronchitis (adults, 26 and over)		$22 ($1.9–$77)
Non-fatal acute myocardial infarctions		
3% discount rate		$14 ($3.9–$35)
7% discount rate		$14 ($3.6–$35)
Hospital admissions for respiratory causes		$0.20 ($0.01–$0.29)
Hospital admissions for cardiovascular causes		$0.91 ($0.58–$1.3)
Emergency room visits for asthma		$0.016 ($0.009–$0.024)
Acute bronchitis (children, age 8–12)		$0.007 ($0–$0.018)
Lower respiratory symptoms (children, 7–14)		$0.022 ($0.009–$0.043)
Upper respiratory symptoms (asthma, 9–11)		$0.027 ($0.008–$0.061)
Asthma exacerbations		$0.058 ($0.006–$0.17)
Work loss days		$1.2 ($1.0–$1.3)
Minor restricted-activity days (MRADs)		$2.9 ($1.7–$4.2)
Ozone-related Health Effect		
Premature Mortality, All ages—Derived from Multi-city analyses.	Bell *et al.,* 2004	−$38 (−$110–$4.2)
	Huang *et al.,* 2005	−$62 (−$180–$4.7)
	Schwartz, 2005	−$58 (−$170–$8.8)
Premature Mortality, All ages—Derived from Meta-analyses.	Bell *et al.,* 2005	−$120 (−$330–−$7.9)
	Ito *et al.,* 2005	−$170 (−$430–−$19)
	Levy *et al.,* 2005	−$170 (−$410–−$21)
Hospital admissions—respiratory causes (adult, 65 and older)		−$0.92 (−$2.1–$0.27)

TABLE III.H.7–5—ESTIMATED MONETARY VALUE OF CHANGES IN INCIDENCE OF HEALTH AND WELFARE EFFECTS—Continued

[In Millions of 2007$] [a b]

$PM_{2.5}$-related health effect	2030 (5th and 95th%ile)
Hospital admissions—respiratory causes (children, under 2)	−$.21 (−$.45–$0.031)
Emergency room visit for asthma (all ages)	−$0.006 (−$0.018–$0.003)
Minor restricted activity days (adults, age 18–65)	−$1.2 (−$2.7–$0.25)
School absence days	−$0.71 (−$1.4–$0.11)

Notes:

[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.

[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2030).

[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.

iii. What are the limitations of the benefits analysis?

Every benefit-cost analysis examining the potential effects of a change in environmental protection requirements is limited to some extent by data gaps, limitations in model capabilities (such as geographic coverage), and uncertainties in the underlying scientific and economic studies used to configure the benefit and cost models. Limitations of the scientific literature often result in the inability to estimate quantitative changes in health and environmental effects, such as potential increases in premature mortality associated with increased exposure to carbon monoxide. Deficiencies in the economics literature often result in the inability to assign economic values even to those health and environmental outcomes which can be quantified. These general uncertainties in the underlying scientific and economics literature, which can lead to valuations that are higher or lower, are discussed in detail in the RIA and its supporting references. Key uncertainties that have a bearing on the results of the benefit-cost analysis of the final rule include the following:

The exclusion of potentially significant and unquantified benefit categories (such as health, odor, and ecological impacts of air toxics, ozone, and PM);

Errors in measurement and projection for variables such as population growth;

Uncertainties in the estimation of future year emissions inventories and air quality;

Uncertainty in the estimated relationships of health and welfare effects to changes in pollutant concentrations including the shape of the C–R function, the size of the effect estimates, and the relative toxicity of the many components of the PM mixture;

Uncertainties in exposure estimation; and

Uncertainties associated with the effect of potential future actions to limit emissions.

As Table III.H.7–5 indicates, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature mortalities each year. Some key assumptions underlying the premature mortality estimates include the following, which may also contribute to uncertainty:

Inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been completely established, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality were explored in the expert elicitation-based results of the PM NAAQS RIA.

All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because PM produced via transported precursors emitted from engines may differ significantly from PM precursors released from electric generating units and other industrial sources. However, no clear scientific grounds exist for supporting differential effects estimates by particle type.

The C–R function for fine particles is approximately linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of PM, including both regions that may be in attainment with $PM_{2.5}$ standards and those that are at risk of not meeting the standards.

There is uncertainty in the magnitude of the association between ozone and premature mortality. The range of ozone impacts associated with the final rule is estimated based on the risk of several sources of ozone-related mortality effect estimates. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council, a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[483] EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits.

Acknowledging omissions and uncertainties, we present a best estimate of the total benefits based on our interpretation of the best available scientific literature and methods supported by EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB–HES). The National Academies of Science (NRC, 2002) has also reviewed EPA's methodology for analyzing the health benefits of measures taken to reduce air pollution. EPA addressed many of these comments in the analysis of the final PM NAAQS.[484 485] This

[483] National Research Council (NRC), 2008. Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution. The National Academies Press: Washington, DC. EPA–HQ–OAR–2009–0472–0322.

[484] National Research Council (NRC). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. The National Academies Press: Washington, DC.

[485] U.S. Environmental Protection Agency. October 2006. *Final Regulatory Impact Analysis (RIA) for the National Ambient Air Quality*

Continued

analysis incorporates this most recent work to the extent possible.

b. PM-Related Monetized Benefits of the Model Year (MY) Analysis

As described in Section III.G, the final standards will reduce emissions of several criteria and toxic pollutants and precursors. In the MY analysis, EPA estimates the economic value of the human health benefits associated with reducing $PM_{2.5}$ exposure. Due to analytical limitations, this analysis does not estimate benefits related to other criteria pollutants (such as ozone, NO_2 or SO_2) or toxics pollutants, nor does it monetize all of the potential health and welfare effects associated with $PM_{2.5}$.

The MY analysis uses a "benefit-per-ton" method to estimate a selected suite of $PM_{2.5}$-related health benefits described below. These $PM_{2.5}$ benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of directly emitted $PM_{2.5}$, or its precursors (such as NO_X, SO_X, and VOCs), from a specified source. Ideally, the human health benefits associated with the MY analysis would be estimated based on changes in ambient $PM_{2.5}$ as determined by full-scale air quality modeling. However, this modeling was not possible in the timeframe for the final rule.

The dollar-per-ton estimates used in this analysis are provided in Table III.H.7–6. In the summary of costs and benefits, Section III.H.10 of this preamble, EPA presents the monetized value of PM-related improvements associated with the rule.

TABLE III.H.7–6—BENEFITS-PER-TON VALUES (2007$) DERIVED USING THE ACS COHORT STUDY FOR PM-RELATED PREMATURE MORTALITY (POPE ET AL., 2002) [a]

Year [c]	All sources [d]		Stationary (non-EGU) sources		Mobile sources	
	SO_X	VOC	NO_X	Direct $PM_{2.5}$	NO_X	Direct $PM_{2.5}$
Estimated Using a 3 Percent Discount Rate [b]						
2015	$28,000	$1,200	$4,700	$220,000	$4,900	$270,000
2020	31,000	1,300	5,100	240,000	5,300	290,000
2030	36,000	1,500	6,100	280,000	6,400	350,000
2040	43,000	1,800	7,200	330,000	7,600	420,000
Estimated Using a 7 Percent Discount Rate [b]						
2015	26,000	1,100	4,200	200,000	4,400	240,000
2020	28,000	1,200	4,600	220,000	4,800	270,000
2030	33,000	1,400	5,500	250,000	5,800	320,000
2040	39,000	1,600	6,600	300,000	6,900	380,000

[a] The benefit-per-ton estimates presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope *et al.,* 2002). If the benefit-per-ton estimates were based on the Six-Cities study (Laden *et al.,* 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.

[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.

[c] Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For 2040, EPA and NHTSA extrapolated exponentially based on the growth between 2020 and 2030.

[d] Note that the benefit-per-ton value for SO_X is based on the value for Stationary (Non-EGU) sources; no SO_X value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.

The benefit per-ton technique has been used in previous analyses, including EPA's recent Ozone National Ambient Air Quality Standards (NAAQS) RIA,[486] the proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[487] and the final NO_2 NAAQS (U.S. EPA, 2009b).[488] Table III.H.7–7 shows the quantified and unquantified $PM_{2.5}$-related co-benefits captured in those benefit-per-ton estimates.

TABLE III.H.7–7—HUMAN HEALTH AND WELFARE EFFECTS OF $PM_{2.5}$

Pollutant/effect	Quantified and monetized in primary estimates	Unquantified effects changes in
$PM_{2.5}$	Adult premature mortality Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular. Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction). Lower and upper respiratory illness	Subchronic bronchitis cases. Low birth weight. Pulmonary function. Chronic respiratory diseases other than chronic bronchitis. Non-asthma respiratory emergency room visits. Visibility.

Standards for Particulate Matter. Prepared by: Office of Air and Radiation. Available at *http://www.epa.gov/ttn/ecas/ria.html.* EPA–HQ–OAR–2009–0472–0240.

[486] U.S. Environmental Protection Agency (U.S. EPA). 2008. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at *http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf.* Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0108.

[487] U.S. Environmental Protection Agency (U.S. EPA). 2009. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at *http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4–20–09.pdf.* Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0241.

[488] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at *http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf.* Accessed March 15, 2010. EPA–HQ–OAR–2009–0472–0237.

TABLE III.H.7–7—HUMAN HEALTH AND WELFARE EFFECTS OF $PM_{2.5}$—Continued

Pollutant/effect	Quantified and monetized in primary estimates	Unquantified effects changes in
	Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Household soiling.

Consistent with the NO_2 NAAQS,[489] the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as chronic bronchitis and a number of respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates.

Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD)[490] accompanying the recent final ozone NAAQS RIA. Readers can also refer to Fann *et al.* (2009)[491] for a detailed description of the benefit-per-ton methodology.[492] A more detailed description of the benefit-per-ton estimates is also provided in the Joint TSD that accompanies this rulemaking.

As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (*e.g.,* NO_2 emitted from mobile sources; direct PM emitted from stationary sources). Our estimate of $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and PM-related precursor emissions controlled by sector and multiplied by each per-ton value.

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties.

Dollar-per-ton estimates do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates. In Section III.G, we describe the full-scale air quality modeling conducted for the 2030 calendar year analysis in an effort to capture this variability.

There are several health benefits categories that EPA was unable to quantify in the MY analysis due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because NO_X and VOC emissions are also precursors to ozone, changes in NO_X and VOC would also impact ozone formation and the health effects associated with ozone exposure. Benefits-per-ton estimates do not exist for ozone, however, due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits. Please refer to Chapter 7 of the RIA that accompanies this rule for a description of the quantification and monetization of health impacts for the CY analysis and a description of the unquantified co-pollutant benefits associated with this rulemaking.

The benefit-per-ton estimates used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines and incomes, technology. These projections introduce some uncertainties to the benefit per ton estimates.

As described above, using the benefit-per-ton value derived from the ACS study (Pope et al., 2002) alone provides an incomplete characterization of $PM_{2.5}$ benefits. When placed in the context of the Expert Elicitation results, this estimate falls toward the lower end of the distribution. By contrast, the estimated $PM_{2.5}$ benefits using the coefficient reported by Laden in that author's reanalysis of the Harvard Six-Cities cohort fall toward the upper end of the Expert Elicitation distribution results.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as there may be localized impacts associated with this rulemaking. Additionally, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. Timing and resource constraints precluded EPA from conducting full-scale photochemical air quality modeling for the MY analysis. We have, however, conducted national-scale air quality modeling for the CY analysis to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

8. Energy Security Impacts

This rule to reduce GHG emissions in light-duty vehicles results in improved fuel efficiency which, in turn, helps to reduce U.S. petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. This reduction in

[489] Although we summarize the main issues in this chapter, we encourage interested readers to see the benefits chapter of the final NO_2 NAAQS for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[490] U.S. Environmental Protection Agency (U.S. EPA). 2008b. Technical Support Document: Calculating Benefit per-Ton estimates, Ozone NAAQS Docket #EPA–HQ–OAR–2007–0225–0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at *http://www.regulations.gov*. EPA–HQ–OAR–2009–0472–0228.

[491] Fann, N. *et al.* (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health. Published online: 09 June, 2009. EPA–HQ–OAR–2009–0472–0229.

[492] The values included in this report are different from those presented in the article cited above. Benefits methods change to reflect new information and evaluation of the science. Since publication of the June 2009 article, EPA has made two significant changes to its benefits methods: (1) We no longer assume that a threshold exists in PM-related models of health impacts; and (2) We have revised the Value of a Statistical Life to equal $6.3 million (year 2000$), up from an estimate of $5.5 million (year 2000$) used in the June 2009 report. Please refer to the following Web site for updates to the dollar-per-ton estimates: *http://www.epa.gov/air/benmap/bpt.html*. EPA–HQ–OAR–2009–0472–0227.

risk is a measure of improved U.S. energy security. This section summarizes our estimate of the monetary value of the energy security benefits of the GHG vehicle standards against the reference case by estimating the impact of the expanded use of lower-GHG vehicle technologies on U.S. oil imports and avoided U.S. oil import expenditures. Additional discussion of this issue can be found in Chapter 5.1 of EPA's RIA and Section 4.2.8 of the TSD.

a. Implications of Reduced Petroleum Use on U.S. Imports

In 2008, U.S. petroleum import expenditures represented 21 percent of total U.S. imports of all goods and services.[493] In 2008, the U.S. imported 66 percent of the petroleum it consumed, and the transportation sector accounted for 70 percent of total U.S. petroleum consumption. This compares to approximately 37 percent of petroleum from imports and 55 percent of consumption from petroleum in the transportation sector in 1975.[494] It is clear that petroleum imports have a significant impact on the U.S. economy. Requiring lower-GHG vehicle technology in the U.S. is expected to lower U.S. petroleum imports.

b. Energy Security Implications

In order to understand the energy security implications of reducing U.S. petroleum imports, EPA worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the economic costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled "*The Energy Security Benefits of Reduced Oil Use, 2006–2015,*" completed in March 2008. This study is included as part of the docket for this rulemaking.[495 496]

When conducting this analysis, ORNL considered the economic cost of importing petroleum into the U.S. The economic cost of importing petroleum into the U.S. is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) The higher costs for oil imports resulting from the effect of increasing U.S. import demand on the world oil price and on OPEC market power (*i.e.,* the "demand" or "monopsony" costs); and (2) the risk of reductions in U.S. economic output and disruption of the U.S. economy caused by sudden disruptions in the supply of imported petroleum to the U.S. (*i.e.,* macroeconomic disruption/adjustment costs). Maintaining a U.S. military presence to help secure stable oil supply from potentially vulnerable regions of the world was not included in this analysis because its attribution to particular missions or activities is hard to quantify.

One commenter on this rule felt that the magnitude of the economic disruption portion of the energy security benefit may be too high. This commenter cites a recent paper written by Stephen P.A. Brown and Hillard G. Huntington, entitled "*Estimating U.S. Oil Security Premiums*" (September 2009) as the basis for their comment. The Agency reviewed this paper and found that it conducted a somewhat different analysis than the one conducted by ORNL in support of this rule. The Brown and Huntington paper focuses on policies and the energy security implications of increasing U.S. demand for oil (or at least holding U.S. oil consumption constant), while the ORNL analysis examines the energy security implications of decreasing U.S. oil consumption and oil imports. These asymmetrical analyses would be expected to yield somewhat different energy security results.

However, even given the different scenarios considered, the Brown and Huntington estimates are roughly similar to the ORNL estimates. For example, for an increase in U.S. consumption that leads to an increase in U.S. imports of oil, Brown and Huntington estimate a 2015 disruption premium of $4.87 per barrel, with an uncertainty range from $1.03 to $14.10 per barrel. The corresponding 2015 estimate for ORNL as the result of a reduction in U.S. oil imports is $6.70 per barrel, with an uncertainty range of $3.11 to $10.67 per barrel. Given that the two studies analyze different scenarios, since the Brown and Huntington disruption premiums are well within the uncertainty range of the ORNL study, and given that the ORNL scenario matches the specific oil market impacts anticipated from the rule while the Brown and Huntington paper does not, the Agency has concluded that the ORNL disruption security premium estimates are more applicable for analyzing this final rule.

In the energy security literature, the macroeconomic disruption component of the energy security premium traditionally has included both (1) increased payments for petroleum imports associated with a rapid increase in world oil prices, and (2) the GDP losses and adjustment costs that result from projected future oil price shocks. One commenter suggested that the increased payments associated with rapid increases in petroleum prices (*i.e.,* price increases in a disrupted market) represent transfers from U.S. oil consumers to petroleum suppliers rather than real economic costs, and therefore, should not be counted as a benefit.

This approach would represent a significant departure from how the macroeconomic disruption costs associated with oil price shocks have been quantified in the broader energy security literature, and the Agencies believe it should be analyzed in more detail before being applied in a regulatory context. In addition, the Agencies also believe that there are compelling reasons to treat higher oil import costs during oil supply disruptions differently than simple wealth transfers that reflect the exercise of market power by petroleum sellers or consumers. According to the OMB definition of a transfer: "Benefit and cost estimates should reflect real resource use. Transfer payments are monetary payments from one group to another that do not affect total resources available to society. * * * The net reduction in the total surplus (consumer plus producer) is a real cost to society, but the transfer from buyers to sellers resulting from a higher price is not a real cost since the net reduction automatically accounts for the transfer from buyers to sellers."[497] In other words, pure transfers do not lead to changes in the allocation or consumption of economic resources, whereas changes in the resource allocation or use produce real economic costs or benefits.

While price increases during oil price disruptions can result in large transfers of wealth, they also result in a combination of real resource shortages, costly short-run shifts in energy supply, behavioral and demand adjustments by energy users, and other response costs. Unlike pure transfers, the root cause of

[493] Source: U.S. Bureau of Economic Analysis, U.S. International Transactions Accounts Data, as shown on June 24, 2009.

[494] Source: U.S. Department of Energy, Annual Energy Review 2008, Report No. DOE/EIA–0384(2008), Tables 5.1 and 5.13c, June 26, 2009.

[495] Leiby, Paul N. "*Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*" Oak Ridge National Laboratory, ORNL/TM–2007/028, Final Report, 2008. (Docket EPA–HQ–OAR–2009–0472).

[496] The ORNL study "*The Energy Security Benefits of Reduced Oil Use, 2006–2015,*" completed in March 2008, is an update version of the approach used for estimating the energy security benefits of U.S. oil import reductions developed in an ORNL 1997 Report by Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, entitled "*Oil Imports: An Assessment of Benefits and Costs.*" (Docket EPA–HQ–OAR–2009–0472).

[497] OMB Circular A–4, September 17, 2003. See *http://www.whitehouse.gov/omb/assets/omb/circulars/a004/a-4.pdf.*

the disruption price increase is a real resource supply reduction due, for example, to disaster or war. Regions where supplies are disrupted (*i.e.,* the U.S.) suffer very high costs. Businesses' and households' emergency responses to supply disruptions and rapid price increases are likely to consume some real economic resources, in addition to causing financial losses to the U.S. economy that are matched by offsetting gains elsewhere in the global economy.

While households and businesses can reduce their petroleum consumption, invest in fuel switching technologies, or use futures markets to insulate themselves in advance against the potential costs of rapid increases in oil prices, when deciding how extensively to do so, they are unlikely to account for the effect of their petroleum consumption on the magnitude of costs that supply interruptions and accompanying price shocks impose on others. As a consequence, the U.S. economy as a whole will not make sufficient use of these mechanisms to insulate itself from the real costs of rapid increases in energy prices and outlays that usually accompany oil supply interruptions.[498] Therefore, the ORNL estimate of macroeconomic disruption and adjustment costs that the Agencies use to value energy security benefits includes the increased oil import costs stemming from oil price shocks that are unanticipated and not internalized by advance actions of U.S. consumers of petroleum products. The Agencies believe that, as the ORNL analysis argues, the uninternalized oil import costs that occur during oil supply interruptions represents a real cost associated with U.S. petroleum consumption and imports, and that reducing its value by lowering domestic petroleum consumption and imports thus represents a real economic benefit from lower fuel consumption.

For this rule, ORNL estimated the energy security premium by incorporating the oil price forecast of the Energy Information Administration's 2009 Annual Energy Outlook (AEO) to its model. The Agency considered, but rejected the option, of further updating this analysis using the oil price estimates provided by the AEO 2010. Given the broad uncertainty bands around oil price forecasts and the relatively modest change in oil price forecasts between the AEO 2009 and AEO 2010, the Agency felt that updating to AEO 2010 oil prices would not significantly change the results of this energy security analysis. Finally, the EPA used its OMEGA model in conjunction with ORNL's energy security premium estimates to develop the total energy security benefits for a number of different years; please refer to Table III.H.8–1 for this information for years 2015, 2020, 2030 and 2040,[499] as well as a breakdown of the components of the energy security premium for each of these years. The components of the energy security premium and their values are discussed in detail in the Joint TSD Chapter 4.

Because the price of oil is determined globally, supply and demand shocks anywhere in the world will have an adverse impact on the United States (and on all other oil consuming countries). The total economic costs of those shocks to the U.S. will depend on both U.S. petroleum consumption and imports of petroleum and refined products. The analysis relied upon to estimate energy security benefits from reducing U.S. petroleum consumption estimates the value of energy security using the estimated oil *import* premium, and is thus consistent with how much of the energy security literature reports energy security impacts. Since this rule is expected to have little impact on the U.S. supply of crude petroleum, a reduction in U.S. fuel consumption is expected to be reflected predominantly in reduced imports of petroleum and refined fuel. The estimated energy security premium associated with a reduction in U.S. petroleum *consumption* that leads to a reduction in imports would likely be somewhat larger, due to diminished sensitivity of the U.S. economy to oil supply shocks that would accompany the reduction in oil consumption.

In addition, while the estimates of energy security externalities used in this analysis depend on a combination of U.S. petroleum consumption and imports, they have been expressed as per barrel of petroleum imported into the U.S. The Agencies' analyses apply these estimates to the reduction in U.S. imports of crude petroleum and refined products that is projected to result from the rule in order to determine the benefits that are likely to result from fuel savings and the consequent reduction in imports. Thus, the estimates of energy security externalities have been used in this analysis in a way that is completely consistent with how they are defined and measured in the ORNL analysis.

TABLE III.H.8–1—ENERGY SECURITY PREMIUM IN 2015, 2020, 2030 AND 2040 (2007$/BARREL)

Year (range)	Monopsony	Macroeconomic disruption/adjustment costs	Total mid-point
2015	$11.79 ($4.26–$21.37)	$6.70 ($3.11–$10.67)	$18.49 ($9.80–$28.08)
2020	$12.31 ($4.46–$22.53)	$7.62 ($3.77–$12.46)	$19.94 ($10.58–$30.47)
2030	$10.57 ($3.84–18.94)	$8.12 ($3.90–$13.04)	$18.69 ($10.52–$27.89)
2040	$10.57 ($3.84–$18.94)	$8.12 ($3.90–$13.04)	$18.69 ($10.52–$27.89)

The literature on the energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global value for the Social Cost of Carbon (SCC) the question arises: How should the energy security premium be used when some benefits from the rule, such as the benefits of reducing greenhouse gas emissions, are calculated using a global value? Monopsony benefits represent avoided payments by the U.S. to oil producers in foreign countries that result from a decrease in the world oil price as the U.S. decreases its consumption of imported oil. Although there is clearly a benefit to the U.S. when considered from the domestic perspective, the decrease in price due to decreased demand in the U.S. also represents a loss of income to oil-

[498] For a more complete discussion of the reasons why the oil import cost component of the macroeconomic disruption and adjustment costs includes some real costs and does not represent a pure transfer, see Paul N. Leiby, Estimating the Energy Security Benefits of Reduced U.S. Oil Imports: Final Report, ORNL–TM–2007–028, Oak Ridge National Laboratory, March 14, 2008, pp. 21–25.

[499] AEO 2009 forecasts energy market trends and values only to 2030. The energy security premium estimates post-2030 were assumed to be the 2030 estimate.

producing countries. Given the redistributive nature of this effect, do the negative effects on other countries "net out" the positive impacts to the U.S.? If this is the case, then the monopsony portion of the energy security premium should be excluded from the net benefits calculation for the rule. OMB's Circular A–4 gives guidance in this regard. Domestic pecuniary benefits (or transfers between buyers and sellers) generally should not be included because they do not represent real resource costs, though A–4 notes that transfers to the U.S. from other countries may be counted as benefits as long as the analysis is conducted from a U.S. perspective.

Energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs. Energy security is inherently a domestic benefit. Accordingly, it is possible to argue that the use of the domestic monopsony benefit may not necessarily be in conflict with the use of the global SCC, because the global SCC represents the benefits against which the costs of our (*i.e.,* the U.S.'s) domestic mitigation efforts should be judged. In the final analysis, the Agency has determined that using only the macroeconomic disruption component of the energy security benefit is the appropriate metric for this rule.

At proposal, the Agency took the position that since a global perspective was being taken with the use of the global SCC, that the monopsony benefits "net out" and were a transfer. Two commenters felt that the monopsony effect should be excluded from net benefits calculations for the rule since it is a "pecuniary" externality or does not represent an efficiency gain. One of the commenters suggested that EPA instead conduct a distributional analysis of the monopsony impacts of the final rule. The Agency disagrees that all pecuniary externalities should necessarily be excluded from net benefits calculations as a general rule. In this case considered here, the oil market is non-competitive, and if the social decision-making unit of interest is the U.S., there is an argument for accounting for the monopsony premium to assess the excess transfer of wealth caused by the exercise of cartel power outside of the U.S.

However, for the final rule, the Agency continues to take a global perspective with respect to climate change by using the global SCC. Therefore, the Agency did not count monopsony benefits since they "net out" with losses to other countries outside the U.S. Since a global perspective has been taken, a distributional analysis was not undertaken for this final rule, since the losses to the losers (oil producers that export oil to the U.S.) would equal the gains to the winners (U.S. consumers of imported oil). As a result, the Agency has included only the macroeconomic disruption portion of the energy security benefits to monetize the total energy security benefits of this rule. Hence, the total annual energy security benefits are derived from the estimated reductions in U.S. imports of finished petroleum products and crude oil using only the macroeconomic disruption/adjustment portion of the energy security premium. These values are shown in Table III.H.8–2.[500] The reduced oil estimates were derived from the OMEGA model, as explained in Section III.F of this preamble. EPA used the same assumption that NHTSA used in its Corporate Average Fuel Economy and CAFE Reform for MY 2008–2011 Light Trucks rule, which assumed that each gallon of fuel saved reduces total U.S. imports of crude oil or refined products by 0.95 gallons.[501]

TABLE III.H.8–2—TOTAL ANNUAL ENERGY SECURITY BENEFITS USING ONLY THE MACROECONOMIC DISRUPTION/ADJUSTMENT COMPONENT OF THE ENERGY SECURITY PREMIUM IN 2015, 2020, 2030 AND 2040

[Billions of 2007$]

Year	Benefits
2015	$0.57
2020	$2.17
2030	$4.55
2040	$6.00

[500] Estimated reductions in U.S. imports of finished petroleum products and crude oil are 95% of 89 million barrels (MMB) in 2015, 300 MMB in 2020, 590 MMB in 2030, and 778 MMB in 2040.

[501] Preliminary Regulatory Impacts Analysis, April 2008. Based on a detailed analysis of differences in fuel consumption, petroleum imports, and imports of refined petroleum products among the Reference Case, High Economic Growth, and Low Economic Growth Scenarios presented in the Energy Information Administration's Annual Energy Outlook 2007, NHTSA estimated that approximately 50 percent of the reduction in fuel consumption is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would be expected to be reflected in reduced domestic fuel refining. Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum. Thus on balance, each gallon of fuel saved is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.

9. Other Impacts

There are other impacts associated with the CO_2 emissions standards and associated reduced fuel consumption that vary with miles driven. Lower fuel consumption would, presumably, result in fewer trips to the filling station to refuel and, thus, time saved. The rebound effect, discussed in detail in Section III.H.4.c, produces additional benefits to vehicle owners in the form of consumer surplus from the increase in vehicle-miles driven, but may also increase the societal costs associated with traffic congestion, motor vehicle crashes, and noise. These effects are likely to be relatively small in comparison to the value of fuel saved as a result of the standards, but they are nevertheless important to include. Table III.H.9–1 summarizes the other economic impacts. Please refer to Preamble Section II.F and the Joint TSD that accompanies this rule for more information about these impacts and how EPA and NHTSA use them in their analyses.

Note that for the estimated value of less frequent refueling events, EPA's estimate is subject to a number of uncertainties which we discuss in detail in Chapter 4.1.11 of the Joint TSD, and the actual value could be higher or lower than the value presented here. Specifically, the analysis makes three assumptions: (a) That manufacturers will not adjust fuel tank capacities downward (from the current average of 19.3 gallons) when they improve the fuel economy of their vehicle models. (b) that the average fuel purchase (55 percent of fuel tank capacity) is the typical fuel purchase. (c) that 100 percent of all refueling is demand-based; *i.e.,* that every gallon of fuel which is saved would reduce the need to return to the refueling station. A new research project is being planned by DOT which will include a detailed study of refueling events, and which is expected to improve upon these assumptions. These assumptions and the new DOT research project are discussed in detail in Joint TSD Chapter 4.2.10.

TABLE III.H.9–1—OTHER IMPACTS ASSOCIATED WITH THE LIGHT-DUTY VEHICLE GHG PROGRAM

[Millions of 2007 dollars]

	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Value of Less Frequent Refueling	$2,400	$4,800	$6,300	$8,000	$87,900	$40,100
Value of Increased Driving [a]	4,200	8,800	13,000	18,400	171,500	75,500
Accidents, Noise, Congestion	−2,300	−4,600	−6,100	−7,800	−84,800	−38,600

[a] Calculated using post-tax fuel prices.

10. Summary of Costs and Benefits

In this section, EPA presents a summary of costs, benefits, and net benefits of the rule. Table III.H.10–1 shows the estimated annual societal costs of the vehicle program for the indicated calendar years. The table also shows the net present values of those costs for the calendar years 2012–2050 using both a 3 percent and a 7 percent discount rate. In this table, fuel savings are calculated using pre-tax fuel prices.

Consumers are expected to receive the fuel savings presented here. The cost estimates for the fuel-saving technology are based on designs that will hold all vehicle attributes constant except fuel economy and technology cost. This analysis also assumes that consumers will not change the vehicles that they purchase. Automakers may redesign vehicles as part of their compliance strategies. The redesigns should be expected to make the vehicles more attractive to consumers, because the ability to hold all other attributes constant means that the only reason to change them is to make them more marketable to consumers. In addition, consumers may choose to purchase different vehicles than they would in the absence of this rule. These changes may affect the net benefits that consumers receive from their vehicles. If consumers can buy the same vehicle as before, except with increased price and fuel economy, then the increase in vehicle price is the maximum loss in welfare to the consumer, because compensating the increase in price would leave her able to buy her previous vehicle with no change. If she decides to purchase a different vehicle, or not to purchase a vehicle, she would do so only if she were better off than buying her original choice. Because of the unsettled state of the modeling of consumer choices (discussed in Section III.H.1 and in RIA Section 8.1.2), this analysis does not measure these effects. If the technology costs are not sufficient to maintain other vehicle attributes, then it is possible that automakers would be required to make less marketable vehicles in order to comply with the rule; as a result, there may be an additional loss in consumer welfare due to the rule. While EPA received comments expressing concern over the possibility of these losses, there were no specific losses identified.

TABLE III.H.10–1—ESTIMATED SOCIETAL COSTS OF THE LIGHT-DUTY VEHICLE GHG PROGRAM

[Millions of 2007 dollars]

Social costs	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Vehicle Compliance Costs	$15,600	$15,800	$17,400	$19,000	$345,900	$191,900
Fuel Savings [a]	−35,700	−79,800	−119,300	−171,200	−1,545,600	−672,600
Quantified Annual Costs	−20,100	−64,000	−101,900	−152,200	−1,199,700	−480,700

[a] Calculated using pre-tax fuel prices.

Table III.H.10–2 presents estimated annual societal benefits for the indicated calendar years. The table also shows the net present values of those benefits for the calendar years 2012–2050 using both a 3 percent and a 7 percent discount rate. The table shows the benefits of reduced CO_2 emissions—and consequently the annual quantified benefits (*i.e.,* total benefits)—for each of four SCC values considered by EPA. As discussed in the RIA Section 7.5, the IPCC Fourth Assessment Report (2007) concluded that that the benefit estimates from CO_2 reductions are "very likely" underestimates. One of the primary reasons is that models used to calculate SCC values do not include information about impacts that have not been quantified.

In addition, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4, N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and SCC and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

TABLE III.H.10–2—ESTIMATED SOCIETAL BENEFITS ASSOCIATED WITH THE LIGHT-DUTY VEHICLE GHG PROGRAM

[Millions of 2007 dollars]

Benefits category	2020	2030	2040	2050	NPV, 3% [a]	NPV, 7% [a]
Reduced CO_2 Emissions at each assumed SCC value [b c]						
Avg SCC at 5%	$900	$2,700	$4,600	$7,200	$34,500	$34,500
Avg SCC at 3%	3,700	8,900	14,000	21,000	176,700	176,700
Avg SCC at 2.5%	5,800	14,000	21,000	30,000	299,600	299,600
95th percentile SCC at 3%	11,000	27,000	43,000	62,000	538,500	538,500
Criteria Pollutant Benefits [d e f g]	B	1,200–1,300	1,200–1,300	1,200–1,300	21,000	14,000
Energy Security Impacts (price shock)	2,200	4,500	6,000	7,600	81,900	36,900

TABLE III.H.10–2—ESTIMATED SOCIETAL BENEFITS ASSOCIATED WITH THE LIGHT-DUTY VEHICLE GHG PROGRAM—Continued

[Millions of 2007 dollars]

Benefits category	2020	2030	2040	2050	NPV, 3% [a]	NPV, 7% [a]
Reduced Refueling	2,400	4,800	6,300	8,000	87,900	40,100
Value of Increased Driving [h]	4,200	8,800	13,000	18,400	171,500	75,500
Accidents, Noise, Congestion	−2,300	−4,600	−6,100	−7,800	−84,800	−38,600
Quantified Annual Benefits at each assumed SCC value [b c]						
Avg SCC at 5%	7,400	17,500	25,100	34,700	312,000	162,400
Avg SCC at 3%	10,200	23,700	34,500	48,500	454,200	304,600
Avg SCC at 2.5%	12,300	28,800	41,500	57,500	577,100	427,500
95th percentile SCC at 3%	17,500	41,800	63,500	89,500	816,000	666,400

[a] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[b] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[c] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

[d] Note that "B" indicates unquantified criteria pollutant benefits in the year 2020. For the final rule, we only modeled the rule's $PM_{2.5}$- and ozone-related impacts in the calendar year 2030. For the purposes of estimating a stream of future-year criteria pollutant benefits, we assume that the benefits out to 2050 are equal to, and no less than, those modeled in 2030 as reflected by the stream of estimated future emission reductions. The NPV of criteria pollutant-related benefits should therefore be considered a conservative estimate of the potential benefits associated with the final rule.

[e] The benefits presented in this table include an estimate of PM-related premature mortality derived from Laden *et al.,* 2006, and the ozone-related premature mortality estimate derived from Bell *et al.,* 2004. If the benefit estimates were based on the ACS study of PM-related premature mortality (Pope *et al.,* 2002) and the Levy *et al.,* 2005 study of ozone-related premature mortality, the values would be as much as 70% smaller.

[f] The calendar year benefits presented in this table assume either a 3% discount rate in the valuation of PM-related premature mortality ($1,300 million) or a 7% discount rate ($1,200 million) to account for a twenty-year segmented cessation lag. Note that the benefits estimated using a 3% discount rate were used to calculate the NPV using a 3% discount rate and the benefits estimated using a 7% discount rate were used to calculate the NPV using a 7% discount rate. For benefits totals presented at each calendar year, we used the mid-point of the criteria pollutant benefits range ($1,250).

[g] Note that the co-pollutant impacts presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. The full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (*e.g.,* changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.

[h] Calculated using pre-tax fuel prices.

Table III.H.10–3 presents estimated annual net benefits for the indicated calendar years. The table also shows the net present values of those net benefits for the calendar years 2012–2050 using both a 3 percent and a 7 percent discount rate. The table includes the benefits of reduced CO_2 emissions (and consequently the annual net benefits) for each of four SCC values considered by EPA. As noted above, the benefit estimates from CO_2 reductions are "very likely," according to the IPCC Fourth Assessment Report, underestimates because, in part, models used to calculate SCC values do not include information about impacts that have not been quantified.

TABLE III.H.10–3—QUANTIFIED NET BENEFITS ASSOCIATED WITH THE LIGHT-DUTY VEHICLE GHG PROGRAM [a]

[Millions of 2007 dollars]

	2020	2030	2040	2050	NPV, 3% [b]	NPV, 7% [b]
Quantified Annual Costs	−$20,100	−$64,000	−$101,900	−$152,200	−$1,199,700	−$480,700
Quantified Annual Benefits at each assumed SCC value [c d]						
Avg SCC at 5%	7,400	17,500	25,100	34,700	312,000	162,400
Avg SCC at 3%	10,200	23,700	34,500	48,500	454,200	304,600
Avg SCC at 2.5%	12,300	28,800	41,500	57,500	577,100	427,500
95th percentile SCC at 3%	17,500	41,800	63,500	89,500	816,000	666,400
Quantified Net Benefits at each assumed SCC value [c d]						
Avg SCC at 5%	27,500	81,500	127,000	186,900	1,511,700	643,100
Avg SCC at 3%	30,300	87,700	136,400	200,700	1,653,900	785,300
Avg SCC at 2.5%	32,400	92,800	143,400	209,700	1,776,800	908,200

TABLE III.H.10–3—QUANTIFIED NET BENEFITS ASSOCIATED WITH THE LIGHT-DUTY VEHICLE GHG PROGRAM [a]—Continued

[Millions of 2007 dollars]

	2020	2030	2040	2050	NPV, 3% [b]	NPV, 7% [b]
95th percentile SCC at 3%	37,600	105,800	165,400	241,700	2,015,700	1,147,100

[a] Fuel impacts were calculated using pre-tax fuel prices.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[d] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: For Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

EPA also conducted a separate analysis of the total benefits over the model year lifetimes of the 2012 through 2016 model year vehicles. In contrast to the calendar year analysis presented in Table III.H.10–1 through Table III.H.10–3, the model year lifetime analysis shows the lifetime impacts of the program on each of these MY fleets over the course of its lifetime. Full details of the inputs to this analysis can be found in RIA Chapter 5. The societal benefits of the full life of each of the five model years from 2012 through 2016 are shown in Tables III.H.10–4 and III.H.10–5 at both a 3 percent and a 7 percent discount rate, respectively. The net benefits are shown in Tables III.H.10–6 and III.H.10–7 for both a 3 percent and a 7 percent discount rate. Note that the quantified annual benefits shown in Table III.H.10–4 and Table III.H.10–5 include fuel savings as a positive benefit. As such, the quantified annual costs as shown in Table III.H.10–6 and Table III.H.10–7 do not include fuel savings since those are included as benefits. Also note that each of the Tables III.H.10–4 through Table III.H.10–7 include the benefits of reduced CO_2 emissions—and consequently the total benefits—for each of four SCC values considered by EPA. As noted above, the benefit estimates from CO_2 reductions are "very likely," according to the IPCC Fourth Assessment Report, underestimates because, in part, models used to calculate SCC values do not include information about impacts that have not been quantified.

TABLE III.H.10–4—ESTIMATED SOCIETAL BENEFITS ASSOCIATED WITH THE LIFETIMES OF 2012–2016 MODEL YEAR VEHICLES

[Millions of 2007 dollars; 3% discount rate]

Monetized values (millions)	2012MY	2013MY	2014MY	2015MY	2016MY	Sum
Cost of Noise, Accident, Congestion ($)	−$1,100	−$1,600	−$2,100	−$2,900	−$3,900	−$11,600
Pretax Fuel Savings ($)	16,100	23,900	32,200	46,000	63,500	181,800
Energy Security (price shock) ($) [a]	900	1,400	1,800	2,500	3,500	10,100
Value of Reduced Refueling time ($)	1,100	1,600	2,100	3,000	4,000	11,900
Value of Additional Driving ($)	2,400	3,400	4,400	6,000	7,900	24,000
Value of $PM_{2.5}$-related Health Impacts ($) [b c d]	700	900	1,300	1,800	2,400	7,000
Reduced CO_2 Emissions at each assumed SCC value [e f g]						
Avg SCC at 5%	400	500	700	1,000	1,300	3,800
Avg SCC at 3%	1,700	2,400	3,100	4,400	5,900	17,000
Avg SCC at 2.5%	2,700	3,900	5,200	7,200	9,700	29,000
95th percentile SCC at 3%	5,100	7,300	9,600	13,000	18,000	53,000
Total Benefits at each assumed SCC value [e f g]						
Avg SCC at 5%	20,500	30,100	40,400	57,400	78,700	227,000
Avg SCC at 3%	21,800	32,000	42,800	60,800	83,300	240,200
Avg SCC at 2.5%	22,800	33,500	44,900	63,600	87,100	252,200
95th percentile SCC at 3%	25,200	36,900	49,300	69,400	95,400	276,200

[a] Note that, due to a calculation error in the proposal, the energy security impacts for the model year analysis were roughly half what they should have been.

[b] Note that the co-pollutant impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling analysis associated with the vehicle model year lifetimes for the final rule.

[c] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope *et al.,* 2002). If the benefit-per-ton estimates were based on the Six Cities study (Laden *et al.,* 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.

[d] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.
[e] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[f] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.
[g] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: For Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

TABLE III.H.10–5—ESTIMATED SOCIETAL BENEFITS ASSOCIATED WITH THE LIFETIMES OF 2012–2016 MODEL YEAR VEHICLES

[Millions of 2007 dollars; 7% discount rate]

Monetized values (millions)	2012MY	2013MY	2014MY	2015MY	2016MY	Sum
Cost of Noise, Accident, Congestion ($)	−$900	−$1,200	−$1,600	−$2,300	−$3,100	−$9,200
Pretax Fuel Savings ($)	12,500	18,600	25,100	36,000	49,600	141,900
Energy Security (price shock) ($) [a]	800	1,100	1,400	2,000	2,700	8,000
Value of Reduced Refueling time ($)	900	1,300	1,700	2,400	3,200	9,400
Value of Additional Driving ($)	1,900	2,700	3,500	4,700	6,200	19,000
Value of $PM_{2.5}$-related Health Impacts ($) [b c d]	500	800	1,000	1,400	1,900	5,600
Reduced CO_2 Emissions at each assumed SCC value [e f g]						
Avg SCC at 5%	400	500	700	1,000	1,300	3,800
Avg SCC at 3%	1,700	2,400	3,100	4,400	5,900	17,000
Avg SCC at 2.5%	2,700	3,900	5,200	7,200	9,700	29,000
95th percentile SCC at 3%	5,100	7,300	9,600	13,000	18,000	53,000
Total Benefits at each assumed SCC value [e f g]						
Avg SCC at 5%	16,100	23,800	31,800	45,200	61,800	178,500
Avg SCC at 3%	17,400	25,700	34,200	48,600	66,400	191,700
Avg SCC at 2.5%	18,400	27,200	36,300	51,400	70,200	203,700
95th percentile SCC at 3%	20,800	30,600	40,700	57,200	78,500	227,700

[a] Note that, due to a calculation error in the proposal, the energy security impacts for the model year analysis were roughly half what they should have been.
[b] Note that the co-pollutant impacts associated with the standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling analysis associated with the vehicle model year lifetimes for the final rule.
[c] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope *et al.,* 2002). If the benefit-per-ton estimates were based on the Six Cities study (Laden *et al.,* 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.
[d] The $PM_{2.5}$-related benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.
[e] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[f] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.
[g] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: For Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

TABLE III.H.10–6—QUANTIFIED NET BENEFITS ASSOCIATED WITH THE LIFETIMES OF 2012–2016 MODEL YEAR VEHICLES

[Millions of 2007 dollars; 3% discount rate]

Monetized Values (millions)	2012MY	2013MY	2014MY	2015MY	2016MY	Sum
Quantified Annual Costs (excluding fuel savings) [a]	$4,900	$8,000	$10,300	$12,700	$15,600	$51,500
Quantified Annual Benefits at each assumed SCC value [b c d]						
Avg SCC at 5%	20,500	30,100	40,400	57,400	78,700	227,000
Avg SCC at 3%	21,800	32,000	42,800	60,800	83,300	240,200

TABLE III.H.10–6—QUANTIFIED NET BENEFITS ASSOCIATED WITH THE LIFETIMES OF 2012–2016 MODEL YEAR VEHICLES—Continued

[Millions of 2007 dollars; 3% discount rate]

Monetized Values (millions)	2012MY	2013MY	2014MY	2015MY	2016MY	Sum
Avg SCC at 2.5%	22,800	33,500	44,900	63,600	87,100	252,200
95th percentile SCC at 3%	25,200	36,900	49,300	69,400	95,400	276,200
Quantified Net Benefits at each assumed SCC value [b c d]						
Avg SCC at 5%	15,600	22,100	30,100	44,700	63,100	175,500
Avg SCC at 3%	16,900	24,000	32,500	48,100	67,700	188,700
Avg SCC at 2.5%	17,900	25,500	34,600	50,900	71,500	200,700
95th percentile SCC at 3%	20,300	28,900	39,000	56,700	79,800	224,700

[a] Quantified annual costs as shown here are the increased costs for new vehicles in each given model year. Since those costs are assumed to occur in the given model year (*i.e.,* not over a several year time span), the discount rate does not affect the costs.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[d] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: For Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

TABLE III.H.10–7—QUANTIFIED NET BENEFITS ASSOCIATED WITH THE LIFETIMES OF 2012–2016 MODEL YEAR VEHICLES

[Millions of 2007 dollars; 7% discount rate]

Monetized values (millions)	2012MY	2013MY	2014MY	2015MY	2016MY	Sum
Quantified Annual Costs (excluding fuel savings) [a]	$4,900	$8,000	$10,300	$12,700	$15,600	$51,500
Quantified Annual Benefits at each assumed SCC value [b c d]						
Avg SCC at 5%	16,100	23,800	31,800	45,200	61,800	178,500
Avg SCC at 3%	17,400	25,700	34,200	48,600	66,400	191,700
Avg SCC at 2.5%	18,400	27,200	36,300	51,400	70,200	203,700
95th percentile SCC at 3%	20,800	30,600	40,700	57,200	78,500	227,700
Quantified Net Benefits at each assumed SCC value [b c d]						
Avg SCC at 5%	11,200	15,800	21,500	32,500	46,200	127,000
Avg SCC at 3%	12,500	17,700	23,900	35,900	50,800	140,200
Avg SCC at 2.5%	13,500	19,200	26,000	38,700	54,600	152,200
95th percentile SCC at 3%	15,900	22,600	30,400	44,500	62,900	176,200

[a] Quantified annual costs as shown here are the increased costs for new vehicles in each given model year. Since those costs are assumed to occur in the given model year (*i.e.,* not over a several year time span), the discount rate does not affect the costs.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[c] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[d] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: For Average SCC at 5%: $5–$16; for Average SCC at 3%: $21–$45; for Average SCC at 2.5%: $36–$65; and for 95th percentile SCC at 3%: $65–$136. Section III.H.6 also presents these SCC estimates.

I. Statutory and Executive Order Reviews

1. Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order (EO) 12866 (58 FR 51735, October 4, 1993), this action is an "economically significant regulatory action" because it is likely to have an annual effect on the economy of $100 million or more. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for review under EO 12866 and any changes made in response to OMB recommendations have been documented in the docket for this action.

In addition, EPA prepared an analysis of the potential costs and benefits associated with this action. This analysis is contained in the Final Regulatory Impact Analysis, which is available in the docket for this rulemaking and at the docket internet address listed under **ADDRESSES** above.

2. Paperwork Reduction Act

The information collection requirements in this final rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.,* and has been assigned OMB control number 0783.57. The information collection requirements are not enforceable until OMB approves them.

The Agency is finalizing requirements for manufacturers to submit information to ensure compliance with the provisions in this rule. This includes a variety of requirements for vehicle manufacturers. Section 208(a) of the Clean Air Act requires that vehicle manufacturers provide information the Administrator may reasonably require to determine compliance with the regulations; submission of the information is therefore mandatory. We will consider confidential all information meeting the requirements of section 208(c) of the Clean Air Act.

As shown in Table III.I.2–1, the total annual burden associated with this rule is about 39,900 hours and $5 million, based on a projection of 33 respondents. The estimated burden for vehicle manufacturers is a total estimate for new reporting requirements. Burden means the total time, effort, or financial resources expended by persons to generate, maintain, retain, or disclose or provide information to or for a Federal agency. This includes the time needed to review instructions; develop, acquire, install, and utilize technology and systems for the purposes of collecting, validating, and verifying information, processing and maintaining information, and disclosing and providing information; adjust the existing ways to comply with any previously applicable instructions and requirements; train personnel to be able to respond to a collection of information; search data sources; complete and review the collection of information; and transmit or otherwise disclose the information.

TABLE III.I.2–1—ESTIMATED BURDEN FOR REPORTING AND RECORDKEEPING REQUIREMENTS

Number of respondents	Annual burden hours	Annual costs
33	39,940	$5,001,000

An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9. In addition, EPA is amending the table in 40 CFR part 9 of currently approved OMB control numbers for various regulations to list the regulatory citations for the information requirements contained in this final rule.

3. Regulatory Flexibility Act

a. Overview

The Regulatory Flexibility Act (RFA) generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities directly subject to the rule. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of this rule on small entities, small entity is defined as: (1) A small business as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201 (see table below); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

Table III.I.3–1 provides an overview of the primary SBA small business categories included in the light-duty vehicle sector:

TABLE III.I.3–1—PRIMARY SBA SMALL BUSINESS CATEGORIES IN THE LIGHT-DUTY VEHICLE SECTOR

Industry [a]	Defined as small entity by SBA if less than or equal to:	NAICS codes [b]
Light-duty vehicles:		
—Vehicle manufacturers *(including small volume manufacturers).*	1,000 employees	336111
—Independent commercial importers	$7 million annual sales	811111, 811112, 811198
	$23 million annual sales	441120
	100 employees	423110, 424990
—Alternative fuel vehicle converters	50 employees	336312, 336322, 336399
	750 employees	335312
	1,000 employees	454312, 485310, 811198
	$7 million annual sales.	

Notes:

[a] Light-duty vehicle entities that qualify as small businesses would not be subject to this rule. We are exempting small vehicle entities, and we intend to address these entities in a future rule.

[b] North American Industrial Classification System.

b. Summary of Potentially Affected Small Entities

EPA has not conducted a Regulatory Flexibility Analysis or a SBREFA SBAR Panel for the rule because we are certifying that the rule would not have a significant economic impact on a substantial number of small entities directly subject to the rule. As proposed, EPA is exempting manufacturers meeting SBA's business size criteria for small business as provided in 13 CFR 121.201, due to the short lead time to develop this rule, the extremely small emissions contribution of these entities, and the potential need to develop a program that would be structured differently for them (which would require more time). EPA would instead consider appropriate GHG standards for these entities as part of a future regulatory action. This includes U.S. and foreign small entities in three distinct categories of businesses for light-duty vehicles: Small volume manufacturers (SVMs), independent commercial importers (ICIs), and alternative fuel vehicle converters. EPA has identified a total of about 47 vehicle businesses; about 13 entities (or 28 percent) fit the Small Business Administration (SBA) criteria of a small business. There are about 2 SVMs, 8 ICIs, and 3 alternative fuel vehicle converters in the light-duty vehicle market which are small businesses (no major vehicle manufacturers meet the small-entity criteria as defined by SBA). EPA estimates that these small entities comprise about 0.03 percent of the total light-duty vehicle sales in the U.S., and therefore the exemption will have a negligible impact on the GHG emissions reductions from the standards.

To ensure that EPA is aware of which companies would be exempt, EPA proposed to require that such entities submit a declaration to EPA containing a detailed written description of how that manufacturer qualifies as a small entity under the provisions of 13 CFR 121.201. EPA has reconsidered the need for this additional submission under the regulations and is deleting it as not necessary. We already have information on the limited number of small entities that we expect would receive the benefits of the exemption, and do not need the proposed regulatory requirement to be able to effectively implement this exemption for those parties who in fact meet its terms. Small entities are currently covered by a number of EPA motor vehicle emission regulations, and they routinely submit information and data on an annual basis as part of their compliance responsibilities. Based on this, EPA is certifying that the rule would not have a significant economic impact on a substantial number of small entities.

c. Conclusions

I therefore certify that this rule will not have a significant economic impact on a substantial number of small entities. However, EPA recognizes that some small entities continue to be concerned about the potential impacts of the statutory imposition of PSD requirements that may occur given the various EPA rulemakings currently under consideration concerning greenhouse gas emissions. As explained in the preamble for the proposed PSD tailoring rule (74 FR 55292, Oct. 27, 2009), EPA used the discretion afforded to it under section 609(c) of the RFA to consult with OMB and SBA, with input from outreach to small entities, regarding the potential impacts of PSD regulatory requirements that might occur as EPA considers regulations of GHGs. Concerns about the potential impacts of statutorily imposed PSD requirements on small entities were the subject of deliberations in that consultation and outreach. EPA has compiled a summary of that consultation and outreach, which is available in the docket for the Tailoring Rule (EPA–HQ–OAR–2009–0517).

4. Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), 2 U.S.C. 1531–1538, requires Federal agencies, unless otherwise prohibited by law, to assess the effects of their regulatory actions on State, local, and tribal governments and the private sector. Under section 202 of the UMRA, EPA generally must prepare a written statement, including a cost-benefit analysis, for proposed and final rules with "Federal mandates" that may result in expenditures to State, local, and tribal governments, in the aggregate, or to the private sector, of $100 million or more in any one year.

This rule is not subject to the requirements of section 203 of UMRA because it contains no regulatory requirements that might significantly or uniquely affect small governments. This rule contains no Federal mandates (under the regulatory provisions of Title II of the UMRA) for State, local, or tribal governments. The rule imposes no enforceable duty on any State, local or tribal governments. EPA has determined that this rule contains no regulatory requirements that might significantly or uniquely affect small governments. EPA has determined that this rule contains a Federal mandate that may result in expenditures of $100 million or more for the private sector in any one year. EPA believes that the action represents the least costly, most cost-effective approach to achieve the statutory requirements of the rule. The costs and benefits associated with the rule are discussed above and in the Final Regulatory Impact Analysis, as required by the UMRA.

5. Executive Order 13132 (Federalism)

This action does not have federalism implications. It will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. This rulemaking applies to manufacturers of motor vehicles and not to State or local governments. Thus, Executive Order 13132 does not apply to this action. Although section 6 of Executive Order 13132 does not apply to this action, EPA did consult with representatives of State governments in developing this action.

In the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and State and local governments, EPA specifically solicited comment on the proposed action from State and local officials. Many State and local governments submitted public comments on the rule, the majority of which were supportive of the EPA's greenhouse gas program. However, these entities did not provide comments indicating there would be a substantial direct effect on State or local governments resulting from this rule.

6. Executive Order 13175 (Consultation and Coordination With Indian Tribal Governments)

This action does not have tribal implications, as specified in Executive Order 13175 (65 FR 67249, November 9, 2000). This rule will be implemented at the Federal level and impose compliance costs only on vehicle manufacturers. Tribal governments will be affected only to the extent they purchase and use regulated vehicles. Thus, Executive Order 13175 does not apply to this action.

7. Executive Order 13045: "Protection of Children From Environmental Health Risks and Safety Risks"

This action is subject to EO 13045 (62 FR 19885, April 23, 1997) because it is an economically significant regulatory action as defined by EO 12866, and EPA believes that the environmental health or safety risk addressed by this action may have a disproportionate effect on children. A synthesis of the science and research regarding how climate change may affect children and other vulnerable subpopulations is contained in the Technical Support Document for Endangerment or Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act, which can be found in the public docket for this rule.[502] A summary of the analysis is presented below.

With respect to GHG emissions, the effects of climate change observed to

[502] U.S. EPA. (2009). Technical Support Document for Endangerment or Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC: U.S. EPA. Docket EPA–HQ–OAR–2009–0472–11292.

date and projected to occur in the future include the increased likelihood of more frequent and intense heat waves. Specifically, EPA's analysis of the scientific assessment literature has determined that severe heat waves are projected to intensify in magnitude, frequency, and duration over the portions of the U.S. where these events already occur, with potential increases in mortality and morbidity, especially among the young, elderly, and frail. EPA has estimated reductions in projected global mean surface temperatures as a result of reductions in GHG emissions associated with the standards finalized in this action (Section III.F). Children may receive benefits from reductions in GHG emissions because they are included in the segment of the population that is most vulnerable to extreme temperatures.

For non-GHG pollutants, EPA has determined that climate change is expected to increase regional ozone pollution, with associated risks in respiratory infection, aggravation of asthma, and premature death. The directional effect of climate change on ambient PM levels remains uncertain. However, disturbances such as wildfires are increasing in the U.S. and are likely to intensify in a warmer future with drier soils and longer growing seasons. PM emissions from forest fires can contribute to acute and chronic illnesses of the respiratory system, particularly in children, including pneumonia, upper respiratory diseases, asthma and chronic obstructive pulmonary diseases.

8. Executive Order 13211 (Energy Effects)

This rule is not a "significant energy action" as defined in Executive Order 13211, "Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use" (66 FR 28355 (May 22, 2001)) because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. In fact, this rule has a positive effect on energy supply and use. Because the GHG emission standards finalized today result in significant fuel savings, this rule encourages more efficient use of fuels. Therefore, we have concluded that this rule is not likely to have any adverse energy effects. Our energy effects analysis is described above in Section III.H.

9. National Technology Transfer Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 ("NTTAA"), Public Law 104–113, 12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.,* materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

The rulemaking involves technical standards. Therefore, the Agency conducted a search to identify potentially applicable voluntary consensus standards. For CO_2, N_2O, and CH_4 emissions, we identified no such standards, and none were brought to our attention in comments. Therefore, EPA is collecting data over the same test cycles that are used for the CAFE program following standardized test methods and sampling procedures. This will minimize the amount of testing done by manufacturers, since manufacturers are already required to run these tests. For A/C system leakage improvement credits, EPA identified a Society of Automotive Engineers (SAE) methodology and EPA's approach is based closely on this SAE methodology. For the A/C system efficiency improvement credits, including the new idle test, EPA generally uses standardized test methods and sampling procedures. However, EPA knows of no consensus standard available for an A/C idle test to measure system efficiency improvements.

10. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order (EO) 12898 (59 FR 7629 (Feb. 16, 1994)) establishes Federal executive policy on environmental justice. Its main provision directs Federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States.

With respect to GHG emissions, EPA has determined that this final rule will not have disproportionately high and adverse human health or environmental effects on minority or low-income populations because it increases the level of environmental protection for all affected populations without having any disproportionately high and adverse human health or environmental effects on any population, including any minority or low-income population. The reductions in CO_2 and other GHGs associated with the standards will affect climate change projections, and EPA has estimated reductions in projected global mean surface temperatures (Section III.F.3). Within communities experiencing climate change, certain parts of the population may be especially vulnerable; these include the poor, the elderly, those already in poor health, the disabled, those living alone, and/or indigenous populations dependent on one or a few resources.[503] In addition, the U.S. Climate Change Science Program[504] stated as one of its conclusions: "The United States is certainly capable of adapting to the collective impacts of climate change. However, there will still be certain individuals and locations where the adaptive capacity is less and these individuals and their communities will be disproportionally impacted by climate change." Therefore, these specific sub-populations may receive benefits from reductions in GHGs.

For non-GHG co-pollutants such as ozone, $PM_{2.5}$, and toxics, EPA has concluded that it is not practicable to determine whether there would be disproportionately high and adverse human health or environmental effects on minority and/or low income populations from this final rule.

11. Congressional Review Act

The Congressional Review Act, 5 U.S.C. 801 *et seq.,* as added by the Small Business Regulatory Enforcement Fairness Act of 1996, generally provides that before a rule may take effect, the agency promulgating the rule must submit a rule report, which includes a copy of the rule, to each House of the Congress and to the Comptroller General of the United States. EPA will submit a report containing this rule and other required information to the U.S. Senate, the U.S. House of Representatives, and the Comptroller General of the United States prior to publication of the rule in the **Federal Register.** A Major rule cannot take effect until 60 days after it

[503] U.S. EPA. (2009). Technical Support Document for Endangerment or Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC: U.S. EPA. Docket EPA–HQ–OAR–2009–0472–11292.

[504] CCSP (2008) *Analyses of the effects of global change on human health and welfare and human systems.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA.

is published in the **Federal Register.** This action is a "major rule" as defined by 5 U.S.C. 804(2). This rule will be effective July 6, 2010, *sixty days after date of publication in the* **Federal Register.**

J. Statutory Provisions and Legal Authority

Statutory authority for the vehicle controls finalized today is found in section 202(a) (which authorizes standards for emissions of pollutants from new motor vehicles which emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare), 202(d), 203–209, 216, and 301 of the Clean Air Act, 42 U.S.C. 7521(a), 7521(d), 7522, 7523, 7524, 7525, 7541, 7542, 7543, 7550, and 7601.

IV. NHTSA Final Rule and Record of Decision for Passenger Car and Light Truck CAFE Standards for MYs 2012–2016

A. Executive Overview of NHTSA Final Rule

1. Introduction

The National Highway Traffic Safety Administration (NHTSA) is establishing Corporate Average Fuel Economy (CAFE) standards for passenger automobiles (passenger cars) and nonpassenger automobiles (light trucks) for model years (MY) 2012–2016. Improving vehicle fuel economy has been long and widely recognized as one of the key ways of achieving energy independence, energy security, and a low carbon economy.[505] NHTSA's CAFE standards will require passenger cars and light trucks to meet an estimated combined average of 34.1 mpg in MY 2016. This represents an average annual increase of 4.3 percent from the 27.6 mpg combined fuel economy level in MY 2011. NHTSA's final rule projects total fuel savings of approximately 61 billion gallons over the lifetimes of the vehicles sold in model years 2012–2016, with corresponding net societal benefits of over $180 billion using a 3 percent discount rate.[506]

The significance accorded to improving fuel economy reflects several factors. Conserving energy, especially reducing the nation's dependence on petroleum, benefits the U.S. in several ways. Improving energy efficiency has benefits for economic growth and the environment, as well as other benefits, such as reducing pollution and improving security of energy supply. More specifically, reducing total petroleum use decreases our economy's vulnerability to oil price shocks. Reducing dependence on oil imports from regions with uncertain conditions enhances our energy security. Additionally, the emission of CO_2 from the tailpipes of cars and light trucks is one of the largest sources of U.S. CO_2 emissions.[507] Using vehicle technology to improve fuel economy, thereby reducing tailpipe emissions of CO_2, is one of the three main measures of reducing those tailpipe emissions of CO_2.[508] The two other measures for reducing the tailpipe emissions of CO_2 are switching to vehicle fuels with lower carbon content and changing driver behavior, *i.e.,* inducing people to drive less.

While NHTSA has been setting fuel economy standards since the 1970s, today's action represents the first-ever joint final rule by NHTSA with another agency, the Environmental Protection Agency. As discussed in Section I, NHTSA's final MYs 2012–2016 CAFE standards are part of a joint National Program. A large majority of the projected benefits are achieved jointly with EPA's GHG rule, described in detail above in Section III of this preamble. These final CAFE standards are consistent with the President's National Fuel Efficiency Policy announcement of May 19, 2009, which called for harmonized rules for all automakers, instead of three overlapping and potentially inconsistent requirements from DOT, EPA, and the California Air Resources Board. And finally, the final CAFE standards and the analysis supporting them also respond to President's Obama's January 26 memorandum regarding the setting of CAFE standards for model years 2011 and beyond.

2. Role of Fuel Economy Improvements in Promoting Energy Independence, Energy Security, and a Low Carbon Economy

The need to reduce energy consumption is more crucial today than it was when EPCA was enacted in the mid-1970s. U.S. energy consumption has been outstripping U.S. energy production at an increasing rate. Net petroleum imports now account for approximately 57 percent of U.S. domestic petroleum consumption, and the share of U.S. oil consumption for transportation is approximately 71 percent.[509] Moreover, world crude oil production continues to be highly concentrated, exacerbating the risks of supply disruptions and their negative effects on both the U.S. and global economies.

Gasoline consumption in the U.S. has historically been relatively insensitive to fluctuations in both price and consumer income, and people in most parts of the country tend to view gasoline consumption as a non-discretionary expense. Thus, when gasoline's share in consumer expenditures rises, the public experiences fiscal distress. This fiscal distress can, in some cases, have macroeconomic consequences for the

[505] Among the reports and studies noting this point are the following:

John Podesta, Todd Stern and Kim Batten, "Capturing the Energy Opportunity; Creating a Low-Carbon Economy," Center for American Progress (November 2007), pp. 2, 6, 8, and 24–29, *available at: http://www.americanprogress.org/issues/2007/11/pdf/energy_chapter.pdf* (last accessed March 1, 2010).

Sarah Ladislaw, Kathryn Zyla, Jonathan Pershing, Frank Verrastro, Jenna Goodward, David Pumphrey, and Britt Staley, "A Roadmap for a Secure, Low-Carbon Energy Economy; Balancing Energy Security and Climate Change," World Resources Institute and Center for Strategic and International Studies (January 2009), pp. 21–22; *available at: http://pdf.wri.org/secure_low_carbon_energy_economy_roadmap.pdf* (last accessed March 1, 2010).

Alliance to Save Energy et al., "Reducing the Cost of Addressing Climate Change Through Energy Efficiency (2009), *available at: http://Aceee.org/energy/climate/leg.htm* (last accessed March 1, 2010).

John DeCicco and Freda Fung, "Global Warming on the Road; The Climate Impact of America's Automobiles," Environmental Defense (2006) pp. iv-vii; a*vailable at: http://www.edf.org/documents/5301_Globalwarmingontheroad.pdf* (last accessed March 1, 2010).

"Why is Fuel Economy Important?," a Web page maintained by the Department of Energy and Environmental Protection Agency, *available at http://www.fueleconomy.gov/feg/why.shtml* (last accessed March 1, 2010); Robert Socolow, Roberta Hotinski, Jeffery B. Greenblatt, and Stephen Pacala, "Solving The Climate Problem: Technologies Available to Curb CO_2 Emissions," *Environment,* volume 46, no. 10, 2004. pages 8–19, a*vailable at: http://www.princeton.edu/mae/people/faculty/socolow/ENVIRONMENTDec2004issue.pdf* (last accessed March 1, 2010).

[506] This value is based on what NHTSA refers to as "Reference Case" inputs, which are based on the assumptions that NHTSA has employed for its main analysis (as opposed to sensitivity analyses to examine the effect of variations in the assumptions on costs and benefits). The Reference Case inputs include fuel prices based on the AEO 2010 Reference Case, a 3 percent discount rate, a 10 percent rebound effect, a value for the social cost of carbon (SCC) of $21/metric ton CO_2 (in 2010, rising to $45/metric ton in 2050, at a 3 percent discount rate), etc. For a full listing of the Reference Case input assumptions, *see* Section IV.C.3 below.

[507] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006 (April 2008), pp. ES–4, ES–8, and 2–24. *Available at http://www.epa.gov/climatechange/emissions/usgginv_archive.html* (last accessed March 1, 2010).

[508] Podesta *et al.,* p. 25; Ladislaw *et al.* p. 21; DeCicco *et al.* p. vii; "Reduce Climate Change," a Web page maintained by the Department of Energy and Environmental Protection Agency at *http://www.fueleconomy.gov/feg/climate.shtml* (last accessed March 1, 2010).

[509] Energy Information Administration, Petroleum Basic Statistics, updated July 2009. *Available at http://www.eia.doe.gov/basics/quickoil.html* (last accessed March 1, 2010).

economy at large. Additionally, since U.S. oil production is only affected by fluctuations in prices over a period of years, any changes in petroleum consumption (as through increased fuel economy) largely flow into changes in the quantity of imports. Since petroleum imports account for about 2 percent of GDP, increase in oil imports can create a discernable fiscal drag. As a consequence, measures that reduce petroleum consumption, such as fuel economy standards, will directly benefit the balance-of-payments account, and strengthen the domestic economy to some degree. And finally, U.S. foreign policy has been affected for decades by rising U.S. and world dependency of crude oil as the basis for modern transportation systems, although fuel economy standards have only an indirect and general impact on U.S. foreign policy.

The benefits of a low carbon economy are manifold. The U.S. transportation sector is a significant contributor to total U.S. and global anthropogenic emissions of greenhouse gases. Motor vehicles are the second largest greenhouse gas-emitting sector in the U.S., after electricity generation, and accounted for 24 percent of total U.S. greenhouse gas emissions in 2006. Concentrations of greenhouse gases are at unprecedented levels compared to the recent and distant past, which means that fuel economy improvements to reduce those emissions are a crucial step toward addressing the risks of global climate change. These risks are well documented in Section III of this notice.

3. The National Program

NHTSA and EPA are each announcing final rules that have the effect of addressing the urgent and closely intertwined challenges of energy independence and security and global warming. These final rules call for a strong and coordinated Federal greenhouse gas and fuel economy program for passenger cars, light-duty-trucks, and medium-duty passenger vehicles (hereafter light-duty vehicles), referred to as the National Program. The final rules represent a coordinated program that can achieve substantial reductions of greenhouse gas (GHG) emissions and improvements in fuel economy from the light-duty vehicle part of the transportation sector, based on technology that will be commercially available and that can be incorporated at a reasonable cost in the rulemaking timeframe. The agencies' final rules will also provide regulatory certainty and consistency for the automobile industry by setting harmonized national standards. They were developed and are designed in ways that recognize and accommodate the relatively short amount of lead time for the model years covered by the rulemaking and the serious current economic situation faced by this industry.

These joint standards are consistent with the President's announcement on May 19, 2009 of a National Fuel Efficiency Policy that will reduce greenhouse gas emissions and improve fuel economy for all new cars and light-duty trucks sold in the United States,[510] and with the Notice of Upcoming Joint Rulemaking signed by DOT and EPA on that date.[511] This joint final rule also responds to the President's January 26, 2009 memorandum on CAFE standards for model years 2011 and beyond, the details of which can be found below.

a. Building Blocks of the National Program

The National Program is both needed and possible because the relationship between improving fuel economy and reducing CO_2 tailpipe emissions is a very direct and close one. CO_2 is the natural by-product of the combustion of fuel in motor vehicle engines. The more fuel efficient a vehicle is, the less fuel it burns to travel a given distance. The less fuel it burns, the less CO_2 it emits in traveling that distance.[512] Since the amount of CO_2 emissions is essentially constant per gallon combusted of a given type of fuel, the amount of fuel consumption per mile is directly related to the amount of CO_2 emissions per mile. In the real world, there is a single pool of technologies for reducing fuel consumption and CO_2 emissions. Using those technologies in the way that minimizes fuel consumption also minimizes CO_2 emissions. While there are emission control technologies that can capture or destroy the pollutants (*e.g.,* carbon monoxide) that are produced by imperfect combustion of fuel, there is at present no such technology for CO_2. In fact, the only way at present to reduce tailpipe emissions of CO_2 is by reducing fuel consumption. The National Program thus has dual benefits: it conserves energy by improving fuel economy, as required of NHTSA by EPCA and EISA; in the process, it necessarily reduces tailpipe CO_2 emissions consonant with EPA's purposes and responsibilities under the Clean Air Act.

i. DOT's CAFE Program

In 1975, Congress enacted the Energy Policy and Conservation Act (EPCA), mandating a regulatory program for motor vehicle fuel economy to meet the various facets of the need to conserve energy, including ones having energy independence and security, environmental and foreign policy implications. EPCA allocates the responsibility for implementing the program between NHTSA and EPA as follows:

NHTSA sets Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks.

Because fuel economy performance is measured during emissions regulation testing, EPA establishes the procedures for testing, tests vehicles, collects and analyzes manufacturers' test data, and calculates the average fuel economy of each manufacturer's passenger cars and light trucks. EPA determines fuel economy by measuring the amount of CO_2 emitted from the tailpipe, rather than by attempting to measure directly the amount of fuel consumed during a vehicle test, a difficult task to accomplish with precision. EPA then uses the carbon content of the test fuel[513] to calculate the amount of fuel that had to be consumed per mile in order to produce that amount of CO_2. Finally, EPA converts that fuel consumption figure into a miles-per-gallon figure.

Based on EPA's calculation, NHTSA enforces the CAFE standards.

The CAFE standards and compliance testing cannot capture all of the real world CO_2 emissions, because EPCA currently requires EPA to use the 1975 passenger car test procedures under which vehicle air conditioners are not turned on during fuel economy testing.[514] CAFE standards also do not address the 5–8 percent of GHG emissions that are not CO_2, *i.e.,* nitrous oxide (N_2O), and methane (CH_4) as well as emissions of hydrofluorocarbons (HFCs) related to operation of the air conditioning system.

NHTSA has been setting CAFE standards pursuant to EPCA since the enactment of the statute. Fuel economy gains since 1975, due both to the standards and to market factors, have resulted in saving billions of barrels of oil and avoiding billions of metric tons

[510] President Obama Announces National Fuel Efficiency Policy, The White House, May 19, 2009. *Available at http://www.whitehouse.gov/the_press_office/President-Obama-Announces-National-Fuel-Efficiency-Policy/* (last accessed March 15, 2010).

[511] 74 FR 24007 (May 22, 2009).

[512] Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, "Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base," National Academies Press, 1992, at 287.

[513] This is the method that EPA uses to determine compliance with NHTSA's CAFE standards.

[514] *See* 49 U.S.C. 32904(c).

of CO_2 emissions. In December 2007, Congress enacted the Energy Independence and Securities Act (EISA), amending EPCA to require, among other things, attribute-based standards for passenger cars and light trucks. The most recent CAFE rulemaking action was the issuance of standards governing model years 2011 cars and trucks.

ii. EPA's Greenhouse Gas Program

On April 2, 2007, the U.S. Supreme Court issued its opinion in *Massachusetts* v. *EPA,*[515] a case involving a 2003 order of the Environmental Protection Agency (EPA) denying a petition for rulemaking to regulate greenhouse gas emissions from motor vehicles under the Clean Air Act.[516] The Court ruled that greenhouse gases are "pollutants" under the CAA and that the Act therefore authorizes EPA to regulate greenhouse gas emissions from motor vehicles if that agency makes the necessary findings and determinations under section 202 of the Act. The Court considered EPCA only briefly, stating that the two obligations may overlap, but there is no reason to think the two agencies cannot both administer their obligations and yet avoid inconsistency.

EPA has been working on appropriate responses that are consistent with the decision of the Supreme Court in *Massachusetts* v. *EPA.*[517] As part of those responses, in July 2008, EPA issued an Advance Notice of Proposed Rulemaking seeking comments on the impact of greenhouse gases on the environment and on ways to reduce greenhouse gas emissions from motor vehicles. EPA recently also issued a final rule finding that emissions of GHGs from new motor vehicles and motor vehicle engines cause or contribute to air pollution that endanger public health and welfare.[518]

iii. California Air Resources Board's Greenhouse Gas Program

In 2004, the California Air Resources Board approved standards for new light-duty vehicles, which regulate the emission of not only CO_2, but also other GHGs. Since then, thirteen states and the District of Columbia, comprising approximately 40 percent of the light-duty vehicle market, have adopted California's standards. These standards apply to model years 2009 through 2016 and require CO_2 emissions levels for passenger cars and some light trucks of 323 g/mil in 2009, decreasing to 205 g/mi in 2016, and 439 g/mi for light trucks in 2009, decreasing to 332 g/mi in 2016. In 2008, EPA denied a request by California for a waiver of preemption under the CAA for its GHG emissions standards. However, consistent with another Presidential Memorandum of January 26, 2009, EPA reconsidered the prior denial of California's request.[519] EPA withdrew the prior denial and granted California's request for a waiver on June 30, 2009.[520] The granting of the waiver permits California's emission standards to come into effect notwithstanding the general preemption of State emission standards for new motor vehicles that otherwise applies under the Clean Air Act.

b. The President's Announcement of National Fuel Efficiency Policy (May 2009)

The issue of three separate regulatory frameworks and overlapping requirements for reducing fuel consumption and CO_2 emissions has been a subject of much controversy and legal disputes. On May 19, 2009 President Obama announced a National Fuel Efficiency Policy aimed at both increasing fuel economy and reducing greenhouse gas pollution for all new cars and trucks sold in the United States, while also providing a predictable regulatory framework for the automotive industry. The policy seeks to set harmonized Federal standards to regulate both fuel economy and greenhouse gas emissions while preserving the legal authorities of the Department of Transportation, the Environmental Protection Agency and the State of California. The program covers model year 2012 to model year 2016 and ultimately requires the equivalent of an average fuel economy of 35.5 mpg in 2016, if all CO_2 reduction were achieved through fuel economy improvements. Building on the MY 2011 standard that was set in March 2009, this represents an average of 5 percent increase in average fuel economy each year between 2012 and 2016.

In conjunction with the President's announcement, the Department of Transportation and the Environmental Protection Agency issued on May 19, 2009, a Notice of Upcoming Joint Rulemaking to propose a strong and coordinated fuel economy and greenhouse gas National Program for Model Year (MY) 2012–2016 light duty vehicles. Consistent, harmonized, and streamlined requirements under that program hold out the promise of delivering environmental and energy benefits, cost savings, and administrative efficiencies on a nationwide basis that might not be available under a less coordinated approach. The National Program makes it possible for the standards of two different Federal agencies and the standards of California and other states to act in a unified fashion in providing these benefits. A harmonized approach to regulating light-duty vehicle greenhouse gas (GHG) emissions and fuel economy is critically important given the interdependent goals of addressing climate change and ensuring energy independence and security. Additionally, a harmonized approach may help to mitigate the cost to manufacturers of having to comply with multiple sets of Federal and State standards

4. Review of CAFE Standard Setting Methodology per the President's January 26, 2009 Memorandum on CAFE Standards for MYs 2011 and Beyond

On May 2, 2008, NHTSA published a Notice of Proposed Rulemaking entitled Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015, 73 FR 24352. In mid-October, the agency completed and released a final environmental impact statement in anticipation of issuing standards for those years. Based on its consideration of the public comments and other available information, including information on the financial condition of the automotive industry, the agency adjusted its analysis and the standards and prepared a final rule for MYs 2011–2015. On November 14, the Office of Information and Regulatory Affairs (OIRA) of the Office of Management and Budget concluded review of the rule as consistent with the Order.[521] However, issuance of the final rule was held in abeyance. On January 7, 2009, the Department of Transportation announced that the final rule would not be issued.

[515] 127 S.Ct. 1438 (2007).

[516] 68 FR 52922 (Sept. 8, 2003).

[517] 549 U.S. 497 (2007). For further information on *Massachusetts* v. *EPA* see the July 30, 2008 Advance Notice of Proposed Rulemaking, "Regulating Greenhouse Gas Emissions under the Clean Air Act," 73 FR 44354 at 44397. There is a comprehensive discussion of the litigation's history, the Supreme Court's findings, and subsequent actions undertaken by the EPA from 2007–2008 in response to the Supreme Court remand.

[518] 74 FR 66496 (Dec. 15, 2009).

[519] 74 FR 66495 (Dec. 15, 2009). The endangerment finding was challenged by industry in a filing submitted December 23, 2009; a hearing date does not appear to have been set.

[520] 74 FR 32744 (July 8, 2009).

[521] Record of OIRA's action can be found at *http://www.reginfo.gov/public/do/eoHistReviewSearch* (last accessed March 1, 2010). To find the report on the clearance of the draft final rule, select "Department of Transportation" under "Economically Significant Reviews Completed" and select "2008" under "Select Calendar Year."

a. Requests in the President's Memorandum

In light of the requirement to prescribe standards for MY 2011 by March 30, 2009 and in order to provide additional time to consider issues concerning the analysis used to determine the appropriate level of standards for MYs 2012 and beyond, the President issued a memorandum on January 26, 2009, requesting the Secretary of Transportation and Administrator of the National Highway Traffic Safety Administration NHTSA to divide the rulemaking into two parts: (1) MY 2011 standards, and (2) standards for MY 2012 and beyond.

i. CAFE Standards for Model Year 2011

The request that the final rule establishing CAFE standards for MY 2011 passenger cars and light trucks be prescribed by March 30, 2009 was based on several factors. One was the requirement that the final rule regarding fuel economy standards for a given model year must be adopted at least 18 months before the beginning of that model year (49 U.S.C. 32902(g)(2)). The other was that the beginning of MY 2011 is considered for the purposes of CAFE standard setting to be October 1, 2010.

ii. CAFE Standards for Model Years 2012 and Beyond

The President requested that, before promulgating a final rule concerning the model years after model year 2011, NHTSA

> [C]onsider the appropriate legal factors under the EISA, the comments filed in response to the Notice of Proposed Rulemaking, the relevant technological and scientific considerations, and to the extent feasible, the forthcoming report by the National Academy of Sciences mandated under section 107 of EISA.

In addition, the President requested that NHTSA consider whether any provisions regarding preemption are appropriate under applicable law and policy.

b. Implementing the President's Memorandum

In keeping with the President's remarks on January 26, 2009 for new national policies to address the closely intertwined issues of energy independence, energy security and climate change, and for the initiation of serious and sustained domestic and international action to address them, NHTSA has developed CAFE standards for MY 2012 and beyond after collecting new information, conducting a careful review of technical and economic inputs and assumptions, and standard setting methodology, and completing new analyses.

The goal of the review and re-evaluation was to ensure that the approach used for MY 2012 and thereafter would produce standards that contribute, to the maximum extent possible under EPCA/EISA, to meeting the energy and environmental challenges and goals outlined by the President. We have sought to craft our program with the goal of creating the maximum incentives for innovation, providing flexibility to the regulated parties, and meeting the goal of making substantial and continuing reductions in the consumption of fuel. To that end, we have made every effort to ensure that the CAFE program for MYs 2012–2016 is based on the best scientific, technical, and economic information available, and that such information was developed in close coordination with other Federal agencies and our stakeholders, including the states and the vehicle manufacturers.

We have also re-examined EPCA, as amended by EISA, to consider whether additional opportunities exist to improve the effectiveness of the CAFE program. For example, EPCA authorizes increasing the amount of civil penalties for violating the CAFE standards.[522] Further, if the test procedures used for light trucks were revised to provide for the operation of air conditioning during fuel economy testing, vehicle manufacturers would have a regulatory incentive to increase the efficiency of air conditioning systems, thereby reducing both fuel consumption and tailpipe emissions of CO_2.[523]

With respect to the President's request that NHTSA consider the issue of preemption, NHTSA is deferring further consideration of the preemption issue. The agency believes that it is unnecessary to address the issue further at this time because of the consistent and coordinated Federal standards that apply nationally under the National Program.

As requested in the President's memorandum, NHTSA reviewed comments received on the MY 2011 rulemaking and revisited its assumptions and methodologies for purposes of developing the proposed MY 2012–2016 standards. For more information on how the proposed CAFE standards were developed with those comments in mind, see the NPRM and the supporting documents.

5. Summary of the Final MY 2012–2016 CAFE Standards

NHTSA is issuing CAFE standards that are, like the standards NHTSA promulgated in March 2009 for MY 2011, expressed as mathematical functions depending on vehicle footprint. Footprint is one measure of vehicle size, and is determined by multiplying the vehicle's wheelbase by the vehicle's average track width.[524] Under the final CAFE standards, each light vehicle model produced for sale in the United States has a fuel economy target. The CAFE levels that must be met by the fleet of each manufacturer will be determined by computing the sales-weighted harmonic average of the targets applicable to each of the manufacturer's passenger cars and light trucks. These targets, the mathematical form and coefficients of which are presented later in today's notice, appear as follows when the values of the targets are plotted versus vehicle footprint:

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[522] Under 49 U.S.C. 32912(c), roughly, NHTSA may raise the penalty amount if the agency decides that doing so will increase energy conservation substantially without having a substantial deleterious impact on the economy, employment, or competition among automobile manufacturers.

[523] Under 49 U.S.C. 32904(c), EPA must use the same procedures for passenger automobiles that the Administrator used for model year 1975 (weighted 55 percent urban cycle and 45 percent highway cycle), or procedures that give comparable results.

[524] *See* 49 CFR 523.2 for the exact definition of "footprint."

Figure IV.A.5-1 Final MY 2011 and Final MY 2012-2016

Passenger Car Fuel Economy Targets

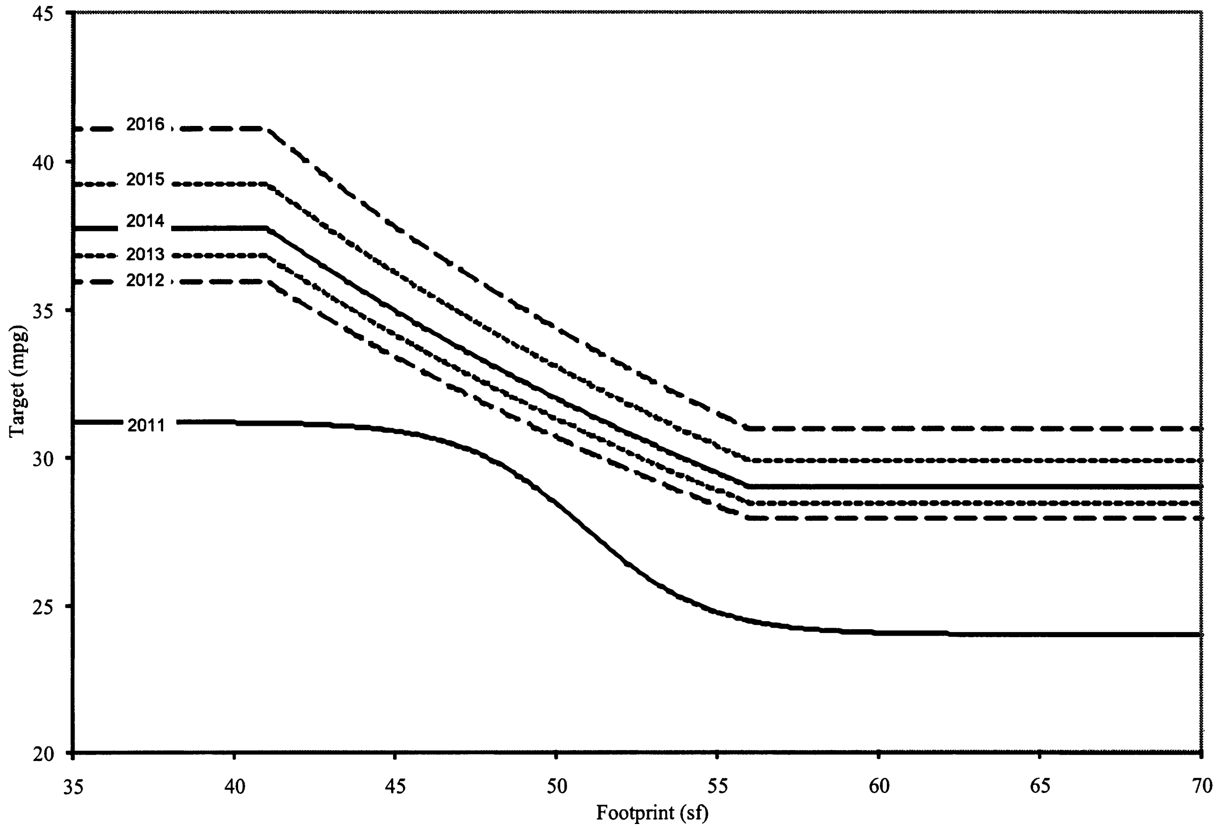
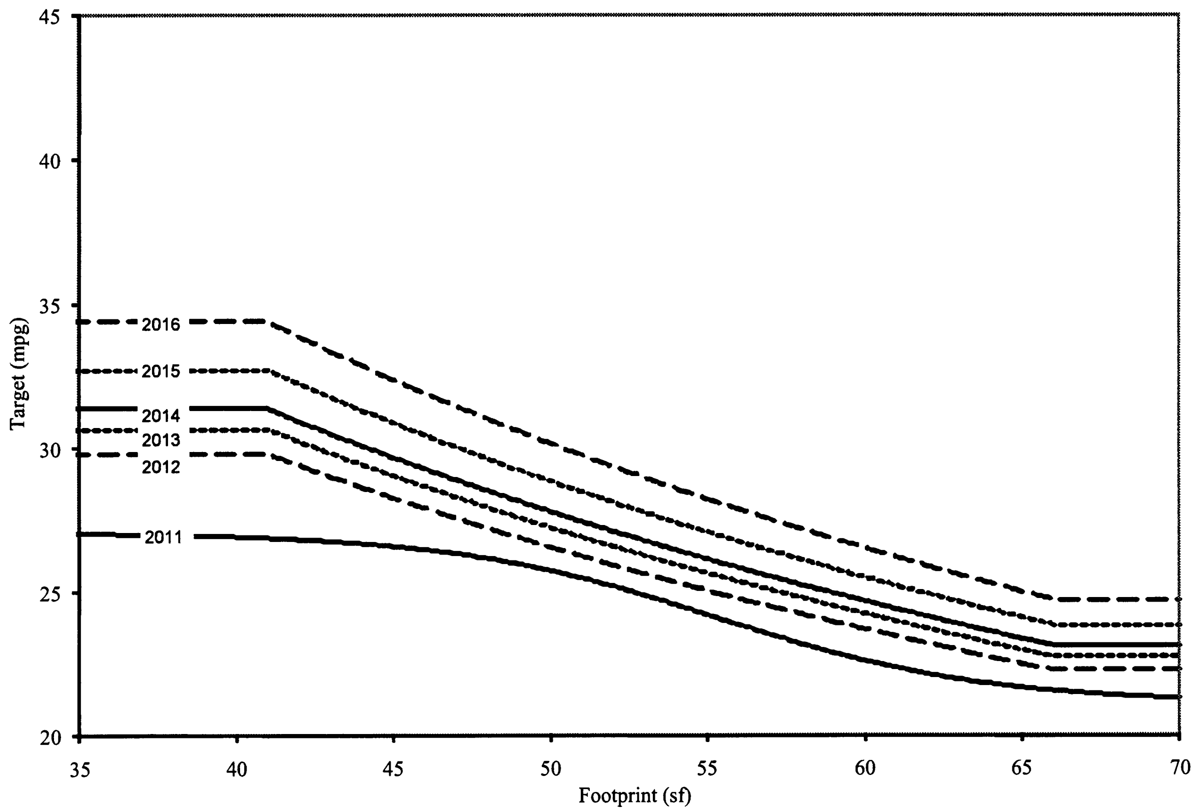


Figure IV.A.5-2 Final MY 2011 and Final MY 2012-2016

Light Truck Fuel Economy Targets



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Under these final footprint-based CAFE standards, the CAFE levels required of individual manufacturers depend, as noted above, on the mix of vehicles sold. It is important to note that NHTSA's CAFE standards and EPA's GHG standards will both be in effect, and each will lead to increases in average fuel economy and CO_2 emissions reductions. The two agencies' standards together comprise the National Program, and this discussion of costs and benefits of NHTSA's CAFE standards does not change the fact that both the CAFE and GHG standards, jointly, are the source of the benefits and costs of the National Program.

Based on the forecast developed for this final rule of the MYs 2012–2016 vehicle fleet, NHTSA estimates that the targets shown above will result in the following estimated average required CAFE levels:

TABLE IV.A.5–1—ESTIMATED AVERAGE REQUIRED FUEL ECONOMY (MPG) UNDER FINAL STANDARDS

	2012	2013	2014	2015	2016
Passenger Cars	33.3	34.2	34.9	36.2	37.8
Light Trucks	25.4	26.0	26.6	27.5	28.8
Combined Cars & Trucks	29.7	30.5	31.3	32.6	34.1

For the reader's reference, these miles per gallon values would be equivalent to the following gallons per 100 miles values for passenger cars and light trucks:

	2012	2013	2014	2015	2016
Passenger Cars	3.00	2.93	2.86	2.76	2.65
Light Trucks	3.94	3.85	3.76	3.63	3.48
Combined Cars & Trucks	3.36	3.28	3.19	3.07	2.93

NHTSA estimates that average achieved fuel economy levels will correspondingly increase through MY 2016, but that manufacturers will, on average, undercomply[525] in some model years and overcomply[526] in others, reaching a combined average fuel economy of 33.7 mpg in MY 2016.[527] Table IV.A.5–1 is the estimated required fuel economy for the final CAFE standards while Table IV.A.5–2 includes the effects of some manufacturers' payment of CAFE fines and use of FFV credits. In addition, Section IV.G.4 below contains an analysis of the achieved levels (and projected fuel savings, costs, and benefits) when the use of FFV credits is assumed.

TABLE IV.A.5–2—ESTIMATED AVERAGE ACHIEVED FUEL ECONOMY (MPG) UNDER FINAL STANDARDS

	2012	2013	2014	2015	2016
Passenger Cars	32.8	34.4	35.3	36.3	37.2
Light Trucks	25.1	26.0	27.0	27.6	28.5
Combined Cars & Trucks	29.3	30.6	31.7	32.6	33.7

For the reader's reference, these miles per gallon values would be equivalent to the following gallons per 100 miles values for passenger cars and light trucks:

	2012	2013	2014	2015	2016
Passenger Cars	3.05	2.91	2.83	2.76	2.69
Light Trucks	3.99	3.84	3.71	3.62	3.50
Combined Cars & Trucks	3.42	3.27	3.15	3.06	2.97

NHTSA estimates that these fuel economy increases will lead to fuel savings totaling 61 billion gallons during the lifetimes of vehicles sold in MYs 2012–2016 (all following tables assume Reference Case economic inputs):

TABLE IV.A.5–3—FUEL SAVED (BILLION GALLONS) UNDER FINAL STANDARDS

	2012	2013	2014	2015	2016	Total
Passenger Cars	2.4	5.2	7.2	9.4	11.4	35.7
Light Trucks	1.8	3.7	5.3	6.5	8.1	25.4
Combined	4.2	8.9	12.5	16.0	19.5	61.0

The agency also estimates that these new CAFE standards will lead to corresponding reductions of CO_2 emissions totaling 655 million metric tons (mmt) during the useful lives of vehicles sold in MYs 2012–2016:

TABLE IV.A.5–4—AVOIDED CARBON DIOXIDE EMISSIONS (MMT) UNDER FINAL STANDARDS

	2012	2013	2014	2015	2016	Total
Passenger Cars	25	54	77	101	123	380
Light Trucks	19	40	57	71	88	275

[525] In NHTSA's analysis, "undercompliance" is mitigated either through use of FFV credits, use of existing or "banked" credits, or through fine payment. Because NHTSA cannot consider availability of credits in setting standards, the estimated achieved CAFE levels presented here do not account for their use. In contrast, because NHTSA is not prohibited from considering fine payment, the estimated achieved CAFE levels presented here include the assumption that BMW, Daimler (*i.e.,* Mercedes), Porsche, and, Tata (*i.e.,* Jaguar and Rover) will only apply technology up to the point that it would be less expensive to pay civil penalties.

[526] In NHTSA's analysis, "overcompliance" occurs through multi-year planning: manufacturers apply some "extra" technology in early model years (*e.g.,* MY 2014) in order to carry that technology forward and thereby facilitate compliance in later model years (*e.g.,* MY 2016).

[527] Consistent with EPCA, NHTSA has not accounted for manufacturers' ability to earn CAFE credits for selling FFVs, carry credits forward and back between model years, and transfer credits between the passenger car and light truck fleets.

TABLE IV.A.5–4—AVOIDED CARBON DIOXIDE EMISSIONS (MMT) UNDER FINAL STANDARDS—Continued

	2012	2013	2014	2015	2016	Total
Combined	44	94	134	172	210	655

The agency estimates that these fuel economy increases would produce other benefits (*e.g.,* reduced time spent refueling), as well as some disbenefits (*e.g.,* increased traffic congestion) caused by drivers' tendency to increase travel when the cost of driving declines (as it does when fuel economy increases). The agency has estimated the total monetary value to society of these benefits and disbenefits, and estimates that the final standards will produce significant benefits to society. NHTSA estimates that, in present value terms, these benefits would total over $180 billion over the useful lives of vehicles sold during MYs 2012–2016:

TABLE IV.A.5–5—PRESENT VALUE OF BENEFITS ($BILLION) UNDER FINAL CAFE STANDARDS

	2012	2013	2014	2015	2016	Total
Passenger Cars	6.8	15.2	21.6	28.7	35.2	107.5
Light Trucks	5.1	10.7	15.5	19.4	24.3	75.0
Combined	11.9	25.8	37.1	48	59.5	182.5

NHTSA attributes most of these benefits—about $143 billion, as noted above—to reductions in fuel consumption, valuing fuel (for societal purposes) at future pretax prices in the Energy Information Administration's (EIA's) reference case forecast from Annual Energy Outlook (AEO) 2010. The Final Regulatory Impact Analysis (FRIA) accompanying today's final rule presents a detailed analysis of specific benefits of the final rule.

	Amount	Monetized value (discounted)	
		3% Discount rate	7% Discount rate
Fuel savings	61.0 billion gallons	$143.0 billion	$112.0 billion.
CO_2 emissions reductions [528]	655 mmt	$14.5 billion	$14.5 billion.

NHTSA estimates that the necessary increases in technology application will involve considerable monetary outlays, totaling $52 billion in incremental outlays (*i.e.,* beyond those attributable to the MY 2011 standards) by new vehicle purchasers during MYs 2012–2016:

TABLE IV.A.5–6—INCREMENTAL TECHNOLOGY OUTLAYS ($B) UNDER FINAL CAFE STANDARDS

	2012	2013	2014	2015	2016	Total
Passenger Cars	4.1	5.4	6.9	8.2	9.5	34.2
Light Trucks	1.8	2.5	3.7	4.3	5.4	17.6
Combined	5.9	7.9	10.5	12.5	14.9	51.7

Corresponding to these outlays and, to a much lesser extent, civil penalties that some companies are expected to pay for noncompliance, the agency estimates that the final standards would lead to increases in average new vehicle prices, ranging from $322 per vehicle in MY 2012 to $961 per vehicle in MY 2016:

TABLE IV.A.5–7—INCREMENTAL INCREASES IN AVERAGE NEW VEHICLE PRICES ($) UNDER FINAL CAFE STANDARDS

	2012	2013	2014	2015	2016
Passenger Cars	505	573	690	799	907
Light Trucks	322	416	621	752	961
Combined	434	513	665	782	926

[528] We note that the net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5 percent, 3 percent, and 2.5 percent) is used to calculate the net present value of the SCC for internal consistency. Additionally, we note that the SCC increases over time. *See Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government, February 2010 (available in Docket No. NHTSA–2009–0059 for more information.

Tables IV.A.5–8 and IV.A.5–9 below present itemized costs and benefits for a 3 percent and a 7 percent discount rate, respectively, for the combined fleet (passenger cars and light trucks) in each model year and for all model years combined, again assuming Reference Case inputs (except for the variation in discount rate). Numbers in parentheses represent negative values.

TABLE IV.A.5–8—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET, 3% DISCOUNT RATE

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Costs:						
Technology Costs	5,903	7,890	10,512	12,539	14,904	51,748
Benefits:						
Savings in Lifetime Fuel Expenditures	9,265	20,178	29,083	37,700	46,823	143,048
Consumer Surplus from Additional Driving	696	1,504	2,150	2,754	3,387	10,491
Value of Savings in Refueling Time	706	1,383	1,939	2,464	2,950	9,443
Reduction in Petroleum Market Externalities	545	1,154	1,630	2,080	2,543	7,952
Reduction in Climate-Related Damages from Lower CO_2 Emissions [529]	921	2,025	2,940	3,840	4,804	14,528
Reduction in Health Damage Costs From Lower Emissions of Criteria Air Pollutants						
CO	0	0	0	0	0	0
VOC	42	76	102	125	149	494
NO_X	70	104	126	146	166	612
PM	205	434	612	776	946	2,974
SO_X	158	332	469	598	731	2,288
Dis-Benefits From Increased Driving						
Congestion Costs	(447)	(902)	(1,282)	(1,633)	(2,000)	(6,264)
Noise Costs	(9)	(18)	(25)	(32)	(39)	(122)
Crash Costs	(217)	(430)	(614)	(778)	(950)	(2,989)
Total Benefits	11,936	25,840	37,132	48,040	59,509	182,457
Net Benefits	6,033	17,950	26,619	35,501	44,606	130,709

TABLE IV.A.5–9—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET, 7% DISCOUNT RATE

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Costs:						
Technology Costs	5,903	7,890	10,512	12,539	14,904	51,748
Benefits:						
Savings in Lifetime Fuel Expenditures	7,197	15,781	22,757	29,542	36,727	112,004
Consumer Surplus from Additional Driving	542	1,179	1,686	2,163	2,663	8,233
Value of Savings in Refueling Time	567	1,114	1,562	1,986	2,379	7,608
Reduction in Petroleum Market Externalities	432	917	1,296	1,654	2,023	6,322
Reduction in Climate-Related Damages From Lower CO_2 Emissions [530]	921	2,025	2,940	3,840	4,804	14,530
Reduction in Health Damage Costs From Lower Emissions of Criteria Air Pollutants						
CO	0	0	0	0	0	0
VOC	32	60	80	99	119	390
NO_x	53	80	98	114	131	476
PM	154	336	480	611	748	2,329
SO_x	125	265	373	475	581	1,819
Dis-Benefits From Increased Driving						
Congestion Costs	(355)	(719)	(1,021)	(1,302)	(1,595)	(4,992)
Noise Costs	(7)	(14)	(20)	(26)	(31)	(98)
Crash Costs	(173)	(342)	(488)	(619)	(756)	(2,378)

[529] *See supra* note 528.

TABLE IV.A.5–9—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET, 7% DISCOUNT RATE—Continued

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Total Benefits	9,488	20,682	29,743	38,537	47,793	146,243
Net Benefits	3,586	12,792	19,231	25,998	32,890	94,497

Neither EPCA nor EISA *requires* that NHTSA conduct a cost-benefitanalysis in determining average fuel economy standards, but too, neither precludes its use.[531] EPCA does require that NHTSA consider economic practicability among other factors, and NHTSA has concluded, as discussed elsewhere herein, that the standards it promulgates today are economically practicable. Further validating and supporting its conclusion that the standards it promulgates today are reasonable, a comparison of the standards' costs and benefits shows that the standards' estimated benefits far outweigh its estimated costs. Based on the figures reported above, NHTSA estimates that the total benefits of today's final standards would be more than three times the magnitude of the corresponding costs, such that the final standards would produce net benefits of over $130 billion over the useful lives of vehicles sold during MYs 2012–2016.

B. Background

1. Chronology of Events Since the National Academy of Sciences Called for Reforming and Increasing CAFE Standards

a. National Academy of Sciences Issues Report on Future of CAFE Program (February 2002)

i. Significantly Increasing CAFE Standards Without Making Them Attribute-Based Would Adversely Affect Safety

In the 2002 congressionally-mandated report entitled "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," [532] a majority of the committee of the National Academy of Sciences (NAS) ("2002 NAS Report") concluded that the then-existing form of passenger car and light truck CAFE standards permitted vehicle manufacturers to comply in part by downweighting and even downsizing their vehicles and that these actions had led to additional fatalities. The committee explained that this safety problem arose because, at that time, the CAFE standards were not attribute-based and thus subjected all passenger cars to the same fuel economy target and all light trucks to the same target, regardless of their weight, size, or load-carrying capacity.[533] The committee said that this experience suggests that consideration should be given to developing a new system of fuel economy targets that reflects differences in such vehicle attributes. Without a thoughtful restructuring of the program, there would be trade-offs that must be made if CAFE standards were increased by any significant amount.[534]

In response to these conclusions, NHTSA considered various attributes and ultimately issued footprint-based CAFE standards for light trucks and sought legislative authority to issue attribute-based CAFE standards for passenger cars before undertaking to raise the car standards. Congress went a step further in enacting EISA, not only authorizing the issuance of attribute-based standards, but also mandating them.

ii. Climate Change and Other Externalities Justify Increasing the CAFE Standards

The NAS committee said that there are two compelling concerns that justify increasing the fuel economy standards, both relating to externalities. The first and most important concern, it argued, is the accumulation in the atmosphere of greenhouse gases, principally carbon dioxide.[535]

A second concern is that petroleum imports have been steadily rising because of the nation's increasing demand for gasoline without a corresponding increase in domestic supply. The high cost of oil imports poses two risks: downward pressure on the strength of the dollar (which drives up the cost of goods that Americans import) and an increase in U.S. vulnerability to macroeconomic shocks that cost the economy considerable real output.

To determine how much the fuel economy standards should be increased, the committee urged that all social benefits of such increases be considered. That is, it urged not only that the dollar value of the saved fuel be considered, but also that the dollar value to society of the resulting reductions in greenhouse gas emissions and in dependence on imported oil should be calculated and considered.

iii. Reforming the CAFE Program Could Address Inequity Arising From the CAFE Structure

The 2002 NAS report expressed concerns about increasing the standards under the CAFE program as it was then structured. While raising CAFE standards under the then-existing structure would reduce fuel consumption, doing so under alternative structures "could accomplish the same end at lower cost, provide more flexibility to manufacturers, or address inequities arising from the present" structure.[536]

To address those structural problems, the report suggested various possible reforms. The report found that the "CAFE program might be improved significantly by converting it to a system in which fuel targets depend on vehicle attributes." [537] The report noted further that under an attribute-based approach, the required CAFE levels could vary among the manufacturers based on the distribution of their product mix. NAS

[530] *See supra* note 529.

[531] *Center for Biological Diversity* v. *NHTSA,* 508 F.3d 508 (9th Cir. 2007) (rejecting argument that EPCA precludes the use of a marginal cost-benefit analysis that attempted to weigh all of the social benefits (*i.e.,* externalities as well as sdirect benefits to consumers) of improved fuel savings in determining the stringency of the CAFE standards). *See* also *Entergy Corp.* v. *Riverkeeper, Inc.,* 129 S.Ct. 1498, 1508 (2009) ("[U]nder *Chevron,* that an agency is not *required* to [conduct a cost-benefit analysis] does not mean that an agency is not *permitted* to do so.")

[532] National Research Council, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, Washington, DC (2002). *Available at http://www.nap.edu/openbook.php?isbn=0309076013* (last accessed March 1, 2010). The conference committee report for the Department of Transportation and Related Agencies Appropriations Act for FY 2001 (Pub. L. 106–346) directed NHTSA to fund a study by NAS to evaluate the effectiveness and impacts of CAFE standards (H. Rep. No. 106–940, p. 117–118). In response to the direction from Congress, NAS published this lengthy report.

[533] NHTSA formerly used this approach for CAFE standards. EISA prohibits its use after MY 2010.

[534] NAS, p. 9. As discussed at length in prior CAFE rules, two members of the NAS Committee dissented from the majority opinion that there would be safety impacts to downweighting under a flat-standard system.

[535] NAS, pp. 2, 13, and 83.

[536] NAS, pp. 4–5 (Finding 10).

[537] NAS, p. 5 (Finding 12).

stated that targets could vary among passenger cars and among trucks, based on some attribute of these vehicles such as weight, size, or load-carrying capacity. The report explained that a particular manufacturer's average target for passenger cars or for trucks would depend upon the fractions of vehicles it sold with particular levels of these attributes.[538]

b. NHTSA Issues Final Rule Establishing Attribute-Based CAFE Standards for MY 2008–2011 Light Trucks (March 2006)

The 2006 final rule reformed the structure of the CAFE program for light trucks by introducing an attribute-based approach and using that approach to establish higher CAFE standards for MY 2008–2011 light trucks.[539] Reforming the CAFE program enabled it to achieve larger fuel savings, while enhancing safety and preventing adverse economic consequences.

As noted above, fuel economy standards were restructured so that they were based on a vehicle attribute, a measure of vehicle size called "footprint." It is the product of multiplying a vehicle's wheelbase by its track width. A target level of fuel economy was established for each increment in footprint (0.1 ft^2). Trucks with smaller footprints have higher fuel economy targets; conversely, larger ones have lower targets. A particular manufacturer's compliance obligation for a model year is calculated as the harmonic average of the fuel economy targets for the manufacturer's vehicles, weighted by the distribution of the manufacturer's production volumes among the footprint increments. Thus, each manufacturer is required to comply with a single overall average fuel economy level for each model year of production.

Compared to non-attribute-based CAFE, attribute-based CAFE enhances overall fuel savings while providing vehicle manufacturers with the flexibility they need to respond to changing market conditions. Attribute-based CAFE also provides a more equitable regulatory framework by creating a level playing field for manufacturers, regardless of whether they are full-line or limited-line manufacturers. We were particularly encouraged that attribute-based CAFE will confer no compliance advantage if vehicle makers choose to downsize some of their fleet as a CAFE compliance strategy, thereby reducing the adverse safety risks associated with the non-attribute-based CAFE program.

c. Ninth Circuit Issues Decision re Final Rule for MY 2008–2011 Light Trucks (November 2007)

On November 15, 2007, the United States Court of Appeals for the Ninth Circuit issued its decision in *Center for Biological Diversity* v. *NHTSA,*[540] the challenge to the MY 2008–11 light truck CAFE rule. The court held that EPCA permits, but does not require, the use of a marginal cost-benefit analysis. The court specifically emphasized NHTSA's discretion to decide how to balance the statutory factors—as long as that balancing does not undermine the fundamental statutory purpose of energy conservation. Although the Court found that NHTSA had been arbitrary and capricious in several respects, the Court did not vacate the standards, but instead said it would remand the rule to NHTSA to promulgate new standards consistent with its opinion "as expeditiously as possible and for the earliest model year practicable." Under the decision, the standards established by the April 2006 final rule would remain in effect unless and until amended by NHTSA. In addition, it directed the agency to prepare an Environmental Impact Statement.

d. Congress Enacts Energy Security and Independence Act of 2007 (December 2007)

As noted above in Section I.B., EISA significantly changed the provisions of EPCA governing the establishment of future CAFE standards. These changes made it necessary for NHTSA to pause in its efforts so that it could assess the implications of the amendments made by EISA and then, as required, revise some aspects of the proposals it had been developing (*e.g.,* the model years covered and credit issues).

e. NHTSA Proposes CAFE Standards for MYs 2011–2015 (April 2008)

The agency could not set out the exact level of CAFE that each manufacturer would have been required to meet for each model year under the passenger car or light truck standards since the levels would depend on information that would not be available until the end of each of the model years, *i.e.,* the final actual production figures for each of those years. The agency could, however, project what the industry-wide level of average fuel economy would have been for passenger cars and for light trucks if each manufacturer produced its expected mix of automobiles and just met its obligations under the proposed "optimized" standards for each model year.

	Passenger cars mpg	Light trucks mpg
MY 2011	31.2	25.0
MY 2012	32.8	26.4
MY 2013	34.0	27.8
MY 2014	34.8	28.2
MY 2015	35.7	28.6

The combined industry-wide average fuel economy (in miles per gallon, or mpg) levels for both cars and light trucks, if each manufacturer just met its obligations under the proposed "optimized" standards for each model year, would have been as follows:

	Combined mpg
MY 2011	27.8
MY 2012	29.2
MY 2013	30.5
MY 2014	31.0
MY 2015	31.6

The annual average increase during this five year period would have been approximately 4.5 percent. Due to the uneven distribution of new model introductions during this period and to the fact that significant technological changes could be most readily made in conjunction with those introductions, the annual percentage increases were greater in the early years in this period.

f. Ninth Circuit Revises Its Decision re Final Rule for MY 2008–2011 Light Trucks (August 2008)

In response to the Government petition for rehearing, the Ninth Circuit modified its decision by replacing its direction to prepare an EIS with a direction to prepare either a new EA or, if necessary, an EIS.[541]

g. NHTSA Releases Final Environmental Impact Statement (October 2008)

On October 17, 2008, EPA published a notice announcing the availability of NHTSA's final environmental impact statement (FEIS) for the MYs 2011–2015 rulemaking.[542] Throughout the FEIS, NHTSA relied extensively on findings of the United Nations Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program (USCCSP). In particular, the agency relied heavily on the most recent, thoroughly peer-reviewed, and credible assessments of global climate change and its impact on the United States: The

[538] NAS, p. 87.

[539] 71 FR 17566 (Apr. 6, 2006).

[540] 508 F.3d 508.

[541] *See CBD* v. *NHTSA,* 538 F.3d 1172 (9th Cir. 2008).

[542] 73 FR 61859 (Oct. 18, 2008).

IPCC Fourth Assessment Report Working Group I4 and II5 Reports, and reports by the USCCSP that include *Scientific Assessments of the Effects of Global Climate Change on the United States* and Synthesis and Assessment Products.

In the FEIS, NHTSA compared the environmental impacts of its preferred alternative and those of reasonable alternatives. It considered direct, indirect, and cumulative impacts and describes these impacts to inform the decision maker and the public of the environmental impacts of the various alternatives.

Among other potential impacts, NHTSA analyzed the direct and indirect impacts related to fuel and energy use, emissions, including carbon dioxide and its effects on temperature and climate change, air quality, natural resources, and the human environment. Specifically, the FEIS used a climate model to estimate and report on four direct and indirect effects of climate change, driven by alternative scenarios of GHG emissions, including:

1. Changes in CO_2 concentrations;
2. Changes in global mean surface temperature;
3. Changes in regional temperature and precipitation; and
4. Changes in sea level.

NHTSA also considered the cumulative impacts of the proposed standards for MY 2011–2015 passenger cars and light trucks, together with estimated impacts of NHTSA's implementation of the CAFE program through MY 2010 and NHTSA's future CAFE rulemaking for MYs 2016–2020.

h. Department of Transportation Decides Not To Issue MY 2011–2015 Final Rule (January 2009)

On January 7, 2009, the Department of Transportation announced that the Bush Administration would not issue the final rule, notwithstanding the Office of Information and Regulatory Affairs' completion of review of the rule under Executive Order 12866, Regulatory Planning and Review, on November 14, 2008.[543]

i. The President Requests NHTSA To Issue Final Rule for MY 2011 Only (January 2009)

As explained above, in his memorandum of January 26, 2009, the President requested the agency to issue a final rule adopting CAFE standards for MY 2011 only. Further, the President requested NHTSA to establish standards for MY 2012 and later after considering the appropriate legal factors, the comments filed in response to the May 2008 proposal, the relevant technological and scientific considerations, and, to the extent feasible, a forthcoming report by the National Academy of Sciences assessing automotive technologies that can practicably be used to improve fuel economy.

j. NHTSA Issues Final Rule for MY 2011 (March 2009)

i. Standards

The final rule established footprint-based fuel economy standards for MY 2011 passenger cars and light trucks. Each vehicle manufacturer's required level of CAFE was based on target levels of average fuel economy set for vehicles of different sizes and on the distribution of that manufacturer's vehicles among those sizes. The curves defining the performance target at each footprint reflect the technological and economic capabilities of the industry. The target for each footprint is the same for all manufacturers, regardless of differences in their overall fleet mix. Compliance would be determined by comparing a manufacturer's harmonically averaged fleet fuel economy levels in a model year with a required fuel economy level calculated using the manufacturer's actual production levels and the targets for each footprint of the vehicles that it produces.

The agency analyzed seven regulatory alternatives, one of which maximizes net benefits within the limits of available information and was known at the time as the "optimized standards." The optimized standards were set at levels, such that, considering all of the manufacturers together, no other alternative is estimated to produce greater net benefits to society. Upon a considered analysis of all information available, including all information submitted to NHTSA in comments, the agency adopted the "optimized standard" alternative as the final standards for MY 2011.[544] By limiting the standards to levels that can be achieved using technologies each of which are estimated to provide benefits that at least equal its costs, the net benefit maximization approach helped, at the time, to assure the marketability of the manufacturers' vehicles and thus economic practicability of the standards, for the reasons discussed extensively in that final rule.

The following levels were projected for what the industry-wide level of average fuel economy will be for passenger cars and for light trucks if each manufacturer produced its expected mix of automobiles and just met its obligations under the "optimized" standards.

	Passenger cars mpg	Light trucks mpg
MY 2011	30.2	24.1

The combined industry-wide average fuel economy (in miles per gallon, or mpg) levels for both cars and light trucks, if each manufacturer just met its obligations under the "optimized" standards, were projected as follows:

	Combined mpg	mpg increase over prior year
MY 2011	27.3	2.0

In addition, per EISA, each manufacturer's domestic passenger fleet is required in MY 2011 to achieve 27.5 mpg or 92 percent of the CAFE of the industry-wide combined fleet of domestic and non-domestic passenger cars[545] for that model year, whichever is higher. This requirement resulted in the following projected alternative minimum standard (not attribute-based) for domestic passenger cars:

	Domestic passenger cars mpg
MY 2011	27.8

ii. Credits

NHTSA also adopted a new part 536 on use of "credits" earned for exceeding applicable CAFE standards. Part 536 implements the provisions in EISA authorizing NHTSA to establish by regulation a credit trading program and directing it to establish by regulation a credit transfer program.[546] Since its enactment, EPCA has permitted manufacturers to earn credits for exceeding the standards and to apply those credits to compliance obligations

[543] The statement can be found at *http://www.dot.gov/affairs/dot0109.htm* (last accessed March 1, 2010).

[544] The agency notes, for NEPA purposes, that the "optimized standard" alternative adopted as the final standards corresponds to the "Optimized Mid-2" scenario described in Section 2.2.2 of the FEIS.

[545] Those numbers set out several paragraphs above.

[546] Congress required that DOT establish a credit "transferring" regulation, to allow individual manufacturers to move credits from one of their fleets to another (*e.g.,* using a credit earned for exceeding the light truck standard for compliance with the domestic passenger car standard). Congress allowed DOT to establish a credit "trading" regulation, so that credits may be bought and sold between manufacturers and other parties.

in years other than the model year in which it was earned. EISA extended the "carry-forward" period to five model years, and left the "carry-back" period at three model years. Under part 536, credit holders (including, but not limited to, manufacturers) will have credit accounts with NHTSA, and will be able to hold credits, apply them to compliance with CAFE standards, transfer them to another "compliance category" for application to compliance there, or trade them. A credit may also be cancelled before its expiry date, if the credit holder so chooses. Traded and transferred credits will be subject to an "adjustment factor" to ensure total oil savings are preserved, as required by EISA. EISA also prohibits credits earned before MY 2011 from being transferred, so NHTSA has developed several regulatory restrictions on trading and transferring to facilitate Congress' intent in this regard.

2. Energy Policy and Conservation Act, as Amended by the Energy Independence and Security Act

NHTSA establishes CAFE standards for passenger cars and light trucks for each model year under EPCA, as amended by EISA. EPCA mandates a motor vehicle fuel economy regulatory program to meet the various facets of the need to conserve energy, including ones having environmental and foreign policy implications. EPCA allocates the responsibility for implementing the program between NHTSA and EPA as follows: NHTSA sets CAFE standards for passenger cars and light trucks; EPA establishes the procedures for testing, tests vehicles, collects and analyzes manufacturers' data, and calculates the average fuel economy of each manufacturer's passenger cars and light trucks; and NHTSA enforces the standards based on EPA's calculations.

a. Standard Setting

We have summarized below the most important aspects of standard setting under EPCA, as amended by EISA.

For each future model year, EPCA requires that NHTSA establish standards at "the maximum feasible average fuel economy level that it decides the manufacturers can achieve in that model year," based on the agency's consideration of four statutory factors: Technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy. EPCA does not define these terms or specify what weight to give each concern in balancing them; thus, NHTSA defines them and determines the appropriate weighting based on the circumstances in each CAFE standard rulemaking.[547]

For MYs 2011–2020, EPCA further requires that separate standards for passenger cars and for light trucks be set at levels high enough to ensure that the CAFE of the industry-wide combined fleet of new passenger cars and light trucks reaches at least 35 mpg not later than MY 2020.

i. Factors That Must Be Considered in Deciding the Appropriate Stringency of CAFE Standards

(1) Technological Feasibility

"Technological feasibility" refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established. Thus, the agency is not limited in determining the level of new standards to technology that is already being commercially applied at the time of the rulemaking. NHTSA has historically considered all types of technologies that improve real-world fuel economy, except those whose effects are not reflected in fuel economy testing. Principal among them are technologies that improve air conditioner efficiency because the air conditioners are not turned on during testing under existing test procedures.

(2) Economic Practicability

"Economic practicability" refers to whether a standard is one "within the financial capability of the industry, but not so stringent as to" lead to "adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice."[548] This factor is especially important in the context of current events, where the automobile industry is facing significantly adverse economic conditions, as well as significant loss of jobs. In an attempt to ensure the economic practicability of attribute-based standards, NHTSA considers a variety of factors, including the annual rate at which manufacturers can increase the percentage of their fleets that employ a particular type of fuel-saving technology, and cost to consumers. Consumer acceptability is also an element of economic practicability, one which is particularly difficult to gauge during times of frequently-changing fuel prices. NHTSA believes this approach is reasonable for the MY 2012–2016 standards in view of the facts before it at this time.

At the same time, the law does not preclude a CAFE standard that poses considerable challenges to any individual manufacturer. The Conference Report for EPCA, as enacted in 1975, makes clear, and the case law affirms, "a determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy."[549] Instead, NHTSA is compelled "to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers." *Id.* The law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole. Thus, while a particular CAFE standard may pose difficulties for one manufacturer, it may also present opportunities for another. The CAFE program is not necessarily intended to maintain the competitive positioning of each particular company. Rather, it is intended to enhance fuel economy of the vehicle fleet on American roads, while protecting motor vehicle safety and being mindful of the risk of harm to the overall United States economy.

(3) The Effect of Other Motor Vehicle Standards of the Government on Fuel Economy

"The effect of other motor vehicle standards of the Government on fuel economy," involves an analysis of the effects of compliance with emission,[550] safety, noise, or damageability standards on fuel economy capability and thus on average fuel economy. In previous CAFE rulemakings, the agency has said that pursuant to this provision, it considers the adverse effects of other motor vehicle standards on fuel economy. It said so because, from the CAFE program's earliest years[551] until present, the effects of such compliance on fuel economy capability over the history of the CAFE program have been negative ones. For example, safety standards that have the effect of increasing vehicle weight lower vehicle

[547] *See Center for Biological Diversity* v. *NHTSA,* 538 F.3d. 1172, 1195 (9th Cir. 2008) ("The EPCA clearly requires the agency to consider these four factors, but it gives NHTSA discretion to decide how to balance the statutory factors—as long as NHTSA's balancing does not undermine the fundamental purpose of the EPCA: energy conservation.")

[548] 67 FR 77015, 77021 (Dec. 16, 2002).

[549] *CEI–I,* 793 F.2d 1322, 1352 (DC Cir. 1986).

[550] In the case of emission standards, this includes standards adopted by the Federal government and can include standards adopted by the States as well, since in certain circumstances the Clean Air Act allows States to adopt and enforce State standards different from the Federal ones.

[551] 42 FR 63184, 63188 (Dec. 15, 1977). *See* also 42 FR 33534, 33537 (Jun. 30, 1977).

fuel economy capability and thus decrease the level of average fuel economy that the agency can determine to be feasible.

NHTSA also recognizes that in some cases the effect of other motor vehicle standards of the Government on fuel economy may be neutral or positive. For example, to the extent the GHG standards set by EPA and California result in increases in fuel economy, they would do so almost exclusively as a result of inducing manufacturers to install the same types of technologies used by manufacturers in complying with the CAFE standards. The primary exception would involve lower-GHG-producing air conditioners. The agency considered EPA's standards and the harmonization benefits of the National Program in developing its own standards.

(4) The Need of the United States To Conserve Energy

"The need of the United States to conserve energy" means "the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum." [552] Environmental implications principally include reductions in emissions of criteria pollutants and carbon dioxide. Prime examples of foreign policy implications are energy independence and security concerns.

(a) Fuel Prices and the Value of Saving Fuel

Projected future fuel prices are a critical input into the preliminary economic analysis of alternative CAFE standards, because they determine the value of fuel savings both to new vehicle buyers and to society. In this rule, NHTSA relies on fuel price projections from the U.S. Energy Information Administration's (EIA) Annual Energy Outlook (AEO) for this analysis. Federal government agencies generally use EIA's projections in their assessments of future energy-related policies.

(b) Petroleum Consumption and Import Externalities

U.S. consumption and imports of petroleum products impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to provide a response option should a disruption in commercial oil supplies threaten the U.S. economy, to allow the United States to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and to provide a national defense fuel reserve. Higher U.S. imports of crude oil or refined petroleum products increase the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above the resource costs of producing them. Conversely, reducing U.S. imports of crude petroleum or refined fuels or reducing fuel consumption can reduce these external costs.

(c) Air Pollutant Emissions

While reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of various pollutants, additional vehicle use associated with the rebound effect [553] from higher fuel economy will increase emissions of these pollutants. Thus, the net effect of stricter CAFE standards on emissions of each pollutant depends on the relative magnitudes of its reduced emissions in fuel refining and distribution, and increases in its emissions from vehicle use.

Fuel savings from stricter CAFE standards also result in lower emissions of CO_2, the main greenhouse gas emitted as a result of refining, distribution, and use of transportation fuels. Lower fuel consumption reduces carbon dioxide emissions directly, because the primary source of transportation-related CO_2 emissions is fuel combustion in internal combustion engines.

NHTSA has considered environmental issues, both within the context of EPCA and the National Environmental Policy Act, in making decisions about the setting of standards from the earliest days of the CAFE program. As courts of appeal have noted in three decisions stretching over the last 20 years,[554] NHTSA defined the "need of the Nation to conserve energy" in the late 1970s as including "the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum." [555] Pursuant to that view, NHTSA declined in the past to include diesel engines in determining the appropriate level of standards for passenger cars and for light trucks because particulate emissions from diesels were then both a source of concern and unregulated.[556] In 1988, NHTSA included climate change concepts in its CAFE notices and prepared its first environmental assessment addressing that subject.[557] It cited concerns about climate change as one of its reasons for limiting the extent of its reduction of the CAFE standard for MY 1989 passenger cars.[558] Since then, NHTSA has considered the benefits of reducing tailpipe carbon dioxide emissions in its fuel economy rulemakings pursuant to the statutory requirement to consider the nation's need to conserve energy by reducing fuel consumption.

ii. Other Factors Considered by NHTSA

NHTSA considers the potential for adverse safety consequences when in establishing CAFE standards. This practice is recognized approvingly in case law.[559] Under the universal or "flat" CAFE standards that NHTSA was previously authorized to establish, manufacturers were encouraged to respond to higher standards by building smaller, less safe vehicles in order to "balance out" the larger, safer vehicles that the public generally preferred to

[552] 42 FR 63184, 63188 (1977).

[553] The "rebound effect" refers to the tendency of drivers to drive their vehicles more as the cost of doing so goes down, as when fuel economy improves.

[554] *Center for Auto Safety* v. *NHTSA,* 793 F.2d 1322, 1325 n. 12 (DC Cir. 1986); *Public Citizen* v. *NHTSA,* 848 F.2d 256, 262–3 n. 27 (DC Cir. 1988) (noting that "NHTSA itself has interpreted the factors it must consider in setting CAFE standards as including environmental effects"); and *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172 (9th Cir. 2007).

[555] 42 FR 63184, 63188 (Dec. 15, 1977) (emphasis added).

[556] For example, the final rules establishing CAFE standards for MY 1981–84 passenger cars, 42 FR 33533, 33540–1 and 33551 (Jun. 30, 1977), and for MY 1983–85 light trucks, 45 FR 81593, 81597 (Dec. 11, 1980).

[557] 53 FR 33080, 33096 (Aug. 29, 1988).

[558] 53 FR 39275, 39302 (Oct. 6, 1988).

[559] *See, e.g., Center for Auto Safety* v. *NHTSA* (CAS), 793 F. 2d 1322 (DC Cir. 1986) (Administrator's consideration of market demand as component of economic practicability found to be reasonable); Public Citizen 848 F.2d 256 (Congress established broad guidelines in the fuel economy statute; agency's decision to set lower standard was a reasonable accommodation of conflicting policies). As the United States Court of Appeals pointed out in upholding NHTSA's exercise of judgment in setting the 1987–1989 passenger car standards, "NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program." *Competitive Enterprise Institute* v. *NHTSA* (CEI I), 901 F.2d 107, 120 at n.11 (DC Cir. 1990).

buy, which resulted in a higher mass differential between the smallest and the largest vehicles, with a correspondingly greater risk to safety. Under the attribute-based standards being proposed today, that risk is reduced because building smaller vehicles would tend to raise a manufacturer's overall CAFE obligation, rather than only raising its fleet average CAFE, and because all vehicles are required to continue improving their fuel economy.

In addition, the agency considers consumer demand in establishing new standards and in assessing whether already established standards remained feasible. In the 1980s, the agency relied in part on the unexpected drop in fuel prices and the resulting unexpected failure of consumer demand for small cars to develop in explaining the need to reduce CAFE standards for a several year period in order to give manufacturers time to develop alternative technology-based strategies for improving fuel economy.

iii. Factors That NHTSA Is Statutorily Prohibited From Considering in Setting Standards

EPCA provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several EPCA provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance.[560] As noted below, manufacturers can earn compliance credits by exceeding the CAFE standards and then use those credits to achieve compliance in years in which their measured average fuel economy falls below the standards. Manufacturers can also increase their CAFE levels through MY 2019 by producing alternative fuel vehicles. EPCA provides an incentive for producing these vehicles by specifying that their fuel economy is to be determined using a special calculation procedure that results in those vehicles being assigned a high fuel economy level.

iv. Weighing and Balancing of Factors

NHTSA has broad discretion in balancing the above factors in determining the average fuel economy level that the manufacturers can achieve. Congress "specifically delegated the process of setting * * * fuel economy standards with *broad* guidelines concerning the factors that the agency must consider. The breadth of those guidelines, the absence of any statutorily prescribed formula for balancing the factors, the fact that the relative weight to be given to the various factors may change from rulemaking to rulemaking as the underlying facts change, and the fact that the factors may often be conflicting with respect to whether they militate toward higher or lower standards give NHTSA discretion to decide what weight to give each of the competing policies and concerns and then determine how to balance them as long as NHTSA's balancing does not undermine the fundamental purpose of the EPCA: Energy conservation, and as long as that balancing reasonably accommodates 'conflicting policies that were committed to the agency's care by the statute.'"

Thus, EPCA does not mandate that any particular number be adopted when NHTSA determines the level of CAFE standards. Rather, any number within a zone of reasonableness may be, in NHTSA's assessment, the level of stringency that manufacturers can achieve. *See, e.g., Hercules Inc.* v. *EPA,* 598 F. 2d 91, 106 (DC Cir. 1978) ("In reviewing a numerical standard we must ask whether the agency's numbers are within a zone of reasonableness, not whether its numbers are precisely right").

v. Other Requirements Related to Standard Setting

The standards for passenger cars and those for light trucks must increase ratably each year. This statutory requirement is interpreted, in combination with the requirement to set the standards for each model year at the level determined to be the maximum feasible level that manufacturers can achieve for that model year, to mean that the annual increases should not be disproportionately large or small in relation to each other.

The standards for passenger cars and light trucks must be based on one or more vehicle attributes, like size or weight, that correlate with fuel economy and must be expressed in terms of a mathematical function. Fuel economy targets are set for individual vehicles and increase as the attribute decreases and vice versa. For example, size-based (*i.e.,* size-indexed) standards assign higher fuel economy targets to smaller (and generally, but not necessarily, lighter) vehicles and lower ones to larger (and generally, but not necessarily, heavier) vehicles. The fleet-wide average fuel economy that a particular manufacturer is required to achieve depends on the size mix of its fleet, *i.e.,* the proportion of the fleet that is small-, medium- or large-sized.

This approach can be used to require virtually all manufacturers to increase significantly the fuel economy of a broad range of both passenger cars and light trucks, *i.e.,* the manufacturer must improve the fuel economy of all the vehicles in its fleet. Further, this approach can do so without creating an incentive for manufacturers to make small vehicles smaller or large vehicles larger, with attendant implications for safety.

b. Test Procedures for Measuring Fuel Economy

EPCA provides EPA with the responsibility for establishing CAFE test procedures. Current test procedures measure the effects of many fuel saving technologies. The principal exception is improvements in air conditioning efficiency. By statutory law in the case of passenger cars and by administrative regulation in the case of light trucks, air conditioners are not turned on during fuel economy testing.

The fuel economy test procedures for light trucks could be amended through rulemaking to provide for air conditioner operation during testing and to take other steps for improving the accuracy and representativeness of fuel economy measurements. NHTSA sought comment in the NPRM regarding implementing such amendments beginning in MY 2017 and also on the more immediate interim alternative step of providing CAFE program credits under the authority of 49 U.S.C. 32904(c) for light trucks equipped with relatively efficient air conditioners for MYs 2012–2016, but decided against finalizing either option for purposes of this final rule, choosing to defer the matter for now. Modernizing the passenger car test procedures, or even providing similar credits, would not be possible under EPCA as currently written.

c. Enforcement and Compliance Flexibility

EPA is responsible for measuring automobile manufacturers' CAFE so that NHTSA can determine compliance with the CAFE standards. When NHTSA finds that a manufacturer is not in compliance, it notifies the manufacturer. Surplus credits generated from the five previous years can be used to make up the deficit. The amount of credit earned is determined by multiplying the number of tenths of a mpg by which a manufacturer exceeds a standard for a particular category of automobiles by the total volume of automobiles of that category manufactured by the manufacturer for a given model year. If there are no (or not

[560] 49 U.S.C. 32902(h).

enough) credits available, then the manufacturer can either pay the fine, or submit a carry back plan to NHTSA. A carry back plan describes what the manufacturer plans to do in the following three model years to earn enough credits to make up for the deficit. NHTSA must examine and determine whether to approve the plan.

In the event that a manufacturer does not comply with a CAFE standard, even after the consideration of credits, EPCA provides for the assessing of civil penalties, unless, as provided below, the manufacturer has earned credits for exceeding a standard in an earlier year or expects to earn credits in a later year.[561] The Act specifies a precise formula for determining the amount of civil penalties for such a noncompliance. The penalty, as adjusted for inflation by law, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year multiplied by the total volume of those vehicles in the affected fleet (*i.e.,* import or domestic passenger car, or light truck), manufactured for that model year. The amount of the penalty may not be reduced except under the unusual or extreme circumstances specified in the statute.

Unlike the National Traffic and Motor Vehicle Safety Act, EPCA does not provide for recall and remedy in the event of a noncompliance. The presence of recall and remedy provisions[562] in the Safety Act and their absence in EPCA is believed to arise from the difference in the application of the safety standards and CAFE standards. A safety standard applies to individual vehicles; that is, each vehicle must possess the requisite equipment or feature that must provide the requisite type and level of performance. If a vehicle does not, it is noncompliant. Typically, a vehicle does not entirely lack an item or equipment or feature. Instead, the equipment or features fails to perform adequately. Recalling the vehicle to repair or replace the noncompliant equipment or feature can usually be readily accomplished.

In contrast, a CAFE standard applies to a manufacturer's entire fleet for a model year. It does not require that a particular individual vehicle be equipped with any particular equipment or feature or meet a particular level of fuel economy. It does require that the manufacturer's fleet, as a whole, comply. Further, although under the attribute-based approach to setting CAFE standards fuel economy targets are established for individual vehicles based on their footprints, the vehicles are not required to comply with those targets. However, as a practical matter, if a manufacturer chooses to design some vehicles that fall below their target levels of fuel economy, it will need to design other vehicles that exceed their targets if the manufacturer's overall fleet average is to meet the applicable standard.

Thus, under EPCA, there is no such thing as a noncompliant vehicle, only a noncompliant fleet. No particular vehicle in a noncompliant fleet is any more, or less, noncompliant than any other vehicle in the fleet.

C. Development and Feasibility of the Final Standards

1. How was the baseline and reference vehicle fleet developed?

a. Why do the agencies establish a baseline and reference vehicle fleet?

As also discussed in Section II.B above, in order to determine what levels of stringency are feasible in future model years, the agencies must project what vehicles will exist in those model years, and then evaluate what technologies can feasibly be applied to those vehicles in order to raise their fuel economy and lower their CO_2 emissions. The agencies therefore established a baseline vehicle fleet representing those vehicles, based on the best available transparent information. Each agency then developed a separate reference fleet, accounting (via their respective analytical models) for the effect that the MY 2011 CAFE standards have on the baseline fleet. This reference fleet is then used for comparisons of technologies' incremental cost and effectiveness, as well as for other relevant comparisons in the rule.

Because NHTSA and EPA have different established practices, the agencies' rulemaking documents (the **Federal Register** notice, Joint Technical Support Document, agency-specific Regulatory Impact Analyses, and NHTSA Environmental Impact Analysis) have some differences in terminology. In connection with its first-ever GHG emissions rule under the CAA, EPA has used the term "baseline fleet" to refer to the MY 2008 fleet (*i.e.,* from EPA certification and fuel economy data for MY 2008) prior to adjustment to reflect projected shifts in market composition. NHTSA, as in recent CAFE rulemakings, refers to the resultant market forecast, as specified in CAFE model input files (and corresponding input files for EPA's OMEGA model), as the "baseline" fleet. EPA refers to this fleet as the "reference fleet." NHTSA refers to the "no action" standards identified in the EIS (that is, the MY 2011 standards carried forward through MY 2016) as defining the "baseline" scenario, and refers to the fleet to which technologies have been added in response to these standards as the "adjusted baseline" fleet.[563] EPA refers to this as the "final reference fleet." These differences in terminology are summarized in the following table:

Fleet description	EPA terminology	NHTSA terminology
MY 2008 Fleet with MY 2008 Production Volumes	Baseline	MY 2008 Fleet
MY 2008 Fleet Adjusted to Reflect Projected Market Shifts	Reference Fleet	Baseline [Market Forecast]
MY 2008 Fleet Adjusted to Reflected Projected Market Shifts and Response to MY 2011 CAFE Standards.	[Final] Reference Fleet	Adjusted Baseline

The agencies have retained this mixed terminology in order to facilitate comparison to past rulemakings. In general, EPA's RIA and the Joint TSD apply EPA's nomenclature, NHTSA's RIA and EIS apply NHTSA's nomenclature, and the joint **Federal Register** notice uses EPA's nomenclature when focusing on GHG emissions standards, and NHTSA's nomenclature when focusing on CAFE standards.

b. What data did the agencies use to construct the baseline, and how did they do so?

As explained in the Technical Support Document (TSD) prepared

[561] EPCA does not provide authority for seeking to enjoin violations of the CAFE standards.

[562] 49 U.S.C. 30120, Remedies for defects and noncompliance.

[563] Some manufacturers' baseline fleets (as reflected in the agencies' market forecast) do not, without applying additional technology and/or CAFE credits, show compliance with the baseline standards.

jointly by NHTSA and EPA, both agencies used a baseline vehicle fleet constructed beginning with EPA fuel economy certification data for the 2008 model year, the most recent model year for which final data is currently available from manufacturers. These data were used as the source for MY 2008 production volumes and some vehicle engineering characteristics, such as fuel economy ratings, engine sizes, numbers of cylinders, and transmission types.

Some information important for analyzing new CAFE standards is not contained in the EPA fuel economy certification data. EPA staff estimated vehicle wheelbase and track widths using data from Motortrend.com and Edmunds.com. This information is necessary for estimating vehicle footprint, which is required for the analysis of footprint-based standards. Considerable additional information regarding vehicle engineering characteristics is also important for estimating the potential to add new technologies in response to new CAFE standards. In general, such information helps to avoid "adding" technologies to vehicles that already have the same or a more advanced technology. Examples include valvetrain configuration (*e.g.,* OHV, SOHC, DOHC), presence of cylinder deactivation, and fuel delivery (*e.g.,* MPFI, SIDI). To the extent that such engineering characteristics were not available in certification data, EPA staff relied on data published by Ward's Automotive, supplementing this with information from Internet sites such as Motortrend.com and Edmunds.com. NHTSA staff also added some more detailed engineering characteristics (*e.g.,* type of variable valve timing) using data available from ALLDATA® Online. Combined with the certification data, all of this information yielded the MY 2008 baseline vehicle fleet.

After the baseline was created the next step was to project the sales volumes for 2011–2016 model years. EPA used projected car and truck volumes for this period from Energy Information Administration's (EIA's) 2009 Annual Energy Outlook (AEO).[564] However, AEO projects sales only at the car and truck level, not at the manufacturer and model-specific level, which are needed in order to estimate the effects new standards will have on individual manufacturers. Therefore, EPA purchased data from CSM–Worldwide and used their projections of the number of vehicles of each type predicted to be sold by manufacturers in 2011–2015.[565] This provided the year-by-year percentages of cars and trucks sold by each manufacturer as well as the percentages of each vehicle segment. The changes between company market share and industry market segments were most significant from 2011–2014, while for 2014–2015 the changes were relatively small. Noting this, and lacking a credible forecast of company and segment shares after 2015, the agencies assumed 2016 market share and market segments to be the same as for 2015. Using these percentages normalized to the AEO projected volumes then provided the manufacturer-specific market share and model-specific sales for model years 2011–2016.

The processes for constructing the MY 2008 baseline vehicle fleet and subsequently adjusting sales volumes to construct the MY 2011–2016 baseline vehicle fleet are presented in detail in Chapter 1 of the Joint Technical Support Document accompanying today's final rule.

c. How is this different from NHTSA's historical approach and why is this approach preferable?

As discussed above in Section II.B.4, NHTSA has historically based its analysis of potential new CAFE standards on detailed product plans the agency has requested from manufacturers planning to produce light-duty vehicles for sale in the United States. In contrast, the current market forecast is based primarily on information sources which are all either in the public domain or available commercially. There are advantages to this approach, namely transparency and the potential to reduce some errors due to manufacturers' misunderstanding of NHTSA's request for information. There are also disadvantages, namely that the current market forecast does not represent certain changes likely to occur in the future vehicle fleet as opposed to the MY 2008 vehicle fleet, such as vehicles being discontinued and newly introduced. On balance, however, the agencies have carefully considered these advantages and disadvantages of using a market forecast derived from public and commercial sources rather than from manufacturers' product plans, and conclude that the advantages outweigh the disadvantages.

Although manufacturers did not comment on the agency's proposal to rely on public and commercial information rather than manufacturers' confidential product plans when developing a market forecast, those organizations that did comment on this issue supported this change. The California Air Resources Board (CARB) and Center for Biological Diversity (CBD) both commended the resultant increase in transparency. CARB further indicated that the use of public and commercial information should produce a better forecast. On the other hand, as discussed above in Section I, CBD and the Northeast States for Coordinated Air Use Management (NESCAUM) both raised concerns regarding the resultant omission of some new vehicle models, and the inclusion of some vehicles to be discontinued, while CARB suggested that the impact of these inaccuracies should be minor.

As discussed above in Section II.B.4, while a baseline developed using publicly and commercially available sources has both advantages and disadvantages relative to a baseline developed using manufacturers' product plans, NHTSA has concluded for today's rule that the advantages outweigh the disadvantages. Today's approach is much more transparent than the agency's past approach of relying on product plans, and as discussed in Section II.B.4, any inaccuracies related to new or discontinued vehicle models should have only a minor impact on the agency's analysis.

For subsequent rulemakings, NHTSA remains hopeful that manufacturers will agree to make public their plans for model years that are very near, so that this information could be incorporated into analysis available for public review and comment. In any event, because NHTSA is releasing market inputs used in the agency's analysis of this final rule, all interested parties can review these inputs fully, as intended in adopting the transparent approach. More information on the advantages and disadvantages of the current approach and the agencies' decision to follow it is available in Section II.B.4.

d. How is this baseline different quantitatively from the baseline that NHTSA used for the MY 2011 (March 2009) final rule?

As discussed above, the current baseline was developed from adjusted MY 2008 compliance data and covers MYs 2011–2016, while the baseline that NHTSA used for the MY 2011 CAFE rule was developed from confidential

[564] Available at *http://www.eia.doe.gov/oiaf/aeo/index.html* (last accessed March 15, 2010). Specifically, while the total volume of both cars and trucks was obtained from AEO 2010, the car-truck split was obtained from AEO 2009. The agencies have also used fuel price forecasts from AEO 2010. Both agencies regard AEO a credible source not only of such forecasts, but also of many underlying forecasts, including forecasts of the size of the future light vehicle market.

[565] EPA also considered other sources of similar information, such as J.D. Powers, and concluded that CSM was more appropriate for purposes of this rulemaking analysis.

manufacturer product plans for MY 2011. This section describes, for the reader's comparison, some of the differences between the current baseline and the MY 2011 CAFE rule baseline. This comparison provides a basis for understanding general characteristics and measures of the difference, in this case, between using publicly (and commercially) available sources and using manufacturers' confidential product plans. The current baseline, while developed using the same methods as the baseline used for MYs 2012–2016 NPRM, reflects updates to the underlying commercially-available forecast of manufacturer and market segment shares of the future light vehicle market. These changes are discussed above in Section II.B.

Estimated vehicle sales:

The sales forecasts, based on the Energy Information Administration's (EIA's) Annual Energy Outlook 2010 (AEO 2010), used in the current baseline indicate that the total number of light vehicles expected to be sold during MYs 2011–2015 is 77 million, or about 15.4 million vehicles annually.[566] NHTSA's MY 2011 final rule forecast, based on AEO 2008, of the total number of light vehicles likely to be sold during MY 2011 through MY 2015 was 83 million, or about 16.6 million vehicles annually. Light trucks are expected to make up 41 percent of the MY 2011 baseline market forecast in the current baseline, compared to 42 percent of the baseline market forecast in the MY 2011 final rule. These changes in both the overall size of the light vehicle market and the relative market shares of passenger cars and light trucks reflect changes in the economic forecast underlying AEO, and changes in AEO's forecast of future fuel prices.

The figures below attempt to demonstrate graphically the difference between the variation of fuel economy with footprint for passenger cars under the current baseline and MY 2011 final rule, and for light trucks under the current baseline and MY 2011 final rule, respectively. Figures IV.C.1–1 and 1–2 show the variation of fuel economy with footprint for passenger car models in the current baseline and in the MY 2011 final rule, while Figures IV.C.1–3 and 1–4 show the variation of fuel economy with footprint for light truck models in the current baseline and in the MY 2011 final rule. However, it is difficult to draw meaningful conclusions by comparing figures from the current baseline with those of the MY 2011 final rule. In the current baseline the number of make/models, and their associated fuel economy and footprint, are fixed and do not vary over time—this is why the number of data points in the current baseline figures appears smaller as compared to the number of data points in the MY 2011 final rule baseline. In contrast, the baseline fleet used in the MY 2011 final rule varies over time as vehicles (with different fuel economy and footprint characteristics) are added to and dropped from the product mix.

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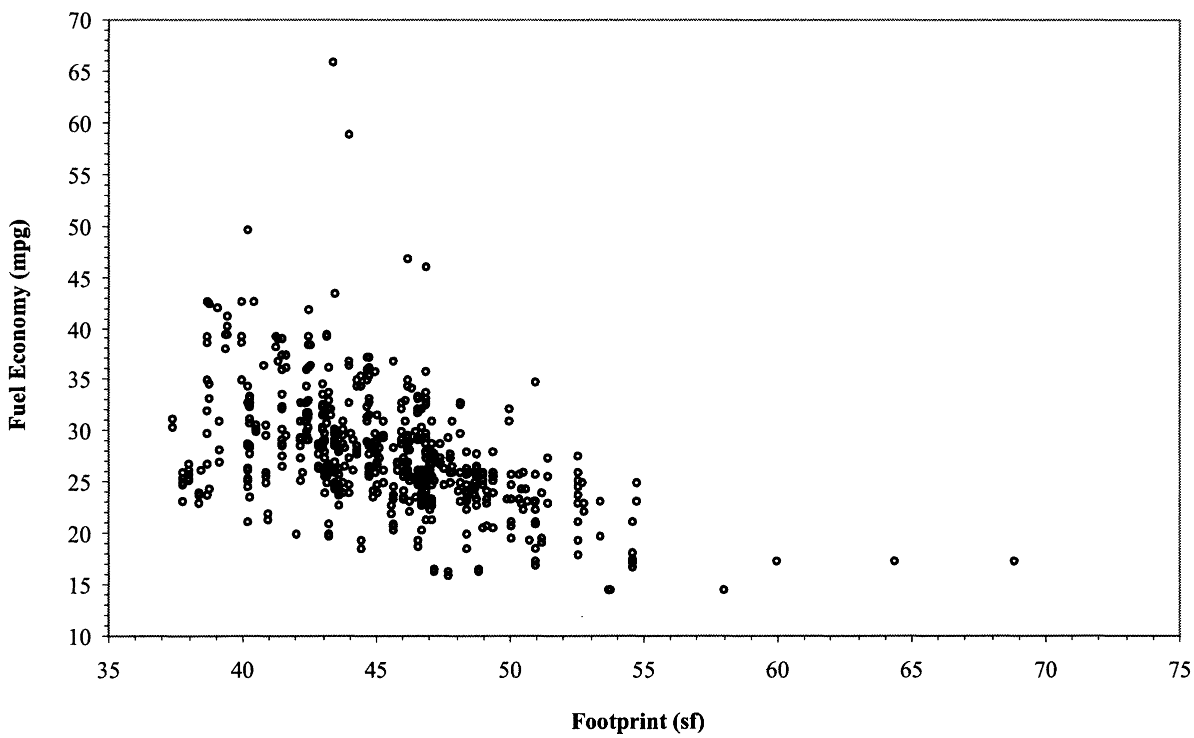
Figure IV.C.1-1 Planned Fuel Economy vs. Footprint, Passenger Cars in Current Baseline



[566] *Please see* Section II.B above and Chapter 1 of the Joint TSD for more discussion on the agencies' use of AEO 2010 to determine the sales forecasts for light vehicles during the model years covered by the rulemaking, as well as the memo available at Docket No. NHTSA–2009–059–0222.

Figure IV.C.1-2 Planned Fuel Economy vs. Footprint, Passenger Cars in MY 2011 Final Rule

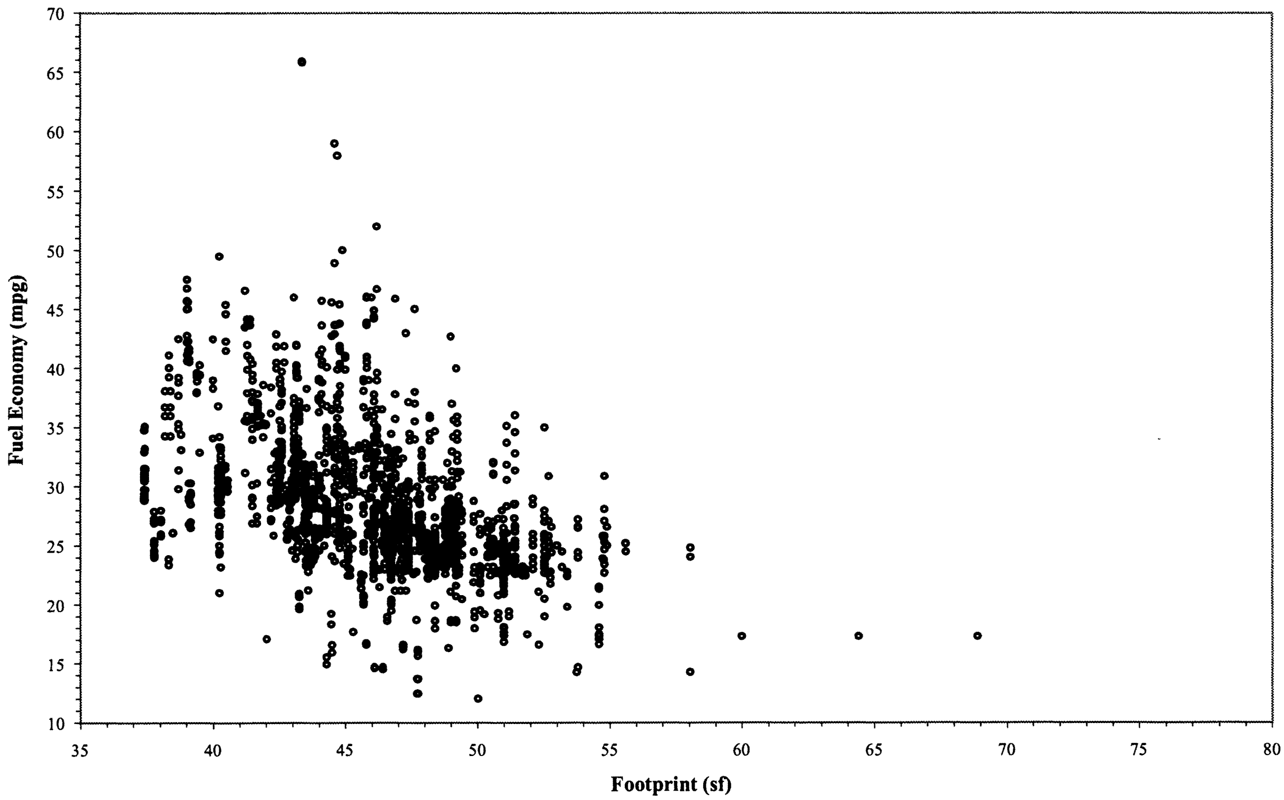


Figure IV.C.1-3 Planned Fuel Economy vs. Footprint, Light Trucks in Current Baseline

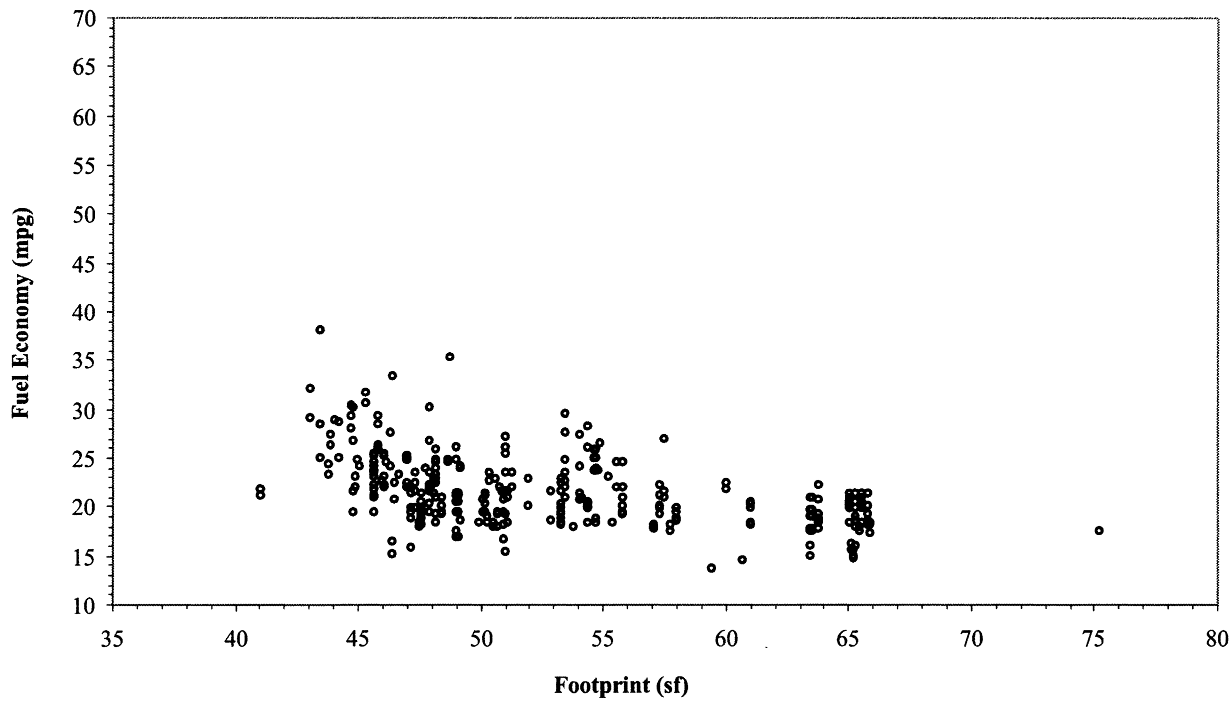
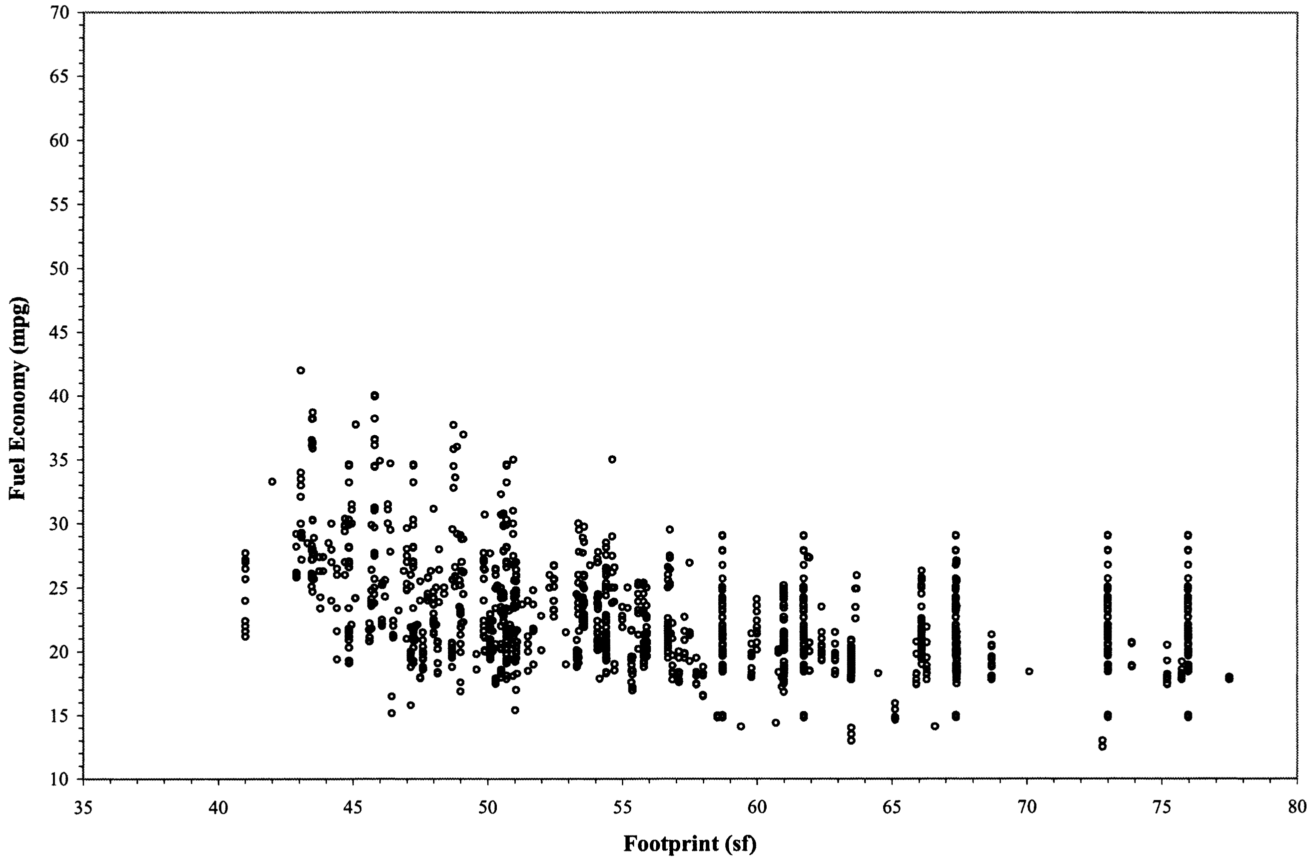


Figure IV.C.1-4 Planned Fuel Economy vs. Footprint, Light Trucks in MY 2011 Final Rule



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Estimated manufacturer market shares:

NHTSA's expectations regarding manufacturers' market shares (the basis for which is discussed below) have also changed since the MY 2011 final rule, given that the agency is relying on different sources of material for these assumptions as discussed in Section II.B above and Chapter 1 of the Joint TSD. These changes are reflected below in Table IV.C.1–1, which shows the agency's sales forecasts for passenger cars and light trucks under the current baseline and the MY 2011 final rule.[567]

TABLE IV.C.1–1—SALES FORECASTS

[Production for U.S. sale in MY 2011, thousand units]

Manufacturer	Current baseline		MY 2011 Final rule	
	Passenger	Nonpassenger	Passenger	Nonpassenger
Chrysler	326	737	707	1,216
Ford	1,344	792	1,615	1,144
General Motors	1,249	1,347	1,700	1,844
Honda	851	585	1,250	470
Hyundai	382	46	655	221
Kia	306	88		
Nissan	612	331	789	479
Toyota	1,356	888	1,405	1,094
Other Asian	664	246	441	191
European	833	396	724	190
Total	7,923	5,458	9,286	6,849

[567] As explained below, although NHTSA normalized each manufacturer's overall market share to produce a realistically-sized fleet, the product mix for each manufacturer that submitted product plans was preserved. The agency has reviewed manufacturers' product plans in detail, and understands that manufacturers do not sell the same mix of vehicles in every model year.

Dual-fueled vehicles:

Manufacturers have also, during and since MY 2008, indicated to the agency that they intend to sell more dual-fueled or flexible-fuel vehicles (FFVs) in MY 2011 than indicated in the current baseline of adjusted MY 2008 compliance data. FFVs create a potential market for alternatives to petroleum-based gasoline and diesel fuel. For purposes of determining compliance with CAFE standards, the fuel economy of a FFV is, subject to limitations, adjusted upward to account for this potential.[568] However, NHTSA is precluded from "taking credit" for the compliance flexibility by accounting for manufacturers' ability to earn and use credits in setting the level of the standards."[569] Some manufacturers plan to produce a considerably greater share of FFVs than can earn full credit under EPCA. The projected average FFV share of the market in MY 2011 is 7 percent for the current baseline, versus 17 percent for the MY 2011 final rule. NHTSA notes that in MY 2008 (the model year providing the vehicle models upon which today's market forecast is based), the three U.S.-based OEMs produced most of the FFVs offered for sale in the U.S., yet these OEMs account are projected to account for a smaller share of the future market in the forecast the agency has used to develop and analyze today's rule than in the forecast the agency used to develop and analyze the MY 2011 standards.

Estimated achieved fuel economy levels:

Because manufacturers' product plans also reflect simultaneous changes in fleet mix and other vehicle characteristics, the relationship between increased technology utilization and increased fuel economy cannot be isolated with any certainty. To do so would require an apples-to-apples "counterfactual" fleet of vehicles that are, except for technology and fuel economy, identical—for example, in terms of fleet mix and vehicle performance and utility. The current baseline market forecast shows industry-wide average fuel economy levels somewhat lower in MY 2011 than shown in the MY 2011 final rule and the MYs 2012–2016 NPRM. Under the current baseline, average fuel economy for MY 2011 is 26.4 mpg, versus 26.5 mpg under the baseline in the MY 2011 final rule, and 26.7 mpg under the baseline in the MYs 2012–2016 NPRM. The 0.3 mpg change relative to the MYs 2012–2016 baseline is the result of changes in manufacturer and market segment shares of the MY 2011 market.

These differences are shown in greater detail below in Table IV.C.1–2, which shows manufacturer-specific CAFE levels (not counting FFV credits that some manufacturers expect to earn) from the current baseline versus the MY 2011 final rule baseline (from manufacturers' 2008 product plans) for passenger cars and light trucks. Table IV.C.1–3 shows the combined averages of these planned CAFE levels in the respective baseline fleets. These tables demonstrate that, while the difference at the industry level is not so large, there are significant differences in CAFE at the manufacturer level between the current baseline and the MY 2011 final rule baseline. For example, while Volkswagen is essentially the same under both, Toyota and Nissan show increased combined CAFE levels under the current baseline (by 1.9 and 0.7 mpg respectively), while Chrysler, Ford, and GM show decreased combined CAFE levels under the current baseline (by 1.4, 1.1, and 0.8 mpg, respectively) relative to the MY 2011 final rule baseline.

TABLE IV.C.1–2—CURRENT BASELINE PLANNED CAFE LEVELS IN MY 2011 VERSUS MY 2011 FINAL RULE PLANNED CAFE LEVELS

[Passenger and nonpassenger]

Manufacturer	Current baseline CAFE levels		MY 2011 planned CAFE levels	
	Passenger	Nonpassenger	Passenger	Nonpassenger
BMW	27.2	23.0	27.0	23.0
Chrysler	27.8	21.8	28.2	23.1
Ford	28.0	21.0	29.3	22.5
Subaru	29.2	26.1	28.6	28.6
General Motors	28.2	21.2	30.3	21.4
Honda	33.5	25.0	32.3	25.2
Hyundai	32.5	24.3	31.7	26.0
Tata	24.6	19.6	24.7	23.9
Kia[570]	31.7	23.7		
Mazda[571]	30.6	26.0		
Daimler	26.4	21.0	25.2	20.6
Mitsubishi	29.4	23.6	29.3	26.7
Nissan	31.7	21.7	31.3	21.4
Porsche	26.2	20.0	27.2	20.0
Ferrari[572]			16.2	
Maserati[573]			18.2	
Suzuki	30.9	23.3	28.7	24.0
Toyota	35.1	23.7	33.2	22.7
Volkswagen	29.1	20.2	28.5	20.1
Total/Average	30.3	22.2	30.4	22.6

[568] *See* 49 U.S.C. 32905 and 32906.

[569] 49 U.S.C. 32902(h).

[570] Again, Kia is not listed in the table for the MY 2011 final rule because it was considered as part of Hyundai for purposes of that analysis (*i.e.,* Hyundai-Kia).

[571] Mazda is not listed in the table for the MY 2011 final rule because it was considered as part of Ford for purposes of that analysis.

[572] EPA did not include Ferrari in the current baseline based on the conclusion that including them would not impact the results, and therefore Ferrari is not listed in the table for the current baseline.

[573] EPA did not include Maserati in the current baseline based on the conclusion that including them would not impact the results, and therefore Maserati is not listed in the table for the current baseline.

TABLE IV.C.1–3—CURRENT BASELINE PLANNED CAFE LEVELS IN MY 2011 VERSUS MY 2011 FINAL RULE PLANNED CAFE LEVELS (COMBINED)

Manufacturer	Current baseline	MY 2011 Final Rule baseline
BMW	25.0	26.0
Chrysler	23.3	24.7
Ford	24.9	26.0
Subaru	27.9	28.6
General Motors	24.1	24.9
Honda	29.5	30.0
Hyundai	31.3	30.0
Tata	21.4	24.4
Kia	29.5	
Mazda	29.8	
Daimler	24.4	23.6
Mitsubishi	27.4	29.1
Nissan	27.3	26.6
Porsche	23.7	22.0
Ferrari		16.2
Maserati		18.2
Suzuki	29.7	27.8
Toyota	29.5	27.6
Volkswagen	27.0	27.1
Total/Average	26.4	26.5

Tables IV.C.1–4 through 1–6 summarize other differences between the current baseline and manufacturers' product plans submitted to NHTSA in 2008 for the MY 2011 final rule. These tables present average vehicle footprint, curb weight, and power-to-weight ratios for each manufacturer represented in the current baseline and of the seven largest manufacturers represented in the product plan data used in that rulemaking, and for the overall industry. The tables containing product plan data do not identify manufacturers by name, and do not present them in the same sequence.

Tables IV.C.1–4a and 1–4b show that the current baseline reflects a slight decrease in overall average passenger vehicle size relative to the manufacturers' plans. This is a reflection of the market segment shifts underlying the sales forecasts of the current baseline.

TABLE IV.C.1–4a—CURRENT BASELINE AVERAGE MY 2011 VEHICLE FOOTPRINT

[Square feet]

Manufacturer	PC	LT	Avg.
BMW	45.4	49.9	47.5
Chrysler	46.8	52.8	50.9
Daimler	47.1	53.3	49.0
Ford	46.3	56.1	49.9
General Motors	46.4	58.2	52.5
Honda	44.3	49.1	46.3
Hyundai	44.4	48.7	44.8
Kia	45.2	51.0	46.5
Mazda	44.4	47.3	44.9
Mitsubishi	43.8	46.5	44.6
Nissan	45.3	53.9	48.3
Porsche	38.6	51.0	42.8
Subaru	43.1	46.2	44.3
Suzuki	40.8	47.2	41.6
Tata	50.3	47.8	48.8
Toyota	44.0	53.0	47.6
Volkswagen	43.5	52.6	45.1
Industry Average	45.2	53.5	48.6

TABLE IV.C.1–4b—MY 2011 FINAL RULE AVERAGE PLANNED MY 2011 VEHICLE FOOTPRINT

[Square feet]

	PC	LT	Avg.
Manufacturer 1	46.7	58.5	52.8
Manufacturer 2	46.0	50.4	47.1
Manufacturer 3	44.9	52.8	48.4
Manufacturer 4	45.4	55.8	49.3
Manufacturer 5	45.2	57.5	50.3
Manufacturer 6	48.5	54.7	52.4
Manufacturer 7	45.1	49.9	46.4
Industry Average	45.6	55.1	49.7

Tables IV.C.1–5a and 1–5b show that the current baseline reflects a decrease in overall average vehicle weight relative to the manufacturers' plans. As above, this is most likely a reflection of the market segment shifts underlying the sales forecasts of the current baseline.

TABLE IV.C.1–5a—CURRENT BASELINE AVERAGE MY 2011 VEHICLE CURB WEIGHT

[Pounds]

Manufacturer	PC	LT	Avg.
BMW	3,535	4,648	4,055
Chrysler	3,572	4,469	4,194
Daimler	3,583	5,127	4,063
Ford	3,526	4,472	3,877
General Motors	3,528	4,978	4,281
Honda	3,040	4,054	3,453
Hyundai	3,014	4,078	3,129
Kia	3,035	4,007	3,252
Mazda	3,258	3,803	3,348
Mitsubishi	3,298	3,860	3,468
Nissan	3,251	4,499	3,689
Porsche	3,159	4,906	3,760
Subaru	3,176	3,470	3,391
Suzuki	2,842	3,843	2,965
Tata	3,906	5,171	4,627
Toyota	3,109	4,321	3,589
Volkswagen	3,445	5,672	3,839
Industry Average	3,313	4,499	3,797

TABLE IV.C.1–5b—MY 2011 FINAL RULE AVERAGE PLANNED MY 2011 VEHICLE CURB WEIGHT

[Pounds]

	PC	LT	Avg.
Manufacturer 1	3,197	4,329	3,692
Manufacturer 2	3,691	4,754	4,363
Manufacturer 3	3,293	4,038	3,481
Manufacturer 4	3,254	4,191	3,510
Manufacturer 5	3,547	5,188	4,401
Manufacturer 6	3,314	4,641	3,815
Manufacturer 7	3,345	4,599	3,865
Industry Average	3,380	4,687	3,935

Tables IV.C.1–6a and IV.C.1–6b show that the current baseline reflects a decrease in average performance relative to that of the manufacturers' product plans. This decreased performance is most likely a reflection of the market segment shifts underlying the sales forecasts of the current baseline, that is, an assumed shift away from higher performance vehicles.

TABLE IV.C.1–6a—CURRENT BASELINE AVERAGE MY 2011 VEHICLE POWER-TO-WEIGHT RATIO

[hp/lb]

Manufacturer	PC	LT	Avg.
BMW	0.072	0.061	0.067
Chrysler	0.055	0.052	0.053
Daimler	0.068	0.056	0.064
Ford	0.058	0.054	0.056
General Motors	0.057	0.056	0.056
Honda	0.056	0.054	0.056
Hyundai	0.052	0.055	0.052
Kia	0.050	0.056	0.051
Mazda	0.052	0.055	0.052
Mitsubishi	0.053	0.056	0.054
Nissan	0.059	0.057	0.058
Porsche	0.105	0.073	0.094
Subaru	0.060	0.056	0.058
Suzuki	0.049	0.062	0.051
Tata	0.077	0.057	0.065
Toyota	0.053	0.062	0.056
Volkswagen	0.057	0.052	0.056
Industry Average	0.057	0.056	0.056

TABLE IV.C.1–6b—MY 2011 FINAL RULE AVERAGE PLANNED MY 2011 VEHICLE POWER-TO-WEIGHT RATIO

[hp/lb]

	PC	LT	Avg.
Manufacturer 1	0.065	0.058	0.060
Manufacturer 2	0.061	0.065	0.062
Manufacturer 3	0.053	0.059	0.056
Manufacturer 4	0.060	0.058	0.059
Manufacturer 5	0.060	0.057	0.059
Manufacturer 6	0.063	0.065	0.065
Manufacturer 7	0.053	0.055	0.053
Industry Average	0.060	0.059	0.060

As discussed above, the agencies' market forecast for MY 2012–2016 holds the performance and other characteristics of individual vehicle models constant, adjusting the size and composition of the fleet from one model year to the next.

Refresh and redesign schedules (for application in NHTSA's modeling):

Expected model years in which each vehicle model will be redesigned or freshened constitute another important aspect of NHTSA's market forecast. As discussed in Section IV.C.2.c below, NHTSA's analysis supporting the current rulemaking times the addition of nearly all technologies to coincide with either a vehicle redesign or a vehicle freshening. Product plans submitted to NHTSA preceding the MY 2011 final rule contained manufacturers' estimates of vehicle redesign and freshening schedules and NHTSA's estimates of the timing of the five-year redesign cycle and the two- to three-year refresh cycle were made with reference to those plans. In the current baseline, in contrast, estimates of the timing of the refresh and redesign cycles were based on historical dates—*i.e.,* counting forward from known redesigns occurring in or prior to MY 2008 for each vehicle in the fleet and assigning refresh and redesign years accordingly. After applying these estimates, the shares of manufacturers' passenger car and light truck estimated to be redesigned in MY 2011 were as summarized below for the current baseline and the MY 2011 final rule. Table IV.C.1–7 below shows the percentages of each manufacturer's fleets expected to be redesigned in MY 2011 for the current baseline. Table IV.C.1–8 presents corresponding estimates from the market forecast used by NHTSA in the analysis supporting the MY 2011 final rule (again, to protect confidential information, manufacturers are not identified by name).

TABLE IV.C.1–7—CURRENT BASELINE, SHARE OF FLEET REDESIGNED IN MY 2011

Manufacturer	PC (percent)	LT (percent)	Avg. (percent)
BMW	32	37	34
Chrysler	0	13	9
Daimler	0	0	0
Ford	12	8	11
General Motors	17	3	9
Honda	29	26	28
Hyundai	26	0	23
Kia	38	83	48
Mazda	0	0	0
Mitsubishi	0	59	18
Nissan	5	25	12
Porsche	0	100	34
Subaru	0	42	16
Suzuki	4	21	6
Tata	28	100	69
Toyota	5	15	9
Volkswagen	16	0	13
Industry Average	13	15	14

TABLE IV.C.1–8—MY 2011 FINAL RULE, SHARE OF FLEET REDESIGNED IN MY 2011

	PC (percent)	LT (percent)	Avg. (percent)
Manufacturer 1	19	0	11
Manufacturer 2	34	27	29
Manufacturer 3	5	0	3
Manufacturer 4	7	0	5
Manufacturer 5	19	0	11
Manufacturer 6	34	28	33
Manufacturer 7	27	28	28
Overall	20	9	15

We continue, therefore, to estimate that manufacturers' redesigns will not be uniformly distributed across model years. This is in keeping with standard industry practices, and reflects what manufacturers actually do—NHTSA has observed that manufacturers in fact do redesign more vehicles in some years than in others. NHTSA staff have closely examined manufacturers' planned redesign schedules, contacting some manufacturers for clarification of some plans, and confirmed that these plans remain unevenly distributed over time. For example, although Table IV.C.1–8 shows that NHTSA expects Company 2 to redesign 34 percent of its passenger car models in MY 2011, current information indicates that this company will then redesign only (a different) 10 percent of its passenger cars in MY 2012. Similarly, although Table IV.C.1–8 shows that NHTSA expects four of the largest seven light truck manufacturers to redesign virtually no light truck models in MY 2011, current information also indicates that these four manufacturers will redesign 21–49 percent of their light trucks in MY 2012.

e. How does manufacturer product plan data factor into the baseline used in this rule?

As discussed in Section II.B.5 above, while the agencies received updated product plans in Spring and Fall 2009 in response to NHTSA's requests, the baseline data used in this final rule is not informed by these product plans, except with respect to specific engineering characteristics (*e.g.,* GVWR) of some MY 2008 vehicle models, because these product plans contain confidential business information that the agencies are legally required to protect from disclosure, and because the agencies have concluded that, for purposes of this final rule, a transparent baseline is preferable.

For the NPRM, NHTSA conducted a separate analysis that did make use of these product plans. NHTSA performed this separate analysis for purposes of comparison only. For today's final rule NHTSA used the publicly available baseline for all analysis related to the development and evaluation of the new CAFE standards. As discussed above in Section II.B.4, while a baseline developed using publicly and commercially available sources has both advantages and disadvantages relative to a baseline developed using manufacturers' product plans, NHTSA has concluded for today's rule that the advantages outweigh the disadvantages. NHTSA plans to consider these advantages and disadvantages further in connection with future rulemakings, taking into account changes in the market, changes in the scope and quality of publicly and commercially available data, and any changes in manufacturers' willingness to make some product planning information publicly available.

2. How were the technology inputs developed?

As discussed above in Section II.E, for developing the technology inputs for the MY 2012–2016 CAFE and GHG standards, the agencies primarily began with the technology inputs used in the MY 2011 CAFE final rule and in the July 2008 EPA ANPRM, and then reviewed, as requested by President Obama in his January 26 memorandum, the technology assumptions that NHTSA used in setting the MY 2011 standards and the comments that NHTSA received in response to its May 2008 Notice of Proposed Rulemaking, as well as the comments received to the NPRM for this rule. In addition, the agencies supplemented their review with updated information from the FEV tear-down studies contracted by EPA, more current literature, new product plans and from EPA certification testing. More detail is available regarding how the agencies developed the technology inputs for this final rule above in Section II.E, in Chapter 3 of the Joint TSD, and in Section V of NHTSA's FRIA.

a. What technologies does NHTSA consider?

Section I*I.E.*1 above describes the fuel-saving technologies considered by the agencies that manufacturers could use to improve the fuel economy of their vehicles during MYs 2012–2016. The majority of the technologies described in this section are readily available, well known, and could be incorporated into vehicles once production decisions are made. As discussed, the technologies considered fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, and hybrid technologies. Table IV.C.2–1 below lists all the technologies considered and provides the abbreviations used for them in the Volpe model,[574] as well as their year of availability, which for purposes of NHTSA's analysis means the first model year in the rulemaking period that the Volpe model is allowed to apply a technology to a manufacturer's fleet.[575] Year of availability recognizes that technologies must achieve a level of technical viability before they can be implemented in the Volpe model, and are thus a means of constraining technology use until such time as it is considered to be technologically feasible. For a more detailed description of each technology and their costs and effectiveness, we refer the reader to Chapter 3 of the Joint TSD and Section V of NHTSA's FRIA.

[574] The abbreviations are used in this section both for brevity and for the reader's reference if they wish to refer to the expanded decision trees and the model input and output sheets, which are available in Docket No. NHTSA–2009–0059–0156 and on NHTSA's Web site.

[575] A date of 2011 means the technology can be applied in all model years, while a date of 2014 means the technology can only be applied in model years 2014 through 2016.

TABLE IV.C.2–1—LIST OF TECHNOLOGIES IN NHTSA'S ANALYSIS

Technology	Model abbreviation	Year available
Low Friction Lubricants	LUB	2011
Engine Friction Reduction	EFR	2011
VVT—Coupled Cam Phasing (CCP) on SOHC	CCPS	2011
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	2011
Cylinder Deactivation on SOHC	DEACS	2011
VVT—Intake Cam Phasing (ICP)	ICP	2011
VVT—Dual Cam Phasing (DCP)	DCP	2011
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	2011
Continuously Variable Valve Lift (CVVL)	CVVL	2011
Cylinder Deactivation on DOHC	DEACD	2011
Cylinder Deactivation on OHV	DEACO	2011
VVT—Coupled Cam Phasing (CCP) on OHV	CCPO	2011
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	2011
Conversion to DOHC with DCP	CDOHC	2011
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2011
Combustion Restart	CBRST	2014
Turbocharging and Downsizing	TRBDS	2011
Exhaust Gas Recirculation (EGR) Boost	EGRB	2013
Conversion to Diesel following CBRST	DSLC	2011
Conversion to Diesel following TRBDS	DSLT	2011
6-Speed Manual/Improved Internals	6MAN	2011
Improved Auto. Trans. Controls/Externals	IATC	2011
Continuously Variable Transmission	CVT	2011
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	2011
Dual Clutch or Automated Manual Transmission	DCTAM	2011
Electric Power Steering	EPS	2011
Improved Accessories	IACC	2011
12V Micro-Hybrid	MHEV	2011
Belt Integrated Starter Generator	BISG	2011
Crank Integrated Starter Generator	CISG	2011
Power Split Hybrid	PSHEV	2011
2-Mode Hybrid	2MHEV	2011
Plug-in Hybrid	PHEV	2011
Mass Reduction 1 (1.5%)	MS1	2011
Mass Reduction 2 (3.5%–8.5%)	MS2	2014
Low Rolling Resistance Tires	ROLL	2011
Low Drag Brakes	LDB	2011
Secondary Axle Disconnect 4WD	SAX	2011
Aero Drag Reduction	AERO	2011

For purposes of this final rule and as discussed in greater detail in the Joint TSD, NHTSA and EPA carefully reviewed the list of technologies used in the agency's analysis for the MY 2011 final rule. NHTSA and EPA concluded that the considerable majority of technologies were correctly defined and continued to be appropriate for use in the analysis supporting the final standards. However, some refinements were made as discussed in the NPRM.[576] Additionally, the following refinements were made for purposes of the final rule.

Specific to its modeling, NHTSA has revised two technologies used in the final rule analysis from those considered in the NPRM. These revisions were based on comments received in response to the NPRM and the identification of area to improve accuracy. In the NPRM, a diesel engine option (DSLT or DSLC) was not available for small vehicles because it did not appear to be a cost-effective option. However, based on comments received in response to the NPRM, the agency added a diesel engine option for small vehicles. Additionally, in the NPRM, the mass reduction/material substitution technology, MS1, assumed engine downsizing. However, for purposes of the final rule, engine downsizing is no longer assumed for MS1, thus slightly lowering the effectiveness estimate to better reflect how manufacturers might implement small amounts of mass reduction/material substitution. Chapter 3 of the Joint TSD and Section V of NHTSA's FRIA provide a more detailed explanation of these revisions.

b. How did NHTSA determine the costs and effectiveness of each of these technologies for use in its modeling analysis?

Building on NHTSA's estimates developed for the MY 2011 CAFE final rule and EPA's Advanced Notice of Proposed Rulemaking, which relied on EPA's 2008 Staff Technical Report,[577] the agencies took a fresh look at technology cost and effectiveness values and incorporated additional FEV tear-down study results for purposes of this final rule. This joint work is reflected in Chapter 3 of the Joint TSD and in Section II of this preamble, as summarized below. For more detailed information on the effectiveness and cost of fuel-saving technologies, please refer to Chapter 3 of the Joint TSD and Section V of NHTSA's FRIA. NHTSA and EPA are confident that the thorough review conducted for purposes of this final rule led to the best available conclusions regarding technology costs and effectiveness estimates for the current rulemaking and resulted in excellent consistency between the agencies' respective analyses for

[576] 74 FR at 49655–56 (Sept. 28, 2009).

[577] EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420–R–08–008, March 2008. *Available at* Docket No. NHTSA–2009–0059–0027.

developing the CAFE and CO_2 standards.

Generally speaking, while NHTSA and EPA found that much of the cost information used in NHTSA's MY 2011 final rule and EPA's 2008 Staff Report was consistent to a great extent, the agencies, in reconsidering information from many sources revised several component costs of several major technologies for purposes of the NRPM: mild and strong hybrids, diesels, SGDI, and Valve Train Lift Technologies. In addition, based on FEV tear-down studies, the costs for turbocharging/downsizing, 6-, 7-, 8-speed automatic transmissions, and dual clutch transmissions were revised for this final rule. These revisions are discussed at length in the Joint TSD and in NHTSA's FRIA.

Most effectiveness estimates used in both the MY 2011 final rule and the 2008 EPA Staff Report were determined to be accurate and were carried forward without significant change into this rulemaking. When NHTSA and EPA's estimates for effectiveness diverged slightly due to differences in how the agencies apply technologies to vehicles in their respective models, we report the ranges for the effectiveness values used in each model. For purposes of the final rule analysis, NHTSA made only a couple of changes to the effectiveness estimates. Specifically, in reviewing the NPRM effectiveness estimates for this final rule NHTSA discovered that the DCTAM effectiveness value for Subcompact and Compact subclasses was incorrect; the (lower) wet clutch effectiveness estimate had been used instead of the intended (higher) dry clutch estimate for these vehicle classes.[578] Thus, NHTSA corrected these effectiveness estimates. Additionally, as discussed above, the effectiveness estimate for MS1 was revised (lowered) to better represent the impact of reducing mass at a refresh. For much more information on the costs and effectiveness of individual technologies, we refer the reader to Chapter 3 of the Joint TSD and Section V of NHTSA's FRIA.

As a general matter, NHTSA received relatively few comments related to technology cost and effectiveness estimates as compared to the number received on these issues in previous CAFE rulemakings. The California Air Resources Board (CARB) generally agreed with cost estimates used in the NPRM analysis. NHTSA also received comments from the Aluminum Association, General Motors, Honeywell, International Council on Clean Transportation (ICCT), Manufacturers of Emission Controls Association (MECA), Motor and Equipment Manufacturers Association (MEMA) and the New Jersey Department of Environmental Protection related to cost and effectiveness estimates for specific technologies, including but not limited to hybrids, diesels, turbocharging and downsizing, and mass reduction/material substitution. A detailed description of these comments and NHTSA's responses can be found in Section V of NHTSA's FRIA.

NHTSA notes that, in developing technology cost and effectiveness estimates, the agencies have made every effort to hold constant aspects of vehicle performance and utility typically valued by consumers, such as horsepower, carrying capacity, and towing and hauling capacity. For example, NHTSA includes in its analysis technology cost and effectiveness estimates that are specific to performance passenger cars (*i.e.,* sports cars), as compared to non-performance passenger cars. NHTSA sought comment on the extent to which commenters believed that the agencies have been successful in holding constant these elements of vehicle performance and utility in developing the technology cost and effectiveness estimates, but received relatively little in response. NHTSA thus concludes that commenters had no significant issues with its approach for purposes of this rulemaking, but the agency will continue to analyze this issue going forward.

Additionally, NHTSA notes that the technology costs included in this final rule take into account only those associated with the initial build of the vehicle. The agencies sought comment on the additional lifetime costs, if any, associated with the implementation of advanced technologies, including warranty, maintenance and replacement costs, such as the replacement costs for low rolling resistance tires, low friction lubricants, and hybrid batteries, and maintenance costs for diesel aftertreatment components, but received no responses. The agency will continue to examine this issue closely for subsequent rulemakings, particularly as manufacturers turn increasingly to even more advanced technologies in the future that may have more significant lifetime costs.

The tables below provide examples of the incremental cost and effectiveness estimates employed by the agency in developing this final rule, according to the decision trees used in the Volpe modeling analysis. Thus, the effectiveness and cost estimates are not absolute to a single reference vehicle, but are incremental to the technology or technologies that precede it.

TABLE IV.C.2–2—TECHNOLOGY EFFECTIVENESS ESTIMATES EMPLOYED IN THE VOLPE MODEL FOR CERTAIN TECHNOLOGIES

	Subcomp. car	Compact car	Midsize car	Large car	Perform. subcomp. car	Perform. compact car	Perform. midsize car	Perform. large car	Minivan LT	Small LT	Midsize LT	Large LT
VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (−%)												
Low Friction Lubricants	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
VVT—Dual Cam Phasing (DCP)	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0
Discrete Variable Valve Lift (DVVL) on DOHC	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0	1.0–3.0
Cylinder Deactivation on OHV	n.a.	n.a.	n.a.	3.9–5.5	n.a.	3.9–5.5	3.9–5.5	3.9–5.5	3.9–5.5	n.a.	3.9–5.5	3.9–5.5

[578] "Dry clutch" DCTAMs and "wet clutch" DCTAMs have different characteristics and different uses. A dry clutch DCTAM is more efficient and less expensive than a wet clutch DCTAM, which requires a wet-clutch-type hydraulic system to cool the clutches. However, without a cooling system, a dry clutch DCTAM has a lower torque capacity. Dry clutch DCTAMs are thus ideal for smaller vehicles with lower torque ratings, like those in the Subcompact and Compact classes, while wet clutch DCTAMs would be more appropriate for, *e.g.,* larger trucks. Thus, it is appropriate to distinguish accordingly in DCTAM effectiveness between subclasses.

TABLE IV.C.2–2—TECHNOLOGY EFFECTIVENESS ESTIMATES EMPLOYED IN THE VOLPE MODEL FOR CERTAIN TECHNOLOGIES—Continued

	Subcomp. car	Compact car	Midsize car	Large car	Perform. subcomp. car	Perform. compact car	Perform. midsize car	Perform. large car	Minivan LT	Small LT	Midsize LT	Large LT
Stoichiometric Gasoline Direct Injection (GDI)	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0
Turbocharging and Downsizing	4.2–4.8	4.2–4.8	4.2–4.8	1.8–1.9	4.2–4.8	1.8–1.9	1.8–1.9	1.8–1.9	1.8–1.9	4.2–4.8	1.8–1.9	1.8–1.9
6/7/8–Speed Auto. Trans with Improved Internals	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4	1.4–3.4
Electric Power Steering	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0	1.0–2.0
12V Micro-Hybrid	2.0–3.0	2.0–3.0	2.0–3.0	2.5–3.5	2.0–3.0	2.5–3.5	2.5–3.5	3.0–4.0	2.5–3.5	2.0–3.0	2.5–3.5	n.a.
Crank mounted Integrated Starter Generator	8.6–8.9	8.6–8.9	8.6–8.9	8.7–8.9	8.6–8.9	8.7–8.9	8.7–8.9	8.7–8.9	8.7–8.9	8.6–8.9	8.7–8.9	14.1–16.3
Power Split Hybrid	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	6.3–12.4	n.a.
Aero Drag Reduction	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0	2.0–3.0

TABLE IV.C.2–3—TECHNOLOGY COST ESTIMATES EMPLOYED IN THE VOLPE MODEL FOR CERTAIN TECHNOLOGIES

	Subcomp. car	Compact car	Midsize car	Large car	Perform. subcomp. car	Perform. compact car	Perform. midsize car	Perform. large car	Minivan LT	Small LT	Midsize LT	Large LT
VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE ($)												
Nominal baseline engine (for cost purpose)	(*)	(*)	(*)	V6	(*)	V6	V6	V8	V6	(*)	V6	V8
Low Friction Lubricants	3	3	3	3	3	3	3	3	3	3	3	3
VVT—Dual Cam Phasing (DCP)	38	38	38	82	38	82	82	82	82	38	82	82
Discrete Variable Valve Lift (DVVL) on DOHC	142	142	142	206	142	206	206	294	206	142	206	294
Cylinder Deactivation on OHV	n.a.	n.a.	n.a.	168	n.a.	168	168	192	168	n.a.	168	192
Stoichiometric Gasoline Direct Injection (GDI)	236	236	236	342	236	342	342	392	342	236	342	392
Turbocharging and Downsizing	445	445	445	325	445	325	325	919	325	445	325	919
6/7/8-Speed Auto. Trans with Improved Internals	112	112	112	112	112–214	112–214	112–214	112–214	112–214	112	112–214	112–214
Electric Power Steering	106	106	106	106	106	106	106	106	106	106	106	106
12V Micro-Hybrid	288	311	342	367	314	337	372	410	337	325	376	n.a.
Crank mounted Integrated Starter Generator	2,791	3,107	3,319	3,547	2,839	3,149	3,335	3,571	3,149	3,141	3,611	5,124
Power Split Hybrid	1,600	2,133	2,742	3,261	3,661	4,018	5,287	6,723	4,018	2,337	3,462	n.a.
Aero Drag Reduction	48	48	48	48	48	48	48	48	48	48	48	48

* Inline 4.

c. How does NHTSA use these assumptions in its modeling analysis?

NHTSA relies on several inputs and data files to conduct the compliance analysis using the Volpe model, as discussed further below and in Section V of the FRIA. For the purposes of applying technologies, the Volpe model primarily uses two data files, one that contains data on the vehicles expected to be manufactured in the model years covered by the rulemaking and identifies the appropriate stage within the vehicle's life-cycle for the technology to be applied, and one that contains data/parameters regarding the available technologies the model can apply. These inputs are discussed below.

As discussed above, the Volpe model begins with an initial state of the domestic vehicle market, which in this case is the market for passenger cars and light trucks to be sold during the period covered by the final standards. The vehicle market is defined on a model-by-model, engine-by-engine, and transmission-by-transmission basis, such that each defined vehicle model refers to a separately defined engine and a separately defined transmission.

For the current standards, which cover MYs 2012–2016, the light-duty vehicle (passenger car and light truck) market forecast was developed jointly by NHTSA and EPA staff using MY 2008 CAFE compliance data. The MY 2008 compliance data includes about 1,100 vehicle models, about 400 specific engines, and about 200 specific transmissions, which is a somewhat lower level of detail in the representation of the vehicle market than that used by NHTSA in recent CAFE analyses—previous analyses would count a vehicle as "new" in any year when significant technology differences are made, such as at a redesign.[579] However, within the limitations of information that can be made available to the public, it provides the foundation for a realistic analysis of manufacturer-specific costs and the analysis of attribute-based CAFE standards, and is much greater than the level of detail used by many other models and analyses relevant to light-duty vehicle fuel economy.[580]

In addition to containing data about each vehicle, engine, and transmission, this file contains information for each technology under consideration as it pertains to the specific vehicle (whether the vehicle is equipped with it or not), the estimated model year the vehicle is undergoing redesign, and information about the vehicle's subclass for purposes of technology application. In essence, the model considers whether it is appropriate to apply a technology to a vehicle.

Is a vehicle already equipped, or can it not be equipped, with a particular technology?

The market forecast file provides NHTSA the ability to identify, on a technology by technology basis, which technologies may already be present (manufactured) on a particular vehicle, engine, or transmission, or which technologies are not applicable (due to technical considerations) to a particular vehicle, engine, or transmission. These identifications are made on a model-by-model, engine-by-engine, and transmission-by-transmission basis. For example, if the market forecast file indicates that Manufacturer X's Vehicle Y is manufactured with Technology Z, then for this vehicle Technology Z will be shown as used. Additionally, NHTSA has determined that some technologies are only suitable or unsuitable when certain vehicle, engine, or transmission conditions exist. For example, secondary axle disconnect is only suitable for 4WD vehicles, and cylinder deactivation is unsuitable for any engine with fewer than 6 cylinders, while CVTs can only be applied to unibody vehicles. Similarly, comments received to the 2008 NPRM indicated that cylinder deactivation could not likely be applied to vehicles equipped with manual transmissions during the rulemaking timeframe, due primarily to the cylinder deactivation system not being able to anticipate gear shifts. The Volpe model employs "engineering constraints" to address issues like these, which are a programmatic method of controlling technology application that is independent of other constraints. Thus, the market forecast file would indicate that the technology in question should not be applied to the particular vehicle/engine/transmission (*i.e.,* is unavailable). Since multiple vehicle models may be equipped with an engine or transmission, this may affect multiple models. In using this aspect of the market forecast file, NHTSA ensures the Volpe model only applies technologies in an appropriate manner, since before any application of a technology can occur, the model checks the market forecast to see if it is either already present or unavailable.

In response to the NPRM, NHTSA received comments from GM that included a description of technical considerations, concerns, limitations and risks that need to be considered when implementing turbocharging and downsizing technologies on full size trucks. These include concerns related to engine knock, drivability, control of boost pressure, packaging complexity, enhanced cooling for vehicles that are designed for towing or hauling, and noise, vibration and harshness. NHTSA judges that the expressed technical considerations, concerns, limitations and risks are well recognized within the industry and it is standard industry practice to address each during the design and development phases of applying turbocharging and downsizing technologies. Cost and effectiveness estimates used in the final rule are based on analysis that assumes each of these factors is addressed prior to production implementation of the technologies. In comments related to full size trucks, GM commented that potential to address knock limit concerns through various alternatives, which include use of higher octane premium fuel and/or the addition of a supplemental ethanol injection system. For this rulemaking, NHTSA has not assumed that either of these approaches is implemented to address knock limit concerns, and these technologies are not included in assessment of turbocharging and downsizing feasibility, cost or effectiveness.[581] In addition, NHTSA has received confidential business information from a manufacturer that supports that turbocharging and downsizing is feasible on a full size truck product during the rulemaking period.

[579] The market file for the MY 2011 final rule, which included data for MYs 2011–2015, had 5500 vehicles, about 5 times what we are using in this analysis of the MY 2008 certification data.

[580] Because CAFE standards apply to the average performance of each manufacturer's fleet of cars and light trucks, the impact of potential standards on individual manufacturers cannot be credibly estimated without analysis of the fleets that manufacturers can be expected to produce in the future. Furthermore, because required CAFE levels under an attribute-based CAFE standard depend on manufacturers' fleet composition, the stringency of an attribute-based standard cannot be predicted without performing analysis at this level of detail.

[581] Note that for one of the teardown analysis cost studies of turbocharging and downsizing conducted by FEV, in which a 2.4L I4 DOHC naturally aspirated engine was replaced by a 1.6L I4 DOHC SGDI turbocharged engine, the particular 1.6L turbocharged engine chosen for the study was a premium octane fuel engine. For this rulemaking, NHTSA intends that a turbocharged and downsized engine achieve comparable performance to a baseline engine without requiring premium octane fuel. For the FEV study of the 1.6L turbocharged engine, this could be achieved through the specification of an engine with a displacement of slightly greater than 1.6L. NHTSA judges that a slightly larger engine would have small effect on the overall cost analysis used in this rulemaking. For all other teardown studies conducted by FEV, both the naturally aspirated engine and the replacement turbocharged and downsized engine were specified to use regular octane fuel.

Is a vehicle being redesigned or refreshed?

Manufacturers typically plan vehicle changes to coincide with certain stages of a vehicle's life cycle that are appropriate for the change, or in this case the technology being applied. In the automobile industry there are two terms that describe *when* technology changes to vehicles occur: Redesign and refresh (*i.e.,* freshening). Vehicle *redesign* usually refers to significant changes to a vehicle's appearance, shape, dimensions, and powertrain. Redesign is traditionally associated with the introduction of "new" vehicles into the market, often characterized as the "next generation" of a vehicle, or a new platform. Vehicle *refresh* usually refers to less extensive vehicle modifications, such as minor changes to a vehicle's appearance, a moderate upgrade to a powertrain system, or small changes to the vehicle's feature or safety equipment content. Refresh is traditionally associated with mid-cycle cosmetic changes to a vehicle, within its current generation, to make it appear "fresh." Vehicle refresh generally occurs no earlier than two years after a vehicle redesign, or at least two years before a scheduled redesign. For the majority of technologies discussed today, manufacturers will only be able to apply them at a refresh or redesign, because their application would be significant enough to involve some level of engineering, testing, and calibration work.[582]

Some technologies (*e.g.,* those that require significant revision) are nearly always applied only when the vehicle is expected to be redesigned, like turbocharging and engine downsizing, or conversion to diesel or hybridization. Other technologies, like cylinder deactivation, electric power steering, and aerodynamic drag reduction can be applied either when the vehicle is expected to be refreshed or when it is expected to be redesigned, while a few others, like low friction lubricants, can be applied at any time, regardless of whether a refresh or redesign event is conducted. Accordingly, the model will only apply a technology at the particular point deemed suitable. These constraints are intended to produce results consistent with manufacturers' technology application practices. For each technology under consideration, NHTSA stipulates whether it can be applied any time, at refresh/redesign, or only at redesign. The data forms another input to the Volpe model. NHTSA develops redesign and refresh schedules for each of a manufacturer's vehicles included in the analysis, essentially based on the last known redesign year for each vehicle and projected forward in a 5-year redesign and a 2–3 year refresh cycle, and this data is also stored in the market forecast file. We note that this approach is different than NHTSA has employed previously for determining redesign and refresh schedules, where NHTSA included the redesign and refresh dates in the market forecast file as provided by manufacturers in confidential product plans. The new approach is necessary given the nature of the new baseline which as a single year of data does not contain its own refresh and redesign cycle cues for future model years, and to ensure the complete transparency of the agency's analysis. Vehicle redesign/refresh assumptions are discussed in more detail in Section V of the FRIA and in Chapter 3 of the TSD.

NHTSA received comments from the Center for Biological Diversity (CBD) and Ferrari regarding redesign cycles. CBD stated that manufacturers do not necessarily adhere to the agencies' assumed five-year redesign cycle, and may add significant technologies by redesigning vehicles at more frequent intervals, albeit at higher costs. CBD argued that NHTSA should analyze the costs and benefits of manufacturers choosing to redesign vehicles more frequently than a 5-year average. Conversely, Ferrari agreed with the agencies that major technology changes are introduced at vehicle redesigns, rather than at vehicle freshenings, stating further that as compared to full-line manufacturers, small-volume manufacturers in fact may have 7 to 8-year redesign cycles. In response, NHTSA recognizes that not all manufacturers follow a precise five-year redesign cycle for every vehicle they produce,[583] but continues to believe that the five-year redesign cycle assumption is a reasonable estimate of how often manufacturers can make major technological changes for purposes of its modeling analysis.[584] NHTSA has considered attempting to quantify the increased cost impacts of setting standards that rise in stringency so rapidly that manufacturers are forced to apply "usual redesign" technologies at non-redesign intervals, but such an analysis would be exceedingly complex and is beyond the scope of this rulemaking given the timeframe and the current condition of the industry. NHTSA emphatically disagrees that the redesign cycle is a barrier to increasing penetration of technologies as CBD suggests, but we also believe that standards so stringent that they would require manufacturers to abandon redesign cycles entirely would be beyond the realm of economic practicability and technological feasibility, particularly in this rulemaking timeframe given lead time and capital constraints. Manufacturers can and will accomplish much improvement in fuel economy and GHG reductions while applying technology consistent with their redesign schedules.

Once the model indicates that a technology should be applied to a vehicle, the model must evaluate which technology should be applied. This will depend on the vehicle subclass to which the vehicle is assigned; what

[582] For example, applying material substitution through weight reduction, or even something as simple as low rolling-resistance tires, to a vehicle will likely require some level of validation and testing to ensure that the vehicle may continue to be certified as compliant with NHTSA's Federal Motor Vehicle Safety Standards (FMVSS). Weight reduction might affect a vehicle's crashworthiness; low rolling-resistance tires might change a vehicle's braking characteristics or how it performs in crash avoidance tests.

[583] In prior NHTSA rulemakings, the agency was able to account for shorter redesign cycles on some models (*e.g.,* some sedans), and longer redesign cycles on others (*e.g.,* cargo vans), but has standardized the redesign cycle in this analysis using the transparent baseline.

[584] In the MY 2011 final rule, NHTSA noted that the CAR report submitted by the Alliance, prepared by the Center for Automotive Research and EDF, stated that "For a given vehicle line, the time from conception to first production may span two and one-half to five years," but that "The time from first production ("Job#1") to the last vehicle off the line ("Balance Out") may span from four to five years to eight to ten years or more, depending on the dynamics of the market segment," The CAR report then stated that "At the point of final production of the current vehicle line, a new model with the same badge and similar characteristics may be ready to take its place, continuing the cycle, or the old model may be dropped in favor of a different product." *See* NHTSA–2008–0089–0170.1, Attachment 16, at 8 (393 of pdf). NHTSA explained that this description, which states that a vehicle model will be redesigned or dropped after 4–10 years, was consistent with other characterizations of the redesign and freshening process, and supported the 5-year redesign and 2–3 year refresh cycle assumptions used in the MY 2011 final rule. See *id.,* at 9 (394 of pdf). Given that the situation faced by the auto industry today is not so wholly different from that in March 2009, when the MY 2011 final rule was published, and given that the commenters did not present information to suggest that these assumptions are unreasonable (but rather simply that different manufacturers may redesign their vehicles more or less frequently, as the range of cycles above indicates), NHTSA believes that the assumptions remain reasonable for purposes of this final rule analysis. *See also* "Car Wars 2009–2012, The U.S. automotive product pipeline," John Murphy, Research Analyst, Merrill Lynch research paper, May 14, 2008 and "Car Wars 2010–2013, The U.S. automotive product pipeline," John Murphy, Research Analyst, Bank of America/Merrill Lynch research paper, July 15, 2009. *Available at http://www.autonews.com/assets/PDF/CA66116716.PDF* (last accessed March 15, 2010).

technologies have already been applied to the vehicle (*i.e.,* where in the "decision tree" the vehicle is); when the technology is first available (*i.e.,* year of availability); whether the technology is still available (*i.e.,* "phase-in caps"); and the costs and effectiveness of the technologies being considered. Technology costs may be reduced, in turn, by learning effects, while technology effectiveness may be increased or reduced by synergistic effects between technologies. In the technology input file, NHTSA has developed a separate set of technology data variables for each of the twelve vehicle subclasses. Each set of variables is referred to as an "input sheet," so for example, the subcompact input sheet holds the technology data that is appropriate for the subcompact subclass. Each input sheet contains a list of technologies available for members of the particular vehicle subclass. The following items are provided for each technology: The name of the technology, its abbreviation, the decision tree with which it is associated, the (first) year in which it is available, the upper and lower cost and effectiveness (fuel consumption reduction) estimates, the learning type and rate, the cost basis, its applicability, and the phase-in values.

To which vehicle subclass is the vehicle assigned?

As part of its consideration of technological feasibility, the agency evaluates whether each technology could be implemented on all types and sizes of vehicles, and whether some differentiation is necessary in applying certain technologies to certain types and sizes of vehicles, and with respect to the cost incurred and fuel consumption and CO_2 emissions reduction achieved when doing so. The 2002 NAS Report differentiated technology application using ten vehicle "classes" (4 car classes and 6 truck classes),[585] but did not determine how cost and effectiveness values differ from class to class. NAS's purpose in separating vehicles into these classes was to create groups of "like" vehicles, *i.e.,* vehicles similar in size, powertrain configuration, weight, and consumer use, and for which similar technologies are applicable. NHTSA similarly differentiates vehicles by "subclass" for the purpose of applying technologies to "like" vehicles and assessing their incremental costs and effectiveness. NHTSA assigns each vehicle manufactured in the rulemaking period to one of 12 subclasses: For passenger cars, Subcompact, Subcompact Performance, Compact, Compact Performance, Midsize, Midsize Performance, Large, and Large Performance; and for light trucks, Small SUV/Pickup/Van, Midsize SUV/Pickup/Van, Large SUV/Pickup/Van, and Minivan.

For this final rule as for the NPRM, NHTSA divides the vehicle fleet into subclasses based on model inputs, and applies subclass-specific estimates, also from model inputs, of the applicability, cost, and effectiveness of each fuel-saving technology. Therefore, the model's estimates of the cost to improve the fuel economy of each vehicle model depend upon the subclass to which the vehicle model is assigned.

Each vehicle's subclass is stored in the market forecast file. When conducting a compliance analysis, if the Volpe model seeks to apply technology to a particular vehicle, it checks the market forecast to see if the technology is available and if the refresh/redesign criteria are met. If these conditions are satisfied, the model determines the vehicle's subclass from the market data file, which it then uses to reference another input called the technology input file. NHTSA reviewed its methodology for dividing vehicles into subclasses for purposes of technology application that it used in the MY 2011 final rule, and concluded that the same methodology would be appropriate for this final rule for MYs 2012–2016. No comments were received on the vehicle subclasses employed in the agency's NPRM analysis, and NHTSA has retained the subclasses and the methodology for dividing vehicles among them for the final rule analysis. Vehicle subclasses are discussed in more detail in Section V of the FRIA and in Chapter 3 of the TSD.

For the reader's reference, the subclasses and example vehicles from the market forecast file are provided in the tables below.

PASSENGER CAR SUBCLASSES EXAMPLE (MY 2008) VEHICLES

Class	Example vehicles
Subcompact	Chevy Aveo, Hyundai Accent.
Subcompact Performance	Mazda MX–5, BMW Z4.
Compact	Chevy Cobalt, Nissan Sentra and Altima.
Compact Performance	Audi S4, Mazda RX–8.
Midsize	Chevy Impala, Toyota Camry, Honda Accord, Hyundai Azera.
Midsize Performance	Chevy Corvette, Ford Mustang (V8), Nissan G37 Coupe.
Large	Audi A8, Cadillac CTS and DTS.
Large Performance	Bentley Arnage, Daimler CL600.

LIGHT TRUCK SUBCLASSES EXAMPLE (MY 2008) VEHICLES

Class	Example vehicles
Minivans	Dodge Caravan, Toyota Sienna.
Small SUV/Pickup/Van	Ford Escape & Ranger, Nissan Rogue.
Midsize SUV/Pickup/Van	Chevy Colorado, Jeep Wrangler, Toyota Tacoma.
Large SUV/Pickup/Van	Chevy Silverado, Ford E-Series, Toyota Sequoia.

What technologies have already been applied to the vehicle (i.e., where in the "decision trees" is it)?

NHTSA's methodology for technology application analysis developed out of the approach taken by NAS in the 2002 Report, and evaluates the application of individual technologies and their incremental costs and effectiveness.

[585] The NAS classes included subcompact cars, compact cars, midsize cars, large cars, small SUVs, midsize SUVs, large SUVs, small pickups, large pickups, and minivans.

Incremental costs and effectiveness of individual technologies are relative to the prior technology state, which means that it is crucial to understand what technologies are already present on a vehicle in order to determine correct incremental cost and effectiveness values. The benefit of the incremental approach is transparency in accounting, insofar as when individual technologies are added incrementally to individual vehicles, it is clear and easy to determine how costs and effectiveness add up as technology levels increase.

To keep track of incremental costs and effectiveness and to know which technology to apply and in which order, the Volpe model's architecture uses a logical sequence, which NHTSA refers to as "decision trees," for applying fuel economy-improving technologies to individual vehicles. In the MY 2011 final rule, NHTSA worked with Ricardo to modify previously-employed decision trees in order to allow for a much more accurate application of technologies to vehicles. For purposes of the final rule, NHTSA reviewed the technology sequencing architecture and updated, as appropriate, the decision trees used in the analysis reported in the final rule for MY 2011 and in the MY 2012–2016 NPRM.

In general, and as described in great detail in the MY 2011 final rule and in Section V of the current FRIA, each technology is assigned to one of the five following categories based on the system it affects or impacts: engine, transmission, electrification/accessory, hybrid or vehicle. Each of these categories has its own decision tree that the Volpe model uses to apply technologies sequentially during the compliance analysis. The decision trees were designed and configured to allow the Volpe model to apply technologies in a cost-effective, logical order that also considers ease of implementation. For example, software or control logic changes are implemented before replacing a component or system with a completely redesigned one, which is typically a much more expensive option. In some cases, and as appropriate, the model may combine the sequential technologies shown on a decision tree and apply them simultaneously, effectively developing dynamic technology packages on an as-needed basis. For example, if compliance demands indicate, the model may elect to apply LUB, EFR, and ICP on a dual overhead cam engine, if they are not already present, in one single step. An example simplified decision tree for engine technologies is provided below; the other simplified decision trees may be found in Chapter 3 of the Joint TSD and in the FRIA. Expanded decision trees are available in the docket for this final rule.

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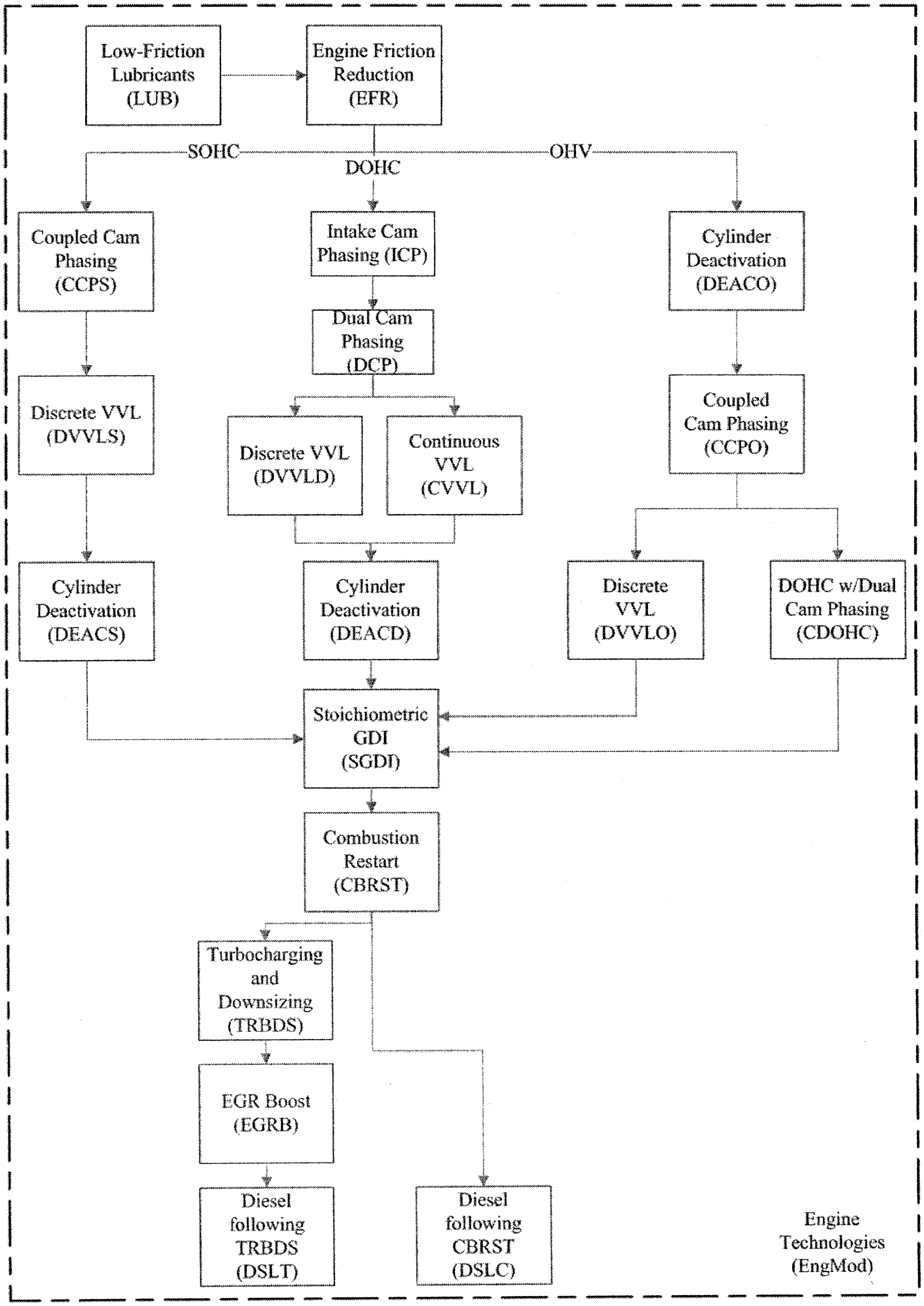
Figure IV.C.2-1 Engine Technology (EngMod) Decision Tree



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Each technology within the decision trees has an incremental cost and an incremental effectiveness estimate associated with it, and estimates are specific to a particular vehicle subclass (*see* the tables in Section V of the FRIA). Each technology's incremental estimate takes into account its position in the decision tree path. If a technology is located further down the decision tree, the estimates for the costs and effectiveness values attributed to that technology are influenced by the incremental estimates of costs and effectiveness values for prior technology applications. In essence, this approach accounts for "in-path" effectiveness synergies, as well as cost effects that occur between the technologies in the same path. When comparing cost and effectiveness estimates from various sources and those provided by commenters in this and the previous CAFE rulemakings, it is important that the estimates evaluated are analyzed in the proper context, especially as concerns their likely position in the decision trees and other technologies that may be present or missing. Not all estimates available in the public domain or that have been offered for the agencies' consideration can be evaluated in an "apples-to-apples" comparison with those used by the Volpe model, since in some cases the order of application, or included technology content, is inconsistent with that assumed in the decision tree.

The MY 2011 final rule discussed in detail the revisions and improvements made to the Volpe model and decision trees during that rulemaking process, including the improved handling and accuracy of valve train technology application and the development and implementation of a method for accounting path-dependent correction factors in order to ensure that technologies are evaluated within the proper context. The reader should consult the MY 2011 final rule documents for further information on these modeling techniques, all of which continued to be utilized in developing this final rule.[586] To the extent that the decision trees have changed for purposes of the NPRM and this final rule, it was due not to revisions in the order of technology application, but rather to redefinitions of technologies or addition or subtraction of technologies.

NHTSA did not receive any comments related to the use or ordering of the decision trees, and the agency continued to use the decision trees as they were proposed in the NPRM.

Is the next technology available in this model year?

As discussed above, the majority of technologies considered are available on vehicles today, and thus will be available for application (albeit in varying degrees) in the model years covered by this rule. Some technologies, however, will not become available for purposes of NHTSA's analysis until later in the rulemaking time frame. When the model is considering whether to add a technology to a vehicle, it checks its year of availability—if the technology is available, it may be added; if it is not available, the model will consider whether to switch to a different decision tree to look for another technology, or will skip to the next vehicle in a manufacturer's fleet. The year of availability for each technology is provided above in Table IV.C.2–1.

CBD commented that because many of the technologies considered in the NPRM are currently available, manufacturers should be able to attain mpg levels equivalent to the MY 2016 standards in MY 2009. In response, as discussed above, technology "availability" is not determined based simply on whether the technology exists, but depends also on whether the technology has achieved a level of technical viability that makes it appropriate for widespread application. This depends in turn on component supplier constraints, capital investment and engineering constraints, and manufacturer product cycles, among other things. Moreover, even if a technology is available for application, it may not be available for every vehicle. Some technologies may have considerable fuel economy benefits, but cannot be applied to some vehicles due to technological constraints—for example, cylinder deactivation cannot be applied to vehicles with current 4-cylinder engines (because not enough cylinders are present to deactivate some and continue moving the vehicle) or on vehicles with manual transmissions within the rulemaking timeframe. The agencies have provided for increases over time to reach the mpg level of the MY 2016 standards precisely because of these types of constraints, because they have a real effect on how quickly manufacturers can apply technology to vehicles in their fleets.

Has the technology reached the phase-in cap for this model year?

Besides the refresh/redesign cycles used in the Volpe model, which constrain the rate of technology application at the vehicle level so as to ensure a period of stability following any modeled technology applications, the other constraint on technology application employed in NHTSA's analysis is "phase-in caps." Unlike vehicle-level cycle settings, phase-in caps constrain technology application at the vehicle manufacturer level.[587] They are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process. At a high level, phase-in caps and refresh/redesign cycles work in conjunction with one another to avoid the modeling process out-pacing an OEM's limited pool of available resources during the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards.

NHTSA has been developing the concept of phase-in caps for purposes of the agency's modeling analysis over the course of the last several CAFE rulemakings, as discussed in greater detail in the MY 2011 final rule,[588] and in Section V of the FRIA and Chapter 3 of the Joint TSD. The MY 2011 final rule employed non-linear phase-in caps (that is, caps that varied from year to year) that were designed to respond to comments raising lead-time concerns in reference to the agency's proposed MY 2011–2015 standards, but because the final rule covered only one model year, many phase-in caps for that model year were lower than had originally been proposed. NHTSA emphasized that the MY 2011 phase-in caps were based on assumptions for the full five year period of the proposal (2011–2015), and stated that it would reconsider the phase-in settings for all years beyond 2011 in a future rulemaking analysis.[589]

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[586] *See, e.g.,* 74 FR 14238–46 (Mar. 30, 2009) for a full discussion of the decision trees in NHTSA's MY 2011 final rule, and Docket No. NHTSA–2009–0062–0003.1 for an expanded decision tree used in that rulemaking.

[587] While phase-in caps are expressed as specific percentages of a manufacturer's fleet to which a technology may be applied in a given model year, phase-in caps cannot always be applied as precise limits, and the Volpe model in fact allows "override" of a cap in certain circumstances. When only a small portion of a phase-in cap limit remains, or when the cap is set to a very low value, or when a manufacturer has a very limited product line, the cap might prevent the technology from being applied at all since any application would cause the cap to be exceeded. Therefore, the Volpe model evaluates and enforces each phase-in cap constraint after it has been exceeded by the application of the technology (as opposed to evaluating it before application), which can result in the described overriding of the cap.

[588] 74 FR 14268–14271 (Mar. 30, 2009).

[589] *See* 74 FR at 14269 (Mar. 20, 2009).

For purposes of this final rule for MYs 2012–2016, as in the MY 2011 final rule, NHTSA combines phase-in caps for some groups of similar technologies, such as valve phasing technologies that are applicable to different forms of engine design (SOHC, DOHC, OHV), since they are very similar from an engineering and implementation standpoint. When the phase-in caps for two technologies are combined, the maximum total application of either or both to any manufacturer's fleet is limited to the value of the cap.[590] In contrast to the phase-in caps used in the MY 2011 final rule, NHTSA has increased the phase-in caps for most of the technologies, as discussed below.

In developing phase-in cap values for purposes of this final rule, NHTSA initially considered the fact that many of the technologies commonly applied by the model, those placed near the top of the decision trees, such as low friction lubes, valve phasing, electric power steering, improved automatic transmission controls, and others, have been commonly available to manufacturers for several years now. Many technologies, in fact, precede the 2002 NAS Report, which estimated that such technologies would take 4 to 8 years to penetrate the fleet. Since this final rule would take effect in MY 2012, nearly 10 years beyond the NAS report, and extends to MY 2016, and in the interest of harmonization with EPA's proposal, NHTSA determined that higher phase-in caps were likely justified. Additionally, NHTSA considered the fact that manufacturers, as part of the agreements supporting the National Program, appear to be anticipating higher technology application rates than those used in the MY 2011 final rule. This also supported higher phase-in caps for purposes of the analysis underlying this final rule.

Thus, while phase-in caps for the MY 2011 final rule reached a maximum of 50 percent for a couple of technologies and generally fell in the range between 0 and 20 percent, phase-in caps for this final rule for the majority of technologies are set to reach 85 or 100 percent by MY 2016, although more advanced technologies like diesels and strong hybrids reach only 15 percent by MY 2016.

NHTSA received comments from the Alliance and ICCT relating to phase-in caps. The Alliance commented that the higher phase-in caps in the NPRM analysis (as compared to the MY 2011 final rule) "ignore OEM engine architecture differences/limitations," arguing that the agency must consider manufacturing investment and lead time implications when defining phase-in caps. ICCT did not raise the issue of phase-in caps directly, but commented that the agencies had not provided information in the proposal documents explaining when each manufacturer can implement the different technologies and how long it will take the technologies to spread across the fleet. ICCT argued that this information was crucial to considering how quickly the stringency of the standards could be increased, and at what cost.

In response to the Alliance comments, the phase-in cap constraint is, in fact, exactly intended to account for manufacturing investment and lead time implications, as discussed above: phase-in caps are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), to help ensure that resource capacity is accounted for in the modeling process. Although the phase-in caps for the analysis supporting these standards are higher than the phase-in caps employed in the MY 2011 final rule, as stated in the NPRM, the agencies considered the fact that manufacturers, as part of the agreements supporting the National Program, appear to be anticipating higher technology application rates during the rulemaking timeframe—indicating that the values selected for the phase-in caps are more likely within the range of practicability. Additionally, the agencies did not receive any comments from manufacturers indicating a direct concern with the proposed application rates, which they were able to review in the detailed manufacturer level model outputs. The agencies believe that as manufacturers focus their resources (*i.e.,* engineering, capital investment, etc.) on fuel economy-improving technologies, many of which have been in production for many years, the application rates being modeled are appropriate for the timeframe being analyzed.

In response to ICCT's comments, the combination of phase-in caps, refresh/redesign cycles, engineering constraints, etc., are intended to simulate manufacturers' technology application decisions, and ultimately define the technology application/implementation rates for each manufacturer. NHTSA has used the best public data available to define refresh and redesign schedules to define technology implementation, which allows us to apply technologies at the specific times each manufacturer is planning. There was full notice of not just the phase-in caps themselves, but their specific application as well. NHTSA notes that the PRIA and the FRIA do contain manufacturer-specific application/implementation rates for prominent technologies, and that manufacturer-specific technology application as employed in the agency's analysis is available in full in the Volpe model outputs available on NHTSA's Web site. The model outputs present the resultant application of technologies at the industry, manufacturer, and vehicle levels.

Theoretically, significantly higher phase-in caps, such as those used in the current proposal and final rule as compared to those used in the MY 2011 final rule, should result in higher levels of technology penetration in the modeling results. Reviewing the modeling output does not, however, indicate unreasonable levels of technology penetration for the final standards.[591] NHTSA believes that this is due to the interaction of the various changes in methodology for this final rule—changes to phase-in caps are but one of a number of revisions to the Volpe model and its inputs that could potentially impact the rate at which technologies are applied in the modeling analysis for this final rule as compared to prior rulemakings. Other revisions that could impact modeled application rates include the use of transparent CAFE certification data in baseline fleet formulation and the use of other data for projecting it forward,[592] or the use of a multi-year planning programming technique to apply technology retroactively to earlier-MY vehicles, both of which may have a direct impact on the modeling process. Conversely the model and inputs remain unchanged in other areas that also could impact technology application, such as in the refresh/redesign cycle settings, estimates used for the technologies, both of which remain largely unchanged from the MY 2011 final rule. These changes together make it difficult to predict how phase-in caps should be expected to function in the new modeling process.

Thus, after reviewing the output files, NHTSA concludes that the higher phase-in caps, and the resulting technology application rates produced by the Volpe model, at both the industry and manufacturer level, are appropriate for the analysis underlying these final

[590] *See* 74 FR at 14270 (Mar. 30, 2009) for further discussion and examples.

[591] The modeling output for the analysis underlying these final standards is available on NHTSA's Web site.

[592] The baseline fleet sets the starting point, from a technology point of view, for where the model begins the technology application process, so changes have a direct impact on the projected net application of technology.

standards, achieving a suitable level of stringency without requiring unrealistic or unachievable penetration rates.

Is the technology less expensive due to learning effects?

Historically, NHTSA did not explicitly account for the cost reductions a manufacturer might realize through learning achieved from experience in actually applying a technology. Since working with EPA to develop the 2008 NPRM for MYs 2011–2015, and with Ricardo to refine the concept for the March 2009 MY 2011 final rule, NHTSA has accounted for these cost reductions through two kinds of mutually exclusive learning, "volume-based" and "time-based" which it continues to use in this rule, as discussed below.

In the 2008 NPRM, NHTSA applied learning factors to technology costs for the first time. These learning factors were developed using the parameters of learning threshold, learning rate, and the initial cost, and were based on the "experience curve" concept which describes reductions in production costs as a function of accumulated production volume. The typical curve shows a relatively steep initial decline in cost which flattens out to a gentle downwardly sloping line as the volume increase to large values. In the NPRM, NHTSA applied a learning rate discount of 20 percent for each successive doubling of production volume (on a per manufacturer basis), and a learning threshold of 25,000 units was assumed (thus a technology was viewed as being fully learned out at 100,000 units). The factor was only applied to certain technologies that were considered emerging or newly implemented on the basis that significant cost improvements would be achieved as economies of scale were realized (*i.e.,* the technologies were on the steep part of the curve).

In the MY 2011 final rule, NHTSA continued to use this learning factor, referring to it as volume-based learning since the cost reductions were determined by production volume increases, and again only applied it to emerging technologies. However, and in response to comments, NHTSA revised its assumptions on learning threshold, basing them instead on an industry-wide production basis, and increasing the threshold to 300,000 units annually.

Commenters to the 2008 NPRM also described another type of learning factor which NHTSA decided to adopt and implement in the MY 2011 final rule. Commenters described a relatively small negotiated cost decrease that occurred on an annual basis through contractual agreements with first tier component and systems suppliers for readily available, high volume technologies commonly in use by multiple OEMs. Based on the same experience curve principal, however at production volumes that were on the flatter part of the curve (and thus the types of volumes that represent annual industry volumes), NHTSA adopted this type learning and referred to it as time-based learning. An annual cost reduction of 3 percent in the second and each subsequent year, which was consistent with estimates from commenters and supported by work Ricardo conducted for NHTSA, was used in the final rule.

In developing the proposed standards, NHTSA and EPA reviewed both types of learning factors, and the thresholds (300,000) and reduction rates (20 percent for volume, 3 percent for time-based) they rely on, and as implemented in the MY 2011 final rule, and agreed that both factors continue to be accurate and appropriate; each agency thus implemented time- and volume-based learning in their analyses. Noting that only one type of learning can be applied to any single technology, if any learning is applied at all, the agencies reviewed each to determine which learning factor was appropriate. Volume-based learning was applied to the higher complexity hybrid technologies, while no learning was applied to technologies likely to be affected by commodity costs (LUB, ROLL) or that have loosely-defined BOMs (EFR, LDB), as was the case in the MY 2011 final rule. Chapter 3 of the Joint TSD shows the specific learning factors that NHTSA has applied in this analysis for each technology, and discusses learning factors and each agencies' use of them further.

ICCT and Ferrari commented on learning curves. ICCT stated the agencies could improve the accuracy of the learning curve assumptions if they used a more dynamic or continuous learning curve that is more technology-specific, rather than using step decreases as the current time- and volume-based learning curves appear to do. ICCT also commented on the appropriate application of volume- versus time-based learning, and stated further that worldwide production volumes should be taken into account when developing learning curves. Ferrari commented that is more difficult for small-volume manufacturers to negotiate cost decreases from things like cost learning effects with their suppliers, implying that learning effects may not be applicable equally for all manufacturers.

NHTSA agrees that a continuous curve, if implemented correctly, could potentially improve the accuracy of modeling cost-learning effects, although the agency cannot estimate at this time how significant the improvement would be. To implement a continuous curve, however, NHTSA would need to develop a learning curve cost model to be integrated into the agency's existing model for CAFE analysis. Due to time constraints the agencies were not able to investigate fully the use of a continuous cost-learning effects curve for each technology, but we will investigate the applicability of this approach for future rulemakings. For purposes of the final rule analysis, however, NHTSA believes that while more detailed cost learning approaches may eventually be possible, the approach taken for this final rule is valid.

Additionally, while the agencies agree that worldwide production volumes can impact learning curves, the agencies do not forecast worldwide vehicle production volumes in addition to the already complex task of forecasting the U.S. market. That said, the agencies do consider current and projected worldwide technology proliferation when determining the maturity of a particular technology used to determine the appropriateness of applying time- or volume-based learning, which helps to account for the effect of globalized production.

With regard to ICCT's comments on the appropriate application of volume- versus time-based learning, however, it seems as though ICCT is referencing a study that defines volume- and time-based learning in a different manner than the current definitions used by the agencies, and so is not directly relevant. The agencies use "volume-based" learning for non-mature technologies that have the potential for significant cost reductions through learning, while "time-based" learning is used for mature technologies that have already had significant cost reductions and only have the potential for smaller cost reductions. For "time-based" learning, the agencies chose to emulate the small year-over-year cost reductions manufacturers realize through defined cost reductions, approximately 3 percent per year, negotiated into contracts with suppliers. A more detailed description of how the agencies define volume- and time-based learning can be found in NHTSA's PRIA.

And finally, in response to Ferrari's comment, NHTSA recognizes that cost negotiations can be different for different manufacturers, but believes that on balance, cost learning at the supplier level will generally impact costs to all purchasers. Thus, if cost reductions are realized for a particular technology, all entities that purchase the technology will benefit from these cost reductions.

Is the technology more or less effective due to synergistic effects?

When two or more technologies are added to a particular vehicle model to improve its fuel efficiency and reduce CO_2 emissions, the resultant fuel consumption reduction may sometimes be higher or lower than the product of the individual effectiveness values for those items.[593] This may occur because one or more technologies applied to the same vehicle partially address the same source (or sources) of engine, drivetrain or vehicle losses. Alternately, this effect may be seen when one technology shifts the engine operating points, and therefore increases or reduces the fuel consumption reduction achieved by another technology or set of technologies. The difference between the observed fuel consumption reduction associated with a set of technologies and the product of the individual effectiveness values in that set is referred to for purposes of this rulemaking as a "synergy." Synergies may be positive (increased fuel consumption reduction compared to the product of the individual effects) or negative (decreased fuel consumption reduction). An example of a positive synergy might be a vehicle technology that reduces road loads at highway speeds (*e.g.,* lower aerodynamic drag or low rolling resistance tires), that could extend the vehicle operating range over which cylinder deactivation may be employed. An example of a negative synergy might be a variable valvetrain system technology, which reduces pumping losses by altering the profile of the engine speed/load map, and a six-speed automatic transmission, which shifts the engine operating points to a portion of the engine speed/load map where pumping losses are less significant. As the complexity of the technology combinations is increased, and the number of interacting technologies grows accordingly, it becomes increasingly important to account for these synergies.

NHTSA and EPA determined synergistic impacts for this rulemaking using EPA's "lumped parameter" analysis tool, which EPA described at length in its March 2008 Staff Technical Report.[594] The lumped parameter tool is a spreadsheet model that represents energy consumption in terms of average performance over the fuel economy test procedure, rather than explicitly analyzing specific drive cycles. The tool begins with an apportionment of fuel consumption across several loss mechanisms and accounts for the average extent to which different technologies affect these loss mechanisms using estimates of engine, drivetrain and vehicle characteristics that are averaged over the EPA fuel economy drive cycle. Results of this analysis were generally consistent with those of full-scale vehicle simulation modeling performed in 2007 by Ricardo, Inc.

For the current rulemaking, NHTSA used the lumped parameter tool as modified in the MY 2011 CAFE final rule. NHTSA modified the lumped parameter tool from the version described in the EPA Staff Technical Report in response to public comments received in that rulemaking. The modifications included updating the list of technologies and their associated effectiveness values to match the updated list of technologies used in the final rule. NHTSA also expanded the list of synergy pairings based on further consideration of the technologies for which a competition for losses would be expected. These losses are described in more detail in Section V of the FRIA.

NHTSA and EPA incorporate synergistic impacts in their analyses in slightly different manners. Because NHTSA applies technologies individually in its modeling analysis, NHTSA incorporates synergistic effects between pairings of individual technologies. The use of discrete technology pair incremental synergies is similar to that in DOE's National Energy Modeling System (NEMS).[595] Inputs to the Volpe model incorporate NEMS-identified pairs, as well as additional pairs from the set of technologies considered in the Volpe model.

NHTSA notes that synergies that occur within a decision tree are already addressed within the incremental values assigned and therefore do not require a synergy pair to address. For example, all engine technologies take into account incremental synergy factors of preceding engine technologies, and all transmission technologies take into account incremental synergy factors of preceding transmission technologies. These factors are expressed in the fuel consumption improvement factors in the input files used by the Volpe model.

For applying incremental synergy factors in separate path technologies, the Volpe model uses an input table (see the tables in Chapter 3 of the TSD and in the FRIA) which lists technology pairings and incremental synergy factors associated with those pairings, most of which are between engine technologies and transmission/electrification/hybrid technologies. When a technology is applied to a vehicle by the Volpe model, all instances of that technology in the incremental synergy table which match technologies already applied to the vehicle (either pre-existing or previously applied by the Volpe model) are summed and applied to the fuel consumption improvement factor of the technology being applied. Synergies for the strong hybrid technology fuel consumption reductions are included in the incremental value for the specific hybrid technology block since the model applies technologies in the order of the most effectiveness for least cost and also applies all available electrification and transmission technologies before applying strong hybrid technologies.

NHTSA received only one comment regarding synergies, from MEMA, who commented that NHTSA's Volpe model adequately addressed synergistic effects. Having received no information to the contrary, NHTSA finalized the synergy approach and values for the final rule.

d. Where can readers find more detailed information about NHTSA's technology analysis?

Much more detailed information is provided in Section V of the FRIA, and a discussion of how NHTSA and EPA jointly reviewed and updated technology assumptions for purposes of this final rule is available in Chapter 3 of the TSD. Additionally, all of NHTSA's model input and output files are now public and available for the reader's review and consideration. The technology input files can be found in the docket for this final rule, Docket No. NHTSA–2009–0059, and on NHTSA's

[593] More specifically, the products of the differences between one and the technology-specific levels of effectiveness in reducing fuel consumption. For example, not accounting for interactions, if technologies A and B are estimated to reduce fuel consumption by 10 percent (*i.e.,* 0.1) and 20 percent (*i.e.,* 0.2) respectively, the "product of the individual effectiveness values" would be 1–0.1 times 1–0.2, or 0.9 times 0.8, which equals 0.72, corresponding to a combined effectiveness of 28 percent rather than the 30 percent obtained by adding 10 percent to 20 percent. The "synergy factors" discussed in this section further adjust these multiplicatively combined effectiveness values.

[594] EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions; EPA420–R–08–008, March 2008. *Available at* Docket No. NHTSA–2009–0059–0027.

[595] U.S. Department of Energy, Energy Information Administration, *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2007,* May 2007, Washington, DC, DOE/EIAM070(2007), at 29–30. *Available at http://tonto.eia.doe.gov/ftproot/modeldoc/m070(2007).pdf* (last accessed March 15, 2010).

Web site. And finally, because much of NHTSA's technology analysis for purposes of this final rule builds on the work that was done for the MY 2011 final rule, we refer readers to that document as well for background information concerning how NHTSA's methodology for technology application analysis has evolved over the past several rulemakings, both in response to comments and as a result of the agency's growing experience with this type of analysis.[596]

3. How did NHTSA develop its economic assumptions?

NHTSA's analysis of alternative CAFE standards for the model years covered by this rulemaking relies on a range of forecast variables, economic assumptions, and parameter values. This section describes the sources of these forecasts, the rationale underlying each assumption, and the agency's choices of specific parameter values. These economic values play a significant role in determining the benefits of alternative CAFE standards, as they have for the last several CAFE rulemakings. Under those alternatives where standards would be established by reference to their costs and benefits, these economic values also affect the levels of the CAFE standards themselves. Some of these variables have more important effects on the level of CAFE standards and the benefits from requiring alternative increases in fuel economy than do others.

In reviewing these variables and the agency's estimates of their values for purposes of this final rule, NHTSA reconsidered previous comments it had received and comments received to the NPRM, as well as reviewed newly available literature. As a consequence, the agency elected to revise some of its economic assumptions and parameter estimates from previous rulemakings at the NPRM stage, while retaining others. Some of the most important changes, which are discussed in greater detail below, as well as in Chapter 4 of the Joint TSD and in Chapter VIII of the FRIA, include significant revisions to the markup factors for technology costs; reducing the rebound effect from 15 to 10 percent; and revising the value of reducing CO_2 emissions based on recent interagency efforts to develop estimates of this value for government-wide use. The comments the agency received and its responses are discussed in detail below, as well as in the TSD and FRIA. For the reader's reference, Table IV.C.3–1 below summarizes the values used to calculate the economic benefits from each alternative.

TABLE IV.C.3–1—ECONOMIC VALUES FOR BENEFITS COMPUTATIONS

[2007$]

Fuel Economy Rebound Effect	10%
"Gap" between test and on-road MPG	20%
Value of refueling time per ($ per vehicle-hour)	$24.64
Average percentage of tank refilled per refueling	55%
Percent of drivers refueling in response to low fuel level	100%
Annual growth in average vehicle use	1.15%
Fuel Prices (2012–50 average, $/gallon)	
Retail gasoline price	$3.66
Pre-tax gasoline price	$3.29
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$0.00
Price Shock Component	$0.17
Military Security Component	$0.00
Total Economic Costs ($/gallon)	$0.17
Emission Damage Costs (2020, $/ton or $/metric ton)	
Carbon monoxide	$0
Volatile organic compounds (VOC)	$1,300
Nitrogen oxides (NO_x)—vehicle use	$5,300
Nitrogen oxides (NO_x)—fuel production and distribution	$5,100
Particulate matter ($PM_{2.5}$)—vehicle use	$290,000
Particulate matter ($PM_{2.5}$)—fuel production and distribution	$240,000
Sulfur dioxide (SO_2)	$31,000
Carbon dioxide (CO_2)	$21 [597]
Annual Increase in CO_2 Damage Cost	Varies by year.
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$0.054
Accidents	$0.023
Noise	$0.001
Total External Costs	$0.078
External Costs from Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.048
Accidents	$0.026
Noise	$0.001
Total External Costs	$0.075
Discount Rate Applied to Future Benefits	3%, 7%

[596] 74 FR 14233–308 (Mar. 30, 2009).

[597] The $21 value is for CO_2 emissions in 2010, which rises to $45/ton in 2050, at an average discount rate of 3 percent.

a. Costs of Fuel Economy-Improving Technologies

NHTSA and EPA previously developed detailed estimates of the costs of applying fuel economy-improving technologies to vehicle models for use in analyzing the impacts of alternative standards considered in the proposed rulemaking, including varying cost estimates for applying certain fuel economy technologies to vehicles of different sizes and body styles. These estimates were modified for purposes of this analysis as a result of extensive consultations among engineers from NHTSA, EPA, and the Volpe Center. Building on NHTSA's estimates developed for the MY 2011 CAFE final rule and EPA's Advanced Notice of Proposed Rulemaking, which relied on EPA's 2008 Staff Technical Report, the two agencies took a fresh look at technology cost and effectiveness values and incorporated FEV tear-down study results for purposes of this joint final rule under the National Program.

While NHTSA generally found that much of the cost information used in the MY 2011 final rule and EPA's 2008 Staff Report was consistent to a great extent, the agencies, in reconsidering information from many sources, revised the component costs of several major technologies including: turbocharging/downsizing, mild and strong hybrids, diesels, SGDI, and Valve Train Lift Technologies for purposes of the NPRM. In addition, based on FEV tear-down studies, the costs for turbocharging/downsizing, 6-, 7-, 8-speed automatic transmissions, and dual clutch transmissions were revised for this final rule.

The technology cost estimates used in this analysis are intended to represent manufacturers' direct costs for high-volume production of vehicles with these technologies and sufficient experience with their application so that all remaining cost reductions due to "learning curve" effects have been fully realized. However, NHTSA recognizes that manufacturers' actual costs for employing these technologies include additional outlays for accompanying design or engineering changes to models that use them, development and testing of prototype versions, recalibrating engine operating parameters, and integrating the technology with other attributes of the vehicle. Manufacturers' indirect costs for employing these technologies also include expenses for product development and integration, modifying assembly processes and training assembly workers to install them, increased expenses for operation and maintaining assembly lines, higher initial warranty costs for new technologies, any added expenses for selling and distributing vehicles that use these technologies, and manufacturer and dealer profit.

In previous CAFE rulemakings and in NHTSA's safety rulemakings, the agency has accounted for these additional costs by using a Retail Price Equivalent (RPE) multiplier of 1.5. For purposes of this rulemaking, based on recent work by EPA, NHTSA has applied indirect cost multipliers ranging from 1.11 to 1.64 to the estimates of vehicle manufacturers' direct costs for producing or acquiring each technology to improve fuel economy.[598] These multipliers vary with the complexity of each technology and the time frame over which costs are estimated. More complex technologies are associated with higher multipliers because of the larger increases in manufacturers' indirect costs for developing, producing (or procuring), and deploying these more complex technologies. The appropriate multipliers decline over time for technologies of all complexity levels, since increased familiarity and experience with their application is assumed to reduce manufacturers' indirect costs for employing them.

NHTSA and EPA received far fewer specific comments on technology cost estimates than in previous CAFE rulemakings, which suggests that most, although not all, stakeholders generally agreed with the agencies' assumptions. Several commenters supported the agencies' use of tear-down studies for developing some of the technology costs, largely citing the agencies' own reasons in support of that methodology. Some specific comments were received with regard to hybrid and other technology costs, to which the agencies are responding directly in Chapter 3 of the Joint TSD and in the agencies' respective FRIAs. Generally speaking, however, to the extent that commenters disagreed with the agencies' cost estimates, often the disagreement stemmed from assumptions about the technology's maturity, which the agencies have tried to account for in the analysis. These issues are discussed further in Chapter 3 of the TSD. Additionally, we note that technology costs will also be addressed in the upcoming revised NAS report.

With regard to the indirect cost multiplier approach, commenters also generally supported the higher level of specificity provided by the ICM approach compared to the RPE approach, although some commenters suggested specific refinements to the measurement of ICMs. For example, while the automotive dealer organization NADA argued that all dealer costs of sales should be included in "dealer profit," another commenter noted expressly that the ICM does not include profits. Comments from ICCT also argued in favor of revising the "technology complexity" component of the ICM to account for the complexity of integrating a new technology into a vehicle, rather than for only the complexity of producing the technology itself. These comments and others on the ICM are addressed in Chapter 3 of the Joint TSD and in the agencies' respective FRIAs. NHTSA notes that profits were not included in the indirect cost estimates of this rule, and also that NHTSA's sensitivity analysis, presented in Chapter X of the FRIA, indicates that using the 1.5 RPE multiplier would result in higher costs compared to today's final rule costs incorporating the ICM multiplier, although even with those higher costs the 1.5 RPE analysis still resulted in significant net benefits for the rulemaking as a whole. NHTSA continues to study this issue and may employ a different approach in future rulemakings.

b. Potential Opportunity Costs of Improved Fuel Economy

An important concern is whether achieving the fuel economy improvements required by alternative CAFE standards might result in manufacturers compromising the performance, carrying capacity, safety, or comfort of their vehicle models. To the extent that it does so, the resulting sacrifice in the value of these attributes to consumers represents an additional cost of achieving the required improvements in fuel economy. (This possibility is addressed in detail in Section IV.G.6.) Although exact dollar values of these attributes to consumers are difficult to infer, differences in vehicle purchase prices and buyers' choices among competing models that feature varying combinations of these characteristics clearly demonstrate that changes in these attributes affect the utility and economic value that vehicles offer to potential buyers.[599]

[598] NHTSA notes that in addition to the technology cost analysis employing this "ICM" approach, the FRIA contains a sensitivity analysis using a technology cost multiplier of 1.5.

[599] *See, e.g.,* Kleit A.N., 1990. "The Effect of Annual Changes in Automobile Fuel Economy Standards." Journal of Regulatory Economics 2: 151–172 (Docket EPA–HQ–OAR–2009–0472–0015); Berry, Steven, James Levinsohn, and Ariel Pakes, 1995. "Automobile Prices in Market Equilibrium," Econometrica 63(4): 841–940 (Docket NHTSA–2009–0059–0031); McCarthy, Patrick S., 1996.

NHTSA and EPA have approached this potential problem by developing cost estimates for fuel economy-improving technologies that include any additional manufacturing costs that would be necessary to maintain the originally planned levels of performance, comfort, carrying capacity, and safety of any light-duty vehicle model to which those technologies are applied. In doing so, the agencies followed the precedent established by the 2002 NAS Report, which estimated "constant performance and utility" costs for fuel economy technologies. NHTSA has used these as the basis for its continuing efforts to refine the technology costs it uses to analyze manufacturer's costs for complying with alternative passenger car and light truck CAFE standards for MYs 2012–2016. Although the agency has revised its estimates of manufacturers' costs for some technologies significantly for use in this rulemaking, these revised estimates are still intended to represent costs that would allow manufacturers to maintain the performance, carrying capacity, and utility of vehicle models while improving their fuel economy.

Although we believe that our cost estimates for fuel economy-improving technologies include adequate provision for accompanying outlays that are necessary to prevent any significant degradation in other attributes that vehicle owners value, it is possible that they do not include adequate allowance for the necessary efforts by manufacturers to prevent sacrifices in these attributes on all vehicle models. If this is the case, the true economic costs of achieving higher fuel economy should include the opportunity costs to vehicle owners of any sacrifices in vehicles' performance, carrying capacity, and utility, and omitting these will cause the agency's estimated technology costs to underestimate the true economic costs of improving fuel economy.

Recognizing this possibility, it would be desirable to estimate explicitly the changes in vehicle buyers' welfare from the combination of higher prices for new vehicle models, increases in their fuel economy, and any accompanying changes in vehicle attributes such as performance, passenger- and cargo-carrying capacity, or other dimensions of utility. The *net* change in buyer's welfare that results from the combination of these changes would provide a more accurate estimate of the true economic costs for improving fuel economy. Although the agency has been unable to develop a procedure for doing so as part of this rulemaking, Section IV.G.6. below includes a detailed analysis and discussion of how omitting possible changes in vehicle attributes other than their prices and fuel economy might affect its estimates of benefits and costs resulting from the standards this rule establishes.

c. The On-Road Fuel Economy "Gap"

Actual fuel economy levels achieved by light-duty vehicles in on-road driving fall somewhat short of their levels measured under the laboratory-like test conditions used by EPA to establish its published fuel economy ratings for different models. In analyzing the fuel savings from alternative CAFE standards, NHTSA has previously adjusted the actual fuel economy performance of each light truck model downward from its rated value to reflect the expected size of this on-road fuel economy "gap." On December 27, 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' rated fuel economy levels closer to their actual on-road fuel economy levels.[600]

In its Final Rule, EPA estimated that actual on-road fuel economy for light-duty vehicles averages 20 percent lower than published fuel economy levels. For example, if the overall EPA fuel economy rating of a light truck is 20 mpg, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80). NHTSA employed EPA's revised estimate of this on-road fuel economy gap in its analysis of the fuel savings resulting from alternative CAFE standards evaluated in the MY 2011 final rule.

For purposes of this final rule, NHTSA conducted additional analysis of this issue. The agency used data on the number of passenger cars and light trucks of each model year that were registered for use during calendar years 2000 through 2006, average rated fuel economy for passenger cars and light trucks produced during each model year, and estimates of average miles driven per year by cars and light trucks of different ages. These data were combined to develop estimates of the average fuel economy that the U.S. passenger vehicle fleet *would have achieved* from 2000 through 2006 if cars and light trucks of each model year achieved the same fuel economy levels in actual on-road driving as they did under test conditions when new.

NHTSA compared these estimates to the Federal Highway Administration's (FHWA) published values of actual on-road fuel economy for passenger cars and light trucks during each of those years.[601] FHWA's estimates of actual fuel economy for passenger cars averaged 22 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions over this period, while FHWA's estimates for light trucks averaged 17 lower than NHTSA's estimates of average light truck fuel economy under test conditions. These results appear to confirm that the 20 percent on-road fuel economy discount or gap represents a reasonable estimate for use in evaluating the fuel savings likely to result from alternative CAFE standards for MY 2012–2016 vehicles.

NHTSA received no comments on this issue in response to the NPRM. Accordingly, it has not revised its estimate of the on-road fuel economy gap from the 20 percent figure used previously.

d. Fuel Prices and the Value of Saving Fuel

Projected future fuel prices are a critical input into the economic analysis of alternative CAFE standards, because they determine the value of fuel savings both to new vehicle buyers and to society. NHTSA relied on the most recent fuel price projections from the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) for this analysis. Specifically, we used the AEO 2010 Early Release (December 2009) Reference Case forecasts of inflation-adjusted (constant-dollar) retail gasoline and diesel fuel prices, which represent the EIA's most up-to-date estimate of the most likely course of future prices for petroleum products.[602] This forecast is

"Market Price and Income Elasticities of New Vehicle Demands." Review of Economics and Statistics 78: 543–547 (Docket NHTSA–2009–0059–0039); and Goldberg, Pinelopi K., 1998. "The Effects of the Corporate Average Fuel Efficiency Standards in the U.S.," *Journal of Industrial Economics* 46(1): 1–33 (Docket EPA–HQ–OAR–2009–0472–0017).

[600] 71 FR 77871 (Dec. 27, 2006).

[601] Federal Highway Administration, Highway Statistics, 2000 through 2006 editions, Table VM–1; *See http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm* (last accessed March 1, 2010).

[602] Energy Information Administration, Annual Energy Outlook 2010 Early Release, Reference Case (December 2009), Table A12. *Available at http://www.eia.doe.gov/oiaf/aeo/pdf/appa.pdf, p. 25* (last accessed March 1, 2010). These forecasts reflect the provisions of the Energy Independence and Security Act of 2007 (EISA), including the requirement that the combined mpg level of U.S. cars and light trucks reach 35 miles per gallon by model year 2020. Because this provision would be expected to reduce future U.S. demand for gasoline and lead to a decline in its future price, there is some concern about whether the AEO 2010 forecast of fuel prices partly reflects the increases in CAFE standards considered in this rule, and thus whether it is suitable for valuing the projected reductions in fuel use. In response to this concern, the agency

Continued

somewhat lower than the AEO 2009 Reference Case forecast the agency relied upon in the analysis it conducted for the NPRM. Over the period from 2010 to 2030, the AEO 2010 Early Release Reference Case forecast of retail gasoline prices used in this analysis averages $3.18 per gallon (in 2007 dollars), in contrast to the $3.38 per gallon average price for that same period forecast in the earlier AEO 2009 Reference Case and used in the NPRM analysis.

While NHTSA relied on the forecasts of fuel prices presented in AEO 2008 High Price Case in the MY 2011 final rule, we noted at the time that we were relying on that estimate primarily because volatility in the oil market appeared to have overtaken the Reference Case. We also anticipated that the Reference Case forecasts would be significantly higher in subsequent editions of AEO, and that in future rulemaking analyses the agency would be likely to rely on the Reference Case rather than High Price Case forecasts. In fact, both EIA's AEO 2009 Reference Case and its subsequent AEO 2010 Early Release Reference Case forecasts project *higher* retail fuel prices in most future years than those forecast in the High Price Case from AEO 2008. NHTSA is thus confident that the AEO 2010 Early Release Reference Case is an appropriate forecast for projected future fuel prices.

NHTSA and EPA received relatively few comments on the fuel prices used in the NPRM analysis, compared to previous CAFE rulemakings. Two commenters, CARB and NADA, supported the use of AEO's Reference Case for use in the agencies' analysis, although they disagreed on the agencies' use of the High and Low Price Cases for sensitivities. Both commenters emphasized the sensitivity of the market and the agencies' analysis to higher and lower gas prices, and on that basis, CARB supported the use of the High and Low Price Cases in sensitivity analysis but urged the agencies to caveat the "Reference Case" results more explicitly. In contrast, NADA argued that the agencies should not use the High and Low Price Cases, because EIA does not assign specific probabilities to either of them. Only one commenter, James Adcock, argued that the agencies should use forecasts of future fuel prices other than those reported in AEO; Adcock stated that future fuel prices should be assumed to be higher than current pump prices.

Measured in constant 2007 dollars, the AEO 2010 Early Release Reference Case forecast of retail gasoline prices during calendar year 2010 is $2.44 per gallon, and rises gradually to $3.83 by the year 2035 (these values include Federal, State and local taxes). However, the agency's analysis of the value of fuel savings over the lifetimes of MY 2012–2016 cars and light trucks requires forecasts extending through calendar year 2050, approximately the last year during which a significant number of MY 2016 vehicles will remain in service. To obtain fuel price forecasts for the years 2036 through 2050, the agency assumes that retail fuel prices will continue to increase after 2035 at the average annual rates projected for 2025 through 2035 in the AEO 2010 Early Release Reference Case.[603] This assumption results in a projected retail price of gasoline that reaches $4.49 in 2007 dollars during the year 2050.

The value of fuel savings resulting from improved fuel economy to buyers of light-duty vehicles is determined by the retail price of fuel, which includes Federal, State, and any local taxes imposed on fuel sales. The agency has updated the estimates of gasoline taxes it employed in the NPRM using the recent data on State fuel tax rates; expressed in 2007 dollars, Federal gasoline taxes are currently $0.178, while State and local gasoline taxes together average $0.231 per gallon, for a total tax burden of $0.401 per gallon. Because fuel taxes represent transfers of resources from fuel buyers to government agencies, however, rather than real resources that are consumed in the process of supplying or using fuel, NHTSA deducts their value from retail fuel prices to determine the true value of fuel savings resulting from more stringent CAFE standards to the U.S. economy.

NHTSA follows the assumptions used by EIA in AEO 2010 Early Release that State and local gasoline taxes will keep pace with inflation in nominal terms, and thus remain constant when expressed in constant dollars. In contrast, EIA assumes that Federal gasoline taxes will remain unchanged in *nominal* terms, and thus decline throughout the forecast period when expressed in constant dollars. These differing assumptions about the likely future behavior of Federal and State/local fuel taxes are consistent with recent historical experience, which reflects the fact that Federal as well as most State motor fuel taxes are specified on a cents-per-gallon rather than an *ad valorem* basis, and typically require legislation to change. The projected value of total taxes is deducted from each future year's forecast of retail gasoline and diesel prices to determine the economic value of each gallon of fuel saved during that year as a result of improved fuel economy. Subtracting fuel taxes from the retail prices forecast in AEO 2010 Early Release results in a projected value for saving gasoline of $2.04 per gallon during 2010, rising to $3.48 per gallon by the year 2035,and averaging $2.91 over this 25-year period.

Although the Early Release of AEO 2010 contains only the Reference Case forecast, EIA includes "High Price Case" and "Low Price Case" forecasts in each year's complete AEO, which reflect uncertainties regarding future levels of oil production and demand. For this final rule, NHTSA has continued to use the most recent "High Price Case" and "Low Price Case" forecasts available, which are those from AEO 2009. While NHTSA recognizes that these forecasts are not probabilistic, as NADA commented, we continue to believe that using them for sensitivity analyses provides valuable information for agency decision-makers, because it illustrates the sensitivity of the rule's primary economic benefit resulting from uncertainty about future growth in world demand for petroleum energy and the strategic behavior of oil suppliers.

These alternative scenarios project retail gasoline prices that range from a low of $2.02 to a high of $5.04 per gallon during 2020, and from $2.04 to $5.47 per gallon during 2030 (all figures in 2007 dollars). In conjunction with our assumption that fuel taxes will remain constant in real or inflation-adjusted terms over this period, these forecasts imply pre-tax values of saving fuel ranging from $1.63 to $4.65 per gallon during 2020, and from $1.66 to $5.09 per gallon in 2030 (again, all figures are in constant 2007 dollars). In conducting the analysis of uncertainty in benefits and costs from alternative CAFE standards required by OMB, NHTSA evaluated the sensitivity of its benefits estimates to these alternative forecasts of future fuel prices. Detailed

notes that EIA issued a revised version of AEO 2008 in June 2008, which modified its previous December 2007 Early Release of AEO 2008 to reflect the effects of then recently-passed EISA legislation. The fuel price forecasts reported in EIA's Revised Release of AEO 2008 differed by less than one cent per gallon throughout the entire forecast period (2008–2030) from those previously issued as part of its initial release of AEO 2008. Thus, the agencies are reasonably confident that the fuel price forecasts presented in AEO 2010 and used to analyze the value of fuel savings projected to result from this rule are not unduly affected by the CAFE provisions of EISA.

[603] This projection uses the rate of increase in fuel prices for 2020–2030 rather than that over the complete forecast period (2009–2030) because there is extreme volatility in the forecasts for the years 2009 through approximately 2020. Using the average rate of change over the complete 2009–2030 forecast period would result in projections of declining fuel prices after 2030.

results and discussion of this sensitivity analysis can be found in the FRIA. Generally, however, this analysis confirmed that as several commenters suggested, the primary economic benefit resulting from the rule—the value of fuel savings—is quite sensitive to forecast fuel prices.

e. Consumer Valuation of Fuel Economy and Payback Period

In estimating the impacts on vehicle sales that would result from alternative CAFE standards to potential vehicle buyers, NHTSA assumes, as in the MY 2011 final rule, that potential vehicle buyers value the resulting fuel savings over only part of the expected lifetime of the vehicles they purchase. Specifically, we assume that buyers value fuel savings over the first five years of a new vehicle's lifetime, and discount the value of these future fuel savings at a 3 percent annual rate. The five-year figure represents approximately the current average term of consumer loans to finance the purchase of new vehicles. We recognize that the period over which individual buyers finance new vehicle purchases may not correspond exactly to the time horizons they apply in valuing fuel savings from higher fuel economy.

The agency deducts the discounted present value of fuel savings over the first five years of a vehicle model's lifetime from the technology costs incurred by its manufacturer to improve that model's fuel economy to determine the increase in its "effective price" to buyers. The Volpe model uses these estimates of effective costs for increasing the fuel economy of each vehicle model to identify the order in which manufacturers would be likely to select models for the application of fuel economy-improving technologies in order to comply with stricter standards. The average value of the resulting increase in effective cost from each manufacturer's simulated compliance strategy is also used to estimate the impact of alternative standards on its total sales for future model years.

One commenter, NADA, supported the agency's assumption of a five-year period for buyers' valuation of fuel economy, on the basis that the considerable majority of consumers seek to recoup costs quickly. However, NADA also encouraged the agencies to ensure that purchaser finance costs, opportunity costs of vehicle ownership, and increased maintenance costs were accounted for. Another commenter, James Adcock, argued that the assumption of a five-year period was irrational, because it did not account for the fact that first purchasers will be able to sell a higher-mpg vehicle for more money than a lower-mpg vehicle.

In response to these comments, the agency notes that it estimates the aggregate value to the U.S. economy of fuel savings resulting from alternative standards—or their "social" value—over the *entire* expected lifetimes of vehicles manufactured under those standards, rather than over the shorter 5-year "payback period" we assume that manufacturers employ to represent the preferences of vehicle buyers. The 5-year payback period is only utilized to identify the likely sequence of improvements in fuel economy that manufacturers are likely to make to their different vehicle models. The procedure the agency uses for calculating lifetime fuel savings is discussed in detail in the following section, while alternative assumptions about the time horizon over which potential buyers consider fuel savings in their vehicle purchasing decisions are analyzed and discussed in detail in Section IV.G.6 below.

Valuing fuel savings over vehicles' entire lifetimes in effect recognizes the gains that future vehicle owners will receive, even if initial purchasers of higher-mpg models are not able to recover the entire remaining value of fuel savings when they re-sell those vehicles. The agency acknowledges, however, that it has not accounted for any effects of increased financing costs for purchasing vehicles with higher fuel economy or increased expenses for maintaining them on benefits to vehicle owners, over either the short-run payback period or the full lifetimes of vehicles.

f. Vehicle Survival and Use Assumptions

NHTSA's first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number expected to remain in service during each year following their production and sale.[604] This is calculated by multiplying the number of vehicles originally produced during a model year by the proportion typically expected to remain in service at their age during each later year, often referred to as a "survival rate."

As discussed in more detail in Section II.B.3 above and in Chapter 1 of the TSD, to estimate production volumes of passenger cars and light trucks for individual manufacturers, NHTSA relied on a baseline market forecast constructed by EPA staff beginning with MY 2008 CAFE certification data. After constructing a MY 2008 baseline, EPA and NHTSA used projected car and truck volumes for this period from Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2009 in the NPRM analysis.[605] For the analysis supporting this final rule, NHTSA substituted the revised forecasts of total volume reported in EIA's Annual Energy Outlook 2010 Early Release. However, Annual Energy Outlook forecasts only total car and light truck sales, rather than sales at the manufacturer and model-specific level, which the agencies require in order to estimate the effects new standards will have on individual manufacturers.[606]

To estimate sales of individual car and light truck models produced by each manufacturer, EPA purchased data from CSM Worldwide and used its projections of the number of vehicles of each type (car or truck) that will be produced and sold by manufacturers in model years 2011 through 2015.[607] This provided year-by-year estimates of the percentage of cars and trucks sold by each manufacturer, as well as the sales percentages accounted for by each vehicle market segment. (The distributions of car and truck sales by manufacturer and by market segment for the 2016 model year and beyond were assumed to be the same as CSM's forecast for the 2015 calendar year.) Normalizing these percentages to the

[604] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 2 during calendar year 2001, and to reach their maximum age of 26 years during calendar year 2025. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 26 years, while light trucks have a maximum lifetime of 36 years. See Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8–11 (January 2006). *Available at http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf* (last accessed March 1, 2010).

[605] *Available at http://www.eia.doe.gov/oiaf/aeo/index.html* (last accessed March 15, 2010). NHTSA and EPA made the simplifying assumption that projected sales of cars and light trucks during each calendar year from 2012 through 2016 represented the likely production volumes for the corresponding model year. The agency did not attempt to establish the exact correspondence between projected sales during individual calendar years and production volumes for specific model years.

[606] Because AEO 2009's "car" and "truck" classes did not reflect NHTSA's recent reclassification (in March 2009 for enforcement beginning MY 2011) of many two wheel drive SUVs from the nonpassenger (*i.e.,* light truck) fleet to the passenger car fleet, EPA staff made adjustments to account for such vehicles in the baseline.

[607] EPA also considered other sources of similar information, such as J.D. Powers, and concluded that CSM was better able to provide forecasts at the requisite level of detail for most of the model years of interest.

total car and light truck sales volumes projected for 2012 through 2016 in AEO 2009 provided manufacturer-specific market share and model-specific sales estimates for those model years. The volumes were then scaled to AEO 2010 total volume for each year.

To estimate the number of passenger cars and light trucks originally produced during model years 2012 through 2016 that will remain in use during each subsequent year, the agency applied age-specific survival rates for cars and light trucks to these adjusted forecasts of passenger car and light truck sales. In 2008, NHTSA updated its previous estimates of car and light truck survival rates using the most current registration data for vehicles produced during recent model years, in order to ensure that they reflected recent increases in the durability and expected life spans of cars and light trucks.[608]

The next step in estimating fuel use is to calculate the total number of miles that model year 2012–2016 cars and light trucks remaining in use will be driven each year. To estimate total miles driven, the number projected to remain in use during each future year is multiplied by the average number of miles they are expected to be driven at the age they will reach in that year. The agency estimated annual usage of cars and light trucks of each age using data from the Federal Highway Administration's 2001 National Household Transportation Survey (NHTS).[609] Because these estimates reflect the historically low gasoline prices that prevailed at the time the 2001 NHTS was conducted, however, NHTSA adjusted them to account for the effect on vehicle use of subsequent increases in fuel prices. Details of this adjustment are provided in Chapter VIII of the FRIA and Chapter 4 of the Joint TSD.

Increases in average annual use of cars and light trucks have been an important source of historical growth in the total number of miles they are driven each year. To estimate future growth in their average annual use for purposes of this rulemaking, NHTSA calculated the rate of growth in the adjusted mileage schedules derived from the 2001 NHTS necessary for *total* car and light truck travel to increase at the rate forecast in the AEO 2010 Early Release Reference Case.[610] This rate was calculated to be consistent with future changes in the overall size and age distributions of the U.S. passenger car and light truck fleets that result from the agency's forecasts of total car and light truck sales and updated survival rates. The resulting growth rate in average annual car and light truck use of 1.15 percent per year was applied to the mileage figures derived from the 2001 NHTS to estimate annual mileage during each year of the expected lifetimes of MY 2012–2016 cars and light trucks.[611]

Finally, the agency estimated total fuel consumption by passenger cars and light trucks remaining in use each year by dividing the total number of miles surviving vehicles are driven by the fuel economy they are expected to achieve under each alternative CAFE standard. Each model year's total lifetime fuel consumption is the sum of fuel use by the cars or light trucks produced during that model year during each year of their life spans. In turn, the *savings* in a model year's lifetime fuel use that will result from each alternative CAFE standard is the difference between its lifetime fuel use at the fuel economy level it attains under the Baseline alternative, and its lifetime fuel use at the higher fuel economy level it is projected to achieve under that alternative standard.[612]

NHTSA and EPA received no comments on their respective NPRMs indicating that these assumptions should be updated or reconsidered. Thus the agencies have continued to employ them in the analysis supporting this final rule.

g. Accounting for the Fuel Economy Rebound Effect

The fuel economy rebound effect refers to the fraction of fuel savings expected to result from an increase in vehicle fuel economy—particularly an increase required by the adoption of higher CAFE standards—that is offset by additional vehicle use. The increase in vehicle use occurs because higher fuel economy reduces the fuel cost of driving, typically the largest single component of the monetary cost of operating a vehicle, and vehicle owners respond to this reduction in operating costs by driving slightly more. By lowering the marginal cost of vehicle use, improved fuel economy may lead to an increase in the number of miles vehicles are driven each year and over their lifetimes. Even with their higher fuel economy, this additional driving consumes some fuel, so the rebound effect reduces the net fuel savings that result when new CAFE standards require manufacturers to improve fuel economy.

The magnitude of the rebound effect is an important determinant of the actual fuel savings that are likely to result from adopting stricter CAFE standards. Research on the magnitude of the rebound effect in light-duty vehicle use dates to the early 1980s, and generally concludes that a statistically significant rebound effect occurs when vehicle fuel efficiency improves.[613] The agency reviewed studies of the rebound effect it had previously relied upon, considered more recently published estimates, and developed new estimates of its magnitude for purposes of the NPRM.[614] Recent studies provide some evidence that the rebound effect has been declining over time, and may decline further over the immediate future if incomes rise faster than gasoline prices. This result appears

[608] Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8–11 (January 2006). *Available at http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf* (last accessed March 1, 2010). These updated survival rates suggest that the expected lifetimes of recent-model passenger cars and light trucks are 13.8 and 14.5 years.

[609] For a description of the Survey, *See http://nhts.ornl.gov/quickStart.shtml* (last accessed March 1, 2010).

[610] This approach differs from that used in the MY 2011 final rule, where it was assumed that future growth in the total number of cars and light trucks in use resulting from projected sales of new vehicles was adequate by itself to account for growth in total vehicle use, without assuming continuing growth in average vehicle use.

[611] While the adjustment for future fuel prices reduces average mileage at each age from the values derived from the 2001 NHTS, the adjustment for expected future growth in average vehicle use increases it. The net effect of these two adjustments is to increase expected lifetime mileage by about 18 percent significantly for both passenger cars and about 16 percent for light trucks.

[612] To illustrate these calculations, the agency's adjustment of the AEO 2009 Revised Reference Case forecast indicates that 9.26 million passenger cars will be produced during 2012, and the agency's updated survival rates show that 83 percent of these vehicles, or 7.64 million, are projected to remain in service during the year 2022, when they will have reached an age of 10 years. At that age, passenger achieving the fuel economy level they are projected to achieve under the Baseline alternative are driven an average of about 800 miles, so surviving model year 2012 passenger cars will be driven a total of 82.5 billion miles (= 7.64 million surviving vehicles × 10,800 miles per vehicle) during 2022. Summing the results of similar calculations for each year of their 26-year maximum lifetime, model year 2012 passenger cars will be driven a total of 1,395 billion miles under the Baseline alternative. Under that alternative, they are projected to achieve a test fuel economy level of 32.4 mpg, which corresponds to actual on-road fuel economy of 25.9 mpg (= 32.4 mpg × 80 percent). Thus their lifetime fuel use under the Baseline alternative is projected to be 53.9 billion gallons (= 1,395 billion miles divided by 25.9 miles per gallon).

[613] Some studies estimate that the long-run rebound effect is significantly larger than the immediate response to increased fuel efficiency. Although their estimates of the adjustment period required for the rebound effect to reach its long-run magnitude vary, this long-run effect is most appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply to future model years.

[614] For details of the agency's analysis, see Chapter VIII of the PRIA and Chapter 4 of the draft Joint TSD accompanying this proposed rule.

plausible, because the responsiveness of vehicle use to variation in fuel costs is expected to decline as they account for a smaller proportion of the total monetary cost of driving, which has been the case until very recently. At the same time, rising personal incomes would be expected to reduce the sensitivity of vehicle use to fuel costs as the time component of driving costs—which is likely to be related to income levels—accounts for a larger fraction the total cost of automobile travel.

NHTSA developed new estimates of the rebound effect by using national data on light-duty vehicle travel over the period from 1950 through 2006 to estimate various econometric models of the relationship between vehicle miles-traveled and factors likely to influence it, including household income, fuel prices, vehicle fuel efficiency, road supply, the number of vehicles in use, vehicle prices, and other factors.[615] The results of NHTSA's analysis are consistent with the findings from other recent research: the average long-run rebound effect ranged from 16 percent to 30 percent over the period from 1950 through 2007, while estimates of the rebound effect in 2007 range from 8 percent to 14 percent. Projected values of the rebound effect for the period from 2010 through 2030, which the agency developed using forecasts of personal income, fuel prices, and fuel efficiency from AEO 2009's Reference Case, range from 4 percent to 16 percent, depending on the specific model used to generate them.

In light of these results, the agency's judgment is that the apparent decline over time in the magnitude of the rebound effect justifies using a value for future analysis that is lower than historical estimates, which average 15–25 percent. Because the lifetimes of vehicles affected by the alternative CAFE standards considered in this rulemaking will extend from 2012 until nearly 2050, a value that is significantly lower than historical estimates appears to be appropriate. Thus NHTSA used a 10 percent rebound effect in its analysis of fuel savings and other benefits from higher CAFE standards for the NPRM. The agency also sought comment on other alternatives for estimating the rebound effect, such as whether it would be appropriate to use the price elasticity of demand for gasoline, or other alternative approaches, to guide the choice of a value for the rebound effect.

[615] The agency used several different model specifications and estimation procedures to control for the effect of fuel prices on fuel efficiency in order to obtain accurate estimates of the rebound effect.

NHTSA and EPA received far fewer comments on the rebound effect than were previously received to CAFE rulemakings. Only one commenter, NJ DEP, expressly supported the agencies' assumption of 10 percent for the rebound effect; other commenters (CARB, CBD, ICCT) argued that 10 percent should be the absolute maximum value and that the rebound effect assumed by the agencies should be lower, and would also be expected to decline over time. ICCT added that the price elasticity of gasoline demand could be a useful comparison for the rebound effect, but should not be used to derive it. Other commenters argued that a rebound effect either was unlikely to occur (James Hyde), or was unlikely to produce a uniform increase in use of all vehicles with improved fuel economy (Missouri DNR). NADA argued, in contrast, that the agencies had not provided sufficient justification for lowering the rebound effect to 10 percent from the "historically justified" range of 15 to 30 percent.

The agency's interpretation of historical and recent evidence on the magnitude of the rebound effect is that a significant fuel economy rebound effect exists, and commenters did not provide any additional data or analysis to justify revising our initial estimates of the rebound effect. Therefore, the data available at this time do not justify using a rebound effect below the 10 percent figure employed in its NPRM analysis. NHTSA believes that projections of a *continued* decline in the magnitude of the rebound effect are unrealistic because they assume the rate at which it declines in response to increasing incomes remain constant, and in some cases imply that the rebound effect will become negative in the near future. In addition, the continued increases in fuel prices used in this analysis will tend to increase the magnitude of the rebound effect, thus offsetting part of the effect of rising incomes. As the preceding discussion indicates, there is a wide range of estimates for both the historical magnitude of the rebound effect and its projected future value, and there is some evidence that the magnitude of the rebound effect appears to be declining over time. Nevertheless, NHTSA requires a single point estimate for the rebound effect as an input to its analysis, although a range of estimates can be used to test the sensitivity to uncertainty about its exact magnitude. For the final rule, NHTSA chose to use 10 percent as its primary estimate of the rebound effect, with a range of 5–15 percent for use in sensitivity testing.

The 10 percent figure is well below those reported in almost all previous research, and it is also below most estimates of the historical and current magnitude of the rebound effect developed by NHTSA. However, other recent research—particularly that conducted by Small and Van Dender and by Greene—reports persuasive evidence that the magnitude of the rebound effect is likely to be declining over time, and the forecasts developed by NHTSA also suggest that this is likely to be the case. As a consequence, NHTSA concluded that a value below the historical estimates reported here is likely to provide a more reliable estimate of its magnitude during the future period spanned by NHTSA's analysis of the impacts of this rule. The 10 percent estimate meets this condition, since it lies below the 15–30 percent range of estimates for the historical rebound effect reported in most previous research, and at the upper end of the 5–10 percent range of estimates for the future rebound effect reported in the recent studies by Small and Van Dender and by Greene. It also lies within the 3–16 percent range of forecasts of the future magnitude of the rebound effect developed by NHTSA in its recent research. In summary, the 10 percent value was not derived from a single point estimate from a particular study, but instead represents a reasonable compromise between the historical estimates and the projected future estimates. NHTSA will continue to review this estimate of the rebound effect in future rulemakings, but the agency has continued to use the 10 percent rebound effect over the entire future period spanned by the analysis it conducted for this final rule.

h. Benefits From Increased Vehicle Use

The increase in vehicle use from the rebound effect provides additional benefits to their owners, who may make more frequent trips or travel farther to reach more desirable destinations. This additional travel provides benefits to drivers and their passengers by improving their access to social and economic opportunities away from home. As evidenced by their decisions to make more frequent or longer trips when improved fuel economy reduces their costs for driving, the benefits from this additional travel exceed the costs drivers and passengers incur in making more frequent or longer trips.

The agency's analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel costs drivers incur plus the consumer surplus they receive from the additional accessibility it provides.[616] Because the increase in travel depends on the extent of improvement in fuel economy, the value of benefits it provides differs among model years and alternative CAFE standards. Under even those alternatives that would impose the highest standards, however, the magnitude of these benefits represents a small fraction of total benefits. Because no comments addressed this issue of benefits from increased vehicle use or the procedure used to estimate them, the agencies have finalized their proposed assumptions for purposes of the final rule analysis.

i. The Value of Increased Driving Range

Improving vehicles' fuel economy may also increase their driving range before they require refueling. By reducing the frequency with which drivers typically refuel, and by extending the upper limit of the range they can travel before requiring refueling, improving fuel economy thus provides some additional benefits to their owners.[617] NHTSA re-examined this issue for purposes of this rulemaking, and found no information in comments or elsewhere that would cause the agency to revise its previous approach. Since no direct estimates of the value of extended vehicle range are available, NHTSA calculates directly the reduction in the annual number of required refueling cycles that results from improved fuel economy, and applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value.[618]

As an illustration, a typical small light truck model has an average fuel tank size of approximately 20 gallons. Assuming that drivers typically refuel when their tanks are 55 percent full (*i.e.,* 11 gallons in reserve), increasing this model's actual on-road fuel economy from 24 to 25 mpg would extend its driving range from 216 miles (= 9 gallons × 24 mpg) to 225 miles (= 9 gallons × 25 mpg). Assuming that it is driven 12,000 miles/year, this reduces the number of times it needs to be refueled each year from 55.6 (= 12,000 miles per year/216 miles per refueling) to 53.3 (= 12,000 miles per year/225 miles per refueling), or by 2.3 refuelings per year.

Weighted by the nationwide mix of urban and rural driving, personal and business travel in urban and rural areas, and average vehicle occupancy for driving trips, the DOT-recommended values of travel time per vehicle-hour is $24.64 (in 2007 dollars).[619]Assuming that locating a station and filling up requires a total of five minutes, the annual value of time saved as a result of less frequent refueling amounts to $4.72 (calculated as 5/60 × 2.3 × $24.64). This calculation is repeated for each future year that model year 2012–2016 cars and light trucks would remain in service. Like fuel savings and other benefits, the value of this benefit declines over a model year's lifetime, because a smaller number of vehicles originally produced during that model year remain in service each year, and those remaining in service are driven fewer miles.

Although the agencies received no public comments on the procedures they used to estimate the benefits from less frequent refueling or the magnitude of those benefits, we note also that the estimated value of less frequent refueling events is subject to a number of uncertainties which we discuss in detail in Chapter 4.1.11 of the Joint TSD, and the actual value could be higher or lower than the value presented here. Specifically, the analysis makes three assumptions: (a) That manufacturers will not adjust fuel tank capacities downward (from the current average of 19.3 gallons) when they improve the fuel economy of their vehicle models. (b) that the average fuel purchase (55 percent of fuel tank capacity) is the typical fuel purchase. (c) that 100 percent of all refueling is demand-based; *i.e.,* that every gallon of fuel which is saved would reduce the need to return to the refueling station. NHTSA has planned a new research project which will include a detailed study of refueling events, and which is expected to improve upon these assumptions. These assumptions and the upcoming research project are discussed in detail in Joint TSD Chapter 4.2.10, as well as in Chapter VIII of NHTSA's FRIA.

j. Added Costs From Congestion, Crashes and Noise

Increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. NHTSA relies on estimates of per-mile congestion, accident, and noise costs caused by increased use of automobiles and light trucks developed by the Federal Highway Administration to estimate these increased costs.[620] NHTSA employed these estimates previously in its analysis accompanying the MY 2011 final rule, and after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values, continues to find them appropriate for use in this final rule. The agency multiplies FHWA's estimates of per-mile costs by the annual increases in automobile and light truck use from the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year.

One commenter, Inrix, Inc., stated that "deeply connected vehicles," *i.e.,* those with built-in computer systems to help drivers identify alternative routes to avoid congestion, are better able to avoid congestion than conventional vehicles. The commenter argued that increased use of these models may be less likely to contribute to increased congestion, and urged the agencies to consider the impact of this on their estimates of fuel use and GHG emissions. NHTSA notes that the number of such vehicles is extremely small at present, and is likely to remain modest for the model years affected by this rule, and has thus continued to employ the estimates of congestion costs from additional rebound-effect vehicle use that it utilized in the NPRM analysis. The agency recognizes that these vehicles may become sufficiently common in the future that their effect on the fuel economy drivers actually experience could become significant, but notes that to the extent this occurs,

[616] The consumer surplus provided by added travel is estimated as one-half of the product of the decline in fuel cost per mile and the resulting increase in the annual number of miles driven.

[617] If manufacturers respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting cost saving will presumably be reflected in lower vehicle sales prices.

[618] See Department of Transportation, Guidance Memorandum, "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations," Apr. 9, 1997. *http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf* (last accessed March 1, 2010); update *available at http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf* (last accessed March 1, 2010).

[619] The hourly wage rate during 2008 is estimated to average $25.50 when expressed in 2007 dollars. Personal travel in urban areas (which represents 94 percent of urban travel) is valued at 50 percent of the hourly wage rate, while business travel (the remaining 6 percent of urban travel) is valued at 100 percent of the hourly wage rate. For intercity travel, personal travel (87 percent of total intercity travel) is valued at 70 percent of the wage rate, while business travel (13 percent) is valued at 100 percent of the wage rate. The resulting values of travel time are $12.67 for urban travel and $17.66 for intercity travel, and must be multiplied by vehicle occupancy (1.6) to obtain the estimated values of time per vehicle hour in urban and rural driving. Finally, about 66% of driving occurs in urban areas, while the remaining 34% takes place in rural areas, and these percentages are used to calculate a weighted average of the value of time in all driving.

[620] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study; See http://www.fhwa.dot.gov/policy/hcas/final/index.htm* (last accessed March 1, 2010).

it would be reflected in the gap between test and on-road fuel economy. NHTSA will continue to monitor the production of such vehicles and their representation in the vehicle fleet in its future rulemakings.

k. Petroleum Consumption and Import Externalities

U.S. consumption and imports of petroleum products also impose costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion against resulting price increases.[621]

Higher U.S. imports of crude oil or refined petroleum products increase the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above their market prices. Conversely, lowering U.S. imports of crude petroleum or refined fuels by reducing domestic fuel consumption can reduce these external costs, and any reduction in their total value that results from improved fuel economy represents an economic benefit of more stringent CAFE standards, in addition to the value of saving fuel itself.

NHTSA has carefully reviewed its assumptions regarding the appropriate value of these benefits for this final rule. In analyzing benefits from its recent actions to increase light truck CAFE standards for model years 2005–07 and 2008–11, NHTSA relied on a 1997 study by Oak Ridge National Laboratory (ORNL) to estimate the value of reduced economic externalities from petroleum consumption and imports.[622] More recently, ORNL updated its estimates of the value of these externalities, using the analytic framework developed in its original 1997 study in conjunction with recent estimates of the variables and parameters that determine their value.[623] The updated ORNL study was subjected to a detailed peer review comissioned by EPA, and ORNL's estimates of the value of oil import externalities were subsequently revised to reflect their comments and recommendations of the peer reviewers.[624] Finally, at the request of EPA, ORNL further revised its 2008 estimates of external costs from U.S. oil imports to reflect recent changes in the outlook for world petroleum prices, as well as continuing changes in the structure and characteristics of global petroleum supply and demand.

These most recent revisions increase ORNL's estimates of the "monopsony premium" associated with U.S. oil imports, which measures the increase in payments from U.S. oil purchasers to foreign oil suppliers *beyond* the increased purchase price of petroleum itself that results when increased U.S. import demand raises the world price of petroleum.[625] However, the monopsony premium represents a financial transfer from consumers of petroleum products to oil producers, which does not entail the consumption of real economic resources. Thus reducing the magnitude of the monopsony premium produces no savings in real economic resources globally or domestically, although it does reduce the value of the financial transfer from U.S. consumers of petroleum products to foreign suppliers of petroleum. Accordingly, NHTSA's analysis of the benefits from adopting proposed CAFE standards for MY 2012–2016 cars and light trucks excluded the reduced value of monopsony payments by U.S. oil consumers that might result from lower fuel consumption by these vehicles. The agency sought comment on whether it would be reasonable to include the reduction in monopsony payments by U.S. consumers of petroleum products in their estimates of total economic benefits from reducing U.S. fuel consumption.

Commenters from NYU School of Law argued that monopsony payments should be treated as a distributional effect, not a standard efficiency benefit. An individual commenter, A.G. Fraas, also supported the agencies' exclusion of the monopsony benefit, arguing that it represents a pecuniary externality that should not be considered in benefit-cost analyses of governmental actions—again, in essence, that it represents a distributional effect. These comments support the agency's decision to exclude any reduction in monopsony premium payments that results from lower U.S. petroleum imports from its accounting of benefits from reduced fuel consumption. Thus the agency continues to exclude any reduction in monopsony premium payments from its estimates of benefits for the stricter CAFE standards this final rule establishes.

ORNL's most recently revised estimates of the increase in the expected costs associated with potential disruptions in U.S. petroleum imports imply that each gallon of imported fuel or petroleum saved reduces the expected costs of oil supply disruptions to the U.S. economy by $0.169 per gallon (in 2007$). In contrast to reduced monopsony premium payments, the reduction in expected disruption costs represents a real savings in resources, and thus contributes economic benefits *in addition* to the savings in fuel production costs that result from increasing fuel economy. NHTSA employs this value in its analysis of the economic benefits from adopting higher CAFE standards for MY 2012–2016 cars and light trucks.

A.G. Fraas commented on this proposed rule and felt that that magnitude of the economic disruption portion of the energy security benefit may be too high. He cites a recent paper written by Stephen P.A. Brown and Hillard G. Huntington, entitled "Estimating U.S. Oil Security Premiums" (September 2009). He commented that the Brown and Huntington premium associated with replacing oil imports by increased domestic oil production while keeping U.S. oil consumption unchanged (*i.e.,* "the cost of displacing a barrel of domestic oil with a barrel of imported oil") ranges from $2.17 per barrel in 2015 to $2.37 per barrel in 2030 (2007$), or $0.052 to $0.056 per gallon.

In contrast, this rule is not a domestic oil supply initiative, but is one intended to reduce domestic oil consumption and thereby also to a significant extent reduce U.S. oil imports. When NHTSA

[621] See, *e.g.,* Bohi, Douglas R. and W. David Montgomery (1982). Oil Prices, Energy Security, and Import Policy Washington, DC: Resources for the Future, Johns Hopkins University Press; Bohi, D.R., and M.A. Toman (1993). "Energy and Security: Externalities and Policies," Energy Policy 21:1093–1109 (Docket NHTSA–2009–0062–24); and Toman, M.A. (1993). "The Economics of Energy Security: Theory, Evidence, Policy," in A.V. Kneese and J.L. Sweeney, eds. (1993) (Docket NHTSA–2009–0062–23). Handbook of Natural Resource and Energy Economics, Vol. III. Amsterdam: North-Holland, pp. 1167–1218.

[622] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs,* ORNL–6851, Oak Ridge National Laboratory, November 1, 1997. *Available at http://pzl1.ed.ornl.gov/ORNL6851.pdf* (last accessed March 1, 2010).

[623] Leiby, Paul N. "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," Oak Ridge National Laboratory, ORNL/TM–2007/028, Revised July 23, 2007. *Available at http://pzl1.ed.ornl.gov/energysecurity.html* (click on link below "Oil Imports Costs and Benefits") (last accessed March 1, 2010).

[624] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports,* ICF, Inc., September 2007. *Available at* Docket No. NHTSA–2009–0059–0160.

[625] The reduction in payments from U.S. oil purchasers to domestic petroleum producers is not included as a benefit, since it represents a transfer that occurs entirely within the U.S. economy.

used the ORNL Energy Security Premium Analysis to calculate the energy security premium for this rule, it based the energy security premium on decreased demand for oil and oil products. The agency estimated that most of the decreased demand for oil and oil products would come from decreased imports of oil, given the inelasticity of U.S. supply and the modest estimated change in world oil price. The Brown and Huntington estimates for this change, considering the disruption component alone, are much in line with the ORNL estimates. For a reduction in U.S. consumption that largely leads to a reduction in imports, Brown and Huntington estimate a midpoint premium of $4.98 per barrel in 2015 rising to $6.82 per barrel by 2030 (2007$). The 2015 disruption premium estimate has an uncertainty range of $1.10 to $14.35 (2007$). The corresponding 2030 estimate from ORNL is only about 19 percent higher ($8.12/bbl), with an uncertainty range—$3.90 to $13.04—completely enclosed by that of Brown and Huntington. Thus, we conclude that the ORNL disruption security premium estimates for this rule is roughly consistent with the Brown and Huntington results.

Commenters from the NYU School of Law agreed that reduced disruption costs should be counted as a benefit, but stated that the agencies should disaggregate and exclude any reduction in wealth transfers that occur during oil shocks from their calculation of this benefit. NHTSA acknowledges that for consistency with its exclusion of reductions in monopsony premium payments from the benefits of reduced fuel consumption and petroleum imports, it may be necessary to exclude reductions in the wealth transfer component of macroeconomic disruption costs from the benefits of reducing U.S. petroleum imports. In future rulemakings, the agency will assess the arguments for excluding the wealth transfer component of disruption costs from its accounting of benefits from reducing domestic fuel consumption and U.S. petroleum imports, and explore whether it is practical to estimate its value separately and exclude it from the benefits calculations.

NHTSA's analysis does not include savings in budgetary outlays to support U.S. military activities among the benefits of higher fuel economy and the resulting fuel savings.[626] NHTSA's analysis of benefits from alternative CAFE standards for MY 2012–2016 also excludes any cost savings from maintaining a smaller SPR from its estimates of the external benefits of reducing gasoline consumption and petroleum imports. This view concurs with that of the recent ORNL study of economic costs from U.S. oil imports, which concludes that savings in government outlays for these purposes are unlikely to result from reductions in consumption of petroleum products and oil imports on the scale of those resulting from higher CAFE standards.

Commenters from the NYU School of Law stated that the agencies were justified in not including a value for military security, as long as the agencies incorporate the increased protection value of the SPR into their calculation of disruption effects. CBD and James Adcock disagreed, and stated that the agencies should, in fact, include a value for military security—CBD cited several studies, and Mr. Adcock presented his own value of $0.275 per gallon. CARB stated simply that the agencies should include a sensitivity analysis for military security at $0.15 per gallon, in addition to the $0.05 per gallon already evaluated. EDF also cited studies claiming a benefit for increased national security.

In response to the comments from CBD and Mr. Adcock, NHTSA's examination of the historical record indicates that while costs for U.S. military security may vary over time in response to long-term changes in the level of oil imports into the U.S., these costs are unlikely to decline in response to the small reductions in U.S. oil imports (relative to total oil imports) that are typically projected to result from raising CAFE standards for light-duty vehicles. U.S. military activities in regions that represent vital sources of oil imports also serve a broader range of security and foreign policy objectives than simply protecting oil supplies, and as a consequence are unlikely to vary significantly in response to the modest changes in the level of oil imports likely to be prompted by higher CAFE standards.

The agency does not find evidence in the historical record that Congress or the Executive Branch has ever attempted to calibrate U.S. military expenditures, overall force levels, or specific deployments to any measure of global oil market activity or U.S. reliance on petroleum imports, or to any calculation of the projected economic consequences of hostilities arising in the Persian Gulf. Instead, changes in U.S. force levels, deployments, and thus military spending in that region have been largely governed by political events, emerging threats, and other military and political considerations, rather than by shifts in U.S. oil consumption or imports. NHTSA thus concludes that the levels of U.S. military activity and expenditures are likely to remain unaffected by even relatively large changes in light duty vehicle fuel consumption, and has continued to exclude any reduction in these outlays from its estimates of the economic benefits resulting from lower U.S. fuel consumption and petroleum imports.

In response to the comments from the NYU School of Law, NHTSA will explore how it might estimate the contribution of the SPR to reducing potential macroeconomic costs from oil supply disruptions, although the agency notes that to some extent the existence of the SPR may already be reflected in the magnitude of price elasticities of the supplies of foreign oil available for import to the U.S. However, the agency notes that the size of the SPR has not appeared to change significantly in response to historical variation in U.S. petroleum consumption or imports, suggesting that its effect on the magnitude of potential macroeconomic costs from disruptions in petroleum imports may be limited.

Finally, in response to the comment from EDF, the agency notes that the value of $0.05 per gallon for the reduction in military security outlays that is used for sensitivity analysis assumes that the *entire* reduction in U.S. petroleum imports resulting from higher CAFE standards would reflect lower imports from Persian Gulf suppliers, that the estimate of annual U.S. military costs for securing Persian Gulf oil supplies reported by Delucchi and Murphy is correct, and that Congress would reduce *half* of these outlays in proportion to any decline in U.S. oil imports from the region. The $0.15 per gallon estimate recommended by CARB would thus require that U.S. military outlays to protect Persian Gulf oil supplies are three times as large as Delucchi and Murphy estimate, or that Congress would reduce military spending in that region more than in proportion to any reduction in U.S. petroleum imports originating there. Because it views these possibilities as unrealistic, NHTSA has continued to use the $0.05 figure in its sensitivity analysis, rather than the higher figure suggested.

Based on a detailed analysis of differences in fuel consumption,

[626] However, the agency conducted a sensitivity analysis of the potential effect of assuming that some reduction military spending would result from fuel savings and reduced petroleum imports in order to investigate its impacts on the standards and fuel savings.

petroleum imports, and imports of refined petroleum products among the Reference Case, High Economic Growth, and Low Economic Growth Scenarios presented in AEO 2009, NHTSA estimated that approximately 50 percent of the reduction in fuel consumption resulting from adopting higher CAFE standards is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would reduce domestic fuel refining.[627] Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum.[628] Thus on balance, each 100 gallons of fuel saved as a consequence of higher CAFE standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 95 gallons.[629]

NHTSA employed this estimate in the analysis presented in the NPRM, and received no comments on the assumptions or data used to develop it. Hence the agency has continued to assume that each 100 gallons of fuel saved as a consequence of the CAFE standards established by this final rule will reduce total U.S. imports of crude petroleum or refined fuel by 95 gallons. NHTSA has applied the estimates of economic benefits from lower U.S. petroleum imports to the resulting estimate of reductions in imports of crude petroleum and refined fuel.

l. Air Pollutant Emissions

i. Changes in Criteria Air Pollutant Emissions

Criteria air pollutants emitted by vehicles and during fuel production include carbon monoxide (CO), hydrocarbon compounds (usually referred to as "volatile organic compounds," or VOC), nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), and sulfur oxides (SO_X). While reductions in domestic fuel refining and distribution that result from lower fuel consumption will reduce U.S. emissions of these pollutants, additional vehicle use associated with the rebound effect from higher fuel economy will increase their emissions. Thus the net effect of stricter CAFE standards on emissions of each criteria pollutant depends on the relative magnitudes of its reduced emissions in fuel refining and distribution, and increases in its emissions from vehicle use. Because the relationship between emissions in fuel refining and vehicle use is different for each criteria pollutant, the net effect of fuel savings from the proposed standards on total emissions of each pollutant is likely to differ. We note that any benefits in terms of criteria air pollutant reductions resulting from this rule would not be direct benefits.

With the exception of SO_2, NHTSA calculated annual emissions of each criteria pollutant resulting from vehicle use by multiplying its estimates of car and light truck use during each year over their expected lifetimes by per-mile emission rates appropriate to each vehicle type, fuel, model year, and age. These emission rates were developed by U.S. EPA using its Motor Vehicle Emission Simulator (MOVES 2010).[630] Emission rates for SO_2 were calculated by NHTSA using average fuel sulfur content estimates supplied by EPA, together with the assumption that the entire sulfur content of fuel is emitted in the form of SO_2.[631] Total SO_2 emissions under each alternative CAFE standard were calculated by applying the resulting emission rates directly to estimated annual gasoline and diesel fuel use by cars and light trucks.

As with other impacts, the *changes* in emissions of criteria air pollutants resulting from alternative increases in CAFE standards for MY 2012–2016 cars and light trucks were calculated from the differences between emissions under each alternative that would increase CAFE standards, and emissions under the baseline alternative.

NHTSA estimated the reductions in criteria pollutant emissions from producing and distributing fuel that would occur under alternative CAFE standards using emission rates obtained by EPA from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model.[632] The GREET model provides separate estimates of air pollutant emissions that occur in different phases of fuel production and distribution, including crude oil extraction, transportation, and storage, fuel refining, and fuel distribution and storage.[633] EPA modified the GREET model to change certain assumptions about emissions during crude petroleum extraction and transportation, as well as to update its emission rates to reflect adopted and pending EPA emission standards. NHTSA converted these emission rates from the mass per fuel energy content basis on which GREET reports them to mass per gallon of fuel supplied using estimates of fuel energy content supplied by GREET.

The resulting emission rates were applied to the agency's estimates of fuel consumption under each alternative CAFE standard to develop estimates of total emissions of each criteria pollutant during fuel production and distribution. The assumptions about the effects of *changes* in fuel consumption on domestic and imported sources of fuel supply discussed above were then employed to calculate the effects of reductions in fuel use from alternative CAFE standards on changes in imports of refined fuel and domestic refining. NHTSA's analysis assumes that reductions in imports of refined fuel would reduce criteria pollutant emissions during fuel storage and distribution only. Reductions in domestic fuel refining using imported crude oil as a feedstock are assumed to reduce emissions during fuel refining, storage, and distribution, because each of these activities would be reduced. Reduced domestic fuel refining using domestically-produced crude oil is assumed to reduce emissions during all four phases of fuel production and distribution.[634]

[627] Differences between forecast annual U.S. imports of crude petroleum and refined products among these three scenarios range from 24–89 percent of differences in projected annual gasoline and diesel fuel consumption in the U.S. These differences average 49 percent over the forecast period spanned by AEO 2009.

[628] Differences between forecast annual U.S. imports of crude petroleum among these three scenarios range from 67–97 percent of differences in total U.S. refining of crude petroleum, and average 85 percent over the forecast period spanned by AEO 2009.

[629] This figure is calculated as 50 gallons + 50 gallons*90% = 50 gallons + 45 gallons = 95 gallons.

[630] The MOVES model assumes that the per-mile rates at which these pollutants are emitted are determined by EPA regulations and the effectiveness of catalytic after-treatment of engine exhaust emissions, and are thus unaffected by changes in car and light truck fuel economy.

[631] These are 30 and 15 parts per million (ppm, measured on a mass basis) for gasoline and diesel respectively, which produces emission rates of 0.17 grams of SO_2 per gallon of gasoline and 0.10 grams per gallon of diesel.

[632] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model,* Version 1.8, June 2007, *available at http://www.transportation.anl.gov/modeling_simulation/GREET/index.html* (last accessed March 15, 2010).

[633] Emissions that occur during vehicle refueling at retail gasoline stations (primarily evaporative emissions of volatile organic compounds, or VOCs) are already accounted for in the "tailpipe" emission factors used to estimate the emissions generated by increased light truck use. GREET estimates emissions in each phase of gasoline production and distribution in mass per unit of gasoline energy content; these factors are then converted to mass per gallon of gasoline using the average energy content of gasoline.

[634] In effect, this assumes that the distances crude oil travels to U.S. refineries are approximately the same regardless of whether it travels from domestic oilfields or import terminals, and that the distances that gasoline travels from refineries to retail stations are approximately the same as those from import terminals to gasoline stations. We note that while assuming that all changes in upstream emissions result from a decrease in petroleum production and

Continued

Finally, NHTSA calculated the net changes in domestic emissions of each criteria pollutant by summing the increases in emissions projected to result from increased vehicle use, and the reductions anticipated to result from lower domestic fuel refining and distribution.[635] As indicated previously, the effect of adopting higher CAFE standards on total emissions of each criteria pollutant depends on the relative magnitudes of the resulting reduction in emissions from fuel refining and distribution, and the increase in emissions from additional vehicle use. Although these net changes vary significantly among individual criteria pollutants, the agency projects that on balance, adopting higher CAFE standards would reduce emissions of all criteria air pollutants except carbon monoxide (CO).

The net changes in domestic emissions of fine particulates ($PM_{2.5}$) and its chemical precursors (such as NO_X, SO_X, and VOCs) are converted to economic values using estimates of the reductions in health damage costs per ton of emissions of each pollutant that is avoided, which were developed and recently revised by EPA. These savings represent the estimated reductions in the value of damages to human health resulting from lower atmospheric concentrations and population exposure to air pollution that occur when emissions of each pollutant that contributes to atmospheric $PM_{2.5}$ concentrations are reduced. The value of reductions in the risk of premature death due to exposure to fine particulate pollution ($PM_{2.5}$) account for a majority of EPA's estimated values of reducing criteria pollutant emissions, although the value of avoiding other health impacts is also included in these estimates.

These values do not include a number of unquantified benefits, such as reduction in the welfare and environmental impacts of $PM_{2.5}$ pollution, or reductions in health and welfare impacts related to other criteria pollutants (ozone, NO_2, and SO_2) and air toxics. EPA estimates different PM-related per-ton values for reducing emissions from vehicle use than for reductions in emissions of that occur during fuel production and distribution.[636] NHTSA applies these separate values to its estimates of changes in emissions from vehicle use and fuel production and distribution to determine the net change in total economic damages from emissions of these pollutants.

EPA projects that the per-ton values for reducing emissions of criteria pollutants from both mobile sources (including motor vehicles) and stationary sources such as fuel refineries and storage facilities will increase over time. These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution, as well as future population growth, which increases population exposure to future levels of air pollution.

NHTSA and EPA received no comments on the procedures they employed to estimate the reductions in emissions of criteria air pollutants reported in their respective NPRMs, or on the unit economic values the agencies applied to those reductions to calculate their total value. Thus the agencies have continued to employ these procedures and values in the analysis reported in this final rule. However, the agencies have made some minor changes in the emission factors used to calculate changes in emissions resulting from increased vehicle use; these revisions are detailed in Chapter 4 of the Final Technical Support Document accompanying this rule.

ii. Reductions in CO_2 Emissions

Emissions of carbon dioxide and other greenhouse gases (GHGs) occur throughout the process of producing and distributing transportation fuels, as well as from fuel combustion itself. By reducing the volume of fuel consumed by passenger cars and light trucks, higher CAFE standards will reduce GHG emissions generated by fuel use, as well as throughout the fuel supply cycle. Lowering these emissions is likely to slow the projected pace and reduce the ultimate extent of future changes in the global climate, thus reducing future economic damages that changes in the global climate are expected to cause. By reducing the probability that climate changes with potentially catastrophic economic or environmental impacts will occur, lowering GHG emissions may also result in economic benefits that exceed the resulting reduction in the expected future economic costs caused by gradual changes in the earth's climatic systems.

Quantifying and monetizing benefits from reducing GHG emissions is thus an important step in estimating the total economic benefits likely to result from establishing higher CAFE standards. The agency estimated emissions of CO_2 from passenger car and light truck use by multiplying the number of gallons of each type of fuel (gasoline and diesel) they are projected to consume under alternative CAFE standards by the quantity or mass of CO_2 emissions released per gallon of fuel consumed. This calculation assumes that the entire carbon content of each fuel is converted to CO_2 emissions during the combustion process. Carbon dioxide emissions account for nearly 95 percent of total GHG emissions that result from fuel combustion during vehicle use.

iii. Economic Value of Reductions in CO_2 Emissions

NHTSA has taken the economic benefits of reducing CO_2 emission into account in this rulemaking, both in developing alternative CAFE standards and in assessing the economic benefits of each alternative that was considered. Since direct estimates of the economic benefits from reducing CO_2 or other GHG emissions are generally not reported in published literature on the impacts of climate change, these benefits are typically assumed to be the "mirror image" of the estimated incremental costs resulting from an increase in those emissions. Thus the benefits from reducing CO_2 emissions are usually measured by the savings in estimated economic damages that an equivalent *increase* in emissions would otherwise have caused.

The "social cost of carbon" (SCC) is intended to be a monetary measure of the incremental damage resulting from increased carbon dioxide (CO_2) emissions, including losses in agricultural productivity, the economic damages caused by adverse effects on human health, property losses and damages resulting from sea level rise, and changes in the value of ecosystem services. The SCC is usually expressed in dollars per additional metric ton of CO_2 emissions occurring during a specified year, and is higher for more distant future years because the damages caused by an additional ton of emissions increase with larger existing concentrations of CO_2 in the earth's atmosphere. Marginal reductions in CO_2 emissions that are projected to result from lower fuel consumption, refining, and distribution during each future year are multiplied by the estimated SCC appropriate for that year, which is used

transport, our analysis of downstream criteria pollutant impacts assumes no change in the composition of the gasoline fuel supply.

[635] All emissions from increased vehicle use are assumed to occur within the U.S., since CAFE standards would apply only to vehicles produced for sale in the U.S.

[636] These reflect differences in the typical geographic distributions of emissions of each pollutant, their contributions to ambient $PM_{2.5}$ concentrations, pollution levels (predominantly those of $PM_{2.5}$), and resulting changes in population exposure.

to represent the value of eliminating each ton of CO_2 emissions, to determine the total economic benefit from reduced emissions during that year. These benefits are then discounted to their present value as usual, using a discount rate that is consistent with that used to develop the estimate of the SCC itself.

The agency's NPRM incorporated the Federal interagency working group's interim guidance on appropriate SCC values for estimating economic benefits from reductions in CO_2 emissions. NHTSA specifically asked for comment on the procedures employed by the group to develop its recommended values, as well as on the reasonableness and correct interpretation of those values. Comments the agency received address several different issues, including (1) the interagency group's procedures for selecting SCC estimates to incorporate in its recommended values; (2) the appropriateness of the procedures the agency used to combine and summarize these estimates; (3) the parameter values and input assumptions used by different researchers to develop their estimates of the SCC; (4) the choice between global and domestic estimates of the SCC for use in Federal regulatory analysis, (5) the discount rates used to derive estimates of the SCC; and (6) the overall level of the agency's SCC estimates.

NHTSA's Procedures for Selecting SCC Estimates

Many of the comments NHTSA received concerned the group's procedures for selecting published estimates and aggregating them to arrive at its range of recommended values. CARB asked for a clearer explanation of why mean SCC estimates from only two of the three major climate models were included in the average values reported in the interim guidance, and whether the arithmetic mean of reported values is the appropriate measure of their central tendency. Students from the University of California at Santa Barbara (UCSB) noted that the interagency group often selected only a single SCC estimate from studies reporting multiple estimates or a range of values to include in developing its summary values, and objected that this procedure caused the group to understate the degree of uncertainty surrounding its recommended values.

Steven Rose also noted that the interagency group's "filtering" of published estimates of the SCC on the basis of their vintage and input assumptions tended to restrict the included estimates to a relatively narrow band that excluded most potentially catastrophic climate changes, and thus was not representative of the wide uncertainty surrounding the "true" SCC. If the purpose of incorporating the SCC into regulatory analysis was effectively to price CO_2 emissions so that emitters would account for climate damages caused by their actions, he reasoned, then the estimate to be used should incorporate the wide range of uncertainty surrounding the magnitude of potential damages.

Rose also noted that many of the more recent studies reporting estimates of the SCC were designed to explore the influence of different factors on the extent and timing of climate damages, rather than to estimate the SCC specifically, and thus that these more recent estimates were not necessarily more informative than SCC estimates reported in some older studies. Rose argued that because there has been little change in major climate models since about 2001, all estimates published after that date should be considered in order to expand the size of the sample represented by average values, rather than limiting it by including only the most recently-reported estimates.

James Adcock objected to the interagency group's reliance on Tol's survey of published estimates of the SCC, since many of the estimates it included were developed by Tol himself. In contrast, Steven Rose argued that the Tol survey offered a useful way to summarize and represent variation among published estimates of the SCC, and thus to indicate the uncertainty surrounding its true value.

Procedures for Summarizing Published SCC Estimates

Steven Rose argued that combining SCC estimates generated using different discount rates was inappropriate, and urged the interagency group instead to select one or more discount rates and then to average only SCC estimates developed using the same discount rate. Rose also noted that the interagency group's explanation of how it applied the procedure developed by Newell and Pizer to incorporate uncertainty in the discount rate was inadequately detailed, and in any case it may not be appropriate for use in combining SCC estimates that were based on different discount rates. UCS also questioned NHTSA's use of averaging to combine estimates of the SCC relying on different discount rates, as well as the agency's equal weighting of upper- and lower-bound SCC estimates reported in published studies.

NESCAUM commented that the interagency group's basis for deriving the $20 SCC estimate from its summary of published values was not adequately clear, and that the group's guidance should clarify the origin of this value. NESCAUM also urged the interagency group to identify a representative range of alternative SCC estimates for use in assessing benefits from reduced emissions, rather than a single value.

Ford commented that the interagency group's methodology for developing an estimate of the SCC was acceptable, but argued that NHTSA agency should rely on the costs of reducing CO_2 emissions in other sectors of the U.S. economy to evaluate economic benefits from reducing motor vehicle emission. Ford asserted that this represented a more reliable estimate of the benefits from reducing emissions than the potential climate damages avoided by reducing vehicle emissions, since lowering vehicle emissions reduces the need to control emissions from other economic sectors.

Parameter Values and Input Assumptions Underlying SCC Estimates

CARB also noted that some of the wide variation in published SCC estimates relied upon by the interagency group could be attributed to authors' differing assumptions about future GHG emissions scenarios and choices of discount rates. Steven Rose noted that SCC estimates derived using future emissions scenarios that assumed significant reductions in emissions were probably inappropriate for use in Federal regulatory analysis, since Federal regulations must be adopted individually and are each likely to lead to only marginal reductions in emissions, so it is unreasonable to assume that their collective effect on future emissions will be large.

CARB also emphasized that SCC estimates were not available over the same range of discount rates for all major climate models, thus making averages of available results less reliable as indicators of any central tendency in estimates of the SCC. To remedy this shortcoming, the Pew Center on Climate Change urged the interagency group to analyze the sensitivity of SCC estimates to systematic variation in uncertain model parameters and input scenarios as a means of identifying the range of uncertainty in the SCC itself, as well as to include a risk premium in its SCC estimates as a means of compensating for climate models' omission of potential economic damages from catastrophic climate changes.

CBD commented that the interim nature of the interagency group's guidance made it impossible for decision-makers to determine whether the agency's proposed CAFE standards were sufficiently stringent. CBD also argued that economic models' exclusion of some potential climate impacts caused them to underestimate the "true" SCC, and that the interagency group's procedure of averaging published estimates failed to convey important information about variation in estimates of the SCC to decision makers. In a related comment, the Pew Center on Climate Change cautioned against use of the interagency group's interim SCC estimates for analyzing benefits from NHTSA's final rule, on the grounds that some older estimates of the SCC surveyed for the interim guidance implausibly suggested that there could be positive net benefits from climate change, while more recent research suggests uniformly negative economic impacts.

James Adcock presented his own estimate of the value of reducing CO_2 emissions, which he derived by assuming that climate change would completely eliminate the economic value of all services provided by the local natural environment within a 50-year time frame. In addition, Adcock urged that Federal agencies use a consistent estimate of the SCC in their regulatory analyses, and that this estimate be updated regularly to reflect new knowledge; he also asserted that the SCC should be above the per-ton price of CO_2 emissions permits under a cap-and-trade system.

Global vs. Domestic SCC Values

NADA argued that NHTSA should employ an estimate of the domestic value of reducing CO_2 emissions for purposes of estimating their aggregate economic benefits, since the agency includes only the domestic value of benefits stemming from reductions in other environmental and energy security externalities. In contrast, both the Pew Center on Climate Change and students from the University of California at Santa Barbara (UCSB) asserted that a global value of the SCC was appropriate for use even in analyzing benefits from U.S. domestic environmental regulations such as CAFE, and Steven Rose added that it was difficult to identify any proper role for a domestic estimate of the SCC. James Adcock commented that the agency's derivation of the fraction of the global SCC it employed (6 percent) to obtain a domestic value was not clearly explained.

Discount Rates Used To Derive SCC Estimates

NRDC also cited the effect of positive discount rates on damages occurring in the distant future, which reduce the present value of those damages to misleadingly low levels. Similarly, Steven Rose argued that the interagency group should have used discount rates below the 3 percent lower bound the group selected, and that the discount rate should also have been allowed to vary over time to account for uncertainty in its true value. The Pew Center also urged NHTSA to account explicitly for uncertainty surrounding the correct discount rate, but did not indicate how the agency should do so.

CARB echoed the recommendation for including SCC values reflecting discount rates below 3 percent, since EPA had previously used lower rates in previously proposed rules to discount benefits that were not expected to occur until the distant future, and thus to be experienced mainly by future generations. The New Jersey Department of Environmental Protection noted that giving nearly equal weight to future generations would imply a discount rate of less than 3 percent—probably in the neighborhood of 2 percent—and endorsed the interagency group's use of the procedure developed by Newell and Pizer to account for uncertainty surrounding the correct discount rate.

The Pew Center urged the agency to ignore SCC estimates derived using discount rates above 5 percent, and instead to use the lowest possible rates, even including the possibility of negative values. Similarly, NRDC asserted that both the 3 percent and 5 percent discount rates selected by the interagency group are inappropriately high, but did not recommend a specific alternative rate. Students from UCSB observed that the interagency group's equal weighting of the 3 percent and 5 percent rates appeared to be inconsistent with the more frequent use of 3 percent in published estimates of the SCC, as well as with OMB's guidance that the 3 percent rate was appropriate for discounting future impacts on consumption. The group urged NHTSA to consider a wider range of discount rates in its revised estimates of the SCC, including some below 3 percent. CBD argued that the discount rate should increase over the future to reflect the potential for catastrophic climate impacts.

CBD asserted that because the potential consequences of climate change are so extreme, that future economic impacts of climate change should not be discounted (*i.e.,* a 0 percent discount rate should be used). James Adcock echoed this view.

Overall Level of SCC Estimates

NRDC argued that the SCC estimate recommended by the interagency group was likely to be too low, because of most models' omission of some important climate impacts, particularly including potential catastrophic impacts resulting from non-incremental changes in climate conditions. CARB argued that it seemed prudent to include SCC values as high as $200 per ton, to reflect the possibility of low-probability but catastrophic changes in the global climate and the resulting economic damages.

The New Jersey Department of Environmental Protection pointed out that SCC estimates reviewed by the IPCC ranged as high as $95/ton, and that the Stern Report's estimate was $85/ton, suggesting the possibility that the interagency group may have inappropriately filtered out the highest estimates of the SCC. Other commenters including NACAA, NESCAUM, NRDC, and UCS urged NHTSA to employ higher SCC values than it used in the NPRM analysis, but did not recommend specific values. CARB urged the agency to use higher values of the SCC than it employed in its NPRM analysis, and recommended a value of $25/ton, growing at 2.4 percent annually, or alternatively, a fixed value of $50/ton.

Steven Rose cautioned against applying a uniform 3 percent annual growth rate to all of the provisional SCC estimates recommended by the interagency group, and noted that the base year where such growth is assumed to begin should be determined carefully for each estimate.

Finally, the Institute for Energy Research commented that NHTSA had probably overstated the reductions in CO_2 emissions that would result from the proposed standards—and thus their economic value—because of the potential for compensating increases in emissions, such as those cause by increased retention and use of older, less fuel-efficient vehicles in the fleet.

After carefully considering comments received to the NPRM, for purposes of this final rule, NHTSA has relied on estimates of the SCC developed by the Federal interagency working group convened for the specific purpose of developing new estimates to be used by U.S. Federal agencies in regulatory evaluations. Under Executive Order 12866, Federal agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The group's purpose in developing new estimates of the SCC was to allow

Federal agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions, as most Federal regulatory actions can be expected to have.

The interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process included the Environmental Protection Agency and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group developed its estimates of the SCC estimates while clearly acknowledging the many uncertainties involved, and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literature. In this way, key uncertainties and model differences transparently and consistently can inform the range of SCC estimates used in the rulemaking process.

The group ultimately selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, using discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent the possibility of higher-than-expected impacts from temperature change that lie further out in the tails of the distribution of SCC estimates. Table IV.C.3–2 summarizes the interagency group’s estimates of the SCC during various future years. The SCC estimates reported in the table assume that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

TABLE IV.C.3–2—SOCIAL COST OF CO_2 EMISSIONS, 2010–2050

[2007 dollars]

Discount rate	5%	3%	2.5%	3%
Source	Average of estimates			95th Percentile estimate
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

As Table IV.C.3–2 shows, the four SCC estimates selected by the interagency group for use in regulatory analyses are $5, $21, $35, and $65 (in 2007 dollars) for emissions occurring in the year 2010. The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, the group elected to use the SCC value for the 95th percentile at a 3 percent discount rate.

The central value identified by the interagency group is the average SCC across models at the 3 percent discount rate, or $21 per metric ton in 2010. To capture the uncertainties involved in regulatory impact analysis, however, the group emphasized the importance of considering the full range of estimated SCC values. As the table also shows, the SCC estimates also rise over time; for example, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

The interagency group is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, the group has set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. U.S. Federal agencies will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

Details of the process used by the interagency group to develop its SCC estimates, complete results including year-by-year estimates of each of the four values, and a thorough discussion of their intended use and limitations is provided in the document *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.[637]

[637] This document is available in the docket for this rulemaking (NHTSA–2009–0059).

m. Discounting Future Benefits and Costs

Discounting future fuel savings and other benefits is intended to account for the reduction in their value to society when they are deferred until some future date, rather than received immediately. The discount rate expresses the percent decline in the value of these benefits—as viewed from today's perspective—for each year they are deferred into the future. In evaluating the benefits from alternative proposed increases in CAFE standards for MY 2012–2016 passenger cars and light trucks, NHTSA employed a discount rate of 3 percent per year, but also presents these benefit and cost estimates at a 7 percent discount rate.

While both discount rates are presented, NHTSA believes that 3 percent is the most appropriate rate for discounting future benefits from increased CAFE standards because most or all of vehicle manufacturers' costs for complying with higher CAFE standards will ultimately be reflected in higher sales prices for their new vehicle models. By increasing sales prices for new cars and light trucks, CAFE regulations will thus primarily affect vehicle purchases and other private consumption decisions. Both economic theory and OMB guidance on discounting indicate that the future benefits and costs of regulations that mainly affect private consumption should be discounted at consumers' rate of time preference.[638]

OMB guidance also indicates that savers appear to discount future consumption at an average real (that is, adjusted to remove the effect of inflation) rate of about 3 percent when they face little risk about its likely level. Since the real rate that savers use to discount future consumption represents a reasonable estimate of consumers' rate of time preference, NHTSA believes that the 3 percent rate to discount projected future benefits and costs resulting from higher CAFE standards for MY 2012–2016 passenger cars and light trucks is more appropriate than 7 percent, but presents both.[639] One commenter, NRDC, supported the agencies' use of a 3 percent discount rate as consistent with DOE practice in energy efficiency-related rulemakings and OMB guidance. OMB guidance actually requires that benefits and costs be presented at both a 3 and a 7 percent discount rate.

Because there is some remaining uncertainty about whether vehicle manufacturers will completely recover their costs for complying with higher CAFE standards by increasing vehicle sales prices, however, NHTSA also presents these benefit and cost estimates using a higher discount rate. OMB guidance indicates that the real economy-wide opportunity cost of capital is the appropriate discount rate to apply to future benefits and costs when the primary effect of a regulation is "* * * to displace or alter the use of capital in the private sector," and OMB estimates that this rate currently averages about 7 percent.[640] Thus the agency has also examined its benefit and cost estimates for alternative MY 2012–2016 CAFE standards using a 7 percent real discount rate.

In its proposed rule, NHTSA sought comment on whether it should evaluate CAFE standards using a discount rate of 3 percent, 7 percent, or an alternative value. NRDC not only opposed the agency's use of a 7 percent discount rate, but also opposed conducting even sensitivity analyses with discount rates higher than 3 percent. In contrast, two other commenters, NADA and the Institute for Energy Research, advised that the agencies should use discount rates of 7 percent or higher. NADA argued that the most appropriate discount rate would be one closer to historical financing rates on motor vehicle loans (which currently average about 6.5 percent), while the Institute for Energy Research argued that consumers may have much higher discount rates than the agencies assumed, perhaps even as high as 25 percent.

After carefully considering these comments, NHTSA has elected to use discount rates of both 3 and 7 percent in the analysis supporting this final rule. As indicated above, the agency believes that vehicle manufacturers will recover most or all of their added costs for complying with the CAFE standards this rule establishes by raising sales prices for some or all vehicle models. As a consequence, this regulation will thus primarily affect vehicle purchases and related consumption decisions, which suggests that its future benefits and costs should be discounted at the rate of time preference vehicle buyers reveal in their consumption and savings behavior. OMB's 3 percent figure appears to be a conservative (*i.e.,* low) estimate of this rate, because it assumes in effect that vehicle buyers face little risk about the value of future fuel savings and other benefits from the rule; nevertheless, in the current economic environment it appears to represent a reasonable estimate of consumers' rate of time preference. Thus NHTSA has mainly relied upon the 3 percent rate to discount projected future benefits and costs resulting from higher CAFE standards for MY 2012–2016 passenger cars and light trucks

One important exception to the 3 percent discount rate is the rates used to discount benefits from reducing CO_2 emissions from the years in which reduced emissions occur, which span the lifetimes of MY 2012–2016 cars and light trucks, to their present values. In order to ensure consistency in the derivation and use of the interagency group's estimates of the unit values of reducing CO_2 emissions, the benefits from reducing those emissions during each future year are discounted using the same "intergenerational" discount rates that were used to derive each of the alternative unit values of reducing CO_2 emissions. As indicate in Table IV.C.3–2 above, these rates are 2.5 percent, 3 percent, and 5 percent depending on which estimate of the SCC is being considered.[641]

n. Accounting for Uncertainty in Benefits and Costs

In analyzing the uncertainty surrounding its estimates of benefits and costs from alternative CAFE standards, NHTSA has considered alternative estimates of those assumptions and parameters likely to have the largest effect. These include the projected costs of fuel economy-improving technologies and their expected effectiveness in reducing vehicle fuel consumption, forecasts of future fuel prices, the magnitude of the rebound effect, the reduction in external economic costs resulting from lower U.S. oil imports, and the discount rate applied to future benefits and costs. The range for each of these variables employed in the uncertainty analysis is presented in the section of this notice discussing each variable.

The uncertainty analysis was conducted by assuming independent normal probability distributions for each of these variables, using the low and high estimates for each variable as the values below which 5 percent and

[638] *Id.*

[639] Office of Management and Budget, Circular A–4, "Regulatory Analysis," September 17, 2003, 33. *Available at http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf* (last accessed August 9, 2009).

[640] *Id.*

[641] The fact that the 3 percent discount rate used by the interagency group to derive its central estimate of the SCC is identical to the 3 percent short-term or "intra-generational" discount rate used by NHTSA to discount future benefits other than reductions in CO_2 emissions is coincidental, and should not be interpreted as a required condition that must be satisfied in future rulemakings.

95 percent of observed values are believed to fall. Each trial of the uncertainty analysis employed a set of values randomly drawn from each of these probability distributions, assuming that the value of each variable is independent of the others. Benefits and costs of each alternative standard were estimated using each combination of variables. A total of 1,000 trials were used to establish the likely probability distributions of estimated benefits and costs for each alternative standard.

o. Where can readers find more information about the economic assumptions?

Much more detailed information is provided in Chapter VIII of the FRIA, and a discussion of how NHTSA and EPA jointly reviewed and updated economic assumptions for purposes of this final rule is available in Chapter 4 of the Joint TSD. In addition, all of NHTSA's model input and output files are now public and available for the reader's review and consideration. The economic input files can be found in the docket for this final rule, NHTSA–2009–0059, and on NHTSA's Web site.[642] Finally, because much of NHTSA's economic analysis for purposes of this final rule builds on the work that was done for the MY 2011 final rule, we refer readers to that document as well for background information concerning how NHTSA's assumptions regarding economic inputs for CAFE analysis have evolved over the past several rulemakings, both in response to comments and as a result of the agency's growing experience with this type of analysis.[643]

4. How does NHTSA use the assumptions in its modeling analysis?

In developing today's final CAFE standards, NHTSA has made significant use of results produced by the CAFE Compliance and Effects Model (commonly referred to as "the CAFE model" or "the Volpe model"), which DOT's Volpe National Transportation Systems Center developed specifically to support NHTSA's CAFE rulemakings. The model, which has been constructed specifically for the purpose of analyzing potential CAFE standards, integrates the following core capabilities:

(1) Estimating how manufacturers could apply technologies in response to new fuel economy standards,

(2) Estimating the costs that would be incurred in applying these technologies,

(3) Estimating the physical effects resulting from the application of these technologies, such as changes in travel demand, fuel consumption, and emissions of carbon dioxide and criteria pollutants, and

(4) Estimating the monetized societal benefits of these physical effects.

An overview of the model follows below. Separate model documentation provides a detailed explanation of the functions the model performs, the calculations it performs in doing so, and how to install the model, construct inputs to the model, and interpret the model's outputs. Documentation of the model, along with model installation files, source code, and sample inputs are available at NHTSA's Web site. The model documentation is also available in the docket for today's final rule, as are inputs for and outputs from analysis of today's final CAFE standards.

a. How does the model operate?

As discussed above, the agency uses the Volpe model to estimate how manufacturers could attempt to comply with a given CAFE standard by adding technology to fleets that the agency anticipates they will produce in future model years. This exercise constitutes a simulation of manufacturers' decisions regarding compliance with CAFE standards.

This compliance simulation begins with the following inputs: (a) The baseline and reference market forecast discussed above in Section IV.C.1 and Chapter 1 of the TSD, (b) technology-related estimates discussed above in Section IV.C.2 and Chapter 3 of the TSD, (c) economic inputs discussed above in Section IV.C.3 and Chapter 4 of the TSD, and (d) inputs defining baseline and potential new CAFE standards. For each manufacturer, the model applies technologies in a sequence that follows a defined engineering logic ("decision trees" discussed in the MY 2011 final rule and in the model documentation) and a cost-minimizing strategy in order to identify a set of technologies the manufacturer could apply in response to new CAFE standards.[644] The model applies technologies to each of the projected individual vehicles in a manufacturer's fleet, until one of three things occurs:

(1) The manufacturer's fleet achieves compliance with the applicable standard;

(2) The manufacturer "exhausts"[645] available technologies; or

(3) For manufacturers estimated to be willing to pay civil penalties, the manufacturer reaches the point at which doing so would be more cost-effective (from the manufacturer's perspective) than adding further technology.[646]

As discussed below, the model has also been modified in order to apply additional technology in early model years if doing so will facilitate compliance in later model years. This is designed to simulate a manufacturer's decision to plan for CAFE obligations several years in advance, which NHTSA believes better replicates manufacturers' actual behavior as compared to the year-by-year evaluation which EPCA would otherwise require.

The model accounts explicitly for each model year, applying most technologies when vehicles are scheduled to be redesigned or freshened, and carrying forward technologies between model years. The CAFE model accounts explicitly for each model year because EPCA requires that NHTSA make a year-by-year determination of the appropriate level of stringency and then set the standard at

[642] *See http://www.nhtsa.dot.gov* (click on "Fuel Economy Standards (CAFE)," click on "Related Links: CAFE Compliance and Effects Modeling System: The Volpe Model").

[643] 74 FR 14308–14358 (Mar. 30, 2009).

[644] NHTSA does its best to remain scrupulously neutral in the application of technologies through the modeling analysis, to avoid picking technology "winners." The technology application methodology has been reviewed by the agency over the course of several rulemakings, and commenters have been generally supportive of the agency's approach. See, *e.g.,* 74 FR 14238–14246 (Mar. 30, 2009).

[645] In a given model year, the model makes additional technologies available to each vehicle model within several constraints, including (a) whether or not the technology is applicable to the vehicle model's technology class, (b) whether the vehicle is undergoing a redesign or freshening in the given model year, (c) whether engineering aspects of the vehicle make the technology unavailable (*e.g.,* secondary axle disconnect cannot be applied to two-wheel drive vehicles), and (d) whether technology application remains within "phase in caps" constraining the overall share of a manufacturer's fleet to which the technology can be added in a given model year. Once enough technology is added to a given manufacturer's fleet in a given model year that these constraints make further technology application unavailable, technologies are "exhausted" for that manufacturer in that model year.

[646] This possibility was added to the model to account for the fact that under EPCA/EISA, manufacturers must pay fines if they do not achieve compliance with applicable CAFE standards. 49 U.S.C. 32912(b). NHTSA recognizes that some manufacturers will find it more cost-effective to pay fines than to achieve compliance, and believes that to assume these manufacturers would exhaust available technologies before paying fines would cause unrealistically high estimates of market penetration of expensive technologies such as diesel engines and strong hybrid electric vehicles, as well as correspondingly inflated estimates of both the costs and benefits of any potential CAFE standards. NHTSA thus includes the possibility of manufacturers choosing to pay fines in its modeling analysis in order to achieve what the agency believes is a more realistic simulation of manufacturer decision-making. Unlike flex-fuel and other credits, NHTSA is not barred by statute from considering fine-payment in determining maximum feasible standards under EPCA/EISA. 49 U.S.C. 32902(h).

that level, while ensuring ratable increases in average fuel economy.[647] The multi-year planning capability mentioned above increases the model's ability to simulate manufacturers' real-world behavior, accounting for the fact that manufacturers will seek out compliance paths for several model years at a time, while accommodating the year-by-year requirement.

The model also calculates the costs, effects, and benefits of technologies that it estimates could be added in response to a given CAFE standard.[648] It calculates costs by applying the cost estimation techniques discussed above in Section IV.C.2, and by accounting for the number of affected vehicles. It accounts for effects such as changes in vehicle travel, changes in fuel consumption, and changes in greenhouse gas and criteria pollutant emissions. It does so by applying the fuel consumption estimation techniques also discussed in Section IV.C.2, and the vehicle survival and mileage accumulation forecasts, the rebound effect estimate and the fuel properties and emission factors discussed in Section IV.C.3. Considering changes in travel demand and fuel consumption, the model estimates the monetized value of accompanying benefits to society, as discussed in Section IV.C.3. The model calculates both the undiscounted and discounted value of benefits that accrue over time in the future.

The Volpe model has other capabilities that facilitate the development of a CAFE standard. It can be used to fit a mathematical function forming the basis for an attribute-based CAFE standard, following the steps described below. It can also be used to evaluate many (*e.g.,* 200 per model year) potential levels of stringency sequentially, and identify the stringency at which specific criteria are met. For example, it can identify the stringency at which net benefits to society are maximized, the stringency at which a specified total cost is reached, or the stringency at which a given average required fuel economy level is attained. This allows the agency to compare more easily the impacts in terms of fuel savings, emissions reductions, and costs and benefits of achieving different levels of stringency according to different criteria. The model can also be used to perform uncertainty analysis (*i.e.,* Monte Carlo simulation), in which input estimates are varied randomly according to specified probability distributions, such that the uncertainty of key measures (*e.g.,* fuel consumption, costs, benefits) can be evaluated.

b. Has NHTSA considered other models?

Nothing in EPCA requires NHTSA to use the Volpe model. In principle, NHTSA could perform all of these tasks through other means. For example, in developing today's final standards, the agency did not use the Volpe model's curve fitting routines; rather, as discussed above in Section II, the agency fitted curves outside the model (as for the NPRM) but elected to retain the curve shapes defining the proposed standards. In general, though, these model capabilities have greatly increased the agency's ability to rapidly, systematically, and reproducibly conduct key analyses relevant to the formulation and evaluation of new CAFE standards.

During its previous rulemaking, which led to the final MY 2011 standards promulgated earlier this year, NHTSA received comments from the Alliance and CARB encouraging NHTSA to examine the usefulness of other models. As discussed in that final rule, NHTSA, having undertaken such consideration, concluded that the Volpe model is a sound and reliable tool for the development and evaluation of potential CAFE standards.[649] Also, although some observers have criticized analyses the agency has conducted using the Volpe model, those criticisms have largely concerned inputs to the model (such as fuel prices and the estimated economic cost of CO_2 emissions), not the model itself. In comments on the NPRM preceding today's final rule, one of these observers, the Center for Biological Diversity (CBD), suggested that the revisions to such inputs have produced an unbiased cost-benefit analysis.

One commenter, the International Council on Clean Transportation (ICCT) suggested that the Volpe model is excessively complex and insufficiently transparent. However, in NHTSA's view, the complexity of the Volpe model has evolved in response to the complex analytical demands surrounding very significant regulations impacting a large and important sector of the economy, and ICCT's own comments illustrate some of the potential pitfalls of model simplification. Furthermore, ICCT's assertions regarding model transparency relate to the use of confidential business information, not to the Volpe model itself; as discussed elsewhere in this final rule, NHTSA and the Volpe Center have taken pains to make the Volpe model transparent by releasing the model and supporting documentation, along with the underlying source code and accompanying model inputs and outputs. Therefore, the agency disagrees with these ICCT comments.

In reconsidering and reaffirming this conclusion for purposes of this NPRM, NHTSA notes that the Volpe model not only has been formally peer-reviewed and tested through three rulemakings, but also has some features especially important for the analysis of CAFE standards under EPCA/EISA. Among these are the ability to perform year-by-year analysis, and the ability to account for engineering differences between specific vehicle models.

EPCA requires that NHTSA set CAFE standards for each model year at the level that would be "maximum feasible" for that year.[650] Doing so requires the ability to analyze each model year and, when developing regulations covering multiple model years, to account for the interdependency of model years in terms of the appropriate levels of stringency for each one. Also, as part of the evaluation of the economic practicability of the standards, as required by EPCA, NHTSA has traditionally assessed the annual costs and benefits of the standards. The first (2002) version of DOT's model treated each model year separately, and did not perform this type of explicit accounting. Manufacturers took strong exception to these shortcomings. For example, GM commented in 2002 that "although the table suggests that the proposed standard for MY 2007, considered in isolation, promises benefits exceeding costs, that anomalous outcome is merely an artifact of the peculiar Volpe methodology, which treats each year independently of any other * * *" In 2002, GM also criticized DOT's analysis for, in some cases, adding a technology in MY 2006 and then replacing it with another technology in MY 2007. GM

[647] 49 U.S.C. 32902(a) states that at least 18 months before the beginning of each model year, the Secretary of Transportation shall prescribe by regulation average fuel economy standards for automobiles manufactured by a manufacturer in that model year, and that each standard shall be the maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that year. NHTSA has long interpreted this statutory language to require year-by-year assessment of manufacturer capabilities. 49 U.S.C. 32902(b)(2)(C) also requires that standards increase ratably between MY 2011 and MY 2020.

[648] As for all of its other rulemakings, NHTSA is required by Executive Order 12866 and DOT regulations to analyze the costs and benefits of CAFE standards. Executive Order 12866, 58 FR 51735 (Oct. 4, 1993); DOT Order 2100.5, "Regulatory Policies and Procedures," 1979, *available at http://regs.dot.gov/rulemakingrequirements.htm* (last accessed February 21, 2010).

[649] 74 FR 14372 (Mar. 30, 2009).

[650] 49 U.S.C. 32902(a).

(and other manufacturers) argued that this completely failed to represent true manufacturer product-development cycles, and therefore could not be technologically feasible or economically practicable.

In response to these concerns, and to related concerns expressed by other manufacturers, DOT modified the CAFE model in order to account for dependencies between model years and to better represent manufacturers' planning cycles, in a way that still allowed NHTSA to comply with the statutory requirement to determine the appropriate level of the standards for each model year. This was accomplished by limiting the application of many technologies to model years in which vehicle models are scheduled to be redesigned (or, for some technologies, "freshened"), and by causing the model to "carry forward" applied technologies from one model year to the next.

During the recent rulemaking for MY 2011 passenger cars and light trucks, DOT further modified the CAFE model to account for cost reductions attributable to "learning effects" related to volume (*i.e.,* economies of scale) and the passage of time (*i.e.,* time-based learning), both of which evolve on year-by-year basis. These changes were implemented in response to comments by environmental groups and other stakeholders.

The Volpe model is also able to account for important engineering differences between specific vehicle models, and to thereby reduce the risk of applying technologies that may be incompatible with or already present on a given vehicle model. Some commenters have previously suggested that manufacturers are most likely to broadly apply generic technology "packages," and the Volpe model does tend to form "packages" dynamically, based on vehicle characteristics, redesign schedules, and schedules for increases in CAFE standards. For example, under the final CAFE standards for passenger cars, the CAFE model estimated that manufacturers could apply turbocharged SGDI engines mated with dual-clutch AMTs to 2.4 million passenger cars in MY 2016, about 22 percent of the MY 2016 passenger car fleet. Recent modifications to the model, discussed below, to represent multi-year planning, increase the model's tendency to add relatively cost-effective technologies when vehicles are estimated to be redesigned, and thereby increase the model's tendency to form such packages.

On the other hand, some manufacturers have indicated that especially when faced with significant progressive increases in the stringency of new CAFE standards, they are likely to also look for narrower opportunities to apply specific technologies. By progressively applying specific technologies to specific vehicle models, the CAFE model also produces such outcomes. For example, under the final CAFE standards for passenger cars, the CAFE model estimated that in MY 2012, some manufacturers could find it advantageous to apply SIDI to some vehicle models without also adding turbochargers.

By following this approach of combining technologies incrementally and on a model-by-model basis, the CAFE model is able to account for important engineering differences between vehicle models and avoid unlikely technology combinations. For example, the model does not apply dual-clutch AMTs (or strong hybrid systems) to vehicle models with 6-speed manual transmissions. Some vehicle buyers prefer a manual transmission; this preference cannot be assumed away. The model's accounting for manual transmissions is also important for vehicles with larger engines: For example, cylinder deactivation cannot be applied to vehicles with manual transmissions because there is no reliable means of predicting when the driver will change gears. By retaining cylinder deactivation as a specific technology rather than part of a pre-determined package and by retaining differentiation between vehicles with different transmissions, DOT's model is able to target cylinder deactivation only to vehicle models for which it is technologically feasible.

The Volpe model also produces a single vehicle-level output file that, for each vehicle model, shows which technologies were present at the outset of modeling, which technologies were superseded by other technologies, and which technologies were ultimately present at the conclusion of modeling. For each vehicle, the same file shows resultant changes in vehicle weight, fuel economy, and cost. This provides for efficient identification, analysis, and correction of errors, a task with which the public can now assist the agency, since all inputs and outputs are public.

Such considerations, as well as those related to the efficiency with which the Volpe model is able to analyze attribute-based CAFE standards and changes in vehicle classification, and to perform higher-level analysis such as stringency estimation (to meet predetermined criteria), sensitivity analysis, and uncertainty analysis, lead the agency to conclude that the model remains the best available to the agency for the purposes of analyzing potential new CAFE standards.

c. What changes has DOT made to the model?

As discussed in the NPRM preceding today's final rule, the Volpe model has been revised to make some minor improvements, and to add one significant new capability: The ability to simulate manufacturers' ability to engage in "multi-year planning." Multi-year planning refers to the fact that when redesigning or freshening vehicles, manufacturers can anticipate future fuel economy or CO_2 standards, and add technologies accounting for these standards. For example, a manufacturer might choose to over-comply in a given model year when many vehicle models are scheduled for redesign, in order to facilitate compliance in a later model year when standards will be more stringent yet few vehicle models are scheduled for redesign.[651] Prior comments have indicated that the Volpe model, by not representing such manufacturer choices, tended to overestimate compliance costs. However, because of the technical complexity involved in representing these choices when, as in the Volpe model, each model year is accounted for separately and explicitly, the model could not be modified to add this capability prior to the statutory deadline for the MY 2011 final standards.

The model now includes this capability, and NHTSA has applied it in conducting analysis to support the NPRM and in analyzing the standards finalized today. Consequently, this new capability often produces results indicating that manufacturers could over-comply in some model years (with corresponding increases in costs and benefits in those model years) and thereby "carry forward" technology into later model years in order to reduce compliance costs in those later model years. NHTSA believes this better represents how manufacturers would actually respond to new CAFE standards, and thereby produces more realistic estimates of the costs and benefits of such standards.

The Volpe model has also been modified to accommodate inputs specifying the amount of CAFE credit to be applied to each manufacturer's fleet.

[651] Although a manufacturer may, in addition, generate CAFE credits in early model years for use in later model years (or, less likely, in later years for use in early years), EPCA does not allow NHTSA, when setting CAFE standards, to account for manufacturers' use of CAFE credits.

Although the model is not currently capable of estimating manufacturers' decisions regarding the generation and use of CAFE credits, and EPCA does not allow NHTSA, in setting CAFE standards, to take into account manufacturers' potential use of credits, this additional capability in the Volpe model provides a basis for more accurately estimating costs, effects, and benefits that may actually result from new CAFE standards. Insofar as some manufacturers actually do earn and use CAFE credits, this provides NHTSA with some ability to examine outcomes more realistically than EPCA allows for purposes of setting new CAFE standards.

In comments on recent NHTSA rulemakings, some reviewers have suggested that the Volpe model should be modified to estimate the extent to which new CAFE standards would induce changes in the mix of vehicles in the new vehicle fleet. NHTSA, like EPA, agrees that a "market shift" model, also called a consumer vehicle choice model, could provide useful information regarding the possible effects of potential new CAFE standards. An earlier experimental version of the Volpe model included a multinomial logit model that estimated changes in sales resulting from CAFE-induced increases in new vehicle fuel economy and prices. A fuller description of this attempt can be found in Section V of the FRIA. However, NHTSA has thus far been unable to develop credible coefficients specifying such a model. In addition, as discussed in Section II.H.4, such a model is sensitive to the coefficients used in it, and there is great variation over some key values of these coefficients in published studies.

In the NPRM preceding today's final rule, NHTSA sought comment on ways to improve on this earlier work and develop this capability effectively. Some comments implied that the agency should continue work to do so, without providing specific recommendations. The Alliance of Automobile Manufacturers identified consumer choice as one of several factors outside the industry's control yet influential with respect to the agencies' analysis. Also, the University of Pennsylvania Environmental Law Project suggested that the rule would change consumers' vehicle purchasing decisions, and the California Air Resources Board expressed support for continued consideration of consumer choice modeling. On the other hand, citing concerns regarding model calibration, handling of advanced technologies, and applicability to the future light vehicle market, ACEEE, ICCT, UCS, and NRDC all expressed opposition to the possibility of using consumer choice models in estimating the costs and benefits of new standards. Notwithstanding comments on this issue, NHTSA has been unable to further develop this capability in time to include it in the analysis supporting decisions regarding final CAFE standards. The agency will, however, continue efforts to develop and make use of this capability in future rulemakings, taking into account comments received in connection with today's final rule.

d. Does the model set the standards?

Since NHTSA began using the Volpe model in CAFE analysis, some commenters have interpreted the agency's use of the model as the way by which the agency chooses the maximum feasible fuel economy standards. This is incorrect. Although NHTSA currently uses the Volpe model as a tool to inform its consideration of potential CAFE standards, the Volpe model does not determine the CAFE standards that NHTSA proposes or promulgates as final regulations. The results it produces are completely dependent on inputs selected by NHTSA, based on the best available information and data available in the agency's estimation at the time standards are set. Although the model has been programmed in previous rulemakings to estimate at what stringency net benefits are maximized, it was not the model's decision to seek that level of stringency, it was the agency's, as it is always the agency's decision what level of CAFE stringency is appropriate. Ultimately, NHTSA's selection of appropriate CAFE standards is governed and guided by the statutory requirements of EPCA, as amended by EISA: NHTSA sets the standard at the maximum feasible average fuel economy level that it determines is achievable during a particular model year, considering technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy.

NHTSA considers the results of analyses conducted by the Volpe model and analyses conducted outside of the Volpe model, including analysis of the impacts of carbon dioxide and criteria pollutant emissions, analysis of technologies that may be available in the long term and whether NHTSA could expedite their entry into the market through these standards, and analysis of the extent to which changes in vehicle prices and fuel economy might affect vehicle production and sales. Using all of this information—not solely that from the Volpe model—the agency considers the governing statutory factors, along with environmental issues and other relevant societal issues such as safety, and promulgates the standards based on its best judgment on how to balance these factors.

This is why the agency considered eight regulatory alternatives, only one of which reflects the agency's final standards, based on the agency's determinations and assumptions. Others assess alternative standards, some of which exceed the final standards and/or the point at which net benefits are maximized.[652] These comprehensive analyses, which also included scenarios with different economic input assumptions as presented in the FEIS and FRIA, are intended to inform and contribute to the agency's consideration of the "need of the United States to conserve energy," as well as the other statutory factors. 49 U.S.C. 32902(f). Additionally, the agency's analysis considers the need of the nation to conserve energy by accounting for economic externalities of petroleum consumption and monetizing the economic costs of incremental CO_2 emissions in the social cost of carbon. NHTSA uses information from the model when considering what standards to propose and finalize, but the model does not determine the standards.

e. How does NHTSA make the model available and transparent?

Model documentation, which is publicly available in the rulemaking docket and on NHTSA's Web site, explains how the model is installed, how the model inputs (all of which are available to the public)[653] and outputs are structured, and how the model is used. The model can be used on any Windows-based personal computer with Microsoft Office 2003 or 2007 and the Microsoft .NET framework installed (the latter available without charge from Microsoft). The executable version of the model and the underlying source code are also available at NHTSA's Web site. The input files used to conduct the core analysis documented in this final rule are available in the public docket. With the model and these input files, anyone is capable of independently

[652] *See* Section IV.F below for a discussion of the regulatory alternatives considered in this rulemaking.

[653] We note, however, that files from any supplemental analysis conducted that relied in part on confidential manufacturer product plans cannot be made public, as prohibited under 49 CFR part 512.

running the model to repeat, evaluate, and/or modify the agency's analysis.

NHTSA is aware of two attempts by commenters to install and use the Volpe model in connection with the NPRM. James Adcock, an individual reviewer, reported difficulties installing the model on a computer with Microsoft® Office 2003 installed. Also, students from the University of California at Santa Barbara, though successful in installing and running the model, reported being unable to reproduce NHTSA's results underlying the development of the shapes of the passenger car and light truck curves.

Regarding the difficulties Mr. Adcock reported encountering, NHTSA staff is aware of no attempts to contact the agency for assistance locating supporting material related to the MYs 2012–2016 CAFE rulemaking. Further, the model documentation provides specific minimum hardware requirements and also indicates operating environment requirements, both of which have remained materially unchanged for more than a year. Volpe Center staff members routinely install and run the model successfully on new laptops, desktops, and servers as part of normal equipment refreshes and interagency support activities. We believe, therefore, that if the minimum hardware and operating environment requirements are met, installing and running the model should be straightforward and successful. The model documentation notes that some of the development and operating environment used by the Volpe model (*e.g.,* the software environment rather than the hardware on which that software environment operates), particularly the version of Microsoft® Excel used by the model, is Microsoft® Office 2003. We recognize that some users may have more recent versions of Microsoft® Office. However, as in the case of other large organizations, software licensing decisions, including the version of Microsoft® Office, is centralized in the Office of the Chief Information Officer. Nonetheless, the Volpe Model is proven on both Microsoft® Office version 2003 and the newer 2007 version.

As discussed in Section II.C, considering comments by the UC Santa Barbara students regarding difficulties reproducing NHTSA's analysis, NHTSA reexamined its analysis, and discovered some erroneous entries in model inputs underlying the analysis used to develop the curves proposed in the NPRM. These errors are discussed in the FRIA and have since been corrected. Updated inputs and outputs have been posted to NHTSA's Web site, and should enable outside replication of the analysis documented in today's notice.

5. How did NHTSA develop the shape of the target curves for the final standards?

In developing the shape of the target curves for today's final standards, NHTSA took a new approach, primarily in response to comments received in the MY 2011 rulemaking. NHTSA's authority under EISA allows consideration of any "attribute related to fuel economy" and any "mathematical function." While the attribute, footprint, is the same for these final standards as the attribute used for the MY 2011 standards, the mathematical function is new.

Both vehicle manufacturers and public interest groups expressed concern in the MY 2011 rulemaking process that the constrained logistic function, particularly the function for the passenger car standards, was overly steep and could lead, on the one hand, to fuel economy targets that were overly stringent for small footprint vehicles, and on the other hand, to a greater incentive for manufacturers to upsize vehicles in order to reduce their compliance obligation (because larger-footprint vehicles have less stringent targets) in ways that could compromise energy and environmental benefits. Given comments received in response to the NPRM preceding this final rule, it appears that the constrained linear function developed here significantly mitigates prior steepness concerns, and appropriately balances, for purposes of this rulemaking, the objectives of (1) discouraging vehicle downsizing that could compromise highway safety and (2) avoiding an overly strong incentive to increase vehicle sizes in ways that could compromise energy and environmental benefits.

a. Standards Are Attribute-Based and Defined by a Mathematical Function

EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy, and be expressed in the form of a mathematical function.[654] Like the MY 2011 standards, the MY 2012–2016 passenger car and light truck standards are attribute-based and defined by a mathematical function.[655] Also like the MY 2011 standards, the MY 2012–2016 standards are based on the footprint attribute. However, unlike the MY 2011 standards, the MY 2012–2016 standards are defined by a constrained linear rather than a constrained logistic function. The reasons for these similarities and differences are explained below.

As discussed above in Section II, under attribute-based standards, the fleet-wide average fuel economy that a particular manufacturer must achieve in a given model year depends on the mix of vehicles that it produces for sale. Until NHTSA began to set "Reformed" attribute-based standards for light trucks in MYs 2008–2011, and until EISA gave NHTSA authority to set attribute-based standards for passenger cars beginning in MY 2011, NHTSA set "universal" or "flat" industry-wide average CAFE standards. Attribute-based standards are preferable to universal industry-wide average standards for several reasons. First, attribute-based standards increase fuel savings and reduce emissions when compared to an equivalent universal industry-wide standard under which each manufacturer is subject to the same numerical requirement. Absent a policy to require all full-line manufacturers to produce and sell essentially the same mix of vehicles, the stringency of the universal industry-wide standards is constrained by the capability of those full-line manufacturers whose product mix includes a relatively high proportion of larger and heavier vehicles. In effect, the standards are based on the mix of those manufacturers. As a result, the standards are generally set below the capabilities of full-line and limited-line manufacturers that sell predominantly lighter and smaller vehicles.

Under an attribute-based system, in contrast, every manufacturer is more likely to be required to continue adding more fuel-saving technology each year because the level of the compliance obligation of each manufacturer is based on its own particular product mix. Thus, the compliance obligation of a manufacturer with a higher percentage of lighter and smaller vehicles will have a higher compliance obligation than a manufacturer with a lower percentage of such vehicles. As a result, all manufacturers must use technologies to enhance the fuel economy levels of the vehicles they sell. Therefore, fuel savings and CO_2 emissions reductions should be higher under an attribute-based system than under a comparable industry-wide standard.

Second, attribute-based standards minimize the incentive for manufacturers to respond to CAFE in

[654] 49 U.S.C. 32902(a)(3)(A).

[655] As discussed in Chapter 2 of the TSD, EPA is also setting attribute-based CO_2 standards that are defined by a mathematical function, given the advantages of using attribute-based standards and given the goal of coordinating and harmonizing the CAFE and CO_2 standards as expressed by President Obama in his announcement of the new National Program and in the joint NOI.

ways harmful to safety.[656] Because each vehicle model has its own target (based on the attribute chosen), attribute-based standards provide no incentive to build smaller vehicles simply to meet a fleet-wide average. Since smaller vehicles are subject to more stringent fuel economy targets, a manufacturer's increasing its proportion of smaller vehicles would simply cause its compliance obligation to increase.

Third, attribute-based standards provide a more equitable regulatory framework for different vehicle manufacturers.[657] A universal industry-wide average standard imposes disproportionate cost burdens and compliance difficulties on the manufacturers that need to change their product plans and no obligation on those manufacturers that have no need to change their plans. Attribute-based standards spread the regulatory cost burden for fuel economy more broadly across all of the vehicle manufacturers within the industry.

And fourth, attribute-based standards respect economic conditions and consumer choice, instead of having the government mandate a certain fleet mix. Manufacturers are required to invest in technologies that improve the fuel economy of their fleets, regardless of vehicle mix. Additionally, attribute-based standards help to avoid the need to conduct rulemakings to amend standards if economic conditions change, causing a shift in the mix of vehicles demanded by the public. NHTSA conducted three rulemakings during the 1980s to amend passenger car standards for MYs 1986–1989 in response to unexpected drops in fuel prices and resulting shifts in consumer demand that made the universal passenger car standard of 27.5 mpg infeasible for several years following the change in fuel prices.

As discussed above in Section II, for purposes of the CAFE standards finalized in this NPRM, NHTSA recognizes that the risk, even if small, does exist that low fuel prices in MYs 2012–2016 might lead indirectly to less than currently anticipated fuel savings and emissions reductions. Section II discusses the reasons that the agency does not believe that fuel savings and emissions reductions will be significantly lower than anticipated such as to warrant additional backstop measures beyond the one mandated by EISA, but the agency will monitor the situation and consider further rulemaking solutions if necessary and as lead time permits. *See* also Section IV.E.3 below for further discussion of NHTSA's backstop authority.

b. What attribute does NHTSA use, and why?

Consistent with the MY 2011 CAFE standards, NHTSA is using footprint as the attribute for the MY 2012–2016 CAFE standards. There are several policy reasons why NHTSA and EPA both believe that footprint is the most appropriate attribute on which to base the standards, as discussed below.

As discussed in Section IV.D.1.a.ii below, in NHTSA's judgment, from the standpoint of vehicle safety, it is important that the CAFE standards be set in a way that does not encourage manufacturers to respond by selling vehicles that are in any way less safe. NHTSA's research indicates that reductions in vehicle mass tend to compromise vehicle safety if applied on an equal basis across the entire light duty vehicle fleet, however if greater mass reduction is applied to the higher mass vehicles (the larger light trucks), an improvement in aggregate fleet safety is possible. Footprint-based standards provide an incentive to use advanced lightweight materials and structures that, if carefully designed and validated, should minimize impacts on safety, although that will be better proven as these vehicles become more prevalent in the future.

Further, although we recognize that weight is better correlated with fuel economy than is footprint, we continue to believe that there is less risk of "gaming" (artificial manipulation of the attribute(s) to achieve a more favorable target) by increasing footprint under footprint-based standards than by increasing vehicle mass under weight-based standards—it is relatively easy for a manufacturer to add enough weight to a vehicle to decrease its applicable fuel economy target a significant amount, as compared to increasing vehicle footprint. We also agree with concerns raised in 2008 by some commenters in the MY 2011 CAFE rulemaking that there would be greater potential for gaming under multi-attribute standards, such as standards under which targets would also depend on attributes such as weight, torque, power, towing capability, and/or off-road capability. Standards that incorporate such attributes in conjunction with footprint would not only be significantly more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they would make it less certain that the future fleet would actually achieve the projected average fuel economy and CO_2 reduction levels.

As discussed above in Section II.C, NHTSA and EPA sought comment on whether the agencies should consider setting standards for the final rule based on another attribute or another combination of attributes. Although NHTSA specifically requested that the commenters address the concerns raised in the paragraphs above regarding the use of other attributes, and explain how standards should be developed using the other attribute(s) in a way that contributes more to fuel savings and CO_2 reductions than the footprint-based standards, without compromising safety, commenters raising the issue largely reiterated comments submitted in prior CAFE rulemakings, which the agency answered in the MY 2011 final rule.[658] As a result, and as discussed further in Section II, the agencies finalized target curve standards based on footprint for MYs 2012–2016.

c. What mathematical function did NHTSA use for the recently-promulgated MY 2011 CAFE standards?

The MY 2011 CAFE standards are defined by a continuous, constrained logistic function, which takes the form of an S-curve, and is defined according to the following formula:

$$TARGET = \frac{1}{\frac{1}{a} + \left(\frac{1}{b} - \frac{1}{a}\right)\frac{e^{(FOOTPRINT-c)/d}}{1+e^{(FOOTPRINT-c)/d}}}$$

[656] The 2002 NAS Report described at length and quantified the potential safety problem with average fuel economy standards that specify a single numerical requirement for the entire industry. *See* NAS Report at 5, finding 12.

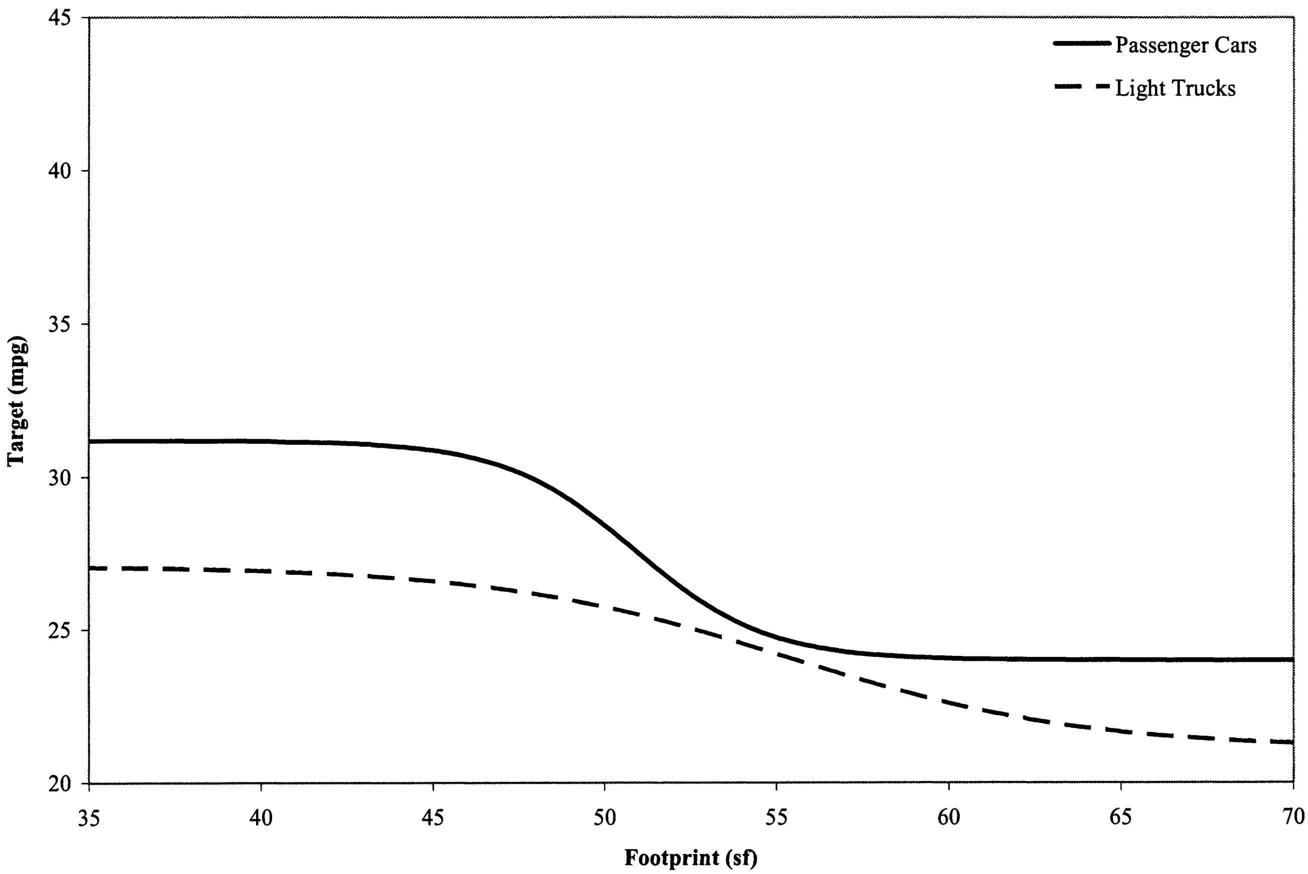
[657] *Id.* at 4–5, finding 10.

[658] *See* 74 FR at 14358–59 (Mar. 30, 2009).

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), *e* is approximately equal to 2.718,[659] *c* is the footprint (in square feet) at which the inverse of the fuel economy target falls halfway between the inverses of the lower and upper asymptotes, and *d* is a parameter (in square feet) that determines how gradually the fuel economy target transitions from the upper toward the lower asymptote as the footprint increases.

After fitting this mathematical form (separately) to the passenger car and light truck fleets and determining the stringency of the standards (*i.e.,* the vertical positions of the curves), NHTSA arrived at the following curves to define the MY 2011 standards:

Figure IV.C.5-1 MY 2011 CAFE Standards for Passenger Cars and Light Trucks



d. What mathematical function is NHTSA using for the MYs 2012–2016 CAFE standards, and why?

In finalizing the MY 2011 standards, NHTSA noted that the agency is not required to use a constrained logistic function and indicated that the agency may consider defining future CAFE standards in terms of a different mathematical function. NHTSA has done so for the final CAFE standards.

In revisiting this question, NHTSA found that the final MY 2011 CAFE standard for passenger cars, though less steep than the MY 2011 standard NHTSA final in 2008, continues to concentrate the sloped portion of the curve (from a compliance perspective, the area in which upsizing results in a slightly lower applicable target) within a relatively narrow footprint range (approximately 47–55 square feet). Further, most passenger car models have footprints smaller than the curve's 51.4 square foot inflection point, and many passenger car models have footprints at which the curve is relatively flat.

For both passenger cars and light trucks, a mathematical function that has some slope at most footprints where vehicles are produced is advantageous in terms of fairly balancing regulatory burdens among manufacturers, and in terms of providing a disincentive to respond to new standards by downsizing vehicles in ways that compromise vehicle safety. For example, a flat standard may be very difficult for a full-line manufacturer to meet, while requiring very little of a manufacturer concentrating on small vehicles, and a flat standard may provide an incentive to manufacturers to downsize certain vehicles, in order to "balance out" other vehicles subject to the same standard. As discussed above in Section II.C, NHTSA and EPA have considered comments by students from UC Santa Barbara indicating that the passenger car and light truck curves should be flatter. The agencies conclude that flatter curves would reduce the incentives intended in shifting from

[659] *e* is the irrational *number* for which the slope of the function *y* = *number*^{x} is equal to 1 when *x* is equal to zero. The first 8 digits of *e* are 2.7182818.

"flat" CAFE standards to attribute-based CAFE and GHG standards—those being the incentive to respond to attribute-based standards in ways that minimize compromises in vehicle safety, and the incentive for more manufacturers (than primarily those selling a wider range of vehicles) across the range of the attribute to have to increase the application of fuel-saving technologies.

As a potential alternative to the constrained logistic function, NHTSA had, in proposing MY 2011 standards, presented information regarding a constrained linear function. As shown in the 2008 NPRM, a constrained linear function has the potential to avoid creating a localized region (in terms of vehicle footprint) over which the slope of the function is relatively steep. Although NHTSA did not receive public comments on this option at that time, the agency indicated that it still believed a linear function constrained by upper (on a gpm basis) and possibly lower limits could merit reconsideration in future CAFE rulemakings.

Having re-examined a constrained linear function for purposes of the final standards, and considered comments discussed above in Section II, NHTSA, with EPA, concludes that for both passenger cars and light trucks, the constrained linear functions finalized today remain meaningfully sloped over a wide footprint range, thereby providing a well-distributed disincentive to downsize vehicles in ways that could compromise highway safety. Further, the constrained linear functions finalized today are not so steeply sloped that they would provide a strong incentive to increase vehicle size in order to obtain a lower CAFE requirement and higher CO_2 limit, thereby compromising energy and environmental benefits. Therefore, today's final CAFE standards are defined by constrained linear functions.

The constrained linear function is defined according to the following formula:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), respectively, *c* is the slope (in gpm per square foot) of the sloped portion of the function, and *d* is the intercept (in gpm) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet. The *MIN* and *MAX* functions take the minimum and maximum, respectively of the included values; for example, *MIN*(1,2) = 1, *MAX*(1,2) = 2, and *MIN*[*MAX*(1,2),3)]=2.

e. How did NHTSA fit the coefficients that determine the shape of the final curves?

For purposes of this final rule and the preceding NPRM, and for EPA's use in developing new CO_2 emissions standards, potential curve shapes were fitted using methods similar to those applied by NHTSA in fitting the curves defining the MY 2011 standards. We began with the market inputs discussed above, but because the baseline fleet is technologically heterogeneous, NHTSA used the CAFE model to develop a fleet to which nearly all the technologies discussed in Section V of the FRIA and Chapter 3 of the Joint TSD [660] were applied, by taking the following steps: (1) Treating all manufacturers as unwilling to pay civil penalties rather than applying technology, (2) applying any technology at any time, irrespective of scheduled vehicle redesigns or freshening, and (3) ignoring "phase-in caps" that constrain the overall amount of technology that can be applied by the model to a given manufacturer's fleet. These steps helped to increase technological parity among vehicle models, thereby providing a better basis (than the baseline fleet) for estimating the statistical relationship between vehicle size and fuel economy.

However, while this approach produced curves that the agencies' judged appropriate for the NPRM, it did not do so for the final rule. Corrections to some engineering inputs in NHTSA's market forecast, while leading to a light truck curve nearly identical to that derived for the NPRM, yielded a considerably steeper passenger car curve. As discussed above in Section II, NHTSA and EPA are concerned about the incentives that would result from a significantly steeper curve. Considering this, and considering that the updated analysis—in terms of the error measure applied by the agency—supports the curve from the NPRM nearly as well as it supports the steeper curve, NHTSA and EPA are promulgating final standards based on the curves proposed in the NPRM.

More information on the process for fitting the passenger car and light truck curves for MYs 2012–2016 is available above in Section II.C, and NHTSA refers the reader to that section and to Chapter 2 of the Joint TSD. Section II.C also discusses comments NHTSA and EPA received on this process, and on the outcomes thereof.

D. Statutory Requirements

1. EPCA, as Amended by EISA

a. Standard Setting

NHTSA must establish separate standards for MY 2011–2020 passenger cars and light trucks, subject to two principal requirements.[661] First, the standards are subject to a minimum requirement regarding stringency: they must be set at levels high enough to ensure that the combined U.S. passenger car and light truck fleet achieves an average fuel economy level of not less than 35 mpg not later than MY 2020.[662] Second, as discussed above and at length in the March 2009 final rule establishing the MY 2011 CAFE standards, EPCA requires that the agency establish standards for all new passenger cars and light trucks at the maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year, based on a balancing of

[660] The agencies excluded diesel engines and strong hybrid vehicle technologies from this exercise (and only this exercise) because the agencies expect that manufacturers would not need to rely heavily on these technologies in order to comply with the final standards. NHTSA and EPA did include diesel engines and strong hybrid vehicle technologies in all other portions of their analyses.

[661] EISA added the following additional requirements: (1) Standards must be attribute-based and expressed in the form of a mathematical function. 49 U.S.C. 32902(b)(3)(A). (2) Standards for MYs 2011–2020 must "increase ratably" in each model year. 49 U.S.C. 32902(b)(2)(C). This requirement does not have a precise mathematical meaning, particularly because it must be interpreted in conjunction with the requirement to set the standards for each model year at the level determined to be the maximum feasible level for that model year. Generally speaking, the requirement for ratable increases means that the annual increases should not be disproportionately large or small in relation to each other.

[662] 49 U.S.C. 32902(b)(2)(A).

express statutory and other factors.[663] The implication of this second requirement is that it calls for setting a standard that exceeds the minimum requirement if the agency determines that the manufacturers can achieve a higher level. When determining the level achievable by the manufacturers, EPCA requires that the agency consider the four statutory factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy. In addition, the agency has the authority to and traditionally does consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety. The ultimate determination of what standards can be considered maximum feasible involves a weighing and balancing of these factors. NHTSA received a number of comments on how the agency interprets its statutory requirements, and will respond to them in this section.

i. Statutory Factors Considered in Determining the Achievable Level of Average Fuel Economy

As none of the four factors is defined in EPCA and each remains interpreted only to a limited degree by case law, NHTSA has considerable latitude in interpreting them. NHTSA interprets the four statutory factors as set forth below.

(1) Technological Feasibility

"Technological feasibility" refers to whether a particular technology for improving fuel economy is available or can become available for commercial application in the model year for which a standard is being established. Thus, the agency is not limited in determining the level of new standards to technology that is already being commercially applied at the time of the rulemaking. It can, instead, set technology-forcing standards, *i.e.,* ones that make it necessary for manufacturers to engage in research and development in order to bring a new technology to market.

Commenters appear to have generally agreed with the agency's interpretation of technological feasibility. NESCAUM commented that the proposed standards were technologically feasible and cost-effective in the rulemaking timeframe. CBD and the UCSB students focused their comments more on the technology-forcing aspects of the definition of technological feasibility. CBD commented that the standards must be below the level of all that is technologically feasible if all the technology necessary to meet them is available today. The UCSB students similarly commented that the agencies should not base regulations for MY 2016 solely on technologies available today, that they should also consider technologies still in the research phase for the later years of the rulemaking timeframe.

While NHTSA agrees that the technological feasibility factor can include a degree of technology forcing, and that this could certainly be appropriate given EPCA's overarching purpose of energy conservation, we note that determining what levels of technology to require in the rulemaking timeframe requires a balancing of all relevant factors. Technologies that are still in the research phase now may be sufficiently advanced to become available for commercial application in, for example, MY 2016. However, given the rate at which the standards already require average mpg to rise, and given the current state of the industry, NHTSA does not believe that it would be reasonable to set standards mandating that manufacturers devote substantial resources to bringing these technologies to market immediately rather than to simply improving the fuel economy of their fleets by applying more of the technologies on the market today. As will be discussed further in Section IV.F below, technological feasibility is one of four factors that the agency balances in determining what standards would be maximum feasible for each model year. As the balancing may vary depending on the circumstances at hand for the model years in which the standards are set, the extent to which technological feasibility is simply met or plays a more dynamic role may also shift.

(2) Economic Practicability

"Economic practicability" refers to whether a standard is one "within the financial capability of the industry, but not so stringent as to" lead to "adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice."[664] In an attempt to ensure the standards' economic practicability, the agency considers a variety of factors, including the annual rate at which manufacturers can increase the percentage of the fleet that has a particular type of fuel saving technology, and cost to consumers. Consumer acceptability is also an element of economic practicability.

At the same time, the law does not preclude a CAFE standard that poses considerable challenges to any individual manufacturer. The Conference Report for EPCA, as enacted in 1975, makes clear, and the case law affirms, "(A) determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy."[665] Instead, the agency is compelled "to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers." *Id.* The law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole. Thus, while a particular CAFE standard may pose difficulties for one manufacturer, it may also present opportunities for another. The CAFE program is not necessarily intended to maintain the competitive positioning of each particular company. Rather, it is intended to enhance fuel economy of the vehicle fleet on American roads, while protecting motor vehicle safety and being mindful of the risk of harm to the overall United States economy.

Thus, NHTSA believes that this factor must be considered in the context of the competing concerns associated with different levels of standards. Prior to the MY 2005–2007 rulemaking, the agency generally sought to ensure the economy practicability of standards in part by setting them at or near the capability of the "least capable manufacturer" with a significant share of the market, *i.e.,* typically the manufacturer whose vehicles are, on average, the heaviest and largest. In the first several rulemakings to establish attribute based standards, the agency applied marginal cost benefit analysis. This ensured that the agency's application of technologies was limited to those that would pay for themselves and thus should have significant appeal to consumers. However, the agency can and has limited its application of technologies to those technologies, with or without the use of such analysis.

Besides the many commenters raising economic practicability as an issue in the context of the stringency of the proposed standards, some commenters also directly addressed the agency's interpretation of economic practicability. AIAM commented that NHTSA has wide discretion to consider economic practicability concerns as long as EPCA's overarching purpose of energy conservation is met, and that it would be within NHTSA's statutory discretion to set standards at levels

[663] 49 U.S.C. 32902(a).

[664] 67 FR 77015, 77021 (Dec. 16, 2002).

[665] *CEI–I,* 793 F.2d 1322, 1352 (DC Cir. 1986).

below those at which net benefits are maximized due to economic practicability. GM and Mitsubishi both commented that consideration of economic practicability should include more focus on individual manufacturers: GM stated that NHTSA must consider sales and employment impacts on individual manufacturers and not just industry in the aggregate, while Mitsubishi emphasized the difficulties of limited-line manufacturers in meeting standards that might be economically practicable for full-line manufacturers. CBD commented that a determination of economic practicability should not be tied to "differences between incremental improvements" that "fail to consider all relevant costs and benefits and fail to analyze the overall impact of the proposed standards." CBD pointed to the three-to-one benefit-cost ratio of the proposed standards to argue that much more stringent standards would still be economically practicable. ACEEE also commented that standards set at the level at which net benefits are maximized should be considered a "lower bound" for determining economic practicability.

While NHTSA agrees with AIAM in general that the agency has wide discretion to consider economic practicability concerns, we do not believe that economic practicability will always counsel setting standards lower than the point at which net benefits are maximized, given that it must be considered in the context of the overall balancing and EPCA's overarching purpose of energy conservation. Depending on the conditions of the industry and the assumptions used in the agency's analysis of alternative stringencies, NHTSA could well find that standards that maximize net benefits, or even higher standards, could be economically practicable. To that end, however, given the current conditions faced by the industry, which is perhaps just now passing the nadir of the economy-wide downturn and looking at a challenging road to recovery, and the relatively limited amount of lead time for MYs 2012–2016, we disagree with CBD's comment that the benefit-cost ratio of the final standards indicates that more stringent standards would be economically practicable during the rulemaking timeframe and with ACEEE's comment that standards higher than those that would maximize net benefits would be economically practicable at this time. These comments overlook the fact that nearly all manufacturers are capital-constrained at this time and may be for the next couple of model years; access to capital in a down market is crucial to making the investments in technology that the final standards will require, and requiring more technology will require significantly more capital, to which manufacturers would not likely have access. Moreover, economic practicability depends as well on manufacturers' ability to sell the vehicles that the standards require them to produce. If per-vehicle costs increase too much too soon, consumers may defer new vehicle purchases, which defeats the object of raising CAFE standards to get vehicles with better mileage on the road sooner and meet the need of the Nation to conserve energy. *See* Section IV.F below for further discussion of these issues.

As for GM's and Mitsubishi's comments, while the agency does consider carefully the impacts on individual manufacturers in the agency's analysis, as shown in the FRIA, we reiterate that economic practicability is not keyed to any single manufacturer. One of the main benefits of attribute-based standards is greater regulatory fairness—for all the manufacturers who build vehicles of a particular footprint, the target for that footprint is the same, yet each manufacturer has their own individual compliance obligation depending on the mix of vehicles they produce for sale. More manufacturers are required to improve their fuel economy, yet in a fairer way. And while some manufacturers may face difficulties under a given CAFE standard, others will find opportunities. The agency's consideration of economic practicability recognizes these difficulties and opportunities in the context of the industry as a whole, and in the context of balancing against the other statutory factors, as discussed further below.

(3) The Effect of Other Motor Vehicle Standards of the Government on Fuel Economy

"The effect of other motor vehicle standards of the Government on fuel economy," involves an analysis of the effects of compliance with emission,[666] safety, noise, or damageability standards on fuel economy capability and thus on average fuel economy. In previous CAFE rulemakings, the agency has said that pursuant to this provision, it considers the adverse effects of other motor vehicle standards on fuel economy. It said so because, from the CAFE program's earliest years[667] until present, the effects of such compliance on fuel economy capability over the history of the CAFE program have been negative ones. In those instances in which the effects are negative, NHTSA has said that it is called upon to "mak[e] a straightforward adjustment to the fuel economy improvement projections to account for the impacts of other Federal standards, principally those in the areas of emission control, occupant safety, vehicle damageability, and vehicle noise. However, only the unavoidable consequences should be accounted for. The automobile manufacturers must be expected to adopt those feasible methods of achieving compliance with other Federal standards which minimize any adverse fuel economy effects of those standards."[668] For example, safety standards that have the effect of increasing vehicle weight lower vehicle fuel economy capability and thus decrease the level of average fuel economy that the agency can determine to be feasible.

The "other motor vehicle standards" consideration has thus in practice functioned in a fashion similar to the provision in EPCA, as originally enacted, for adjusting the statutorily-specified CAFE standards for MY 1978–1980 passengers cars.[669] EPCA did not permit NHTSA to amend those standards based on a finding that the maximum feasible level of average fuel economy for any of those three years was greater or less than the standard specified for that year. Instead, it provided that the agency could only reduce the standards and only on one basis: If the agency found that there had been a Federal standards fuel economy reduction, *i.e.,* a reduction in fuel economy due to changes in the Federal vehicle standards, *e.g.,* emissions and safety, relative to the year of enactment, 1975.

The "other motor vehicle standards" provision is broader than the Federal standards fuel economy reduction provision. Although the effects analyzed to date under the "other motor vehicle standards" provision have been negative, there could be circumstances in which the effects are positive. In the event that the agency encountered such circumstances, it would be required to consider those positive effects. For example, if changes in vehicle safety technology led to NHTSA's amending a

[666] In the case of emission standards, this includes standards adopted by the Federal government and can include standards adopted by the States as well, since in certain circumstances the Clean Air Act allows States to adopt and enforce State standards different from the Federal ones.

[667] 42 FR 63184, 63188 (Dec. 15, 1977). *See* also 42 FR 33534, 33537 (Jun. 30, 1977).

[668] 42 FR 33534, 33537 (Jun. 30, 1977).

[669] That provision was deleted as obsolete when EPCA was codified in 1994.

safety standard in a way that permits manufacturers to reduce the weight added in complying with that standard, that weight reduction would increase vehicle fuel economy capability and thus increase the level of average fuel economy that could be determined to be feasible.

In the wake of *Massachusetts* v. *EPA* and of EPA's endangerment finding, its granting of a waiver to California for its motor vehicle GHG standards, and its own GHG standards for light-duty vehicles, NHTSA is confronted with the issue of how to treat those standards under the "other motor vehicle standards" provision. To the extent the GHG standards result in increases in fuel economy, they would do so almost exclusively as a result of inducing manufacturers to install the same types of technologies used by manufacturers in complying with the CAFE standards. The primary exception would involve increases in the efficiency of air conditioners.

In the NPRM, NHTSA tentatively concluded that the effects of the EPA and California standards are neither positive nor negative because the proposed rule resulted in consistent standards among all components of the National Program, but sought comment on whether and in what way the effects of the California and EPA standards should be considered under the "other motor vehicle standards" provision or other provisions of EPCA in 49 U.S.C. 32902, consistent with NHTSA's independent obligation under EPCA/EISA to issue CAFE standards. NHTSA stated that it had already considered EPA's proposal and the harmonization benefits of the National Program in developing its own proposed maximum feasible standards.

The Alliance commented that the extent to which the consideration of other motor vehicle standards of the government should affect NHTSA's standard-setting process was entirely within the agency's discretion. The Alliance agreed with NHTSA that the original intent of the factor was to ensure that NHTSA accounted for other government standards that might reduce fuel economy or inhibit fuel economy improvements, but stated that since GHG standards set by EPA and California overlap CAFE standards so extensively, and are thus functionally equivalent to CAFE standards (plus air conditioning), those standards should be "basically irrelevant to NHTSA's mission to set fuel economy standards, unless some specific aspect of the GHG standards actually makes it harder for mfrs to improve fuel economy." The Alliance stated further that NHTSA must still determine what levels of CAFE standards would be maximum feasible regardless of the findings or standards set by EPA and California. Thus, the Alliance stated, for purposes of the MYs 2012–2016 CAFE standards, EPA's GHG standards could be sufficiently considered by NHTSA given the agency's decision to harmonize as part of the National Program,[670] while California's GHG standards need not be considered because of the state's agreement under the National Program that compliance with EPA's standards would constitute compliance with its own. Ford concurred individually with the Alliance comments. NADA, in contrast, commented that EPA's GHG standards should not be considered as an "other vehicle standard" for purposes of this statutory factor, and argued that NHTSA need not and should not consider California's GHG standards due to preemption under EPCA.

Commenters from the state of California (the Attorney General and the Air Resources Board), in contrast, stated that NHTSA must consider the effects of the California GHG standards on fuel economy as a baseline for NHTSA's analysis, to give credit to the state's leadership role in achieving the levels required by the National Program. CBD seconded this comment.[671] The California Attorney General further stated that Congress discussed both positive and negative impacts of other standards on fuel economy in the 1975 Conference Reports preceding EPCA's enactment.[672] CARB and the University of Pennsylvania Environmental Law Project both cited the *Green Mountain Chrysler*[673] and *Central Valley Chrysler*[674] cases as supporting NHTSA's consideration of CARB's GHG standards pursuant to this factor.

NHTSA believes that these comments generally support the agency's interpretation of this factor as stated in the NPRM. While the agency may consider both positive and negative effects of other motor vehicle standards of the Government on fuel economy in determining what level of CAFE standards would be maximum feasible, given the fact that the final rule results in consistent standards among all components of the National Program, and given that NHTSA considered the harmonization benefits of the National Program in developing its own standards, the agency's obligation to balance this factor with the others may be considered accounted for.

(4) The Need of the United States To Conserve Energy

"The need of the United States to conserve energy" means "the consumer cost, national balance of payments, environmental, and foreign policy implications of our need for large quantities of petroleum, especially imported petroleum."[675] Environmental implications principally include those associated with reductions in emissions of criteria pollutants and CO_2. A prime example of foreign policy implications are energy independence and security concerns.

While a number of commenters cited the need of the nation to conserve energy in calling for the agency to set more stringent CAFE standards, none disagreed with the agency's interpretation of this factor and its influence on the statutory balancing required by EPCA. CBD, for example, commented that "Increasing mileage standards for this vehicle fleet is the single most effective and quickest available step the U.S. can take to conserve energy and to reduce the U.S. dependence on foreign oil, and also has an immediate and highly significant effect on total U.S. GHG emissions," and that accordingly, NHTSA should consider the need of the nation to conserve energy as counseling the agency to raise standards at a faster rate. NHTSA agrees that this factor tends to influence stringency upwards, but reiterates that the need of the nation to conserve energy is still but one of four factors that must be balanced, as discussed below.

ii. Other Factors Considered by NHTSA

The agency historically has considered the potential for adverse safety consequences in setting CAFE standards. This practice is recognized approvingly in case law. As the courts have recognized, "NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program." *Competitive Enterprise Institute* v. *NHTSA,* 901 F.2d 107, 120 n. 11 (DC Cir. 1990) ("*CEI I*") (citing 42 FR 33534, 33551 (June 30, 1977)). The courts have consistently upheld NHTSA's implementation of EPCA in this manner. *See, e.g., Competitive*

[670] The University of Pennsylvania Environmental Law Project offered a similar comment.

[671] NHTSA answered similar comments in the FEIS. See FEIS Section 10.2.4.2 for the agency's response.

[672] *Citing* HR Rep 94–340 at 86–87, 89–91 (1975 USCCAN 1762, 1848–49, 1851–53).

[673] *Green Mountain Chrysler Plymouth Dodge Jeep* v. *Crombie,* 508 F.Supp.2d 295 (D.Vt. 2007).

[674] *Central Valley Chrysler Jeep, Inc.* v. *Goldstene,* 529 F.Supp.2d 1151 (E.D. Cal. 2007).

[675] 42 FR 63184, 63188 (1977).

Enterprise Institute v. *NHTSA,* 956 F.2d 321, 322 (DC Cir. 1992) ("*CEI II*") (in determining the maximum feasible fuel economy standard, "NHTSA has always taken passenger safety into account.") (citing *CEI I,* 901 F.2d at 120 n. 11); *Competitive Enterprise Institute* v. *NHTSA,* 45 F.3d 481, 482–83 (DC Cir. 1995) ("*CEI III*") (same); *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1203–04 (9th Cir. 2008) (upholding NHTSA's analysis of vehicle safety issues associated with weight in connection with the MY 2008–11 light truck CAFE rule). Thus, in evaluating what levels of stringency would result in maximum feasible standards, NHTSA assesses the potential safety impacts and considers them in balancing the statutory considerations and to determine the appropriate level of the standards.

Under the universal or "flat" CAFE standards that NHTSA was previously authorized to establish, manufacturers were encouraged to respond to higher standards by building smaller, less safe vehicles in order to "balance out" the larger, safer vehicles that the public generally preferred to buy, which resulted in a higher mass differential between the smallest and the largest vehicles, with a correspondingly greater risk to safety. Under the attribute-based standards being finalized today, that risk is reduced because building smaller vehicles would tend to raise a manufacturer's overall CAFE obligation, rather than only raising its fleet average CAFE, and because all vehicles are required to continue improving their fuel economy. In prior rulemakings, NHTSA limited the application of mass reduction/material substitution in our modeling analysis to vehicles over 5,000 lbs GVWR,[676] but for purposes of today's final standards, NHTSA has revised its modeling analysis to allow some application of mass reduction/material substitution for all vehicles, although it is concentrated in the largest and heaviest vehicles, because we believe that this is more consistent with how manufacturers will actually respond to the standards. However, as discussed above, NHTSA does not mandate the use of any particular technology by manufacturers in meeting the standards. More information on the new approach to modeling manufacturer use of downweighting/material substitution is available in Chapter 3 of the Joint TSD and in Section V of the FRIA; and the estimated safety impacts that may be due to the final standards are described below.

iii. Factors that NHTSA is Prohibited from Considering

EPCA also provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several EPCA provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance.[677] As discussed further below, manufacturers can earn compliance credits by exceeding the CAFE standards and then use those credits to achieve compliance in years in which their measured average fuel economy falls below the standards. Manufacturers can also increase their CAFE levels through MY 2019 by producing alternative fuel vehicles. EPCA provides an incentive for producing these vehicles by specifying that their fuel economy is to be determined using a special calculation procedure that results in those vehicles being assigned a high fuel economy level.

The effect of the prohibitions against considering these flexibilities in setting the CAFE standards is that the flexibilities remain voluntarily-employed measures. If the agency were instead to assume manufacturer use of those flexibilities in setting new standards, that assumption would result in higher standards and thus tend to require manufacturers to use those flexibilities.

iv. Determining the Level of the Standards by Balancing the Factors

NHTSA has broad discretion in balancing the above factors in determining the appropriate levels of average fuel economy at which to set the CAFE standards for each model year. Congress "specifically delegated the process of setting * * * fuel economy standards with *broad* guidelines concerning the factors that the agency must consider."[678] The breadth of those guidelines, the absence of any statutorily prescribed formula for balancing the factors, the fact that the relative weight to be given to the various factors may change from rulemaking to rulemaking as the underlying facts change, and the fact that the factors may often be conflicting with respect to whether they militate toward higher or lower standards give NHTSA broad discretion to decide what weight to give each of the competing policies and concerns and then determine how to balance them. The exercise of that discretion is subject to the necessity of ensuring that NHTSA's balancing does not undermine the fundamental purpose of the EPCA: Energy conservation,[679] and as long as that balancing reasonably accommodates "conflicting policies that were committed to the agency's care by the statute."[680] The balancing of the factors in any given rulemaking is highly dependent on the factual and policy context of that rulemaking. Given the changes over time in facts bearing on assessment of the various factors, such as those relating to the economic conditions, fuel prices and the state of climate change science, the agency recognizes that what was a reasonable balancing of competing statutory priorities in one rulemaking may not be a reasonable balancing of those priorities in another rulemaking.[681] Nevertheless, the agency retains substantial discretion under EPCA to choose among reasonable alternatives.

EPCA neither requires nor precludes the use of any type of cost-benefit analysis as a tool to help inform the balancing process. While NHTSA used marginal cost-benefit analysis in the first two rulemakings to establish attribute-based CAFE standards, as noted above, it was not required to do so and is not required to continue to do so. Regardless of what type of analysis is or is not used, considerations relating to costs and benefits remain an important part of CAFE standard setting.

Because the relevant considerations and factors can reasonably be balanced in a variety of ways under EPCA, and because of uncertainties associated with the many technological and cost inputs, NHTSA considers a wide variety of alternative sets of standards, each reflecting different balancing of those policies and concerns, to aid it in discerning reasonable outcomes. Among the alternatives providing for an increase in the standards in this rulemaking, the alternatives range in stringency from a set of standards that increase, on average, 3 percent annually to a set of standards that increase, on average, 7 percent annually.

v. Other Standards—Minimum Domestic Passenger Car Standard

The minimum domestic passenger car standard was added to the CAFE

[676] *See* 74 FR 14396–14407 (Mar. 30, 2009).

[677] 49 U.S.C. 32902(h).

[678] *Center for Auto Safety v. NHTSA,* 793 F.2d 1322, 1341 (C.A.D.C. 1986).

[679] *Center for Biological Diversity* v. *NHTSA,* 538 F.3d 1172, 1195 (9th Cir. 2008).

[680] *CAS*, 1338 (quoting *Chevron U.S.A., Inc.* v. *Natural Resources Defense Council, Inc.,* 467 U.S. 837, 845).

[681] *CBD* v. *NHTSA,* 538 F.3d 1172, 1198 (9th Cir. 2008).

program through EISA, when Congress gave NHTSA explicit authority to set universal standards for domestically-manufactured passenger cars at the level of 27.5 mpg or 92 percent of the average fuel economy of the combined domestic and import passenger car fleets in that model year, whichever was greater.[682] This minimum standard was intended to act as a "backstop," ensuring that domestically-manufactured passenger cars reached a given mpg level even if the market shifted in ways likely to reduce overall fleet mpg. Congress was silent as to whether the agency could or should develop similar backstop standards for imported passenger cars and light trucks. NHTSA has struggled with this question since EISA was enacted.

In the MY 2011 final rule, facing comments split fairly evenly between support and opposition to additional backstop standards, NHTSA noted Congress' silence and "accept[ed] at least the possibility that * * * [it] could be reasonably interpreted as permissive rather than restrictive," but concluded based on the record for that rulemaking as a whole that additional backstop standards were not necessary for MY 2011, given the lack of leadtime for manufacturers to change their MY 2011 vehicles, the apparently-growing public preference for smaller vehicles, and the anti-backsliding characteristics of the footprint-based curves.[683] NHTSA stated, however, that it would continue to monitor manufacturers' product plans and compliance, and would revisit the backstop issue if it became necessary in future rulemakings.[684]

Thus, in the MYs 2012–2016 NPRM, NHTSA again sought comment on the issue of additional backstop standards, recognizing the possibility that low fuel prices during the years that the MYs 2012–2016 vehicles are in service might lead to less than anticipated fuel savings.[685] NHTSA asked commenters, in addressing this issue, to consider reviewing the agency's discussion in the MY 2011 final rule, which the agency described as concluding that its authority was likely limited by Congress' silence to setting only the backstop that Congress expressly provided for.[686] EPA also sought comment on whether it should set backstop standards under the CAA for MYs 2012–2016.

As discussed above in Section II, many commenters addressed the backstop issue, and again comments were fairly evenly split between support and opposition to additional backstop standards. While commenters opposed to additional backstops, such as the Alliance, largely reiterated NHTSA's previous statements with regard to its backstop authority, some commenters in favor of additional backstops provided more detailed legal arguments than have been previously presented for the agency's consideration. Section II provides NHTSA's and EPA's general response to comments on the backstop issue; this section provides NHTSA's specific response to the legal arguments by Sierra Club *et al.*[687] on the agency's authority to set additional backstop standards.

The Sierra Club *et al.* commented that a more permissive reading of Congress' silence in EISA was appropriate given the context of the statute, the 9th Circuit's revised opinion in *CBD* v. *NHTSA*, and the assumptions employed in the NPRM analysis. The commenters stated that given that EISA includes the 35-in-2020 and ratable increase requirements, and given that CAFE standards were only just starting to rise for light trucks at the time of EISA's enactment and had remained at the statutory level of 27.5 mpg for passenger cars for many years, it appears that Congress' intent in EISA was to raise CAFE standards as rapidly as possible. Thus, the commenters stated, if the purpose of EISA was to promote the maximum feasible increase in fuel economy with ratable increases, then there was no reason to think that backstop standards would be inconsistent with that purpose—if they were inconsistent, Congress would not have included one for domestic passenger cars. Similarly, Congress could not have thought that additional backstops were inconsistent with attribute-based standards, or it would not have included one for domestic passenger cars.[688] The commenters also cited D.C. Circuit case law stating that congressional silence leaves room for agency discretion; specifically, that "[w]hen interpreting statutes that govern agency action, [the courts] have consistently recognized that a congressional mandate in one section and silence in another often 'suggests not a prohibition but simply a decision not to mandate any solution in the second context, *i.e.,* to leave the question to agency discretion.' "[689]

The Sierra Club *et al.* also commented that it appeared that the 9th Circuit's revised opinion in *CBD* v. *NHTSA* supported the agency's discretion to set additional backstops, since it was revised after the passage of EISA and did not change its earlier holding (pertaining to the original EPCA language) that backstop standards were within the agency's discretion.[690]

And finally, the commenters stated that NHTSA's rationale for not adopting additional backstops in the MY 2011 final rule should not be relied on for MYs 2012–2016, namely, that the agency's belief that backstop standards were unnecessary to ensure the expected levels of fuel savings given the short lead time between the promulgation of the final standards and the beginning of MY 2011, the apparent growing consumer preference for smaller vehicles, and the existing anti-backsliding measures in the attribute-based curves. As described above in Section II, these commenters (and many others) expressed concern about the agencies' fleet mix assumptions and their potential effect on estimated fuel savings.

In response, and given DC Circuit precedent as cited above, NHTSA agrees that whether to adopt additional minimum standards for imported passenger cars and light trucks is squarely within the agency's discretion, and that such discretion should be exercised as necessary to avoid undue losses in fuel savings due to market shifts or other forces while still respecting the statutorily-mandated manufacturer need for lead time in establishing CAFE standards. However, as discussed above in Section II.C, NHTSA remains confident that the projections of the future fleet mix are reliable, and that future changes in the fleet mix of footprints and sales are not likely to lead to more than modest changes in projected emissions reductions or fuel savings. There are only a relatively few model years at issue, and market trends today are consistent with the agencies' estimates, showing shifts from light trucks to passenger cars and increased emphasis on fuel economy from all vehicles. The shapes of the curves also tend to avoid

[682] 49 U.S.C. 32902(b)(4).

[683] 74 FR at 14412 (Mar. 30, 2009).

[684] *Id.*

[685] 74 FR at 49685 (Sept. 28, 2009).

[686] *Id.* at 49637, 49685 (Sept. 28, 2009).

[687] NHTSA refers to these commenters by the shorthand "Sierra Club *et al.*," but the group consists of the Sierra Club, the Safe Climate Campaign, the Coalition for Clean Air, the Alliance for Climate Protection, and Environment America. Their comments may be found at Docket No. EPA–HQ–OAR–2009–0472–7278.1.

[688] The commenters also suggested that NHTSA could set attribute-based backstop standards if it was concerned that Congress' mandate to set attribute-based standards generally precluded additional flat backstops.

[689] *Citing Catawba County, N.C.* v. *EPA,* 571 F.3d 20, 36 (DC Cir. 2009) (quoting *Cheney R. Co.* v. *ICC,* 902 F.2d 66, 69 (DC Cir. 1990)).

[690] *Citing CBD* v. *NHTSA,* 538 F.3d at 1204–06 (9th Cir. 2008).

or minimize regulatory incentives for manufacturers to upsize their fleet to change their compliance burden, and the risk of vehicle upsizing or changing vehicle offerings to "game" the passenger car and light truck definitions to which commenters refer is not so great for the model years in question, because the changes that commenters suggest manufacturers might make are neither so simple nor so likely to be accepted by consumers, as discussed above.

Thus, NHTSA is confident that the anticipated increases in average fuel economy and reductions in average CO_2 emission rates can be achieved without backstops under EISA, as noted above. Nevertheless, we acknowledge that the MY 2016 fuel economy goal of 34.1 mpg is an estimate and not a standard,[691] and that changes in fuel prices, consumer preferences, and/or vehicle survival and mileage accumulation rates could result in either smaller or larger oil savings. However, as explained above and elsewhere in the rule, NHTSA believes that the possibility of not meeting (or, alternatively, exceeding) fuel economy goals exists, but is not likely to lead to more than modest changes in the currently-projected levels of fuel and GHG savings. NHTSA plans to conduct retrospective analysis to monitor progress, and has the authority to revise standards if warranted, as long as sufficient lead time is provided. Given this, and given the potential complexities in designing an appropriate backstop, NHTSA believes that the balance here points to not adopting additional backstops at this time for the MYs 2012–2016 standards other than NHTSA's issuing the ones required by EPCA/EISA for domestic passenger cars. If, during the timeframe of this rule, NHTSA observes a significant shift in the manufacturer's product mix resulting in a relaxation of their estimated targets, NHTSA and EPA will reconsider options, both for MYs 2012–2016 and future rulemakings.

2. Administrative Procedure Act

To be upheld under the "arbitrary and capricious" standard of judicial review in the APA, an agency rule must be rational, based on consideration of the relevant factors, and within the scope of the authority delegated to the agency by the statute. The agency must examine the relevant data and articulate a satisfactory explanation for its action including a "rational connection between the facts found and the choice made." *Burlington Truck Lines, Inc.* v. *United States,* 371 U.S. 156, 168 (1962).

Statutory interpretations included in an agency's rule are subjected to the two-step analysis of *Chevron, U.S.A., Inc.* v. *Natural Resources Defense Council,* 467 U.S. 837, 104 S.Ct. 2778, 81 L.Ed.2d 694 (1984). Under step one, where a statute "has directly spoken to the precise question at issue," *id.* at 842, 104 S.Ct. 2778, the court and the agency "must give effect to the unambiguously expressed intent of Congress," *id.* at 843, 104 S.Ct. 2778. If the statute is silent or ambiguous regarding the specific question, the court proceeds to step two and asks "whether the agency's answer is based on a permissible construction of the statute." *Id.*

If an agency's interpretation differs from the one that it has previously adopted, the agency need not demonstrate that the prior position was wrong or even less desirable. Rather, the agency would need only to demonstrate that its *new* position is consistent with the statute and supported by the record, and acknowledge that this is a departure from past positions. The Supreme Court emphasized this recently in *FCC* v. *Fox Television,* 129 S.Ct. 1800 (2009). When an agency changes course from earlier regulations, "the requirement that an agency provide reasoned explanation for its action would ordinarily demand that it display awareness that it *is* changing position," but "need not demonstrate to a court's satisfaction that the reasons for the new policy are *better* than the reasons for the old one; it suffices that the new policy is permissible under the statute, that there are good reasons for it, and that the agency *believes* it to be better, which the conscious change of course adequately indicates."[692]

The APA also requires that agencies provide notice and comment to the public when proposing regulations.[693] Two commenters, the American Chemistry Council and the American Petroleum Institute, argued that the agreements by auto manufacturers and California to support the National Program indicated that a "deal" had been struck between the agencies and these parties, which was not available as part of the administrative record and which the public had not been given the opportunity to comment on. The commenters argued that this violated the APA.

In response, under the APA, agencies "must justify their rulemakings solely on the basis of the record [they] compile[] and make[] public."[694] Any informal contacts that occurred prior to the release of the NPRM may have been informative for the agencies and other parties involved in developing the NPRM, but they did not release the agencies of their obligation consider and respond to public comments on the NPRM and to justify the final standards based on the public record. The agencies believe that the record fully justifies the final standards, demonstrating analytically that they are the maximum feasible and reasonable for the model years covered. Thus, we disagree that there has been any violation of the APA.

3. National Environmental Policy Act

As discussed above, EPCA requires the agency to determine what level at which to set the CAFE standards for each model year by considering the four factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy. NEPA directs that environmental considerations be integrated into that process. To accomplish that purpose, NEPA requires an agency to compare the potential environmental impacts of its proposed action to those of a reasonable range of alternatives.

To explore the environmental consequences in depth, NHTSA has prepared both a draft and a final environmental impact statement. The purpose of an EIS is to "provide full and fair discussion of significant environmental impacts and [to] inform decisionmakers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the human environment." 40 CFR 1502.1.

NEPA is "a procedural statute that mandates a process rather than a particular result." *Stewart Park & Reserve Coal., Inc.* v. *Slater,* 352 F.3d at 557. The agency's overall EIS-related obligation is to "take a 'hard look' at the environmental consequences before taking a major action." *Baltimore Gas & Elec. Co.* v. *Natural Res. Def. Council, Inc.,* 462 U.S. 87, 97, 103 S.Ct. 2246, 76 L.Ed.2d 437 (1983). Significantly, "[i]f the adverse environmental effects of the proposed action are adequately identified and evaluated, the agency is not constrained by NEPA from deciding that other values outweigh the environmental costs." *Robertson* v. *Methow Valley Citizens Council,* 490

[691] The MYs 2012–2016 passenger car and light truck curves are the actual standards.

[692] *Ibid.,* 1181.

[693] 5 U.S.C. 553.

[694] *Sierra Club* v. *Costle,* 657 F.2d 298, 401 (DC Cir. 1981).

U.S. 332, 350, 109 S.Ct. 1835, 104 L.Ed.2d 351 (1989).

The agency must identify the "environmentally preferable" alternative, but need not adopt it. "Congress in enacting NEPA * * * did not require agencies to elevate environmental concerns over other appropriate considerations." *Baltimore Gas and Elec. Co.* v. *Natural Resources Defense Council, Inc.,* 462 U.S. 87, 97 (1983). Instead, NEPA requires an agency to develop alternatives to the proposed action in preparing an EIS. 42 U.S.C. 4332(2)(C)(iii). The statute does not command the agency to favor an environmentally preferable course of action, only that it make its decision to proceed with the action after taking a hard look at environmental consequences.

This final rule also constitutes a Record of Decision for NHTSA under NEPA. Section IV.K below provides much more information on the agency's NEPA analysis for this rulemaking, and on how this final rule constitutes a Record of Decision.

E. What are the final CAFE standards?

1. Form of the Standards

Each of the CAFE standards that NHTSA is finalizing today for passenger cars and light trucks is expressed as a mathematical function that defines a fuel economy target applicable to each vehicle model and, for each fleet, establishes a required CAFE level determined by computing the sales-weighted harmonic average of those targets.[695]

As discussed above in Section II.C, NHTSA has determined fuel economy targets using a constrained linear function defined according to the following formula:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), respectively, *c* is the slope (in gpm per square foot) of the sloped portion of the function, and *d* is the intercept (in gpm) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet. The *MIN* and *MAX* functions take the minimum and maximum, respectively of the included values.

In the NPRM preceding today's final rule (as under the recently-promulgated MY 2011 standards), NHTSA proposed that the CAFE level required of any given manufacturer be determined by calculating the production-weighted harmonic average of the fuel economy targets applicable to each vehicle model:

$$CAFE_{required} = \frac{\sum_i SALES_i}{\sum_i \frac{SALES_i}{TARGET_i}}$$

Here, $CAFE_{required}$ is the required level for a given fleet, *SALESi* is the number of units of model $_i$ produced for sale in the United States, $TARGET_i$ is the fuel economy target applicable to model $_i$ (according to the equation shown in Chapter II and based on the footprint of model *i*), and the summations in the numerator and denominator are both performed over all models in the fleet in question.

However, comments by Honda and Toyota indicate that the defined variables used in the equations could be interpreted differently by vehicle manufacturers. The term "footprint of a vehicle model" could be interpreted to mean that a manufacturer only has to use one representative footprint within a model type or that it is necessary to use all the unique footprints and corresponding fuel economy target standards within a model type when determining a fleet target standard.

In the same NPRM, EPA proposed new regulations which also include the calculation of standards based on the attribute of footprint. The EPA regulation text is specific and states that standards will be derived using the target values "for each unique combination of model type and footprint value" (proposed regulation text 40 CFR 86.1818–12(c)(2)(ii)(B) for passenger automobiles and (c)(3)(ii)(B) for light trucks). Also, in an EPA final rule issued November 25, 2009, the manufacturers are required to provide in their final model year reports to EPA data for "each unique footprint within each model type" used to calculate the new CAFE program fuel economy levels (40 CFR 600.512–08(c)(8) and (9)). Using this term would be more definitive than using terms such as "footprint of a vehicle model" and would more fully harmonize the NHTSA and EPA regulations. Therefore, under the final CAFE standards promulgated today, a manufacturer's "fleet target standard" will be derived from the summation of the targets for all and every unique footprint within each model type for all model types that make up a fleet of vehicles. Also, to provide greater clarity, the equation will use the variable name *PRODUCTION* rather than *SALES* to refer to production of vehicles for sale in the United States. Otherwise, for purposes of the final rule the same equation will apply:

[695] Required CAFE levels shown here are *estimated* required levels based on NHTSA's current projection of manufacturers' vehicle fleets in MYs 2012–2016. *Actual* required levels are not determined until the end of each model year, when all of the vehicles produced by a manufacturer in that model year are known and their compliance obligation can be determined with certainty. The target curves, as defined by the constrained linear function, and as embedded in the function for the sales-weighted harmonic average, are the real "standards" being established today.

$$CAFE_{required} = \frac{\sum_i PRODUCTION_i}{\sum_i \frac{PRODUCTION_i}{TARGET_i}}$$

However, $PRODUCTION_i$ is the number of units produced for sale in the United States of each i^{th} unique footprint within each model type, produced for sale in the United States, and $TARGET_i$ is the corresponding fuel economy target (according to the equation shown in Chapter II and based on the corresponding footprint), and the summations in the numerator and denominator are both performed over all unique footprint and model type combinations in the fleet in question. The equations and terms specified for calculating the required CAFE fleet values in Part 531.5(b) and (c) for MYs 2012–2016, and Part 533.5(g), (h) and (i) for MYs 2008–2016 will be updated accordingly. Although the agency is not changing the equations for the MY 2011 standards, we would expect manufacturers to follow the same procedures for calculating their required levels for that model year. Also, the Appendices in each of these parts will also be updated to provide corresponding examples of calculating the fleet standards.

Corresponding changes to regulatory text defining CAFE standards are discussed below in Section IV.I.

The final standards are, therefore, specified by the four coefficients defining fuel economy targets:

a = upper limit (mpg)

b = lower limit (mpg)

c = slope (gpm per square foot)

d = intercept (gpm)

The values of the coefficients are different for the passenger car standards and the light truck standards.

2. Passenger Car Standards for MYs 2012–2016

For passenger cars, NHTSA proposed CAFE standards defined by the following coefficients during MYs 2012–2016:

TABLE IV.E.2–1—COEFFICIENTS DEFINING PROPOSED MY 2012–2016 FUEL ECONOMY TARGETS FOR PASSENGER CARS

Coefficient	2012	2013	2014	2015	2016
a (mpg)	36.23	37.15	38.08	39.55	41.38
b (mpg)	28.12	28.67	29.22	30.08	31.12
c (gpm/sf)	0.0005308	0.0005308	0.0005308	0.0005308	0.0005308
d (gpm)	0.005842	0.005153	0.004498	0.003520	0.002406

After updating inputs to its analysis, and revisiting the form and stringency of both passenger cars and light truck standards, as discussed in Section II, NHTSA is finalizing passenger car CAFE standards defined by the following coefficients during MYs 2012–2016:

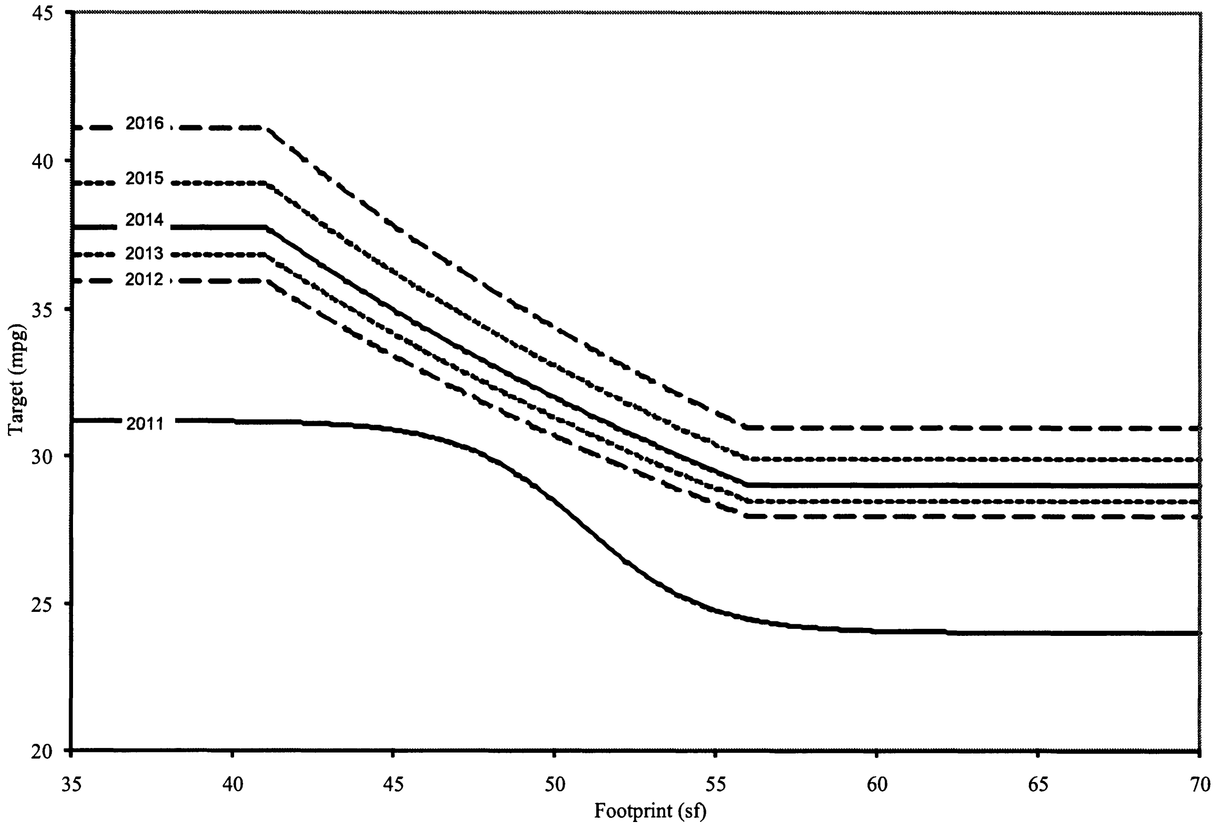
TABLE IV.E.2–2—COEFFICIENTS DEFINING FINAL MY 2012–2016 FUEL ECONOMY TARGETS FOR PASSENGER CARS

Coefficient	2012	2013	2014	2015	2016
a (mpg)	35.95	36.80	37.75	39.24	41.09
b (mpg)	27.95	28.46	29.03	29.90	30.96
c (gpm/sf)	0.0005308	0.0005308	0.0005308	0.0005308	0.0005308
d (gpm)	0.006057	0.005410	0.004725	0.003719	0.002573

These coefficients reflect the agency's decision, discussed above in Section II, to leave the shapes of both the passenger car and light truck curves unchanged. They also reflect the agency's reevaluation of the "gap" in stringency between the passenger car and light truck standard, also discussed in Section II.

These coefficients result in the footprint-dependent target curves shown graphically below. The MY 2011 final standard, which is specified by a constrained logistic function rather than a constrained linear function, is shown for comparison.

Figure IV.E.2-1 Final MY 2011 and Final MY 2012-2016 Fuel Economy Target Curves for Passenger Cars



As discussed, the CAFE levels required of individual manufacturers will depend on the mix of vehicles they produce for sale in the United States. Based on the market forecast of future sales that NHTSA has used to examine today's final CAFE standards, the agency estimates that the targets shown above will result in the following average required fuel economy levels for individual manufacturers during MYs 2012–2016 (an updated estimate of the average required fuel economy level under the final MY 2011 standard is shown for comparison):[696]

TABLE IV.E.2–3—ESTIMATED AVERAGE FUEL ECONOMY REQUIRED UNDER FINAL MY 2011 AND FINAL MY 2012–2016 CAFE STANDARDS FOR PASSENGER CARS

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	30.2	33.0	33.7	34.5	35.7	37.3
Chrysler	29.4	32.6	33.3	34.1	35.2	36.7
Daimler	29.2	32.0	32.7	33.3	34.4	35.8
Ford	29.7	32.9	33.7	34.4	35.6	37.1
General Motors	30.3	32.7	33.5	34.2	35.4	36.9
Honda	30.8	33.8	34.6	35.4	36.7	38.3
Hyundai	30.9	33.8	34.3	35.1	36.6	38.2
Kia	30.6	33.4	34.2	35.0	36.3	37.9
Mazda	30.6	33.8	34.6	35.5	36.8	38.4
Mitsubishi	31.0	34.2	35.0	35.8	37.1	38.7
Nissan	30.7	33.3	34.1	34.9	36.1	37.7

[696] In the March 2009 final rule establishing MY 2011 standards for passenger cars and light trucks, NHTSA estimated that the required fuel economy levels for passenger cars would average 30.2 mpg under the MY 2011 passenger car standard. Based on the agency's current forecast of the MY 2011 passenger car market, which anticipates greater numbers of passenger cars than the forecast used in the MY 2011 final rule, NHTSA now estimates that the average required fuel economy level for passenger cars will be 30.4 mpg in MY 2011. This does not mean that the agency is making the standards more stringent for that model year, or that any manufacturer will necessarily face a more difficult CAFE standard, it simply reflects the change in assumptions about what vehicles will be produced for sale in that model year. The target curve remains the same, and each manufacturer's compliance obligation will still be determined at the end of the model year.

TABLE IV.E.2–3—ESTIMATED AVERAGE FUEL ECONOMY REQUIRED UNDER FINAL MY 2011 AND FINAL MY 2012–2016 CAFE STANDARDS FOR PASSENGER CARS—Continued

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Porsche	31.2	35.9	36.8	37.8	39.2	41.1
Subaru	31.0	34.6	35.5	36.3	37.7	39.4
Suzuki	31.2	35.8	36.6	37.5	39.0	40.8
Tata	28.0	30.7	31.4	32.1	33.3	34.7
Toyota	30.8	33.9	34.7	35.5	36.8	38.4
Volkswagen	30.8	34.3	35.0	35.9	37.2	38.8
Average	30.4	33.3	34.2	34.9	36.2	37.8

Because a manufacturer's required average fuel economy level for a model year under the final standards will be based on its actual production numbers in that model year, its official required fuel economy level will not be known until the end of that model year. However, because the targets for each vehicle footprint will be established in advance of the model year, a manufacturer should be able to estimate its required level accurately.

3. Minimum Domestic Passenger Car Standards

EISA expressly requires each manufacturer to meet a minimum fuel economy standard for domestically manufactured passenger cars in addition to meeting the standards set by NHTSA. According to the statute (49 U.S.C. 32902(b)(4)) the minimum standard shall be the greater of (A) 27.5 miles per gallon; or (B) 92 percent of the average fuel economy projected by the Secretary for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year. The agency must publish the projected minimum standards in the **Federal Register** when the passenger car standards for the model year in question are promulgated.

As published in the MY 2011 final rule, the domestic minimum passenger car standard for MY 2011 was set at 27.8 mpg, which represented 92 percent of the final projected passenger car standards promulgated for that model year.[697] NHTSA stated at the time that "The final calculated minimum standards will be updated to reflect any changes in the projected passenger car standards."[698] Subsequently, in the NPRM proposing the MYs 2012–2016 standards, NHTSA noted that given changes in the projected estimated required passenger car standard for MY 2011,[699] 92 percent of that standard would be 28.0 mpg, not 27.8 mpg, and proposed to raise the minimum domestic passenger car standard accordingly.

The Alliance commented to the NPRM that the minimum domestic passenger car standard is subject to the 18-month lead time rule for standards per 49 U.S.C. per 49 U.S.C. 32902(a), and that NHTSA therefore cannot revise it at this time. Toyota individually offered identical comments.

49 U.S.C. 32902(b)(4)(B) does state that the minimum domestic passenger car standard shall be 92 percent of the projected average fuel economy for the passenger car fleet, "which projection shall be published in the **Federal Register** when the standard for that model year is promulgated in accordance with this section." In reviewing the statute, the agency concurs that the minimum domestic passenger car standard should be based on the agency's fleet assumptions when the passenger car standard for that year is promulgated, which would make it inappropriate to change the minimum standard for MY 2011 at this time. However, we note that we do not read this language to preclude any change in the minimum standard after it is first promulgated for a model year. As long as the 18-month lead-time requirement of 49 U.S.C. 32902(a) is respected, NHTSA believes that the language of the statute suggests that the 92 percent should be determined anew any time the passenger car standards are revised.

The Alliance also commented that the minimum domestic passenger car standard should be based on the projected "actual" (NHTSA refers to this as "estimated achieved") mpg level for the combined passenger car fleet, rather than based on the projected "target" mpg level (NHTSA refers to this as "estimated required") for the combined fleet. The Alliance argued that the plain language of the statute states that 92 percent should be taken of the "average fuel economy projected * * * for the combined * * * fleets," which is different than the average fuel economy *standard* projected. The Alliance further argued that using the "estimated achieved" value to determine the 92 percent will avoid inadvertently "considering" FFV credits in setting the minimum standard, since the "estimated achieved" value is determined by ignoring FFV credits. Toyota individually offered identical comments.

NHTSA disagrees that the minimum standard should be based on the estimated achieved levels rather than the estimated required levels. NHTSA interprets Congress' reference in the second clause of 32902(b)(4)(B) to the standard promulgated in that model year as indicating that Congress intended "projected average fuel economy" in the first clause to pertain to the estimated required level, not the estimated achieved level. The Alliance's concern that a minimum standard based on the estimated required level "inadvertently considers" FFV credits is misplaced, because NHTSA is statutorily prohibited from considering FFV credits in setting maximum feasible standards. Thus, NHTSA has continued to determine the minimum domestic passenger car standard based on the estimated required mpg levels projected for the model years covered by the rulemaking.

Based on NHTSA's current market forecast, the agency's estimates of these minimum standards under the final MY 2012–2016 CAFE standards (and, for comparison, the final MY 2011 minimum domestic passenger car standard) are summarized below in Table IV.E.3–1.

[697] *See* 74 FR at 14410 (Mar. 30, 3009).

[698] *Id.*

[699] Readers should remember, of course, that the "estimated required standard" is not necessarily the ultimate mpg level with which manufacturers will have to comply, because the ultimate mpg level for each manufacturer is determined at the end of the model year based on the target curves and the mix of vehicles that each manufacturer has produced for sale. The mpg level designated as "estimated required' is exactly that, an estimate.

TABLE IV.E.3–1—ESTIMATED MINIMUM STANDARD FOR DOMESTICALLY MANUFACTURED PASSENGER CARS UNDER FINAL MY 2011 AND FINAL MY 2012–2016 CAFE STANDARDS FOR PASSENGER CARS

2011	2012	2013	2014	2015	2016
27.8	30.7	31.4	32.1	33.3	34.7

4. Light Truck Standards

For light trucks, NHTSA proposed CAFE standards defined by the following coefficients during MYs 2012–2016:

TABLE IV.E.4–1—COEFFICIENTS DEFINING PROPOSED MY 2012–2016 FUEL ECONOMY TARGETS FOR LIGHT TRUCKS

Coefficient	2012	2013	2014	2015	2016
a (mpg)	29.44	30.32	31.30	32.70	34.38
b (mpg)	22.06	22.55	23.09	23.84	24.72
c (gpm/sf)	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546
d (gpm)	0.01533	0.01434	0.01331	0.01194	0.01045

After updating inputs to its analysis, and revisiting the form and stringency of both passenger cars and light truck standards, as discussed in Section II, NHTSA is finalizing light truck CAFE standards defined by the following coefficients during MYs 2012–2016:

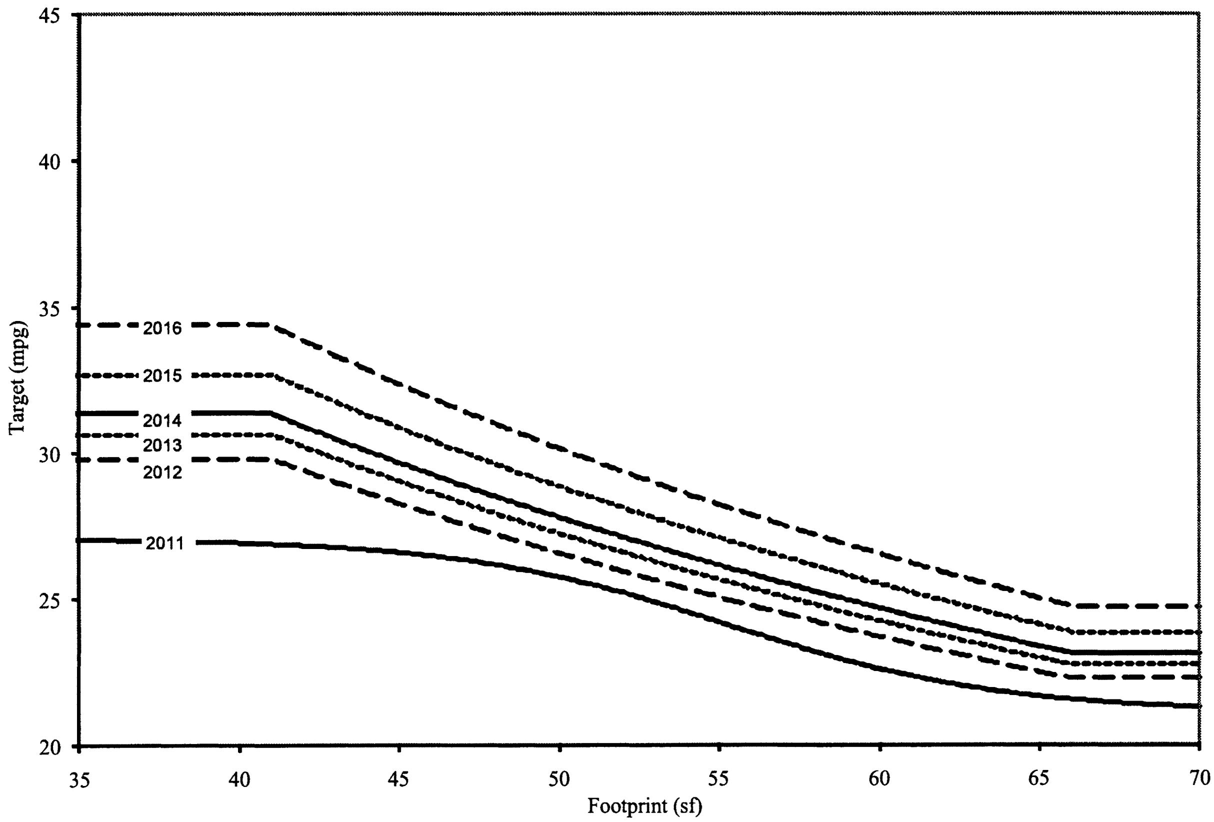
TABLE IV.E.4–2—COEFFICIENTS DEFINING FINAL MY 2012–2016 FUEL ECONOMY TARGETS FOR LIGHT TRUCKS

Coefficient	2012	2013	2014	2015	2016
a (mpg)	29.82	30.67	31.38	32.72	34.42
b (mpg)	22.27	22.74	23.13	23.85	24.74
c (gpm/sf)	0.0004546	0.0004546	0.0004546	0.0004546	0.0004546
d (gpm)	0.014900	0.013968	0.013225	0.011920	0.010413

As for passenger cars, these coefficients reflect the agency's decision, discussed above in Section II, to leave the shapes of both the passenger car and light truck curves unchanged. They also reflect the agency's reevaluation of the "gap" in stringency between the passenger car and light truck standard, also discussed in Section II.

These coefficients result in the footprint-dependent targets shown graphically below. The MY 2011 final standard, which is specified by a constrained logistic function rather than a constrained linear function, is shown for comparison.

Figure IV.E.4-1 Final MY 2011 and Final MY 2012-2016 Fuel Economy Targets for Light Trucks



Again, given these targets, the CAFE levels required of individual manufacturers will depend on the mix of vehicles they produce for sale in the United States. Based on the market forecast NHTSA has used to examine today's final CAFE standards, the agency estimates that the targets shown above will result in the following average required fuel economy levels for individual manufacturers during MYs 2012–2016 (an updated estimate of the average required fuel economy level under the final MY 2011 standard is shown for comparison): [700]

TABLE IV.E.4–3—ESTIMATED AVERAGE FUEL ECONOMY REQUIRED UNDER FINAL MY 2011 AND FINAL MY 2012–2016 CAFE STANDARDS FOR LIGHT TRUCKS

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	25.6	26.6	27.3	27.9	28.9	30.2
Chrysler	24.5	25.7	26.2	26.8	27.8	29.0
Daimler	24.7	25.6	26.3	26.9	27.8	29.1
Ford	23.7	24.8	25.4	26.0	27.0	28.1
General Motors	23.3	24.2	24.8	25.2	26.1	27.2
Honda	25.7	26.9	27.5	28.0	29.1	30.4
Hyundai	25.9	27.0	27.6	28.2	29.3	30.7
Kia	25.2	26.2	26.7	27.3	28.3	29.5
Mazda	26.2	27.6	28.4	28.9	30.1	31.5
Mitsubishi	26.4	27.8	28.5	29.1	30.2	31.7
Nissan	24.5	25.6	26.2	26.8	27.8	29.1
Porsche	25.5	26.3	26.9	27.5	28.5	29.8
Subaru	26.5	27.9	28.6	29.2	30.4	31.9
Suzuki	26.3	27.5	28.2	28.8	29.9	31.4
Tata	26.2	27.4	28.2	28.8	29.9	31.3
Toyota	24.6	25.7	26.2	26.8	27.8	29.1

[700] In the March 2009 final rule establishing MY 2011 standards for passenger cars and light trucks, NHTSA estimated that the required fuel economy levels for light trucks would average 24.1 mpg under the MY 2011 light truck standard. Based on the agency's current forecast of the MY 2011 light truck market, NHTSA now estimates that the required fuel economy levels will average 24.4 mpg in MY 2011. The increase in the estimate reflects a decrease in the size of the average light truck.

TABLE IV.E.4–3—ESTIMATED AVERAGE FUEL ECONOMY REQUIRED UNDER FINAL MY 2011 AND FINAL MY 2012–2016 CAFE STANDARDS FOR LIGHT TRUCKS—Continued

Manufacturer	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Volkswagen	25.0	25.8	26.4	27.0	28.0	29.2
Average	24.4	25.4	26.0	26.6	27.5	28.8

As discussed above with respect to the final passenger cars standards, we note that a manufacturer's required fuel economy level for a model year under the final standards will be based on its actual production numbers in that model year.

F. How do the final standards fulfill NHTSA's statutory obligations?

In developing the proposed MY 2012–16 standards, the agency developed and considered a wide variety of alternatives. In response to comments received in the last round of rulemaking, in our March 2009 notice of intent to prepare an environmental impact statement, the agency selected a range of candidate stringencies that increased annually, on average, 3% to 7%.[701] That same approach has been carried over to this final rule and to the accompanying FEIS and FRIA. Thus, the majority of the alternatives considered in this rulemaking are defined as average percentage increases in stringency—3 percent per year, 4 percent per year, 5 percent per year, and so on. NHTSA believes that this approach clearly communicates the level of stringency of each alternative and allows us to identify alternatives that represent different ways to balance NHTSA's statutory requirements under EPCA/EISA.

In the NPRM, we noted that each of the listed alternatives represents, in part, a different way in which NHTSA could conceivably balance different policies and considerations in setting the standards. We were mindful that the agency needs to weigh and balance many factors, such as technological feasibility, economic practicability, including lead time considerations for the introduction of technologies and impacts on the auto industry, the impacts of the standards on fuel savings and CO_2 emissions, and fuel savings by consumers, as well as other relevant factors such as safety. For example, the 7% Alternative weighs energy conservation and climate change considerations more heavily and technological feasibility and economic practicability less heavily. In contrast, the 3% Alternative, the least stringent alternative, places more weight on technological feasibility and economic practicability. We recognized that the "feasibility" of the alternatives also may reflect differences and uncertainties in the way in which key economic (*e.g.,* the price of fuel and the social cost of carbon) and technological inputs could be assessed and estimated or valued. We also recognized that some technologies (*e.g.,* PHEVs and EVs) will not be available for more than limited commercial use through MY 2016, and that even those technologies that could be more widely commercialized through MY 2016 cannot all be deployed on every vehicle model in MY 2012 but require a realistic schedule for more widespread commercialization to be within the realm of economically practicability.

In addition to the alternatives that increase evenly at annual rates ranging from 3% to 7%, NHTSA also included alternatives developed using benefit-cost criteria. The agency emphasized benefit-cost-related alternatives in its rulemakings for MY 2008–2011 and, subsequently, MY 2011 standards. By including such alternatives in its current analysis, the agency is providing a degree of analytical continuity between the two approaches to defining alternatives in an effort to illustrate the similarities and dissimilarities. To that end, we included and analyzed two additional alternatives, one that sets standards at the point where net benefits are maximized (labeled "MNB" in the table below), and another that sets standards at the point at which total costs are most nearly equal to total benefits (labeled "TCTB" in the table below).[702] With respect to the first of those alternatives, we note that Executive Order 12866 focuses attention on an approach that maximizes net benefits. Further, since NHTSA has thus far set attribute-based CAFE standards at the point at which net benefits are maximized, we believed it would be useful and informative to consider the potential impacts of that approach as compared to the new approach for MYs 2012–2016.

After working with EPA in thoroughly reviewing and in some cases reassessing the effectiveness and costs of technologies (most of which are already being incorporated in at least some vehicles), market forecasts and economic assumptions, NHTSA used the Volpe model extensively to assess the technologies that the manufacturers could apply in order to comply with each of the alternatives. This allowed us to assess the variety, amount and cost of the technologies that could be used to enable the manufacturers to comply with each of the alternatives. NHTSA estimated how the application of these and other technologies could increase vehicle costs, reduce fuel consumption, and reduce CO_2 emissions.

The agency then assessed which alternative would represent a reasonable balancing of the statutory criteria, given the difficulties confronting the industry and the economy, and other relevant goals and priorities. Those priorities and goals include maximizing energy conservation and achieving a nationally harmonized and coordinated program for regulating fuel economy and GHG emissions.

Part of that assessment of alternatives entailed an evaluation of the stringencies necessary to achieve both Federal and State GHG emission reduction goals, especially those of California and the States that have adopted its GHG emission standard for motor vehicles. Given that EPCA requires attribute-based standards, NHTSA and EPA determined the level at which a national attribute-based GHG emissions standard would need to be set to achieve the same emission reductions in California as the California GHG program. This was done by evaluating a nationwide Clean Air Act standard for MY 2016 that would apply across the country and require the levels of emissions reduction which California standards would require for the subset

[701] Notice of intent to prepare an EIS, 74 FR 14857, 14859–60, April 1, 2009.

[702] The stringency indicated by each of these alternatives depends on the value of inputs to NHTSA's analysis. Results presented here for these two alternatives are based on NHTSA's reference case inputs, which underlie the central analysis of the proposed standards. In the accompanying FRIA, the agency presents the results of that analysis to explore the sensitivity of results to changes in key economic inputs. Because of numerous changes in model inputs (*e.g.,* discount rate, rebound effect, CO_2 value, technology cost estimates), our analysis often exhausts all available technologies before reaching the point at which total costs equal total benefits. In these cases, the stringency that exhausts all available technologies is considered.

of vehicles sold in California under the California standards for MY 2009–2016 (known as "Pavley 1"). In essence, the stringency of the California Pavley 1 program was evaluated, but for a national standard. For a number of reasons discussed in Section III.D, an assessment was developed of national new vehicle fleet-wide CO_2 performance standards for model year 2016 which would result in the new light-duty vehicle fleet in the State of California having CO_2 performance equal to the performance from the California Pavley 1 standards. That level, 250 g/mi, is equivalent to 35.5 mpg if the GHG standard were met exclusively by fuel economy improvements—and the overall result is the model year 2016 goals of the National Program.

However, the level of stringency for the National Program goal of 250 g/mi CO_2 can be met with both fuel economy "tailpipe" improvements as well as other GHG-reduction related improvements, such as A/C refrigerant leakage reductions. CAFE standards, as discussed elsewhere in this final rule, cannot be met by improvements that cannot be accounted for on the FTP/HFET tests. Thus, setting CAFE standards at 35.5 mpg would require more tailpipe technology (at more expense to manufacturers) than would be required under such a CAA standard. To obtain an equivalent CAFE standard, we determined how much tailpipe technology would be necessary in order to meet an mpg level of 35.5 if manufacturers also employed what EPA deemed to be an average amount of A/C "credits" (leakage and efficiency) to reach the 250 g/mi equivalent. This results in a figure of 34.1 mpg as the appropriate counterpart CAFE standard. This differential gives manufacturers the opportunity to reach 35.5 mpg equivalent under the CAA in ways that would significantly reduce their costs. Were NHTSA instead to establish its standard at the same level, manufacturers would need to make substantially greater expenditures on fuel-saving technologies to reach 35.5 mpg under EPCA.

Thus, as part of the process of considering all of the factors relevant under EPCA for setting standards, in a context where achieving a harmonized National Program is important, for the proposal we created a new alternative whose annual percentage increases would achieve 34.1 mpg by MY 2016. That alternative is one which increases on average at 4.3% annually. This new alternative, like the seven alternatives presented above, represents a unique balancing of the statutory factors and other relevant considerations. For the reader's reference, the estimated required levels of stringency for each alternative in each model year are presented below:

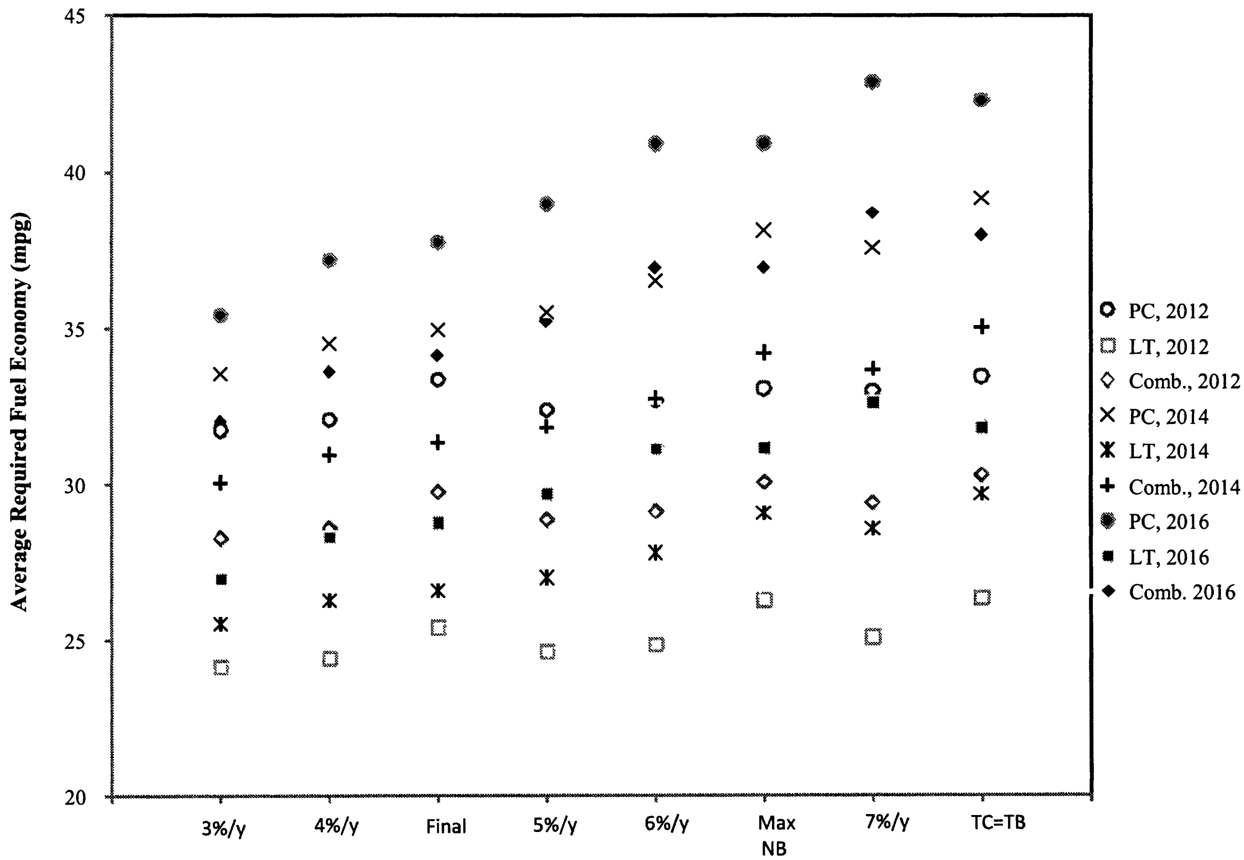
TABLE IV.F–1—ESTIMATED REQUIRED FUEL ECONOMY LEVEL FOR REGULATORY ALTERNATIVES [703]

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8	Alt. 9
	No action	3%/year increase	4%/year increase	~4.3%/year increase	5%/year increase	~6.0%/year increase MNB	6%/year increase	7%/year increase	~6.6%/year increase TCTB
2012:									
Passenger Cars	30.5	31.7	32.1	33.3	32.4	33.0	32.7	33.0	33.4
Light Trucks	24.4	24.1	24.4	25.4	24.6	26.3	24.9	25.1	26.3
Combined	27.8	28.3	28.6	29.7	28.8	30.0	29.1	29.4	30.3
2013:									
Passenger Cars	30.5	32.6	33.3	34.2	33.9	36.1	34.5	35.2	36.7
Light Trucks	24.4	24.8	25.3	26.0	25.8	27.7	26.3	26.8	28.0
Combined	27.8	29.1	29.7	30.5	30.3	32.3	30.8	31.4	32.8
2014:									
Passenger Cars	30.5	33.5	34.5	34.9	35.5	38.1	36.5	37.6	39.2
Light Trucks	24.5	25.5	26.3	26.6	27.0	29.1	27.8	28.6	29.7
Combined	28.0	30.0	30.9	31.3	31.8	34.2	32.7	33.7	35.0
2015:									
Passenger Cars	30.5	34.4	35.8	36.2	37.1	39.4	38.6	40.1	40.7
Light Trucks	24.4	26.2	27.2	27.5	28.3	30.3	29.4	30.5	30.7
Combined	28.0	31.0	32.2	32.6	33.4	35.6	34.7	36.0	36.5
2016:									
Passenger Cars	30.5	35.4	37.2	37.8	39.0	40.9	40.9	42.9	42.3
Light Trucks	24.4	27.0	28.3	28.8	29.7	31.1	31.1	32.6	31.8
Combined	28.1	32.0	33.6	34.1	35.2	36.9	36.9	38.7	38.0

The following figure presents this same information but in a different way, comparing estimated average fuel economy levels required of manufacturers under the eight regulatory alternatives in MYs 2012, 2014, and 2016. Required levels for MY 2013 and MY 2015 fall between those for MYs 2012 and 2014 and MYs 2014 and 2016, respectively. Although required levels for these interim years are not presented in the following figure to limit the complexity of the figure, they do appear in the accompanying FRIA.

[703] Also, the "MNB" and the "TCTB" alternatives depend on the inputs to the agencies' analysis. The sensitivity analysis presented in the FRIA documents the response of these alternatives to changes in key economic inputs. For example, the combined average required fuel economy under the "MNB" alternative is 36.9 mpg under the reference case economic inputs presented here, and ranges from 33.7 mpg to 37.2 mpg under the alternative economic inputs presented in the FRIA. *See* Table X–14 in the FRIA.

Figure IV.F-1 Average Estimated Required Fuel Economy (MYs 2012, 2014, and 2016)



As this figure illustrates, the final standards involve a "faster start" toward increased stringency than do any of the alternatives that increase steadily (*i.e.,* the 3%/y, 4%/y, 5%/y, 6%/y, and 7%/y alternatives). However, by MY 2016, the stringency of the final standards reflects an average annual increase of 4.3%/y. The final standards, therefore, represent an alternative that could be referred to as "4.3% per year with a fast start" or a "front-loaded 4.3% average annual increase."

For each alternative, including today's final standards, NHTSA has estimated all corresponding effects for each model year, including fuel savings, CO_2 reductions, and other effects, as well as the estimated societal benefits of these effects. The accompanying FRIA presents a detailed analysis of these results. Table IV.F–2 presents fuel savings, CO_2 reductions, and total industry cost outlays for model year 2012—2016 for the eight alternatives.

TABLE IV.F–2—FUEL SAVINGS, CO_2 REDUCTIONS, AND TECHNOLOGY COSTS FOR REGULATORY ALTERNATIVES

Regulatory alternative	Fuel savings (b. gal)	CO_2 reductions (mmt)	Cost ($b)
3% per Year	34	373	23
4% per Year	50	539	39
Final (4.3% per Year)	61	655	52
5% per Year	68	709	63
6% per Year	82	840	90
Maximum Net Benefit	90	925	103
7% per Year	93	945	111
Total Cost = Total Benefit	96	986	114

As noted earlier, NHTSA has used the Volpe model to analyze each of these alternatives based on analytical inputs determined jointly with EPA. For a given regulatory alternative, the Volpe model estimates how each manufacturer could apply technology in response to the MY 2012 standard (separately for cars and trucks), carries technologies applied in MY 2012 forward to MY 2013, and then estimates how each manufacturer could apply technology in response to the MY 2013 standard. When analyzing MY 2013, the model considers the potential to add "extra" technology in MY 2012 in order to carry that technology into MY 2013, thereby avoiding the use of more expensive technologies in MY 2013. The model continues in this fashion through MY 2016, and then performs calculations to estimate the costs, effects, and benefits of the applied technologies, and to estimate any civil penalties owed based on projected noncompliance. For each regulatory alternative, the model calculates incremental costs, effects, and benefits relative to the regulatory baseline (*i.e.,* the no-action alternative), under which the MY 2011 CAFE standards continue through MY 2016. The model calculates results for each model year, because EPCA requires that NHTSA set its standards for each model year at the "maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year" considering four statutory factors. Pursuant to EPCA's requirement that NHTSA not consider statutory credits in establishing CAFE standards, NHTSA did not consider FFV credits, credits carried forward and backward, and transferred credits in this calculation[704, 705] In addition, the analysis incorporates fines for some manufacturers that have traditionally paid fines rather than comply with the standards. Because it entails year-by-year examination of eight regulatory alternatives for, separately, passenger cars and light trucks, NHTSA's analysis involves a large amount of information. Detailed results of this analysis are presented separately in NHTSA's FRIA.

In reviewing the results of the various alternatives, NHTSA confirmed that progressive increases in stringency require progressively greater deployment of fuel-saving technology and corresponding increases in technology outlays and related costs, fuel savings, and CO_2 emission reductions. To begin, NHTSA estimated total incremental outlays for additional technology in each model year. The following figure shows cumulative results for MYs 2012–2016 for industry as a whole and Chrysler, Ford, General Motors, Honda, Nissan, and Toyota. This figure focuses on these manufacturers as they currently (in MY 2010) represent three large U.S.-headquartered and three large foreign-headquartered full-line manufacturers.

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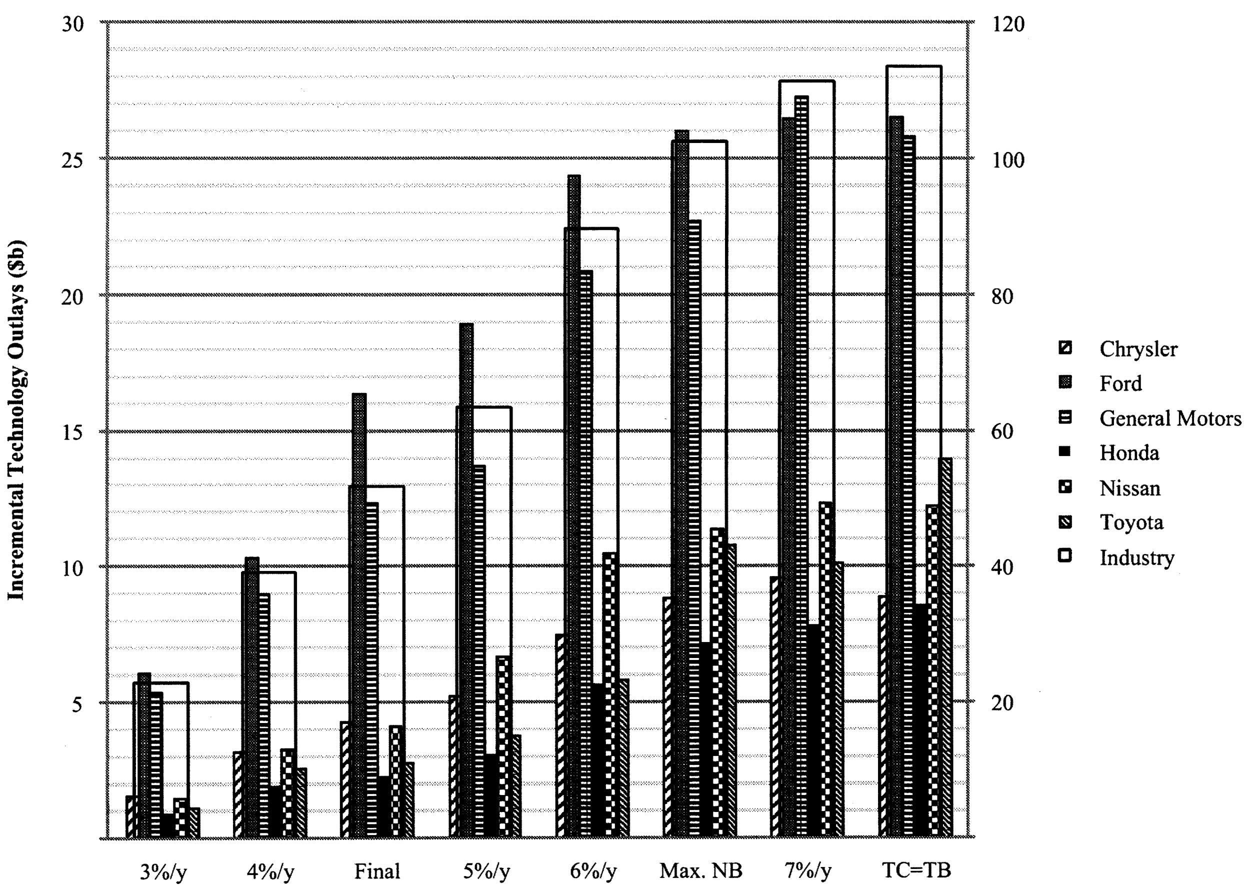
Figure IV.F-2 Incremental Technology Outlays (MYs 2012-2016)



[704] NHTSA has conducted a separate analysis, discussed above in Section I, which accounts for EPCA's provisions regarding FFVs.

[705] For a number of reasons, the results of this modeling differ from EPA's for specific manufacturers, fleets, and model years. These reasons include representing every model year explicitly, accounting for estimates of when vehicle model redesigns will occur, and not considering those compliance flexibilities where EPCA forbids such consideration in setting CAFE standards. It should be noted, however, that these flexibilities in fact provide manufacturers significant latitude to manage their compliance obligations.

As part of the incremental technology outlays, NHTSA also analyzes which technologies manufacturers could apply to meet the standards. In NHTSA's analysis, manufacturers achieve compliance with the fuel economy levels through application of technology rather than through changes in the mix of vehicles produced for sale in the U.S. The accompanying FRIA presents detailed estimates of additional technology penetration into the NHTSA reference fleet associated with each regulatory alternative. The following four charts illustrate the results of this analysis, considering the application of four technologies by six manufacturers and by the industry as a whole. Technologies include gasoline direct injection (GDI), engine turbocharging and downsizing, diesel engines, and strong HEV systems (including CISG systems). GDI and turbocharging are presented because they are among the technologies that play an important role in achieving the fuel economy improvements shown in NHTSA's analysis, and diesels and strong HEVs are presented because they represent technologies involving significant cost and related lead time challenges for widespread use through MY 2016. These figures focus on Chrysler, Ford, General Motors, Honda, Nissan, and Toyota, as above. For each alternative, the figures show additional application of technology by MY 2016.[706]

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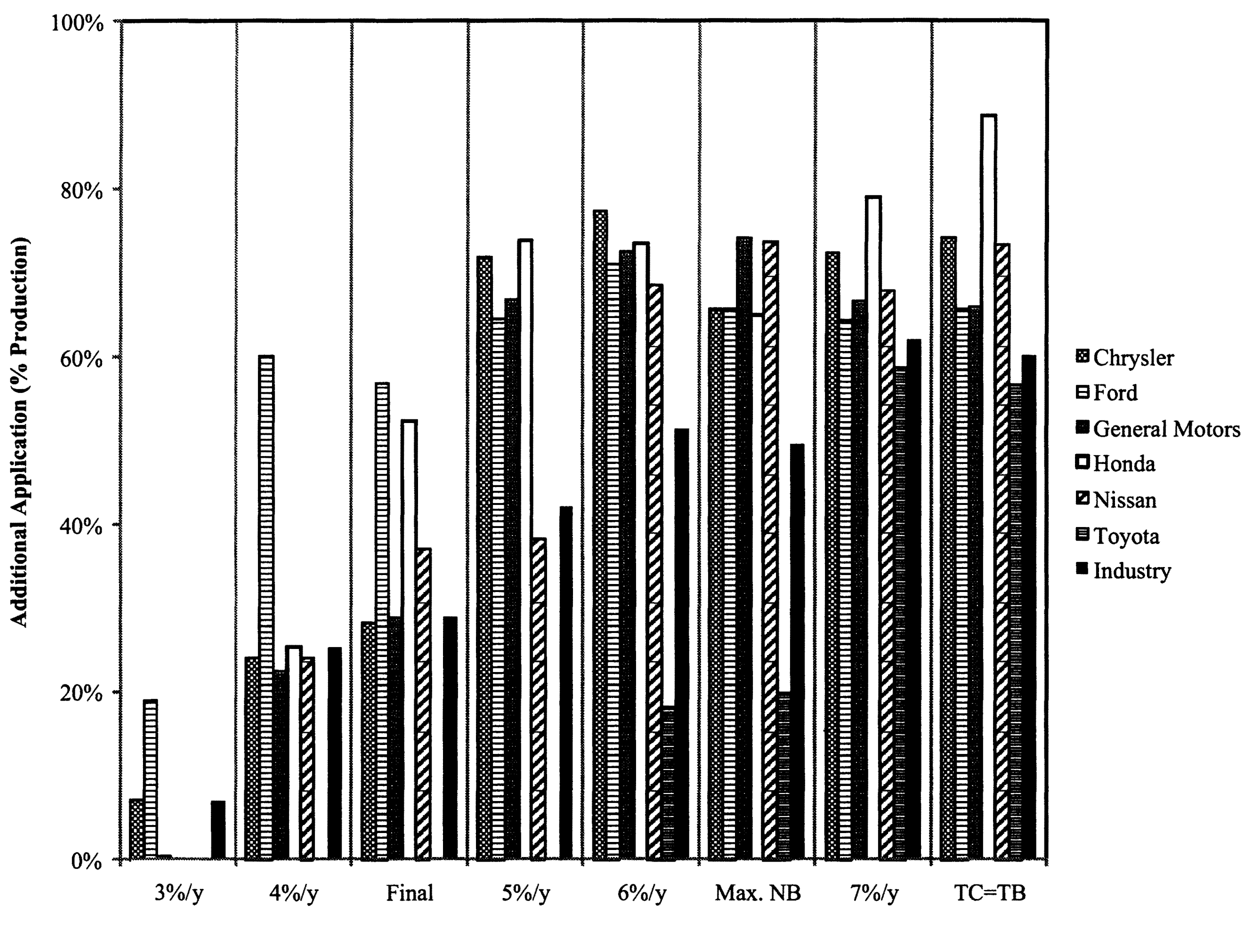
Figure IV.F-3 Additional Application of GDI (MY 2016)



[706] The FRIA presents results for all model years, technologies, and manufacturers, and NHTSA has considered these broader results when considering the eight regulatory alternatives.

Figure IV.F-4 Additional Application of Engine Turbocharging & Downsizing

(MY 2016)

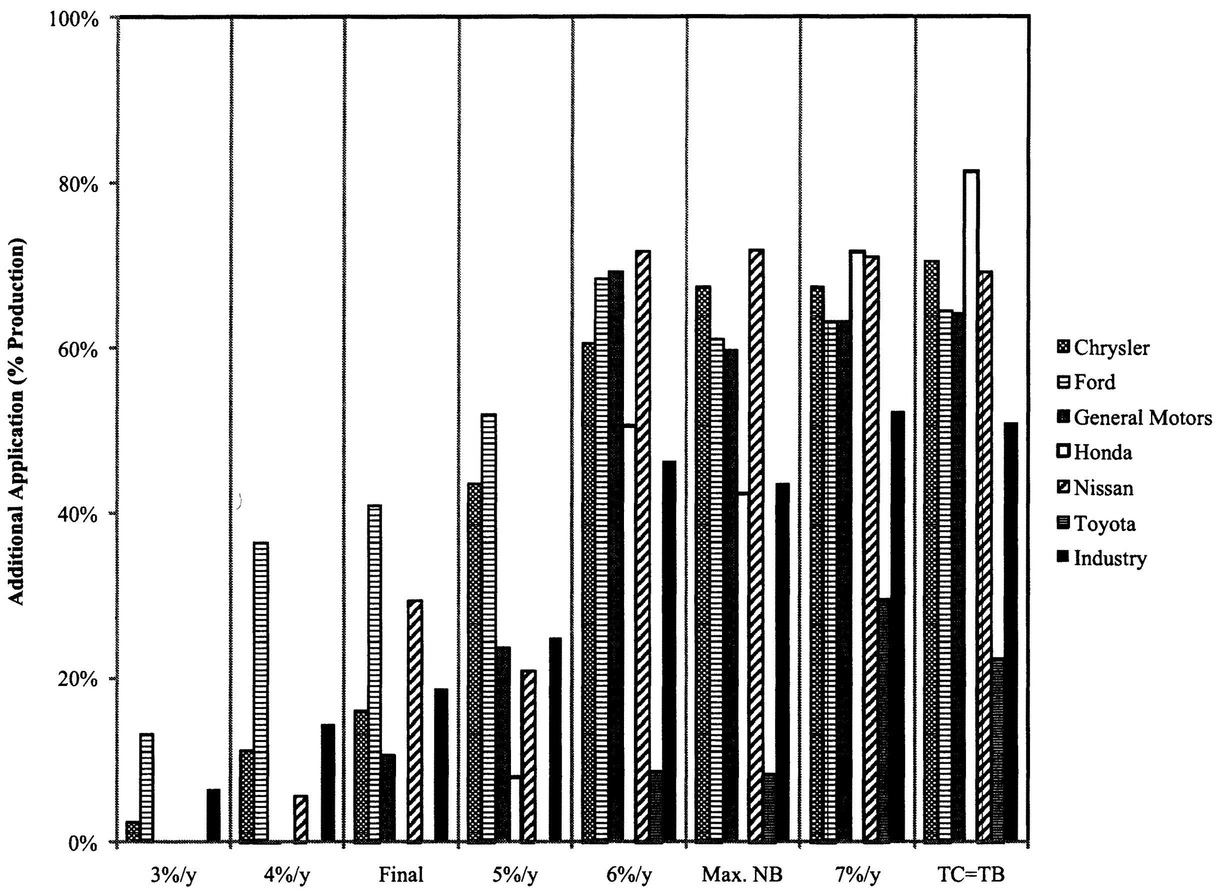


Figure IV.F-5 Additional Application of Diesel Engines (MY 2016)

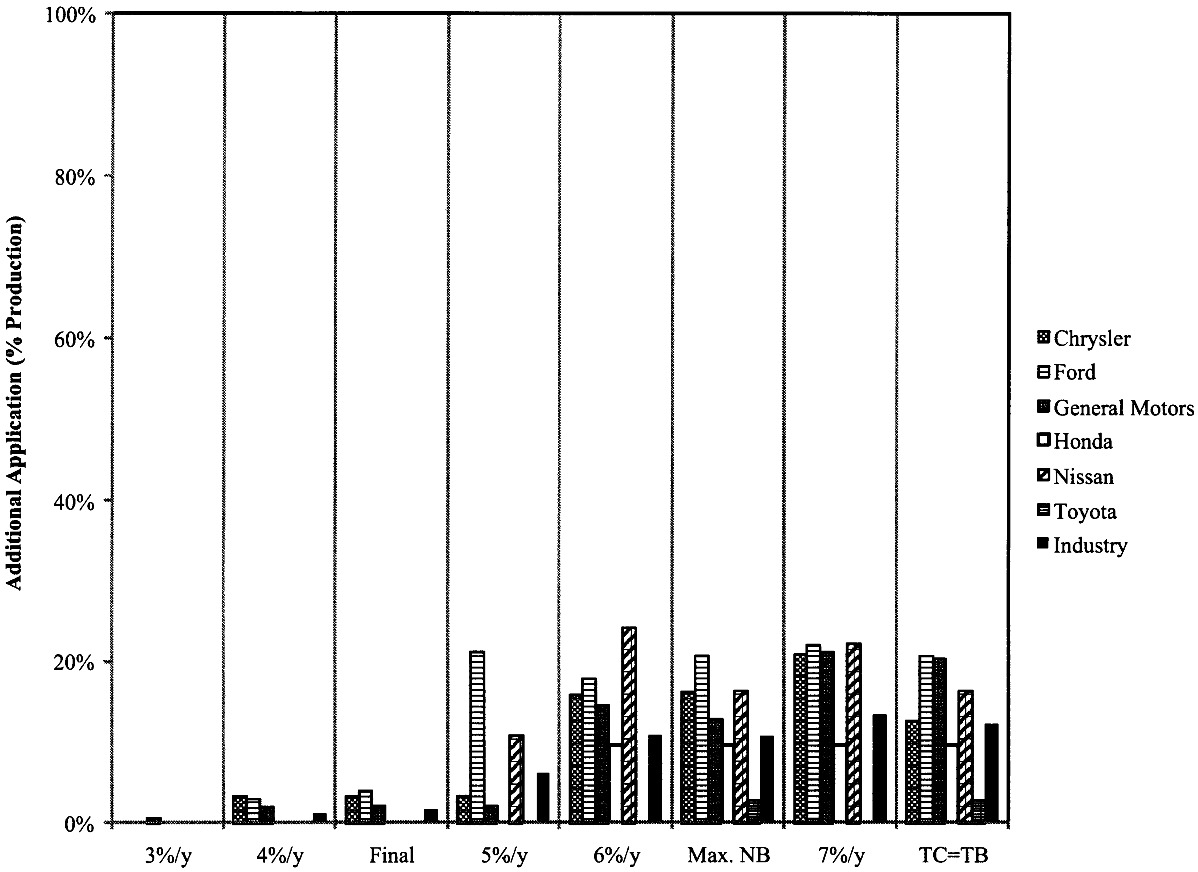
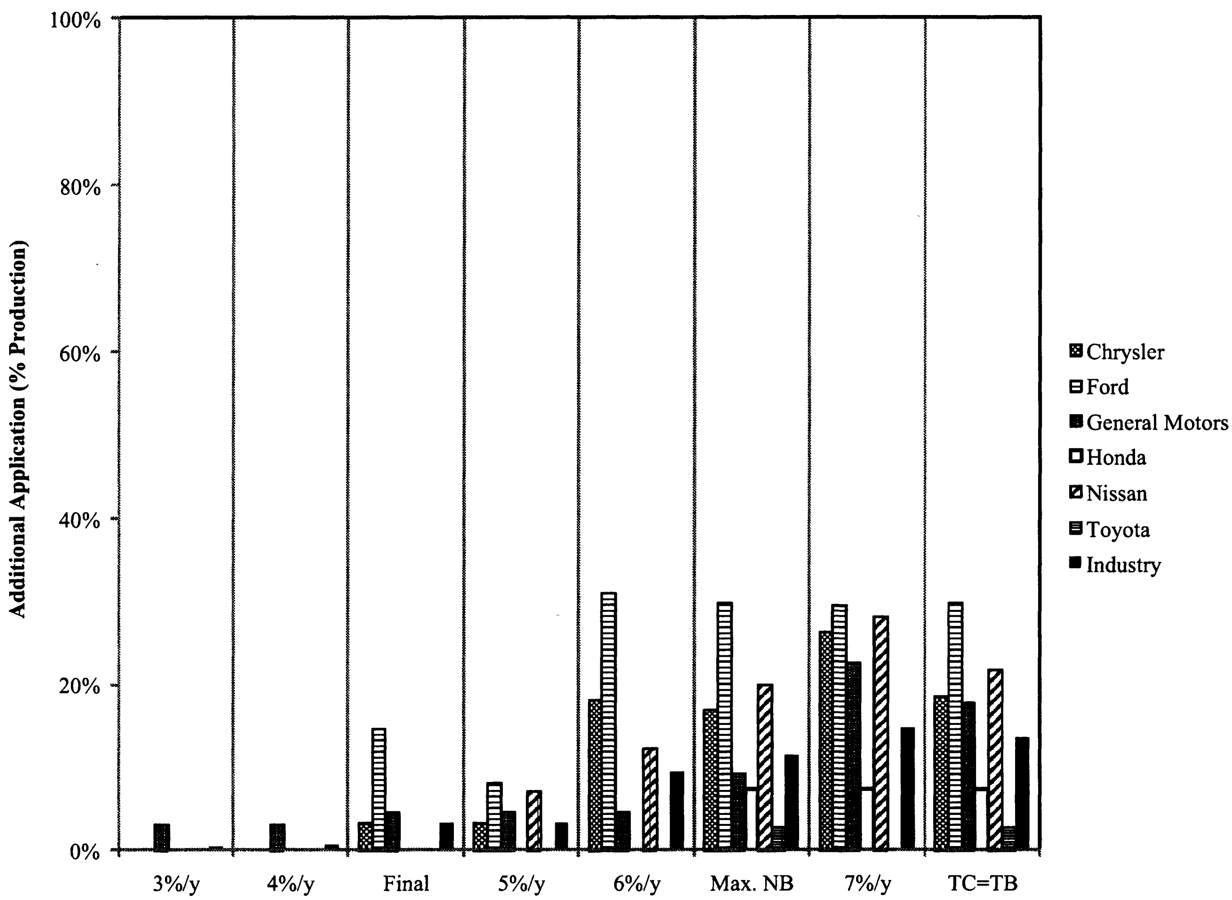
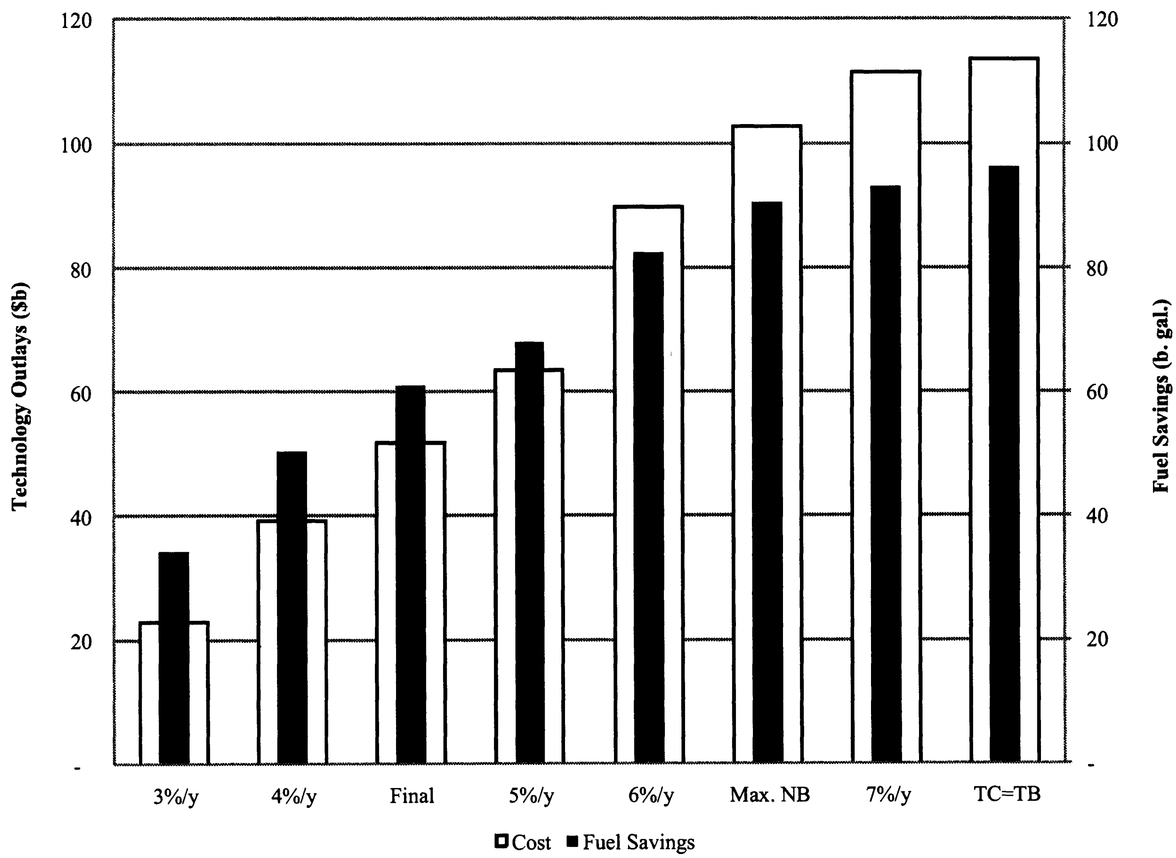


Figure IV.F-6 Additional Application of CISG and Strong HEV Systems (MY 2016)



The modeling analysis demonstrates that applying these technologies, of course, results in fuel savings. Relevant to EPCA's requirement that NHTSA consider, among other factors, economic practicability and the need of the nation to conserve energy, the following figure compares the incremental technology outlays and related cost presented above for the industry to the corresponding cumulative fuel savings.

Figure IV.F-7 Incremental Technology Outlays and Fuel Savings (MYs 2012-2016)



These incremental technology outlays (and corresponding fuel savings) also result in corresponding increases in incremental cost per vehicle, as shown below. The following five figures show industry-wide average incremental (*i.e.,* relative to the reference fleet) per-vehicle costs, for each model year, each fleet, and the combined fleet. Estimates specific to each manufacturer are shown in NHTSA's FRIA.

Figure IV.F-8 Average Incremental Per-Vehicle Costs (MY 2012)

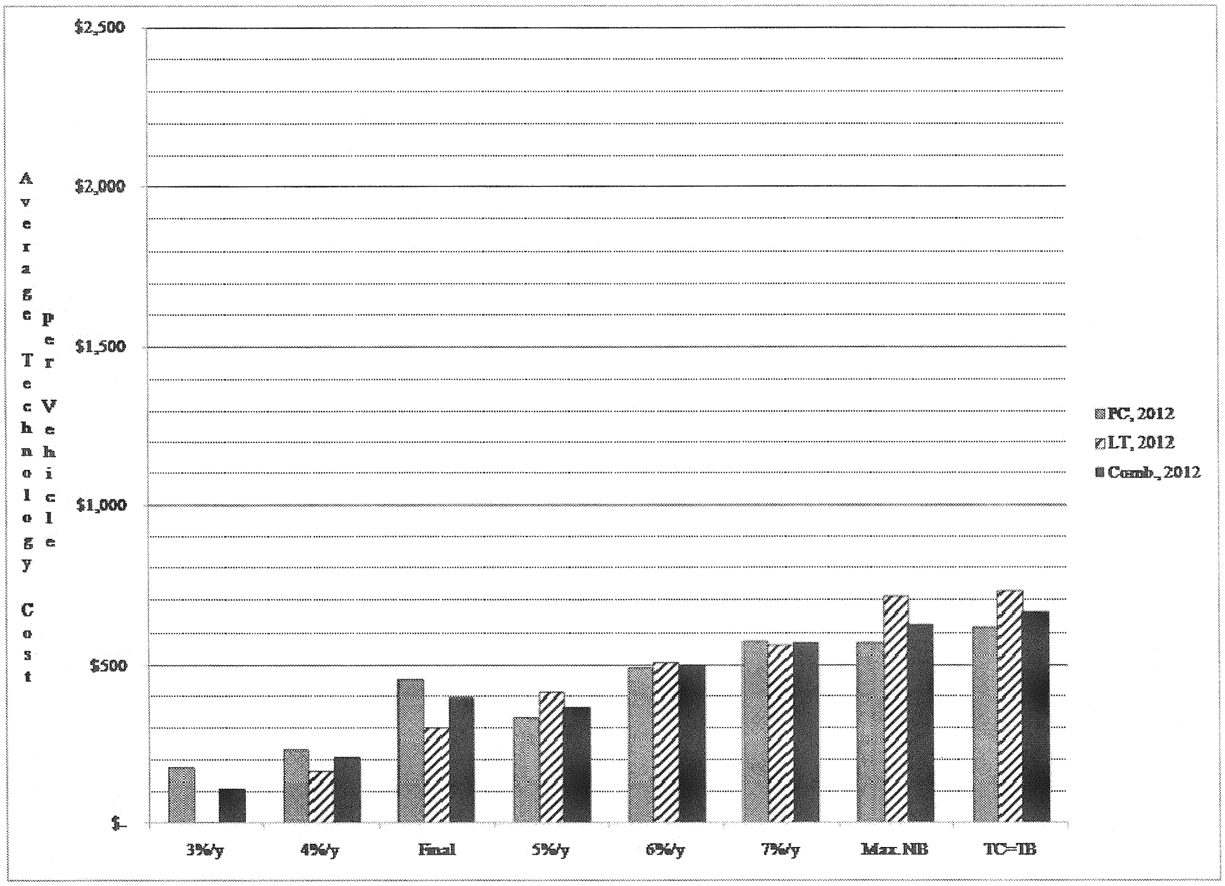


Figure IV.F-9 Average Incremental Per-Vehicle Costs (MY 2013)

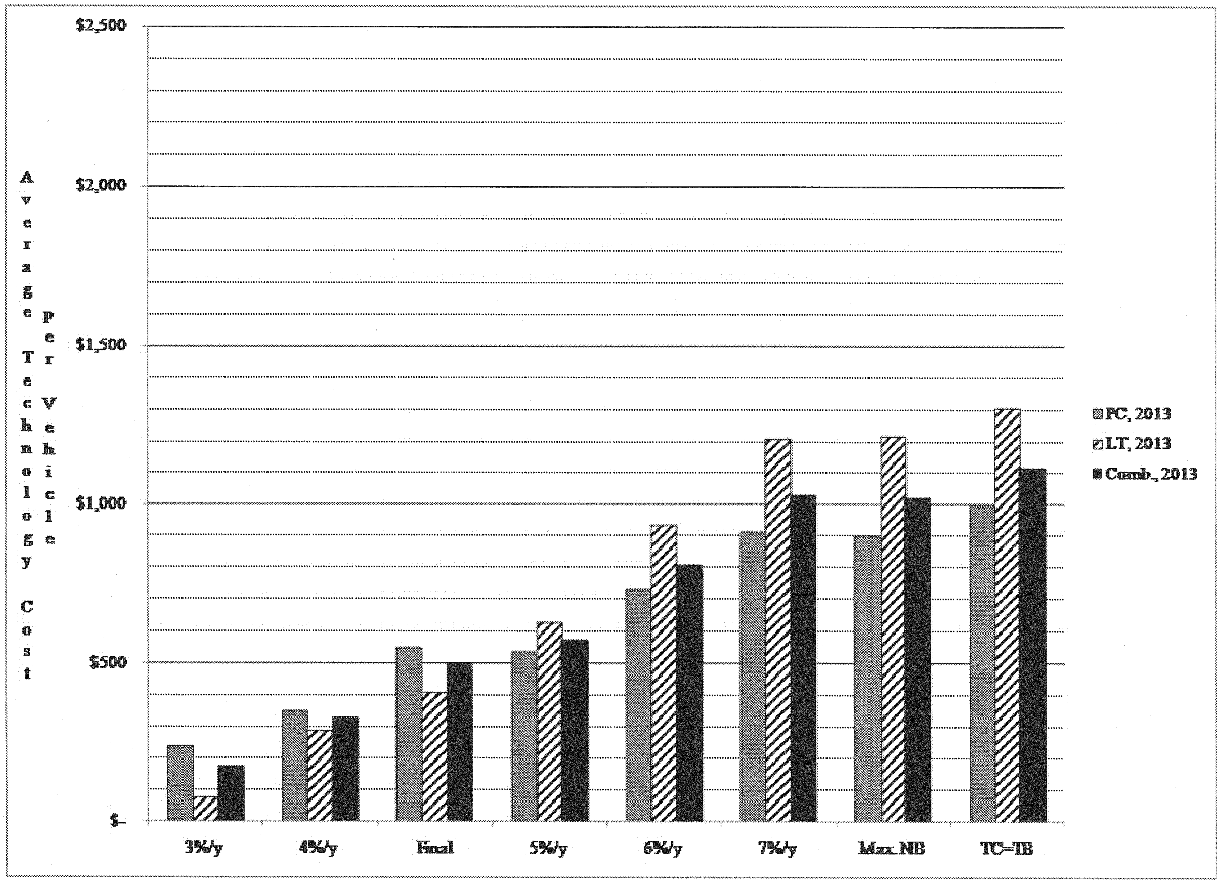


Figure IV.F-10 Average Incremental Per-Vehicle Costs (MY 2014)

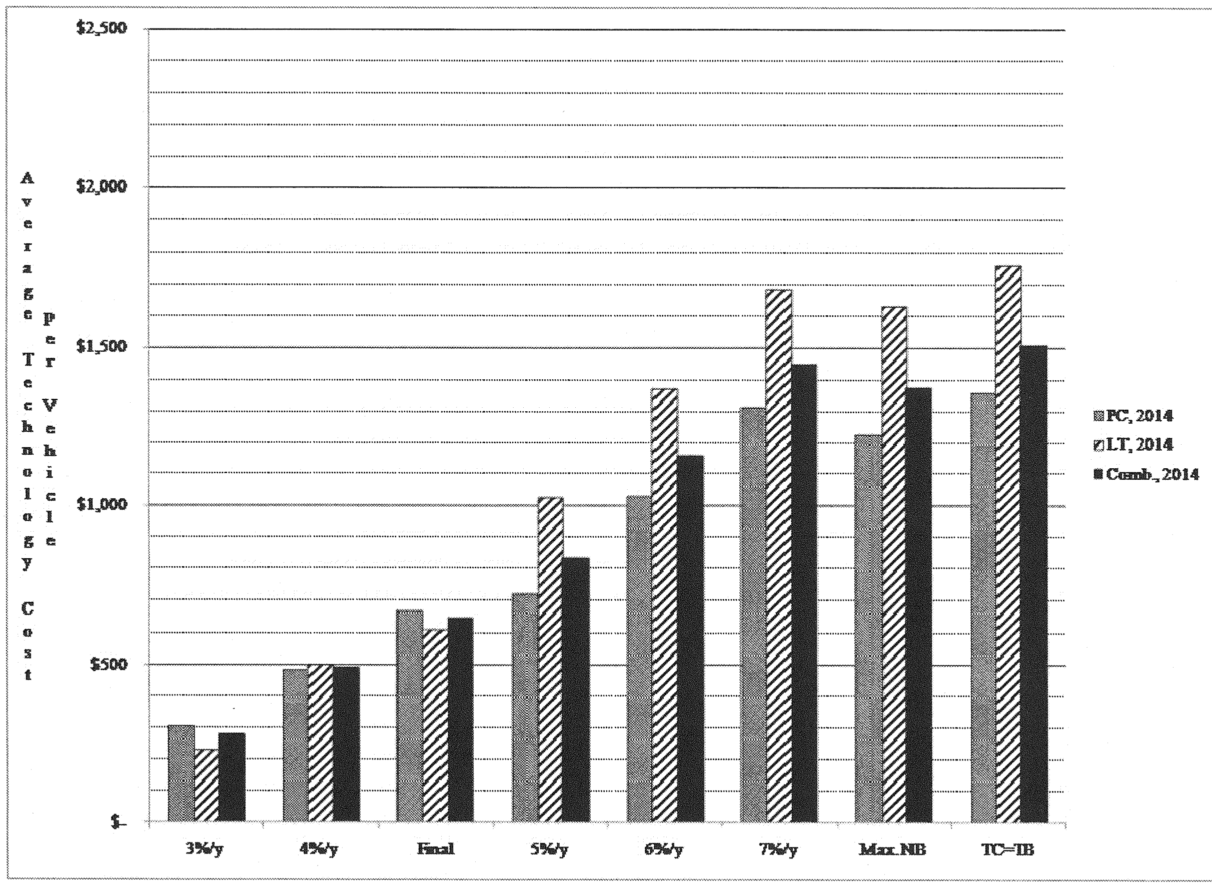


Figure IV.F-11 Average Incremental Per-Vehicle Costs (MY 2015)

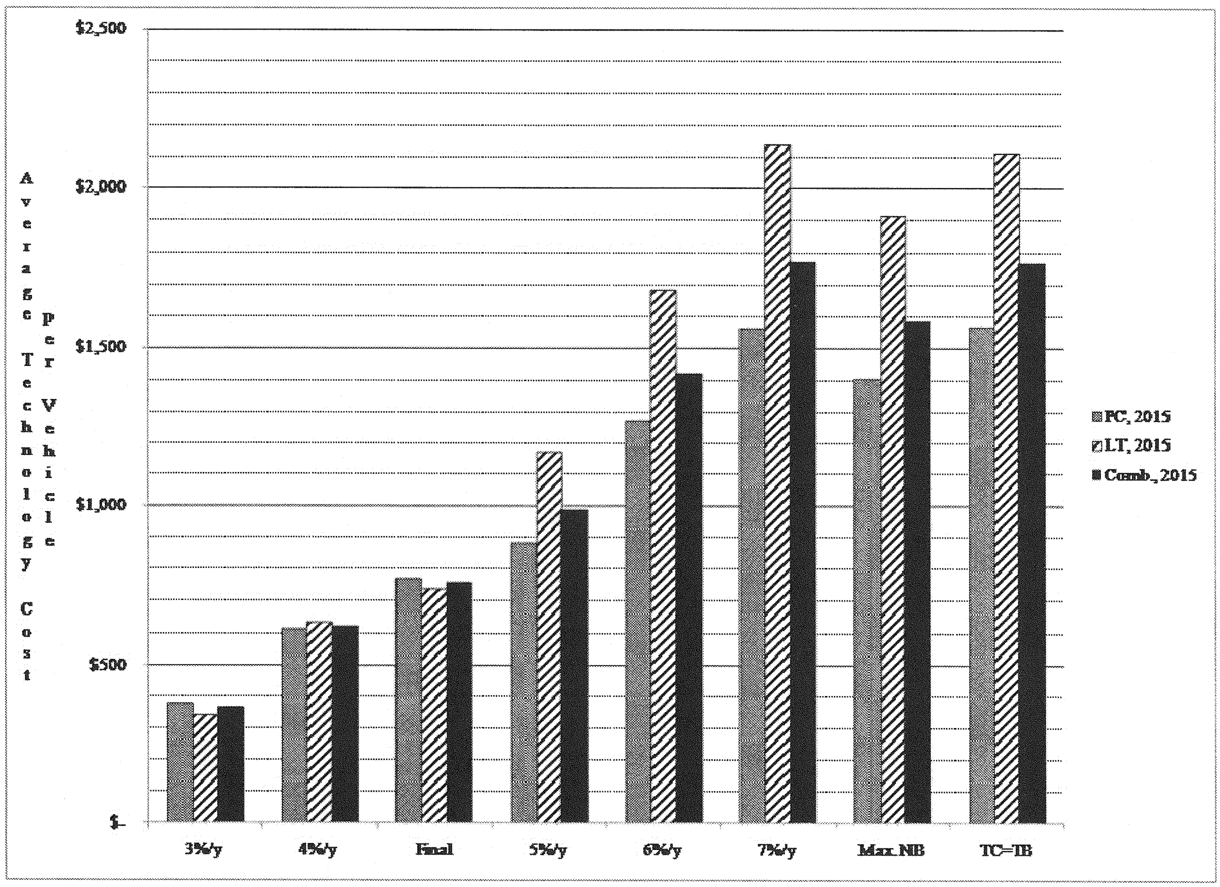
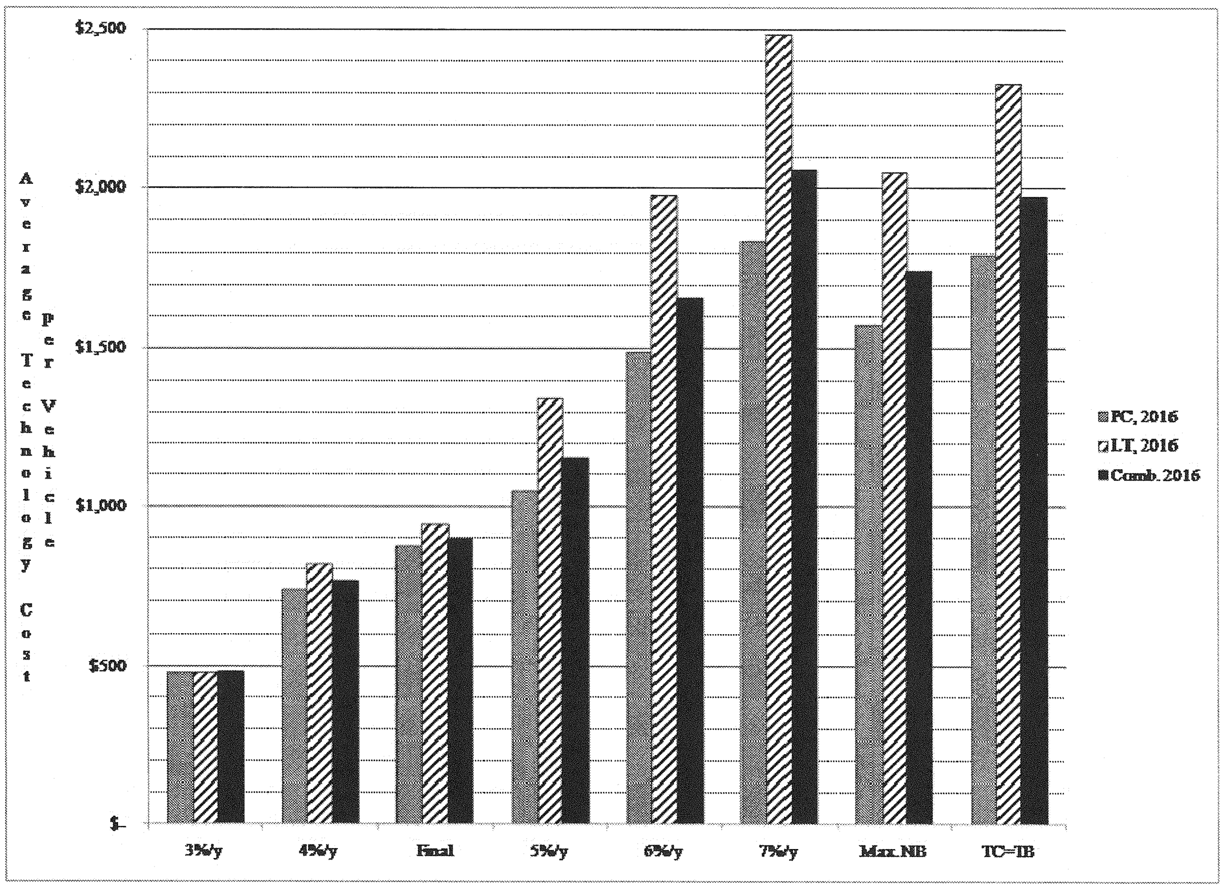


Figure IV.F-12 Average Incremental Per-Vehicle Costs (MY 2016)



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As discussed in the NPRM, the agency began the process of winnowing the alternatives by determining whether any of the lower stringency alternatives should be eliminated from consideration. To begin with, the agency needs to ensure that its standards are high enough to enable the combined fleet of passenger cars and light trucks to achieve at least 35 mpg not later than MY 2020, as required by EISA. Achieving that level makes it necessary for the chosen alternative to increase at over 3 percent annually. Additionally, given that CO_2 and fuel savings are very closely correlated, the 3%/y and 4%/y alternative would not produce the reductions in fuel savings and CO_2 emissions that the Nation needs at this time. Picking either of those alternatives would unnecessarily result in foregoing substantial benefits, in terms of fuel savings and reduced CO_2 emissions, which would be achievable at reasonable cost. And finally, neither the 3%/y nor the 4%/y alternatives would lead to the regulatory harmonization that forms a vital core principle of the National Program that EPA and NHTSA are jointly striving to implement. These alternatives would give inadequate weight to other standards of the Government, specifically EPA's and CARB's. Thus, the agency concluded that alternatives less stringent than the proposed standards would not yield the emissions reductions required to produce a harmonized national program and would not produce corresponding fuel savings, and therefore would not place adequate emphasis on the nation's need to conserve energy. NHTSA has therefore concluded that it must reject the 3%/y and 4%/y alternatives.

NHTSA then considered the "environmentally-preferable" alternative. Based on the information provided in the FEIS, the environmentally-preferable alternative would be that involving stringencies that increase at 7% annually.[707] NHTSA notes that NEPA does not require that agencies choose the environmentally-preferable alternative if doing so would be contrary to the choice that the agency would otherwise make under its governing statute. Given the levels of technology and cost required by the environmentally-preferable alternative and the lack of lead time to achieve such levels between now and MY 2016, as discussed further below, NHTSA concludes that the environmentally-preferable alternative would not be economically practicable or technologically feasible, and thus concludes that it would result in standards that would be beyond the level achievable for MYs 2012–2016.

For the other alternatives, NHTSA determined that it would be inappropriate to choose any of the other more stringent alternatives due to concerns over lead time and economic practicability. There are real-world technological and economic time constraints which must be considered due to the short lead time available for the early years of this program, in particular for MYs 2012 and 2013. The alternatives more stringent than the final standards begin to accrue costs considerably more rapidly than they accrue fuel savings and emissions reductions, and at levels that are increasingly economically burdensome, especially considering the need to make underlying investments (*e.g.,* for

[707] *See, e.g.,* FEIS, figure S–12, p. 18, which shows that 7%/y alternative yields greatest cumulative effect on global mean temperature.

engineering and tooling) well in advance of actual production. As shown in Figures IV–2 to IV–6 above, while the final standards already require aggressive application of technologies, more stringent standards would require more widespread use (including more substantial implementation of advanced technologies such as stoichiometric gasoline direct injection engines, diesel engines, and strong hybrids), and would raise serious issues of adequacy of lead time, not only to meet the standards but to coordinate such significant changes with manufacturers' redesign cycles. The agency maintains, as it has historically, that there is an important distinction between considerations of technological feasibility and economic practicability, both of which enter into the agency's determination of the maximum feasible levels of stringency. A given level of performance may be technologically feasible (*i.e.,* setting aside economic constraints) for a given vehicle model. However, it would not be economically practicable to require a level of fleet average performance that assumes every vehicle will immediately (*i.e.,* within 18 months of the rule's promulgation) perform at its highest technologically feasible level, because manufacturers do not have unlimited access to the financial resources or the time required to hire enough engineers, build enough facilities, and install enough tooling. The lead time reasonably needed to make capital investments and to devote the resources and time to design and prepare for commercial production of a more fuel efficient vehicle is an important element that NHTSA takes into consideration in establishing the standards.

In addition, the figures presented above reveal that increasing stringency beyond the final standards would entail significant additional application of technology. Among the more stringent alternatives, the one closest in stringency to the standards being finalized today is the alternative under which combined CAFE stringency increases at 5% annually. As indicated above, this alternative would yield fuel savings and CO_2 reductions about 11% and 8% higher, respectively, than the final standards. However, compared to the final standards, this alternative would increase outlays for new technologies during MY 2012–2016 by about 22%, or $12b. Average MY 2016 cost increases would, in turn, rise from $903 under the final standards to $1,152 when stringency increases at 5% annually. This represents a 28% increase in per-vehicle cost for only a 3% increase in average performance (on a gallon-per-mile basis to which fuel savings are proportional). Additionally, the 5%/y alternative disproportionally burdens the light truck fleet requiring a nearly $400 (42 percent) cost increase in MY 2016 compared to the final standards. The following three tables summarize estimated manufacturer-level average incremental costs for the 5%/y alternative and the average of the passenger and light truck fleets:

TABLE IV.F–3—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER THE 5%/Y ALTERNATIVE CAFE STANDARDS FOR PASSENGER CARS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	3	4	24	184	585
Chrysler	734	1,303	1,462	1,653	1,727
Daimler	....	....	410	801	1,109
Ford	743	1,245	1,261	1,583	1,923
General Motors	448	823	1,187	1,425	1,594
Honda	50	109	271	375	606
Hyundai	747	877	1,057	1,052	1,124
Kia	49	128	197	261	369
Mazda	555	718	1,166	1,407	1,427
Mitsubishi	534	507	2,534	3,213	3,141
Nissan	294	491	965	1,064	1,125
Porsche	68	(52)	(51)	(50)	(49)
Subaru	292	324	1,372	1,723	1,679
Suzuki	....	959	1,267	1,316	1,540
Tata	111	93	183	306	710
Toyota	31	29	52	129	212
Volkswagen	145	428	477	492	783
Average	337	540	726	886	1,053

TABLE IV.F–4—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER THE 5%/Y ALTERNATIVE CAFE STANDARDS FOR LIGHT TRUCKS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	169	160	201	453	868
Chrysler	360	559	1,120	1,216	1,432
Daimler	60	55	51	52	51
Ford	1,207	1,663	1,882	2,258	2,225
General Motors	292	628	866	968	1,136
Honda	258	234	611	750	1,047
Hyundai	711	685	1,923	1,909	1,862
Kia	47	293	556	782	1,157
Mazda	248	408	419	519	768
Mitsubishi	....	....	1,037	1,189	1,556
Nissan	613	723	2,142	2,148	2,315
Porsche	....	(0)	(1)	469	469
Subaru	1,225	1,220	1,365	1,374	1,330
Suzuki	....	1,998	1,895	1,837	2,096

TABLE IV.F–4—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER THE 5%/Y ALTERNATIVE CAFE STANDARDS FOR LIGHT TRUCKS—Continued

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Tata	....	....	....	....	503
Toyota	63	187	594	734	991
Volkswagen	....	....	514	458	441
Average	415	628	1,026	1,173	1,343

TABLE IV.F–5—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER THE 5%/Y ALTERNATIVE CAFE STANDARDS FOR PASSENGER CARS AND LIGHT TRUCKS COMBINED

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	72	64	84	265	666
Chrysler	499	870	1,272	1,414	1,569
Daimler	20	20	281	554	773
Ford	914	1,407	1,498	1,838	2,034
General Motors	371	726	1,033	1,205	1,379
Honda	135	157	396	518	769
Hyundai	742	838	1,237	1,186	1,235
Kia	49	168	273	355	506
Mazda	500	667	1,053	1,272	1,330
Mitsubishi	371	352	1,973	2,386	2,506
Nissan	399	565	1,344	1,387	1,467
Porsche	52	(39)	(35)	130	124
Subaru	617	628	1,369	1,597	1,553
Suzuki	....	1,134	1,381	1,404	1,630
Tata	61	56	101	182	629
Toyota	43	82	239	333	466
Volkswagen	117	333	486	486	723
Average	367	573	836	987	1,152

These cost increases derive from increased application of advanced technologies as stringency increases past the levels in the final standards. For example, under the final standards, additional diesel application rates average 1.6% for the industry and range from 0% to 3% among Chrysler, Ford, GM, Honda, Nissan, and Toyota. Under standards increasing in combined stringency at 5% annually, these rates more than triple, averaging 6.2% for the industry and ranging from 0% to 21% for the same six manufacturers.

These technology and cost increases are significant, given the amount of lead-time between now and model years 2012–2016. In order to achieve the levels of technology penetration for the final standards, the industry needs to invest significant capital and product development resources right away, in particular for the 2012 and 2013 model year, which is only 2–3 years from now. For the 2014–2016 time frame, significant product development and capital investments will need to occur over the next 2–3 year in order to be ready for launching these new products for those model years. Thus a major part of the required capital and resource investment will need to occur now and over the next few years, under the final standards. NHTSA believes that the final rule requires significant investment and product development costs for the industry, focused on the next few years.

It is important to note, and as discussed later in this preamble, as well as in the Joint Technical Support Document and the agency's Regulatory Impact Analysis, the average model year 2016 per-vehicle cost increase of more than $900 includes an estimate of both the increase in capital investments by the auto companies and the suppliers as well as the increase in product development costs. These costs can be significant, especially as they must occur over the next 2–3 years. Both the domestic and transplant auto firms, as well as the domestic and world-wide automotive supplier base, are experiencing one of the most difficult markets in the U.S. and internationally that has been seen in the past 30 years. One major impact of the global downturn in the automotive industry and certainly in the U.S. is the significant reduction in product development engineers and staffs, as well as a tightening of the credit markets which allow auto firms and suppliers to make the near-term capital investments necessary to bring new technology into production.

The agency concludes that the levels of technology penetration required by the final standards are reasonable. Increasing the standards beyond those levels would lead to rapidly increasing dependence on advanced technologies with higher costs—technology that, though perhaps technologically feasible for individual vehicle models, would, at the scales involved, pose too great an economic burden given the state of the industry, particularly in the early years of the rulemaking time frame.[708]

Therefore, the agency concluded that these more stringent alternatives would give insufficient weight to economic practicability and related lead time

[708] Although the final standards are projected to be slightly more costly than the 5% alternative in MY 2012, that alternative standard becomes progressively more costly than the final standards in the remaining model years. See Figures IV.F.8 through IV.F.10 above. Moreover, as discussed above, after MY 2012, the 5% alternative standard yields less incremental fuel economy benefits at increased cost (both industry-wide and per vehicle), directionally the less desirable result. These increased costs incurred to increase fuel economy through MY 2016 would impose significantly increased economic burden on the manufacturers in the next few calendar years to prepare for these future model years. In weighing the statutory factors, NHTSA accordingly rejected this alternative in favor of the final standard.

concerns, given the current state of the industry and the rate of increase in stringency that would be required. Overall, the agency concluded that among the alternatives considered by the agency, the proposed alternative contained the maximum feasible CAFE standards for MYs 2012–2016 as they were the most appropriate balance of the various statutory factors.

Some commenters argued that the agency should select a more stringent alternative than that proposed in the NPRM. The Union of Concerned Scientists (UCS) commented that NHTSA should set standards to produce the "maximum environmental benefit" available at "reasonable" cost, and at least at the stringency maximizing net benefits. Students from the University of California at Santa Barbara commented that the agency should have based standards not just on technologies known to be available, but also on technologies that may be available in the future—and should do so in order to force manufacturers to "reach" to greater levels of performance. Also, the Center for Biological Diversity (CBD) commented that, having conducted an unbiased cost-benefit analysis showing benefits three times the magnitude of costs for the proposed alternative, the agency should select a more stringent alternative. CBD also argued that the agency should have evaluated the extent to which manufacturers could deploy technology more rapidly than suggested by a five-year redesign cycle.

Conversely, other commenters argued that NHTSA should select a less stringent alternative, either in all model years or at least in the earlier model years. Chrysler, VW, and the Alliance of Automobile Manufacturers commented that the stringency of NHTSA's CAFE standards should be further reduced relative to that of EPA's GHG emissions standards, so that manufacturers would not be required by CAFE to add any tailpipe technology beyond what they thought would be necessary to meet an mpg level of 35.5 minus the maximum possible A/C credits that could be obtained under the EPA program. Also, Chrysler, Daimler, Toyota, Volkswagen, and the Alliance argued that the agency should reduce the rate of increase in stringency to produce steadier and more "linear" increases between MY 2011 and MY 2016. In addition, the Heritage Foundation commented that the proposed standards would, in effect, force accelerated progress toward EISA's "35 mpg by 2020" requirement, causing financially-stressed manufacturers to incur undue costs that would be passed along to consumers.

However, most commenters supported the agency's selection of the proposed standards. The American Chemical Society, the New York Department of Environmental Conservation, the Washington State Department of Ecology, and several individuals all expressed general support for the levels of stringency proposed by NHTSA as part of the joint proposal. General Motors and Nissan both indicated that the proposed standards are consistent with the National Program announced by the President and supported in letters of commitment signed by these companies' executives. Finally, the California Air Resources Board (CARB) strongly supported the stringency of the proposed standards, as well as the agencies' underlying technical analysis and weighing of statutory factors. CARB further commented that the stringency increases in the earlier model years are essential to providing environmental benefits at least as great as would be achieved through state-level enforcement of CARB's GHG emissions standards.[709]

The agency has considered these comments and all others, and having considered those comments, believes the final standards best balance all relevant factors that the agency considers when determining maximum feasible CAFE standards. As discussed below, having updated inputs to its analysis and correspondingly updated its definition and analysis of these regulatory alternatives, the agency continues to conclude that manufacturers can respond to the proposed standards with technologies that will be available at reasonable cost. The agency finds that alternatives less stringent that the one adopted today would leave too much technology "on the shelf" unnecessarily, thereby failing to deliver the fuel savings that the nation needs or to yield environmental benefits necessary to support a harmonized national program. In response to some manufacturers' suggestion that NHTSA's CAFE standards should be made even less stringent compared to EPA's GHG emissions standards, NHTSA notes that the difference, consistent with the underlying Notice of Intent, is based on the agencies' estimate of the *average* amount of air conditioning credit earned, not the maximum theoretically available, and that NHTSA's analysis indicates that most manufacturers can achieve the CAFE standards by MY 2016 using tailpipe technologies. This is fully consistent with the agency's historical position. As NHTSA explained in the NPRM, the Conference Report for EPCA, as enacted in 1975, makes clear, and applicable law affirms, "a determination of maximum feasible average fuel economy should not be keyed to the single manufacturer which might have the most difficulty achieving a given level of average fuel economy." *CEI–I,* 793 F.2d 1322, 1352 (DC Cir. 1986). Instead, NHTSA is compelled "to weigh the benefits to the nation of a higher fuel economy standard against the difficulties of individual automobile manufacturers." *Id.* Thus, the law permits CAFE standards exceeding the projected capability of any particular manufacturer as long as the standard is economically practicable for the industry as a whole.

While some manufacturers may find greater A/C improvements to be a more cost-effective way of meeting the GHG standards, that does not mean those manufacturers will be *unable* to meet the CAFE standards with tailpipe technologies. NHTSA's analysis has demonstrated a feasible path to compliance with the CAFE standards for most manufacturers using those technologies. "Economic practicability" means just that, practicability, and need not always mean what is "cheapest" or "most cost-effective" for a specific manufacturer. Moreover, many of the A/C improvements on which manufacturers intend to rely for meeting the GHG standards will reduce GHG emissions, specifically HFC emissions, but they will not lead to greater fuel savings.[710] The core purpose of the CAFE standards under EPCA is to reduce fuel consumption. NHTSA believes that less stringent standards would allow tailpipe fuel economy technologies to be left on the table that can be feasibly and economically applied, and failing to apply them would lead to a loss in fuel savings. This would not place appropriate emphasis on the core CAFE purpose of conserving fuel. For this reason, we decline to reduce the stringency of our standards as requested by some manufacturers. Similarly, we decline to pursue with EPA in this rulemaking the suggestion by one commenter that that

[709] Generally speaking, the cumulative benefits (in terms of fuel savings and GHG reductions) of front-loaded standards will be greater than standards that increase linearly.

[710] This is not to say that NHTSA means, in any way, to deter manufacturers from employing A/C technologies to meet EPA's standards, but simply to say that NHTSA's independent obligation to set maximum feasible CAFE standards to be met through application of tailpipe technologies alone must be fulfilled, while recognizing the flexibilities offered in another regulatory program.

agency's calculation authority under EPCA be used to provide A/C credits.

With respect to some manufacturers' concerns regarding the increase in stringency through MY 2013, the agency notes that stringency increases in these model years are especially important in terms of the accumulation of fuel savings and emission reductions over time. In addition, a weakening would risk failing to produce emission reductions at least as great as might be achieved through CARB's GHG standards. Therefore, the agency believes that alternatives less stringent than the one adopted today would not give sufficient emphasis to the nation's need to conserve energy. The requirement to set standards that increase ratably between MYs 2011 and 2020 must also be considered in the context of what levels of standards would be maximum feasible. The agency believes that the rate of increase of the final standards is reasonable.

On the other hand, the agency disagrees with comments by UCS, CBD, and others indicating that more stringent standards would be appropriate. As discussed above, alternatives more stringent than the one adopted today would entail a rapidly increasing dependence on the most expensive technologies and those which are technically more demanding to implement, with commensurately rapid increases in costs. In the agency's considered judgment, these alternatives are not economically practicable, nor do they provide correspondingly sufficient lead time. The agency also disagrees with CBD's assertion that NHTSA and EPA have been overly conservative in assuming an average redesign cycle of 5 years. There are some manufacturers who apply longer cycles (such as smaller manufacturers described above), there are others who have shorter cycles for some of their products, and there are some products (*e.g.,* cargo vans) that tend to be redesigned on longer cycles. NHTSA believes that there are no full line manufacturers who can maintain significant redesigns of vehicles (with relative large sales) in 1 or 2 years, and CBD has provided no evidence indicating this would be practicable. A complete redesign of the entire U.S. light-duty fleet by model year 2012 is clearly infeasible, and NHTSA and EPA believe that several model years additional lead time is necessary in order for the manufacturers to meet the most stringent standards. The graduated increase in the stringency of the standards from MYs 2012 through 2016 accounts for the economic necessity of timing the application of many major technologies to coincide with scheduled model redesigns.

In contrast, through analysis of the illustrative results shown above, as well as the more complete and detailed results presented in the accompanying FRIA, NHTSA has concluded that the final standards are technologically feasible and economically practicable. The final standards will require manufacturers to apply considerable additional technology, starting with very significant investment in technology design, development and capital investment called for in the next few years. Although NHTSA cannot predict how manufacturers *will* respond to the final standards, the agency's analysis indicates that the standards could lead to significantly greater use of advanced engine and transmission technologies. As shown above, the agency's analysis shows considerable increases in the application of SGDI systems and engine turbocharging and downsizing. Though not presented above, the agency's analysis also shows similarly large increases in the use of dual-clutch automated manual transmissions (AMTs). However, the agency's analysis does not suggest that the additional application of these technologies in response to the final standards would extend beyond levels achievable by the industry. These technologies are likely to be applied to at least some extent even in the absence of new CAFE standards. In addition, the agency's analysis indicates that most manufacturers would rely only to a limited extent on the most costly technologies, such as diesel engines and advanced technologies, such as strong HEVs.

As shown below, NHTSA estimates that the final standards could lead to average incremental costs ranging from $303 per vehicle (for light trucks in MY 2012) to $947 per vehicle (for light trucks in MY 2016), increasing steadily from $396 per vehicle for all light vehicles in MY 2012 to $903 for all light vehicle in MY 2016. NHTSA estimates that these costs would vary considerably among manufacturers, but would rarely exceed $1,800 per vehicle. The following three tables summarize estimated manufacturer-level average incremental costs for the final standards and the average of the passenger and light truck fleets:

TABLE IV.F–6—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER FINAL PASSENGER CAR CAFE STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	3	4	24	184	585
Chrysler	734	1,043	1,129	1,270	1,358
Daimler			410	801	1,109
Ford	1,619	1,537	1,533	1,713	1,884
General Motors	448	896	1,127	1,302	1,323
Honda	33	98	205	273	456
Hyundai	559	591	768	744	838
Kia	110	144	177	235	277
Mazda	555	656	799	854	923
Mitsubishi	534	460	1,588	1,875	1,831
Nissan	119	323	707	723	832
Porsche	68	(52)	(51)	(50)	(49)
Subaru	292	324	988	1,385	1,361
Suzuki		625	779	794	1,005
Tata	111	93	183	306	710
Toyota	31	29	41	121	126
Volkswagen	145	428	477	492	783
Average	455	552	670	774	880

TABLE IV.F–7—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER FINAL LIGHT TRUCK CAFE STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	252	239	277	281	701
Chrysler	360	527	876	931	1,170
Daimler	60	51	51	52	51
Ford	465	633	673	1,074	1,174
General Motors	292	513	749	807	986
Honda	233	217	370	457	806
Hyundai	693	630	1,148	1,136	1,113
Kia	400	467	582	780	1,137
Mazda	144	241	250	354	480
Mitsubishi			553	686	1,371
Nissan	398	489	970	1,026	1,362
Porsche		(1)	(1)	469	469
Subaru	1,036	995	1,016	1,060	1,049
Suzuki		1,797	1,744	1,689	1,732
Tata					503
Toyota	130	150	384	499	713
Volkswagen			514	458	441
Average	303	411	615	741	947

TABLE IV.F–8—AVERAGE INCREMENTAL COSTS ($/VEHICLE) UNDER FINAL CAFE STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	106	94	110	213	618
Chrysler	499	743	989	1,084	1,257
Daimler	20	18	281	554	773
Ford	1,195	1,187	1,205	1,472	1,622
General Motors	371	705	946	1,064	1,165
Honda	116	144	266	343	585
Hyundai	577	599	847	805	879
Kia	176	221	263	334	426
Mazda	482	587	716	778	858
Mitsubishi	371	319	1,200	1,389	1,647
Nissan	211	376	792	813	984
Porsche	52	(39)	(35)	130	124
Subaru	551	552	998	1,267	1,248
Suzuki		823	954	946	1,123
Tata	61	56	101	182	629
Toyota	67	70	159	248	317
Volkswagen	117	333	486	486	723
Average	396	498	650	762	903

In summary, NHTSA has considered eight regulatory alternatives, including the final standards, examining technologies that could be applied in response to each alternative, as well as corresponding costs, effects, and benefits. The agency has concluded that alternatives less stringent than the final standards would not produce the fuel savings and CO_2 reductions necessary at this time to achieve either the overarching purpose of EPCA, *i.e.,* energy conservation, or an important part of the regulatory harmonization underpinning the National Program, and would forego these benefits even though there is adequate lead time to implement reasonable and feasible technology for the vehicles. Conversely, the agency has concluded that more stringent standards would involve levels of additional technology and cost that would be economically impracticable and, correspondingly, would provide inadequate lead time, considering the economic state of the automotive industry, would not be economically practicable. Therefore, having considered these eight regulatory alternatives, and the statutorily-relevant factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy, along with other relevant factors such as the safety impacts of the final standards,[711] NHTSA concludes that the final standards represent a reasonable balancing of all of these concerns, and are the maximum feasible average fuel economy levels that the manufacturers can achieve in MYs 2012–2016.

G. Impacts of the Final CAFE Standards

1. How will these standards improve fuel economy and reduce GHG emissions for MY 2012–2016 vehicles?

As discussed above, the CAFE level required under an attribute-based standard depends on the mix of vehicles produced for sale in the U.S. Based on the market forecast that NHTSA and EPA have used to develop and analyze new CAFE and CO_2 emissions standards, NHTSA estimates that the new CAFE standards will require CAFE levels to increase by an average of 4.3 percent annually through MY 2016, reaching a combined average fuel

[711] *See* Section IV.G.7 below.

economy requirement of 34.1 mpg in that model year:

TABLE IV.G.1–1—ESTIMATED AVERAGE REQUIRED FUEL ECONOMY (mpg) UNDER FINAL STANDARDS

Model year	2012	2013	2014	2015	2016
Passenger Cars	33.3	34.2	34.9	36.2	37.8
Light Trucks	25.4	26.0	26.6	27.5	28.8
Combined	29.7	30.5	31.3	32.6	34.1

NHTSA estimates that average achieved fuel economy levels will correspondingly increase through MY 2016, but that manufacturers will, on average, undercomply [712] in some model years and overcomply [713] in others, reaching a combined average fuel economy of 33.7 mpg in MY 2016: [714]

TABLE IV.G.1–2—ESTIMATED AVERAGE ACHIEVED FUEL ECONOMY (mpg) UNDER FINAL STANDARDS

Model year	2012	2013	2014	2015	2016
Passenger Cars	32.8	34.4	35.3	36.3	37.2
Light Trucks	25.1	26.0	27.0	27.6	28.5
Combined	29.3	30.6	31.7	32.6	33.7

NHTSA estimates that these fuel economy increases will lead to fuel savings totaling 61 billion gallons during the useful lives of vehicles manufactured in MYs 2012–2016:

TABLE IV.G.1–3—FUEL SAVED (BILLION GALLONS) UNDER FINAL STANDARDS

Model year	2012	2013	2014	2015	2016	Total
Passenger Cars	2.4	5.2	7.2	9.4	11.4	35.7
Light Trucks	1.8	3.7	5.3	6.5	8.1	25.4
Combined	4.2	8.9	12.5	16.0	19.5	61.0

The agency also estimates that these new CAFE standards will lead to corresponding reductions of CO_2 emissions totaling 655 million metric tons (mmt) during the useful lives of vehicles sold in MYs 2012–2016:

TABLE IV.G.1–4—CARBON DIOXIDE EMISSIONS (mmt) AVOIDED UNDER FINAL STANDARDS

Model year	2012	2013	2014	2015	2016	Total
Passenger Cars	25	54	77	101	123	380
Light Trucks	19	40	57	71	88	275
Combined	44	94	134	172	210	655

2. How will these standards improve fleet-wide fuel economy and reduce GHG emissions beyond MY 2016?

Under the assumption that CAFE standards at least as stringent as those being finalized today for MY 2016 would be established for subsequent model years, the effects of the final standards on fuel consumption and GHG emissions will continue to increase for many years. This will occur because over time, a growing fraction of the U.S. light-duty vehicle fleet will be comprised of cars and light trucks that meet the MY 2016 standard. The impact of the new standards on fuel use and GHG emissions will continue to grow through approximately 2050, when virtually all cars and light trucks in service will have met standards as stringent as those established for MY 2016.

As Table IV.G.2–1 shows, NHTSA estimates that the fuel economy

[712] In NHTSA's analysis, "undercompliance" is mitigated either through use of FFV credits, use of existing or "banked" credits, or through fine payment. Because NHTSA cannot consider availability of credits in setting standards, the estimated achieved CAFE levels presented here do not account for their use. In contrast, because NHTSA is not prohibited from considering fine payment, the estimated achieved CAFE levels presented here include the assumption that BMW, Daimler (*i.e.,* Mercedes), Porsche, and, Tata (*i.e.,* Jaguar and Rover) will only apply technology up to the point that it would be less expensive to pay civil penalties.

[713] In NHTSA's analysis, "overcompliance" occurs through multi-year planning: manufacturers apply some "extra" technology in early model years (*e.g.,* MY 2014) in order to carry that technology forward and thereby facilitate compliance in later model years (*e.g.,* MY 2016).

[714] Consistent with EPCA, NHTSA has not accounted for manufacturers' ability to earn CAFE credits for selling FFVs, carry credits forward and back between model years, and transfer credits between the passenger car and light truck fleets.

increases resulting from the final standards will lead to reductions in total fuel consumption by cars and light trucks of 10 billion gallons during 2020, increasing to 32 billion gallons by 2050. Over the period from 2012, when the final standards would begin to take effect, through 2050, cumulative fuel savings would total 729 billion gallons, as Table IV.G.2–1 also indicates.

TABLE IV.G.2–1—REDUCTION IN FLEET-WIDE FUEL USE (BILLION GALLONS) UNDER FINAL STANDARDS

Calendar year	2020	2030	2040	2050	Total, 2012–2050
Passenger Cars	6	13	17	21	469
Light Trucks	4	7	9	11	260
Combined	10	20	26	32	729

The energy security analysis conducted for this rule estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products outside the U.S., which would in turn lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. While additional information would be needed to analyze this “leakage effect” in detail, NHTSA provides a sample estimate of its potential magnitude in its Final EIS.[715] This analysis indicates that the leakage effect is likely to offset only a modest fraction of the reductions in emissions projected to result from the rule.

As a consequence of these reductions in fleet-wide fuel consumption, the agency also estimates that the new CAFE standards for MYs 2012–2016 will lead to corresponding reductions in CO_2 emissions from the U.S. light-duty vehicle fleet. Specifically, NHTSA estimates that total annual CO_2 emissions associated with passenger car and light truck use in the U.S. use will decline by 116 million metric tons (mmt) in 2020 as a consequence of the new standards, as Table IV.G.2–2 reports. The table also shows that the this annual reduction is estimated to grow to nearly 400 million metric tons by the year 2050, and will total nearly 9 billion metric tons over the period from 2012, when the final standards would take effect, through 2050.

TABLE IV.G.2–2—REDUCTION IN FLEET-WIDE CARBON DIOXIDE EMISSIONS (mmt) FROM PASSENGER CAR AND LIGHT TRUCK USE UNDER FINAL STANDARDS

Calendar year	2020	2030	2040	2050	Total, 2012–2050
Passenger Cars	69	153	205	255	5,607
Light Trucks	49	89	112	136	3,208
Combined	117	242	316	391	8,815

These reductions in fleet-wide CO_2 emissions, together with corresponding reductions in other GHG emissions from fuel production and use, would lead to small but significant reductions in projected changes in the future global climate. These changes, based on analysis documented in the final Environmental Impact Statement (EIS) that informed the agency’s decisions regarding this rule, are summarized in Table IV.G.2–3 below.

TABLE IV.G.2–3—EFFECTS OF REDUCTIONS IN FLEET-WIDE CARBON DIOXIDE EMISSIONS (mmt) ON PROJECTED CHANGES IN GLOBAL CLIMATE

Measure	Units	Date	Projected change in measure		
			No action	With proposed standards	Difference
Atmospheric CO_2 Concentration	ppm	2100	783.0	780.3	−2.7
Increase in Global Mean Surface Temperature.	C	2100	3.136	3.125	−0.011
Sea Level Rise	cm	2100	38.00	37.91	−0.09
Global Mean Precipitation	% change from 1980–1999 avg.	2090	4.59%	4.57%	−0.02%

[715] NHTSA Final Environmental Impact Statement: Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2012–2016, February 2010, page 3–14.

3. How will these final standards impact non-GHG emissions and their associated effects?

Under the assumption that CAFE standards at least as stringent as those proposed for MY 2016 would be established for subsequent model years, the effects of the new standards on air quality and its associated health effects will continue to be felt over the foreseeable future. This will occur because over time a growing fraction of the U.S. light-duty vehicle fleet will be comprised of cars and light trucks that meet the MY 2016 standard, and this growth will continue until approximately 2050.

Increases in the fuel economy of light-duty vehicles required by the new CAFE standards will cause a slight increase in the number of miles they are driven, through the fuel economy "rebound effect." In turn, this increase in vehicle use will lead to increases in emissions of criteria air pollutants and some airborne toxics, since these are products of the number of miles vehicles are driven.

At the same time, however, the projected reductions in fuel production and use reported in Table IV.G.2–1 above will lead to corresponding reductions in emissions of these pollutants that occur during fuel production and distribution ("upstream" emissions). For most of these pollutants, the reduction in upstream emissions resulting from lower fuel production and distribution will outweigh the increase in emissions from vehicle use, resulting in a net decline in their total emissions.[716]

Tables IV.G.3–1a and 3–1b report estimated reductions in emissions of selected criteria air pollutants (or their chemical precursors) and airborne toxics expected to result from the final standards during calendar year 2030. By that date, the majority of light-duty vehicles in use will have met the MY 2016 CAFE standards, so these reductions provide a useful index of the long-term impact of the final standards on air pollution and its consequences for human health.

TABLE IV.G.3–1a—PROJECTED CHANGES IN EMISSIONS OF CRITERIA AIR POLLUTANTS FROM CAR AND LIGHT TRUCK USE

[Calendar year 2030; tons]

Vehicle class	Source of emissions	Criteria air pollutant			
		Nitrogen oxides (NO_X)	Particulate matter ($PM_{2.5}$)	Sulfur oxides (SO_X)	Volatile organic compounds (VOC)
Passenger Cars	Vehicle use	2,718	465	−2,442	2,523
	Fuel production and distribution	−20,970	−2,831	−12,698	−75,342
	All sources	−18,252	−2,366	−15,140	−72,820
Light Trucks	Vehicle use	3,544	176	−1,420	1,586
	Fuel production and distribution	−12,252	−1,655	−7,424	−43,763
	All sources	−8,707	−1,479	−8,845	−42,177
Total	Vehicle use	6,263	642	−3,862	4,108
	Fuel production and distribution	−33,222	−4,487	−20,122	−119,106
	All sources	−26,959	−3,845	−23,984	−114,997

TABLE IV.G.3–1b—PROJECTED CHANGES IN EMISSIONS OF AIRBORNE TOXICS FROM CAR AND LIGHT TRUCK USE

[Calendar year 2030; tons]

Vehicle class	Source of emissions	Toxic air pollutant		
		Benzene	1,3-Butadiene	Formaldehyde
Passenger Cars	Vehicle use	72	18	59
	Fuel production and distribution	−161	−2	−58
	All sources	−89	16	1
Light Trucks	Vehicle use	38	10	65
	Fuel production and distribution	−94	−1	−34
	All sources	−55	9	32
Total	Vehicle use	111	28	124
	Fuel production and distribution	−254	−3	−91
	All sources	−144	25	33

Note: Positive values indicate increases in emissions; negative values indicate reductions.

In turn, the reductions in emissions reported in Tables IV.G.3–1a and 3–1b are projected to result in significant declines in the health effects that result from population exposure to these pollutants. Table IV.G.3–2 reports the estimated reductions in selected $PM_{2.5}$-related human health impacts that are expected to result from reduced

[716] As stated elsewhere, while the agency's analysis assumes that all changes in upstream emissions result from a decrease in petroleum production and transport, the analysis of non-GHG emissions in future calendar years also assumes that retail gasoline composition is unaffected by this rule; as a result, the impacts of this rule on downstream non-GHG emissions (more specifically, on air toxics) may be underestimated. *See* also Section III.G above for more information.

population exposure to unhealthful atmospheric concentrations of $PM_{2.5}$. The estimates reported in Table IV.G.3–2, based on analysis documented in the final Environmental Impact Statement (EIS) that informed the agency's decisions regarding this rule, are derived from $PM_{2.5}$-related dollar-per-ton estimates that include only quantifiable reductions in health impacts likely to result from reduced population exposure to particular matter (PM). They do not include all health impacts related to reduced exposure to PM, nor do they include any reductions in health impacts resulting from lower population exposure to other criteria air pollutants (particularly ozone) and air toxics. However, emissions changes and dollar-per-ton estimates alone are not necessarily a good indication of local or regional air quality and health impacts, as there may be localized impacts associated with this rulemaking, because the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone, and air toxics is very complex. Full-scale photochemical modeling provides the necessary spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. Although EPA conducted such modeling for purposes of the final rule, it was not available in time to be included in NHTSA's FEIS. See Section III.G above for EPA's description of the full-scale air quality modeling it conducted for the 2030 calendar year in an effort to capture this variability.

TABLE IV.G.3–2—PROJECTED REDUCTIONS IN HEALTH IMPACTS OF EXPOSURE TO CRITERIA AIR POLLUTANTS FROM FINAL STANDARDS

[Calendar year 2030]

Health impact	Measure	Projected reduction (2030)
Mortality (ages 30 and older)	premature deaths per year	243 to 623.
Chronic Bronchitis	cases per year	160.
Emergency Room Visits for Asthma	number per year	222.
Work Loss	workdays per year	28,705.

4. What are the estimated costs and benefits of these final standards?

NHTSA estimates that the final standards could entail significant additional technology beyond the levels reflected in the baseline market forecast used by NHTSA. This additional technology will lead to increases in costs to manufacturers and vehicle buyers, as well as fuel savings to vehicle buyers. The following three tables summarize the extent to which the agency estimates technologies could be added to the passenger car, light truck, and overall fleets in each model year in response to the proposed standards. Percentages reflect the technology's additional application in the market, and are negative in cases where one technology is superseded (*i.e.,* displaced) by another. For example, the agency estimates that many automatic transmissions used in light trucks could be displaced by dual clutch transmissions.

TABLE IV.G.4–1—ADDITION OF TECHNOLOGIES TO PASSENGER CAR FLEET UNDER FINAL STANDARDS

Technology	MY 2012 (percent)	MY 2013 (percent)	MY 2014 (percent)	MY 2015 (percent)	MY 2016 (percent)
Low Friction Lubricants	14	18	19	21	21
Engine Friction Reduction	15	37	41	43	52
VVT—Coupled Cam Phasing (CCP) on SOHC	2	3	3	5	7
Discrete Variable Valve Lift (DVVL) on SOHC	0	1	1	4	4
Cylinder Deactivation on SOHC	0	0	0	0	0
VVT—Intake Cam Phasing (ICP)	0	0	0	0	0
VVT—Dual Cam Phasing (DCP)	11	15	16	17	24
Discrete Variable Valve Lift (DVVL) on DOHC	9	19	22	23	29
Continuously Variable Valve Lift (CVVL)	0	0	0	0	0
Cylinder Deactivation on DOHC	0	0	0	1	2
Cylinder Deactivation on OHV	0	1	1	1	1
VVT—Coupled Cam Phasing (CCP) on OHV	0	1	2	2	2
Discrete Variable Valve Lift (DVVL) on OHV	0	1	1	2	3
Conversion to DOHC with DCP	0	0	0	0	0
Stoichiometric Gasoline Direct Injection (GDI)	9	18	21	24	28
Combustion Restart	0	0	1	4	9
Turbocharging and Downsizing	8	14	16	19	21
Exhaust Gas Recirculation (EGR) Boost	0	8	10	13	17
Conversion to Diesel following TRBDS	2	2	2	2	2
Conversion to Diesel following CBRST	0	0	0	0	0
6-Speed Manual/Improved Internals	1	1	1	1	1
Improved Auto. Trans. Controls/Externals	0	3	4	1	−3
Continuously Variable Transmission	0	0	0	0	0
6/7/8-Speed Auto. Trans with Improved Internals	0	0	1	1	2
Dual Clutch or Automated Manual Transmission	12	26	34	47	54
Electric Power Steering	9	22	25	26	38
Improved Accessories	18	25	27	31	41
12V Micro-Hybrid	0	0	0	0	0
Belt mounted Integrated Starter Generator	4	11	19	24	25

TABLE IV.G.4–1—ADDITION OF TECHNOLOGIES TO PASSENGER CAR FLEET UNDER FINAL STANDARDS—Continued

Technology	MY 2012 (percent)	MY 2013 (percent)	MY 2014 (percent)	MY 2015 (percent)	MY 2016 (percent)
Crank mounted Integrated Starter Generator	3	3	3	3	3
Power Split Hybrid	2	2	2	2	2
2-Mode Hybrid	0	0	0	0	0
Plug-in Hybrid	0	0	0	0	0
Mass Reduction (1.5)	18	26	32	39	46
Mass Reduction (3.5 to 8.5)	0	0	17	31	40
Low Rolling Resistance Tires	4	16	23	32	35
Low Drag Brakes	2	3	4	4	6
Secondary Axle Disconnect—Unibody	0	0	0	0	0
Secondary Axle Disconnect—Ladder Frame	1	2	2	2	2
Aero Drag Reduction	6	20	29	34	38

TABLE IV.G.4–2—ADDITION OF TECHNOLOGIES TO LIGHT TRUCK FLEET UNDER FINAL STANDARDS

Technology	MY 2012 (percent)	MY 2013 (percent)	MY 2014 (percent)	MY 2015 (percent)	MY 2016 (percent)
Low Friction Lubricants	18	20	22	23	23
Engine Friction Reduction	14	34	35	40	51
VVT—Coupled Cam Phasing (CCP) on SOHC	2	3	3	2	2
Discrete Variable Valve Lift (DVVL) on SOHC	1	2	2	2	3
Cylinder Deactivation on SOHC	6	6	6	6	5
VVT—Intake Cam Phasing (ICP)	0	0	0	1	1
VVT—Dual Cam Phasing (DCP)	6	8	13	13	17
Discrete Variable Valve Lift (DVVL) on DOHC	9	12	17	17	18
Continuously Variable Valve Lift (CVVL)	0	0	0	0	0
Cylinder Deactivation on DOHC	1	1	1	1	0
Cylinder Deactivation on OHV	0	1	1	2	7
VVT—Coupled Cam Phasing (CCP) on OHV	0	0	0	0	13
Discrete Variable Valve Lift (DVVL) on OHV	0	13	14	19	19
Conversion to DOHC with DCP	0	0	0	0	0
Stoichiometric Gasoline Direct Injection (GDI)	12	17	23	24	31
Combustion Restart	0	0	3	5	18
Turbocharging and Downsizing	3	6	10	10	14
Exhaust Gas Recirculation (EGR) Boost	0	2	6	6	9
Conversion to Diesel following TRBDS	1	1	1	1	1
Conversion to Diesel following CBRST	0	0	0	0	0
6-Speed Manual/Improved Internals	0	0	0	0	0
Improved Auto. Trans. Controls/Externals	0	−11	−17	−28	−32
Continuously Variable Transmission	0	0	0	0	0
6/7/8-Speed Auto. Trans with Improved Internals	−2	−2	−2	−2	−1
Dual Clutch or Automated Manual Transmission	10	32	46	58	65
Electric Power Steering	7	11	11	20	27
Improved Accessories	7	9	10	15	23
12V Micro-Hybrid	0	0	0	0	0
Belt mounted Integrated Starter Generator	5	10	19	20	21
Crank mounted Integrated Starter Generator	0	0	0	0	0
Power Split Hybrid	1	1	1	1	1
2-Mode Hybrid	0	0	0	0	0
Plug-in Hybrid	0	0	0	0	0
Mass Reduction (1.5)	4	5	21	35	48
Mass Reduction (3.5 to 8.5)	0	0	19	33	54
Low Rolling Resistance Tires	11	12	13	16	17
Low Drag Brakes	14	32	30	31	40
Secondary Axle Disconnect—Unibody	0	0	0	0	0
Secondary Axle Disconnect—Ladder Frame	17	19	20	21	28
Aero Drag Reduction	13	15	20	22	25

TABLE IV.G.4–3—ADDITION OF TECHNOLOGIES TO OVERALL FLEET UNDER FINAL STANDARDS

Technology	MY 2012 (percent)	MY 2013 (percent)	MY 2014 (percent)	MY 2015 (percent)	MY 2016 (percent)
Low Friction Lubricants	16	18	20	22	22
Engine Friction Reduction	15	36	39	42	51
VVT—Coupled Cam Phasing (CCP) on SOHC	2	3	3	4	5
Discrete Variable Valve Lift (DVVL) on SOHC	0	1	2	3	3
Cylinder Deactivation on SOHC	2	3	2	2	2
VVT—Intake Cam Phasing (ICP)	0	0	0	0	0

TABLE IV.G.4–3—ADDITION OF TECHNOLOGIES TO OVERALL FLEET UNDER FINAL STANDARDS—Continued

Technology	MY 2012 (percent)	MY 2013 (percent)	MY 2014 (percent)	MY 2015 (percent)	MY 2016 (percent)
VVT—Dual Cam Phasing (DCP)	9	13	15	16	22
Discrete Variable Valve Lift (DVVL) on DOHC	9	16	20	21	25
Continuously Variable Valve Lift (CVVL)	0	0	0	0	0
Cylinder Deactivation on DOHC	0	1	0	1	1
Cylinder Deactivation on OHV	0	1	1	1	3
VVT—Coupled Cam Phasing (CCP) on OHV	0	1	1	1	6
Discrete Variable Valve Lift (DVVL) on OHV	0	6	6	8	8
Conversion to DOHC with DCP	0	0	0	0	0
Stoichiometric Gasoline Direct Injection (GDI)	10	17	22	24	29
Combustion Restart	0	0	1	4	12
Turbocharging and Downsizing	6	11	14	16	19
Exhaust Gas Recirculation (EGR) Boost	0	6	8	11	14
Conversion to Diesel following TRBDS	1	2	2	2	2
Conversion to Diesel following CBRST	0	0	0	0	0
6-Speed Manual/Improved Internals	0	0	0	0	1
Improved Auto. Trans. Controls/Externals	0	−2	−4	−10	−13
Continuously Variable Transmission	0	0	0	0	0
6/7/8-Speed Auto. Trans with Improved Internals	−1	0	0	0	1
Dual Clutch or Automated Manual Transmission	11	28	38	51	58
Electric Power Steering	8	18	20	24	34
Improved Accessories	13	19	21	25	35
12V Micro-Hybrid	0	0	0	0	0
Belt mounted Integrated Starter Generator	5	11	19	23	23
Crank mounted Integrated Starter Generator	2	2	2	2	2
Power Split Hybrid	2	2	2	1	1
2-Mode Hybrid	0	0	0	0	0
Plug-in Hybrid	0	0	0	0	0
Mass Reduction (1.5)	13	18	28	37	47
Mass Reduction (3.5 to 8.5)	0	0	18	32	45
Low Rolling Resistance Tires	7	14	19	26	29
Low Drag Brakes	6	14	14	14	18
Secondary Axle Disconnect—Unibody	0	0	0	0	0
Secondary Axle Disconnect—Ladder Frame	7	8	8	8	11
Aero Drag Reduction	9	18	26	30	34

In order to pay for this additional technology (and, for some manufacturers, civil penalties), NHTSA estimates that the cost of an average passenger car and light truck will, relative to levels resulting from compliance with baseline (MY 2011) standards, increase by $505–$907 and $322–$961, respectively, during MYs 2011–2016. The following tables summarize the agency's estimates of average cost increases for each manufacturer's passenger car, light truck, and overall fleets (with corresponding averages for the industry):

TABLE IV.G.4–4—AVERAGE PASSENGER CAR INCREMENTAL COST INCREASES ($) UNDER FINAL STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	157	196	255	443	855
Chrysler	794	1,043	1,129	1,270	1,358
Daimler	160	198	564	944	1,252
Ford	1,641	1,537	1,533	1,713	1,884
General Motors	552	896	1,127	1,302	1,323
Honda	33	98	205	273	456
Hyundai	559	591	768	744	838
Kia	110	144	177	235	277
Mazda	632	656	799	854	923
Mitsubishi	644	620	1,588	1,875	1,831
Nissan	119	323	707	723	832
Porsche	316	251	307	390	496
Subaru	413	472	988	1,385	1,361
Suzuki	242	625	779	794	1,005
Tata	243	258	370	532	924
Toyota	31	29	41	121	126
Volkswagen	293	505	587	668	964
Total/Average	505	573	690	799	907

TABLE IV.G.4–5—AVERAGE LIGHT TRUCK INCREMENTAL COST INCREASES ($) UNDER FINAL STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	252	272	338	402	827
Chrysler	409	527	876	931	1,170
Daimler	98	123	155	189	260
Ford	465	633	673	1,074	1,174
General Motors	336	513	749	807	986
Honda	233	217	370	457	806
Hyundai	693	630	1,148	1,136	1,113
Kia	406	467	582	780	1,137
Mazda	144	241	250	354	480
Mitsubishi	39	77	553	686	1,371
Nissan	398	489	970	1,026	1,362
Porsche	44	76	109	568	640
Subaru	1,036	995	1,016	1,060	1,049
Suzuki	66	1,797	1,744	1,689	1,732
Tata	66	110	137	198	690
Toyota	130	150	384	499	713
Volkswagen	44	77	552	557	606
Total/Average	322	416	621	752	961

TABLE IV.G.4–6—AVERAGE INCREMENTAL COST INCREASES ($) BY MANUFACTURER UNDER FINAL STANDARDS

Manufacturer	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
BMW	196	225	283	430	847
Chrysler	553	743	989	1,084	1,257
Daimler	139	171	417	695	937
Ford	1,209	1,187	1,205	1,472	1,622
General Motors	446	705	946	1,064	1,165
Honda	116	144	266	343	585
Hyundai	577	599	847	805	879
Kia	177	221	263	334	426
Mazda	545	587	716	778	858
Mitsubishi	459	453	1,200	1,389	1,647
Nissan	211	376	792	813	984
Porsche	250	207	243	452	544
Subaru	630	650	998	1,267	1,248
Suzuki	231	823	954	946	1,123
Tata	164	199	265	396	832
Toyota	67	70	159	248	317
Volkswagen	245	410	579	648	901
Total/Average	434	513	665	782	926

Based on the agencies' estimates of manufacturers' future sales volumes, these cost increases will lead to a total of $51.7 billion in incremental outlays during MYs 2012–2016 for additional technology attributable to the final standards:

TABLE IV.G.4–7—INCREMENTAL TECHNOLOGY OUTLAYS ($b) UNDER FINAL STANDARDS

	2012	2013	2014	2015	2016	Total
Passenger Cars	4.1	5.4	6.9	8.2	9.5	34.2
Light Trucks	1.8	2.5	3.7	4.3	5.4	17.6
Combined	5.9	7.9	10.5	12.5	14.9	51.7

NHTSA notes that these estimates of the economic costs for meeting higher CAFE standards omit certain potentially important categories of costs, and may also reflect underestimation (or possibly overestimation) of some costs that are included. For example, although the agency's analysis is intended to hold vehicle performance, capacity, and utility constant in estimating the costs of applying fuel-saving technologies to vehicles, the analysis imputes no cost to any actual reductions in vehicle performance, capacity, and utility that may result from manufacturers' efforts to comply with the final CAFE standards. Although these costs are difficult to estimate accurately, they nonetheless represent a notable category of omitted costs if they have not been adequately accounted for in the cost estimates. Similarly, the agency's estimates of net benefits for meeting higher CAFE standards does not estimate the economic value of potential changes in motor vehicle fatalities and injuries that could result from reductions in the size or weight of vehicles. While NHTSA reports a range of estimates of these potential safety effects below and in the FRIA (ranging from a net negative monetary impact to a net positive benefits for society), no estimate of their economic value is included in the agency's estimates of the net benefits resulting from the final standards.

Finally, while NHTSA is confident that the cost estimates are the best available and appropriate for purposes of this final rule, it is possible that the agency may have underestimated or overestimated manufacturers' direct costs for applying some fuel economy technologies, or the increases in manufacturer's indirect costs associated with higher vehicle manufacturing costs. In either case, the technology outlays reported here will not correctly represent the costs of meeting higher CAFE standards. Similarly, NHTSA's estimates of increased costs of congestion, accidents, and noise associated with added vehicle use are drawn from a 1997 study, and the correct magnitude of these values may have changed since they were developed. If this is the case, the costs of increased vehicle use associated with the fuel economy rebound effect will differ from the agency's estimates in this analysis. Thus, like the agency's estimates of economic benefits, estimates of total compliance costs reported here may underestimate or overestimate the true economic costs of the final standards.

However, offsetting these costs, the achieved increases in fuel economy will also produce significant benefits to society. NHTSA attributes most of these benefits to reductions in fuel consumption, valuing fuel savings at future pretax prices in EIA's reference case forecast from AEO 2010. The total benefits also include other benefits and dis-benefits, examples of which include the social values of reductions in CO_2 and criteria pollutant emissions, the value of additional travel (induced by the rebound effect), and the social cost of additional congestion, accidents, and noise attributable to that additional travel. The FRIA accompanying today's final rule presents a detailed analysis of the rule's specific benefits.

As Table IV.G.4–8 shows, NHTSA estimates that at the discount rate of 3 percent prescribed in OMB guidance for regulatory analysis, the present value of total benefits from the final CAFE standards over the lifetimes of MY 2012–2016 passenger cars and light trucks will be $182.5 billion.

TABLE IV.G.4–8—PRESENT VALUE OF BENEFITS ($BILLION) UNDER FINAL STANDARDS USING 3 PERCENT DISCOUNT RATE [717]

	2012	2013	2014	2015	2016	Total
Passenger Cars	6.8	15.2	21.6	28.7	35.2	107.5
Light Trucks	5.1	10.7	15.5	19.4	24.3	75.0
Combined	11.9	25.8	37.1	48.0	59.5	182.5

Table IV.G.4–9 reports that the present value of total benefits from requiring cars and light trucks to achieve the fuel economy levels specified in the final CAFE standards for MYs 2012–16 will be $146.2 billion when discounted at the 7 percent rate also required by OMB guidance. Thus the present value of fuel savings and other benefits over the lifetimes of the vehicles covered by the final standards is $36.3 billion—or about 20 percent—lower when discounted at a 7 percent annual rate than when discounted using the 3 percent annual rate.[718]

TABLE IV.G.4–9—PRESENT VALUE OF BENEFITS ($BILLION) UNDER FINAL STANDARDS USING 7 PERCENT DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	5.5	12.3	17.5	23.2	28.6	87.0
Light Trucks	4.0	8.4	12.2	15.3	19.2	59.2
Combined	9.5	20.7	29.7	38.5	47.8	146.2

For both the passenger car and light truck fleets, NHTSA estimates that the benefits of today's final standards will exceed the corresponding costs in every model year, so that the *net* social benefits from requiring higher fuel economy—the difference between the total benefits that result from higher fuel economy and the technology outlays required to achieve it—will be substantial. Because the technology outlays required to achieve the fuel economy levels required by the final standards are incurred during the model years when vehicles are produced and sold, however, they are not subject to discounting, so that their present value does not depend on the discount rate used.[719] Thus the net benefits of the final standards differ depending on whether the 3 percent or 7 percent discount rate is used, but only because the choice of discount rates affects the present value of total benefits, and not that of technology costs.

As Table IV.G.4–10 shows, over the lifetimes of the affected (MY 2012–2016)

[717] Unless otherwise indicated, all tables in Section IV report benefits calculated using the Reference Case input assumptions, with future benefits resulting from reductions in carbon dioxide emissions discounted at the 3 percent rate prescribed in the interagency guidance on the social cost of carbon.

[718] For tables that report total or net benefits using a 7 percent discount rate, future benefits from reducing carbon dioxide emissions are discounted at 3 percent, in order to maintain consistency with the discount rate used to develop the reference case estimate of the social cost of carbon. All other future benefits reported in these tables are discounted using the 7 percent rate.

[719] Although technology costs are incurred at the beginning of each model year's lifetime and thus are not subject to discounting, the discount rate does influence the effective cost of some technologies. Because NHTSA assumes some manufacturers will be willing to pay civil penalties when compliance costs become sufficiently high, It is still possible for the discount rate to affect the agency's estimate of total technology outlays. However, this does not occur under the alternative NHTSA has adopted for its final MY 2012–16 CAFE standards.

vehicles, the agency estimates that when the benefits of the final standards are discounted at a 3 percent rate, they will exceed the costs of the final standards by $130.7 billion:

TABLE IV.G.4–10—PRESENT VALUE OF NET BENEFITS ($BILLION) UNDER FINAL STANDARDS USING 3 PERCENT DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	2.7	9.7	14.8	20.5	25.7	73.3
Light Trucks	3.4	8.2	11.8	15.0	18.9	57.4
Combined	6.0	18.0	26.6	35.5	44.6	130.7

As indicated previously, when fuel savings and other future benefits resulting from the final standards are discounted at the 7 percent rate prescribed in OMB guidance, they are $36.3 billion lower than when the 3 percent discount rate is applied. Because technology costs are not subject to discounting, using the higher 7 percent discount rate reduces net benefits by exactly this same amount. Nevertheless, Table IV.G.4–11 shows that the net benefits from requiring passenger cars and light trucks to achieve higher fuel economy are still substantial even when future benefits are discounted at the higher rate, totaling $94.5 billion over MYs 2012–16. Net benefits are thus about 28 percent lower when future benefits are discounted at a 7 percent annual rate than at a 3 percent rate.

TABLE IV.G.4–11—PRESENT VALUE OF NET BENEFITS ($BILLION) UNDER FINAL STANDARDS USING 7 PERCENT DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	1.3	6.8	10.6	15.0	19.0	52.9
Light Trucks	2.3	5.9	8.6	11.0	13.9	41.6
Combined	3.6	12.8	19.2	26.0	32.9	94.5

NHTSA's estimates of economic benefits from establishing higher CAFE standards are subject to considerable uncertainty. Most important, the agency's estimates of the fuel savings likely to result from adopting higher CAFE standards depend critically on the accuracy of the estimated fuel economy levels that will be achieved under both the baseline scenario, which assumes that manufacturers will continue to comply with the MY 2011 CAFE standards, and under alternative increases in the standards that apply to MYs 2012–16 passenger cars and light trucks. Specifically, if the agency has underestimated the fuel economy levels that manufacturers would have achieved under the baseline scenario—or is too optimistic about the fuel economy levels that manufacturers will actually achieve under the final standards—its estimates of fuel savings and the resulting economic benefits attributable to this rule will be too large.

Another major source of potential overestimation in the agency's estimates of benefits from requiring higher fuel economy stems from its reliance on the Reference Case fuel price forecasts reported in AEO 2010. Although NHTSA believes that these forecasts are the most reliable that are available, they are nevertheless significantly higher than the fuel price projections reported in most previous editions of EIA's Annual Energy Outlook, and reflect projections of world oil prices that are well above forecasts issued by other firms and government agencies. If the future fuel prices projected in AEO 2010 prove to be too high, the agency's estimates of the value of future fuel savings—the major component of benefits from this rule—will also be too high.

In addition, it is possible that NHTSA's estimates of economic benefits from the effects of saving fuel on U.S. petroleum consumption and imports are too high. The estimated "energy security premium" the agency uses to value reductions in U.S. petroleum imports includes both increased payments for petroleum imports that occur when world oil prices increase rapidly, and losses in U.S. GDP losses and adjustment costs that result from oil price shocks. One commenter suggested increased import costs associated with rapid increases in petroleum prices represent transfers from U.S. oil consumers to petroleum suppliers rather than real economic costs, so any reduction in their potential magnitude should be excluded when calculating benefits from lower U.S. petroleum imports. If this view is correct, then the agency's estimates of benefits from the effect of reduced fuel consumption on U.S. petroleum imports would indeed be too high.[720]

However, it is also possible that NHTSA's estimates of economic benefits from establishing higher CAFE standards *under*estimate the true economic benefits of the fuel savings those standards would produce. If the AEO 2010 forecast of fuel prices proves to be too low, for example, NHTSA will have underestimated the value of fuel savings that will result from adopting higher CAFE standards for MY 2012–16. As another example, the agency's estimate of benefits from reducing the threat of economic damages from disruptions in the supply of imported petroleum to the U.S. applies to

[720] Doing so, however, would represent a significant departure from how disruption costs associated with oil price shocks have been quantified in research on the value of energy security, and NHTSA believes this issue should be analyzed in more detail before these costs are excluded. Moreover, the agency believes that increases in import costs during oil supply disruptions differ from transfers due to the existence of U.S. monopsony power in the world oil market, since they reflect real resource shortages and costly short-run shifts in demand by energy users, rather than losses to consumers of petroleum products that that are matched by offsetting gains to suppliers. Thus the agency believes that reducing their expected value provides real economic benefits, and they do not represent pure transfers.

calendar year 2015. If the magnitude of this estimate would be expected to grow after 2015 in response to increases in U.S. petroleum imports, growth in the level of U.S. economic activity, or increases in the likelihood of disruptions in the supply of imported petroleum, the agency may have underestimated the benefits from the reduction in petroleum imports expected to result from adopting higher CAFE standards.

NHTSA's benefit estimates could also be too low because they exclude or understate the economic value of certain potentially significant categories of benefits from reducing fuel consumption. As one example, EPA's estimates of the economic value of reduced damages to human health resulting from lower exposure to criteria air pollutants includes only the effects of reducing population exposure to $PM_{2.5}$ emissions. Although this is likely to be the most significant component of health benefits from reduced emissions of criteria air pollutants, it excludes the value of reduced damages to human health and other impacts resulting from lower emissions and reduced population exposure to other criteria air pollutants, including ozone and nitrous oxide (N_2O), as well as airborne toxics. EPA's estimates exclude these benefits because no reliable dollar-per-ton estimates of the health impacts of criteria pollutants other than $PM_{2.5}$ or of the health impacts of airborne toxics were available to use in developing estimates of these benefits.

Similarly, the agency's estimate of the value of reduced climate-related economic damages from lower emissions of GHGs excludes many sources of potential benefits from reducing the pace and extent of global climate change.[721] For example, none of the three models used to value climate-related economic damages includes ocean acidification or loss of species and wildlife. The models also may not adequately capture certain other impacts, such as potentially abrupt changes in climate associated with thresholds that govern climate system responses, inter-sectoral and inter-regional interactions, including global security impacts of high-end extreme warming, or limited near-term substitutability between damage to natural systems and increased consumption. Including monetized estimates of benefits from reducing the extent of climate change and these associated impacts would increase the agency's estimates of benefits from adopting higher CAFE standards.

The following tables present itemized costs and benefits for the combined passenger car and light truck fleets for each model year affected by the final standards as well as for all model years combined, using both discount rates prescribed by OMB regulatory guidance. Table IV.G.4–12 reports technology outlays, each separate component of benefits (including costs associated with additional driving due to the rebound effect, labeled "dis-benefits"), the total value of benefits, and net benefits, using the 3 percent discount rate. (Numbers in parentheses represent negative values.)

TABLE IV.G.4–12—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET USING 3 PERCENT DISCOUNT RATE ($M)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Costs						
Technology Costs	5,903	7,890	10,512	12,539	14,904	51,748
Benefits						
Savings in Lifetime Fuel Expenditures	9,265	20,178	29,083	37,700	46,823	143,048
Consumer Surplus from Additional Driving	696	1,504	2,150	2,754	3,387	10,491
Value of Savings in Refueling Time	706	1,383	1,939	2,464	2,950	9,443
Reduction in Petroleum Market Externalities	545	1,154	1,630	2,080	2,543	7,952
Reduction in Climate-Related Damages from Lower CO_2 Emissions[722]	921	2,025	2,940	3,840	4,804	14,528
Reduction in Health Damage Costs from Lower Emissions of Criteria Air Pollutants:						
CO	0	0	0	0	0	0
VOC	42	76	102	125	149	494
NO_X	70	104	126	146	166	612
PM	205	434	612	776	946	2,974
SO_X	158	332	469	598	731	2,288
Dis-Benefits from Increased Driving:						
Congestion Costs	(447)	(902)	(1,282)	(1,633)	(2,000)	(6,264)
Noise Costs	(9)	(18)	(25)	(32)	(39)	(122)
Crash Costs	(217)	(430)	(614)	(778)	(950)	(2,989)
Total Benefits	11,936	25,840	37,132	48,040	59,509	182,457

[721] *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Interagency Working Group on Social Cost of Carbon, United States Government, February 2010. Available in Docket No. NHTSA–2009–0059.

[722] Using the central value of $21 per metric ton for the SCC, and discounting future benefits from reduced CO_2 emissions at a 3 percent annual rate. Additionally, we note that the $21 per metric ton value for the SCC applies to calendar year 2010, and increases over time. See the interagency guidance on SCC for more information.

TABLE IV.G.4–12—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET USING 3 PERCENT DISCOUNT RATE ($M)—Continued

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Net Benefits	6,033	17,950	26,619	35,501	44,606	130,709

Similarly, Table IV.G.4–13 below reports technology outlays, the individual components of benefits (including "dis-benefits" resulting from additional driving) and their total, and net benefits, using the 7 percent discount rate. (Again, numbers in parentheses represent negative values.)

TABLE IV.G.4–13—ITEMIZED COST AND BENEFIT ESTIMATES FOR THE COMBINED VEHICLE FLEET USING 7 PERCENT DISCOUNT RATE ($M)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Costs						
Technology Costs	5,903	7,890	10,512	12,539	14,904	51,748
Benefits						
Savings in Lifetime Fuel Expenditures	7,197	15,781	22,757	29,542	36,727	112,004
Consumer Surplus from Additional Driving	542	1,179	1,686	2,163	2,663	8,233
Value of Savings in Refueling Time	567	1,114	1,562	1,986	2,379	7,608
Reduction in Petroleum Market Externalities	432	917	1,296	1,654	2,023	6,322
Reduction in Climate-Related Damages from Lower CO_2 Emissions [723]	921	2,025	2,940	3,840	4,804	14,530
Reduction in Health Damage Costs from Lower Emissions of Criteria Air Pollutants:						
CO	0	0	0	0	0	0
VOC	32	60	80	99	119	390
NO_X	53	80	98	114	131	476
PM	154	336	480	611	748	2,329
SO_X	125	265	373	475	581	1,819
Dis-Benefits from Increased Driving:						
Congestion Costs	(355)	(719)	(1,021)	(1,302)	(1,595)	(4,992)
Noise Costs	(7)	(14)	(20)	(26)	(31)	(98)
Crash Costs	(173)	(342)	(488)	(619)	(756)	(2,378)
Total Benefits	9,488	20,682	29,743	38,537	47,793	146,243
Net Benefits	3,586	12,792	19,231	25,998	32,890	94,497

The above benefit and cost estimates did not reflect the availability and use of flexibility mechanisms, such as compliance credits and credit trading, because EPCA prohibits NHTSA from considering the effects of those mechanisms in setting CAFE standards. However, the agency noted that, in reality, manufacturers were likely to rely to some extent on flexibility mechanisms provided by EPCA and would thereby reduce the cost of complying with the final standards to a meaningful extent.

As discussed in the FRIA, NHTSA has performed an analysis to estimate the costs and benefits if EPCA's provisions regarding FFVs are accounted for. The agency considered also attempting to account for other EPCA flexibility mechanisms, in particular credit transfers between the passenger and nonpassenger fleets, but has concluded that, at least within a context in which each model year is represented explicitly, technologies carry forward between model years, and multi-year planning effects are represented, there is no basis to estimate reliably how manufacturers might use these mechanisms. Accounting for the FFV provisions indicates that achieved fuel economies would be 0.5–1.3 mpg lower than when these provisions are not considered (for comparison see Table IV.G.1–2 above):

[723] Using the central value of $21 per metric ton for the SCC, and discounting future benefits from reduced CO_2 emissions at a 3 percent annual rate. Additionally, we note that the $21 per metric ton value for the SCC applies to calendar year 2010, and increases over time. *See* the interagency guidance on SCC for more information.

TABLE IV.G.4–14—AVERAGE ACHIEVED FUEL ECONOMY (mpg) UNDER FINAL STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016
Passenger Cars	32.3	33.5	34.2	35.0	36.2
Light Trucks	24.5	25.1	25.9	26.7	27.5
Combined	28.7	29.7	30.6	31.5	32.7

As a result, NHTSA estimates that, when FFV credits are taken into account, fuel savings will total 58.6 billion gallons—about 3.9 percent less than the 61.0 billion gallons estimated when these credits are not considered:

TABLE IV.G.4–15—FUEL SAVED (BILLION GALLONS) UNDER FINAL STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Passenger Cars	2.7	4.7	6.4	8.4	11.0	33.1
Light Trucks	2.3	3.6	5.0	6.6	8.1	25.5
Combined	4.9	8.2	11.3	15.0	19.1	58.6

The agency similarly estimates CO_2 emissions reductions will total 636 million metric tons (mmt), about 2.9 percent less than the 655 mmt estimated when these credits are not considered: [724]

TABLE IV.G.4–16—AVOIDED CARBON DIOXIDE EMISSIONS (mmt) UNDER FINAL STANDARDS (WITH FFV CREDITS)

	2012	2013	2014	2015	2016	Total
Passenger Cars	28	50	69	91	119	357
Light Trucks	25	39	54	72	88	279
Combined	53	89	123	163	208	636

This analysis further indicates that significant reductions in outlays for additional technology will result when FFV provisions are taken into account. Table IV.G.4–17 below shows that as a result, total technology costs are estimated to decline to $37.5 billion, or about 27 percent less than the $51.7 billion estimated when excluding these provisions:

TABLE IV.G.4–17—INCREMENTAL TECHNOLOGY OUTLAYS ($B) UNDER FINAL STANDARDS WITH FFV CREDITS

	2012	2013	2014	2015	2016	Total
Passenger Cars	2.6	3.6	4.8	6.1	7.5	24.6
Light Trucks	1.1	1.5	2.5	3.4	4.4	12.9
Combined	3.7	5.1	7.3	9.5	11.9	37.5

Because NHTSA's analysis indicated that FFV provisions will not significantly reduce fuel savings, the agency's estimate of the present value of total benefits will be $175.6 billion when discounted at a 3 percent annual rate, as Table IV.G.4–18 following reports. This estimate of total benefits is $6.9 billion, or about 3.8 percent, lower than the $182.5 billion reported previously for the analysis that excluded these provisions:

TABLE IV.G.4–18—PRESENT VALUE OF BENEFITS ($BILLION) UNDER FINAL STANDARDS WITH FFV CREDITS USING 3 PERCENT DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	7.6	13.7	19.1	25.6	34.0	100.0
Light Trucks	6.4	10.4	14.6	19.8	24.4	75.6
Combined	14.0	24.1	33.7	45.4	58.4	175.6

[724] Differences in the application of diesel engines lead to differences in the incremental percentage changes in fuel consumption and carbon dioxide emissions.

Similarly, because the FFV are not expected to reduce fuel savings significantly, NHTSA estimates that the present value of total benefits will decline only slightly from its previous estimate when future fuel savings and other benefits are discounted at the higher 7 percent rate. Table IV.G.4–19 reports that the present value of benefits from requiring higher fuel economy for MY 2012–16 cars and light trucks will total $140.7 billion when discounted using a 7 percent rate, about $5.5 billion (or again, 3.8 percent) below the previous $146.2 billion estimate of total benefits when FFV credits were not permitted:

TABLE IV.G.4–19—PRESENT VALUE OF BENEFITS ($BILLION) UNDER FINAL STANDARDS WITH FFV CREDITS USING 7 PERCENT DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	6.1	11.1	15.5	20.7	27.6	80.9
Light Trucks	5.0	8.2	11.5	15.6	19.3	59.7
Combined	11.2	19.3	27.0	36.4	46.9	140.7

Although the discounted present value of total benefits will be slightly lower when FFV provisions are taken into account, the agency estimates that these provisions will slightly *increase* net benefits. This occurs because the flexibility these provisions provide to manufacturers will allow them to reduce technology costs for meeting the new standards by considerably more than the reduction in the value of fuel savings and other benefits. As Table IV.G.4–20 shows, the agency estimates that the availability of FFV credits will increase net benefits from the final CAFE standards to $138.2 billion from the previously-reported estimate of $130.7 billion without those credits, or by about 5.7 percent.

TABLE IV.G.4–20—PRESENT VALUE OF NET BENEFITS ($BILLION) UNDER FINAL STANDARDS WITH FFV CREDITS USING 3% DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	5.1	10.1	14.3	19.5	26.5	75.4
Light Trucks	5.3	8.8	12.1	16.4	20.0	62.7
Combined	10.4	19.0	26.5	35.9	46.5	138.2

Similarly, Table IV.G.4–21 immediately below shows that NHTSA estimates manufacturers' use of FFV credits will raise net benefits from requiring higher fuel economy for MY 2012–16 cars and light trucks to $103.2 billion if a 7 percent discount rate is applied to future benefits. This estimate is $8.7 billion—or about 9.2%—higher than the previously-reported $94.5 billion estimate of net benefits without the availability of FFV credits using that same discount rate.

TABLE IV.G.4–21—PRESENT VALUE OF NET BENEFITS ($BILLION) UNDER FINAL STANDARDS WITH FFV CREDITS USING 7% DISCOUNT RATE

	2012	2013	2014	2015	2016	Total
Passenger Cars	3.6	7.5	10.7	14.6	20.0	56.4
Light Trucks	3.9	6.6	9.1	12.3	14.9	46.8
Combined	7.5	14.1	19.7	26.9	35.0	103.2

The agency has also performed several sensitivity analyses to examine the effects of varying important assumptions that affect its estimates of benefits and costs from higher CAFE standards for MY 2012–16 cars and light trucks. We examine the sensitivity of fuel savings, total economic benefits, and technology costs with respect to the following five economic parameters:

(1) The price of gasoline: The Reference Case uses the AEO 2010 reference case estimate for the price of gasoline. In this sensitivity analysis we examine the effect of instead using the AEO 2009 high and low price forecasts.

(2) The rebound effect: The Reference Case uses a rebound effect of 10 percent to project increased miles traveled as the cost per mile driven decreases. In the sensitivity analysis, we examine the effect of instead using a 5 percent or 15 percent rebound effect.

(3) The values of CO_2 benefits: The Reference Case uses $21 per ton (in 2010 in 2007$, rising over time to $45 in 2030) to quantify the benefits of reducing CO_2 emissions and $0.17 per gallon to quantify the energy security benefits from reducing fuel consumption. In the sensitivity analysis, we examine the effect of using values of $5, and $65 per ton instead of the reference value of $21 per ton to value CO_2 benefits. These values can be translated into cents per gallon by multiplying by 0.0089,[725] giving the following values:

($5 per ton CO_2) × 0.0089 = $0.045 per gallon

[725] The molecular weight of Carbon (C) is 12, the molecular weight of Oxygen (O) is 16, thus the molecular weight of CO_2 is 44. One ton of C = 44/12 tons CO_2 = 3.67 tons CO_2. 1 gallon of gas weighs 2,819 grams, of that 2,433 grams are carbon. $1.00 CO_2 = $3.67 C and $3.67/ton * ton/1,000kg * kg/1,000g * 2,433g/gallon = (3.67 * 2,433)/1,000 * 1,000 = $0.0089/gallon.

(\$21 per ton CO_2) × 0.0089 = \$0.187 per gallon
(\$35 per ton CO_2) × 0.0089 = \$0.312 per gallon
(\$67 per ton CO_2) × 0.0089 = \$0.596 per gallon

(4) Military security: The Reference Case uses \$0 per gallon to quantify the military security benefits of reducing fuel consumption. In the sensitivity analysis, we examine the impact of instead using a value of 5 cents per gallon.

Varying each of these four parameters in isolation results in 9 additional economic scenarios, in addition to the Reference case. These are listed in Table IV.G.4–22 below, together with two additional scenarios that use combinations of these parameters that together produce the lowest and highest benefits.

TABLE IV.G.4–22—SENSITIVITY ANALYSES EVALUATED IN NHTSA'S FRIA

Name	Fuel price	Discount rate (percent)	Rebound effect (percent)	SCC	Military security
Reference	AEO 20210 Reference Case	3	10	\$21	0¢/gal.
High Fuel Price	AEO 2009 High Price Case	3	10	21	0¢/gal.
Low Fuel Price	AEO 2009 Low Price Case	3	10	21	0¢/gal.
5% Rebound Effect	AEO 20210 Reference Case	3	5	21	0¢/gal.
15% Rebound Effect	AEO 20210 Reference Case	3	15	21	0¢/gal.
\$67/ton CO_2 Value	AEO 20210 Reference Case	3	10	67	0¢/gal.
\$35/ton CO_2 Value	AEO 20210 Reference Case	3	10	35	0¢/gal.
\$5/ton CO_2 Value	AEO 20210 Reference Case	3	10	5	0¢/gal.
\$5/ton CO_2	AEO 20210 Reference Case	3	10	5	0¢/gal.
5¢/gal Military Security Value	AEO 20210 Reference Case	3	10	21	5¢/gal.
Lowest Discounted Benefits	AEO 2009 Low Price Case	7	15	5	0¢/gal.
Highest Discounted Benefits	AEO 2009 High Price Case	3	5	67	5¢/gal.

The basic results of the sensitivity analyses were as follows:

(1) The various economic assumptions have no effect on the final passenger car and light truck standards established by this rule, because these are determined without reference to economic benefits.

(2) Varying the economic assumptions *individually* has comparatively modest impacts on fuel savings resulting from the adopted standards. The range of variation in fuel savings in response to changes in individual assumptions extends from a reduction of nearly 5 percent to an increase of that same percentage.

(3) The economic parameter with the greatest impacts on fuel savings is the magnitude of the rebound effect. Varying the rebound effect from 5 percent to 15 percent is responsible for a 4.6 percent increase and 4.6 percent reduction in fuel savings compared to the Reference results.

(4) The only other parameter that has a significant effect on fuel savings is forecast fuel prices, although its effect is complex because changes in fuel prices affect vehicle use and fuel consumption in both the baseline and under the final standards.

(5) Variation in forecast fuel prices and in the value of reducing CO_2 emissions have significant effects on the total economic benefits resulting from the final standards. Changing the fuel price forecast to AEO's High Price forecast raises estimated economic benefits by almost 40 percent, while using AEO's Low Price forecast reduces total economic benefits by only about 5 percent. Raising the value of eliminating each ton of CO_2 emissions to \$67 increases total benefits by 15 percent.

(6) Varying all economic parameters simultaneously has a significant effect on total economic benefits. The combination of parameter values producing the highest benefits increases their total by slightly more than 50 percent, while that producing the lowest benefits reduces their value by almost 55 percent. However, varying these parameters in combination has less significant effects on other measures; for example, the high- and low-benefit combinations of parameter values raise or lower fuel savings and technology costs by only about 5 percent.

For more detailed information regarding NHTSA's sensitivity analyses for this final rule, please see Chapter X of NHTSA's FRIA.

5. How would these final standards impact vehicle sales?

The effect of this rule on sales of new vehicles depends partly on how potential buyers evaluate and respond to its effects on vehicle prices and fuel economy. The rule will make new cars and light trucks more expensive, as manufacturers attempt to recover their costs for complying with the rule by raising vehicle prices, which by itself would discourage sales. At the same time, the rule will require manufacturers to improve the fuel economy of at least some of their models, which will lower their operating costs.

However, this rule will *not* change the way that potential buyers evaluate improved fuel economy. If some consumers find it difficult to estimate the value of future fuel savings and correctly compare it with the increased cost of purchasing higher fuel economy (possibilities discussed below in Section IV.G.6)—or if they simply have low values of saving fuel—this rule will not change that situation, and they are unlikely to purchase the more fuel-efficient models that manufacturers offer. To the extent that other consumers more completely or correctly account for the value of fuel savings and the costs of acquiring higher fuel economy in their purchasing decisions, they will also continue to do so, and they are likely to view models with improved fuel economy as more attractive purchases than currently available models. The effect of the rule on sales of new vehicles will depend on which form of behavior is more widespread.

In general we would expect that the net effect of this rule would be to reduce sales of new vehicles or leave them unchanged. If consumers are satisfied with the combinations of fuel economy levels and prices that current models offer, we would expect some to decide that the higher prices of those models no longer justify purchasing them, even though they offer higher fuel economy. Other potential buyers may decide to purchase the same vehicle they would have before the rule took effect, or to adjust their purchases in favor of models offering other attributes. Thus sales of new models would decline, regardless of whether “consumer-side” failures in the market for fuel economy currently lead buyers to under-invest in fuel economy. However, if there is some market failure on the producer or supply side that currently inhibits manufacturers from offering increases in fuel economy that would increase their profits—for example, if producers have underestimated the demand for fuel economy, or do not compete vigorously to provide as much as buyers would prefer—then the new standards would make vehicles more attractive to many buyers, and their sales should increase (potential explanations for such producer market failures are discussed in Section IV.G.6 below).

NHTSA examined the potential impact of higher vehicle prices on sales on an industry-wide basis for passenger cars and light trucks separately. We note that the analysis conducted for this rule does not have the precision to examine effects on individual manufacturers or different vehicle classes. The methodology NHTSA used for estimating the impact on vehicle sales in effect assumes that the latter situation will prevail; although it is relatively straightforward, it relies on a number of simplifying assumptions.

There is a broad consensus in the economic literature that the price elasticity for demand for automobiles is approximately −1.0.[726] Thus, every one percent increase in the price of the vehicle would reduce sales by one percent. Elasticity estimates assume no perceived change in the quality of the product. However, in this case, vehicle price increases result from adding technologies that improve fuel economy. If consumers did not value improved fuel economy at all, and considered nothing but the increase in price in their purchase decisions, then the estimated impact on sales from price elasticity could be applied directly. However, NHTSA believes that consumers do value improved fuel economy, because it reduces the operating cost of the vehicles. NHTSA also believes that consumers consider other factors that affect their costs and have included these in the analysis.

The main question, however, is how much of the retail price needed to cover the technology investments to meet higher fuel economy standards will manufacturers be able to pass on to consumers. The ability of manufacturers to pass the compliance costs on to consumers depends upon how consumers value the fuel economy improvements.[727] The estimates reported below as part of NHTSA’s analysis on sales impacts assume that manufacturers will be able to pass all of their costs to improve fuel economy on to consumers. To the extent that NHTSA has accurately predicted the price of gasoline and consumers reactions, and manufacturers can pass on all of the costs to consumers, then the sales and employment impact analyses are reasonable. On the other hand, if manufacturers only increase retail prices to the extent that consumers value these fuel economy improvements (*i.e.,* to the extent that they value fuel savings), then there would be no impact on sales, although manufacturers’ profit levels would fall. Sales losses are predicted to occur only if consumers fail to value fuel economy improvements at least as much as they pay in higher vehicle prices. Likewise, if fuel prices rise beyond levels used in this analysis, consumer valuation of improved fuel economy could potentially increase beyond that estimated here, which could result in an increase in sales levels.

To estimate the average value consumers place on fuel savings at the time of purchase, NHTSA assumes that the average purchaser considers the fuel savings they would receive over a 5 year time frame. NHTSA chose 5 years because this is the average length of time of a financing agreement.[728] The present values of these savings were calculated using a 3 percent discount rate. NHTSA used a fuel price forecast that included taxes, because this is what consumers must pay. Fuel savings were calculated over the first 5 years and discounted back to a present value.

NHTSA believes that consumers may consider several other factors over the 5 year horizon when contemplating the purchase of a new vehicle. NHTSA added these factors into the calculation to represent how an increase in technology costs might affect consumers’ buying considerations.

First, consumers might consider the sales taxes they have to pay at the time of purchasing the vehicle. NHTSA took sales taxes in 2007 by state and weighted them by population by state to determine a national weighted-average sales tax of 5.5 percent.

Second, NHTSA considered insurance costs over the 5 year period. More expensive vehicles will require more expensive collision and comprehensive (*e.g.,* theft) car insurance. The increase in insurance costs is estimated from the average value of collision plus comprehensive insurance as a proportion of average new vehicle price. Collision plus comprehensive insurance is the portion of insurance costs that depend on vehicle value. The Insurance Information Institute provides the average value of collision plus comprehensive insurance in 2006 as $448.[729] This is compared to an average price for light vehicles of $24,033 for 2006.[730] Average prices and estimated sales volumes are needed because price elasticity is an estimate of how a percent increase in price affects the percent decrease in sales.

Dividing the insurance cost by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.86 percent of the price of a vehicle. If we assume that this premium is proportional to the new vehicle price, it represents about 1.86 percent of the new vehicle price and insurance is paid each year for the five year period we are considering for payback. Discounting that stream of insurance costs back to present value indicates that the present value of the component of insurance costs that vary with vehicle price is equal to 8.5 percent of the vehicle’s price at a 3 percent discount rate.

Third, NHTSA considered that 70 percent of new vehicle purchasers take out loans to finance their purchase. The average new vehicle loan is for 5 years at a 6 percent rate.[731] At these terms, the average person taking a loan will pay 16 percent more for their vehicle over the 5 years than a consumer paying cash for

[726] Kleit, A.N. (1990). “The Effect of Annual Changes in Automobile Fuel Economy Standards,” *Journal of Regulatory Economics,* vol. 2, pp 151–172 (Docket EPA–HQ–OAR–2009–0472–0015); Bordley, R. (1994). “An Overlapping Choice Set Model of Automotive Price Elasticities,” *Transportation Research B,* vol 28B, no 6, pp 401–408 (Docket NHTSA–2009–0059–0153); McCarthy, P.S. (1996). “Market Price and Income Elasticities of New Vehicle Demands,” *The Review of Economics and Statistics,* vol. LXXVII, no. 3, pp. 543–547 (Docket NHTSA–2009–0059–0039).

[727] Gron, Ann and Swenson, Deborah, 2000, “Cost Pass-Through in the U.S. Automobile Market,” *The Review of Economics and Statistics,* 82: 316–324. (Docket EPA–HQ–OAR–2009–0472–0007).

[728] National average financing terms for automobile loans are available from the Board of Governors of the Federal Reserve System G.19 “Consumer Finance” release. *See http://www.federalreserve.gov/releases/g19/* (last accessed February 26, 2010).

[729] Insurance Information Institute, 2008, “Average Expenditures for Auto Insurance By State, 2005–2006.” *Available at http://www.iii.org/media/facts/statsbyissue/auto/* (last accessed March 15, 2010).

[730] $29,678/$26,201 = 1.1327 * $22,651 = $25,657 average price for light trucks. In 2006, passenger cars were 54 percent of the on-road fleet and light trucks were 46 percent of the on-road fleet, resulting in an average light vehicle price for 2006 of $24,033.

[731] New car loan rates in 2007 averaged about 7.8 percent at commercial banks and 4.5 percent at auto finance companies, so their average is close to 7 percent.

the vehicle at the time of purchase.[732] Discounting the additional 3.2 percent (16 percent/5 years) per year over the 5 years using a 3 percent mid-year discount rate [733] results in a discounted present value of 14.87 percent higher for those taking a loan. Multiplying that by the 70 percent of consumers who take out a loan means that the average consumer would pay 10.2 percent more than the retail price for loans the consumer discounted at a 3 percent discount rate.

Fourth, NHTSA considered the residual value (or resale value) of the vehicle after 5 years and expressed this as a percentage of the new vehicle price. In other words, if the price of the vehicle increases due to fuel economy technologies, the resale value of the vehicle will go up proportionately. The average resale price of a vehicle after 5 years is about 35 percent of the original purchase price.[734] Discounting the residual value back 5 years using a 3 percent discount rate (35 percent * .8755) gives an effective residual value at new of 30.6 percent.

NHTSA then adds these four factors together. At a 3 percent discount rate, the consumer considers she could get 30.6 percent back upon resale in 5 years, but will pay 5.5 percent more for taxes, 8.5 percent more in insurance, and 10.2 percent more for loans, results in a 6.48 percent return on the increase in price for fuel economy technology. Thus, the increase in price per vehicle is multiplied by 0.9352 (1 − 0.0648) before subtracting the fuel savings to determine the overall net consumer valuation of the increase of costs on her purchase decision.

The following table shows the estimated impact on sales for passenger cars, light trucks, and both combined for the final standards. For all model years except MY 2012, NHTSA anticipates an increase in sales, based on consumers valuing the improvement in fuel economy more than the increase in price.

TABLE IV.G.5–1—POTENTIAL IMPACT ON SALES, PASSENGER CARS AND LIGHT TRUCKS, AND COMBINED

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016
Passenger Cars	−65,202	46,801	103,422	168,334	227,039
Light Trucks	48,561	106,658	139,893	171,920	213,868
Combined	−16,641	153,459	243,315	340,255	440,907

The estimates provided in the tables above are meant to be illustrative rather than a definitive prediction. When viewed at the industry-wide level, they give a general indication of the potential impact on vehicle sales. As shown below, the overall impact is positive and growing over time for both cars and trucks. Because the fuel savings associated with this rule are expected to exceed the technology costs, the effective prices of vehicles (the adjusted increase in technology cost less the fuel savings over five years) to consumers will fall, and consumers will buy more new vehicles. As a result, the lower net cost of the vehicles is projected to lead to an increase in sales for both cars and trucks.

As discussed above, this result depends on the assumption that more fuel efficient vehicles yielding net consumer benefits over their first five years would not otherwise be offered, due to market failures on the part of vehicle manufacturers. However, vehicle models that achieve the fuel economy targets prescribed by today's rulemaking are already available, and consumers do not currently purchase a combination of them that meets the fuel economy levels this rule requires. This suggests that the rule may not result in an increase in vehicle sales, because it does not alter how consumers currently make decisions about which models to purchase. In addition, this analysis has not accounted for a number of factors that might affect consumer vehicle purchases, such as changing market conditions, changes in vehicle characteristics that might accompany improvements in fuel economy, or consumers considering a different "payback period" for their fuel economy purchases. If consumers use a shorter payback period, sales will increase by less than estimated here, and might even decline, while if consumers use longer payback periods, the increase in sales is likely to be larger than reported. In addition, because this is an aggregate analysis some individual consumers (including those who drive less than estimated here) will receive lower net benefits from the increase n fuel economy this rule requires, while others (who drive more than estimated here) will realize even greater savings. These complications—which have not been taken into account in our analysis—add considerable uncertainty to our estimates of changes in vehicle sales resulting from this rule.

6. Potential Unquantified Consumer Welfare Impacts of the Final Standards

The underlying goal of the CAFE and GHG standards is to increase social welfare, in the broadest sense, and as shown in earlier sections, NHTSA projects that the MY 2012–2016 CAFE standards will yield large net social benefits. In its net benefits analysis, NHTSA made every attempt to include all of the costs and benefits that could be identified and quantified.

It is important to highlight several features of the rulemaking analysis that NHTSA believes gives high confidence to its conclusion that there are large net social benefits from these standards. First, the agencies adopted footprint-based standards in large part so that the full range of vehicle choices in the marketplace could be maintained. Second, the agencies performed a rigorous technological feasibility, cost, and leadtime analysis that showed that the standards could be met while maintaining current levels of other vehicle attributes such as safety, utility, and performance. Third, widespread automaker support for the standards, in conjunction with the future product plans that have been provided by automakers to the agencies and recent industry announcements on new product offerings, provides further indication that the standards can be met while retaining the full spectrum of vehicle choices.

Notwithstanding these points, and its high degree of confidence that the benefits amply justify the costs, NHTSA recognizes the possibility of consumer welfare impacts that are not accounted for in its analysis of benefits and costs

[732] Based on *http://www.bankrate.com* auto loan calculator for a 5 year loan at 6 percent.

[733] For a 3 percent discount rate, the summation of 3.2 percent × 0.9853 in year one, 3.2 × 0.9566 in year two, 3.2 × 0.9288 in year three, 3.2 × 0.9017 in year 4, and 3.2 × 0.8755 in year five.

[734] Consumer Reports, August 2008, "What That Car Really Costs to Own." *Available at http://www.consumerreports.org/cro/cars/pricing/what-that-car-really-costs-to-own-4-08/overview/what-that-car-really-costs-to-own-ov.htm* (last accessed February 26, 2010).

from higher CAFE standards. The agencies received public comments expressing diverging views on this issue. The majority of commenters suggested that potential losses in welfare from requiring higher fuel economy were unlikely to be a significant concern, because of the many imperfections in the market for fuel economy. In contrast, other comments suggested that potential unidentified and unquantified consumer welfare losses could be large. Acknowledging the comments, the FRIA provides a sensitivity analysis showing how various levels of unidentified consumer welfare losses would affect the projected net social benefits from the CAFE standards established by this final rule.

There are two viewpoints for evaluating the costs and benefits of the increase in CAFE standards: The private perspective of vehicle buyers themselves on the higher fuel economy levels that the rule would require, and the economy-wide or "social" perspective on the costs and benefits of requiring higher fuel economy. It is important, in short, to distinguish between costs and benefits that are "private" and costs and benefits that are "social." The agency's analysis of benefits and costs from requiring higher fuel efficiency, presented above, includes several categories of benefits ("social benefits") that are not limited to automobile purchasers and that extend throughout the U.S. economy, such as reductions in the energy security costs associated with U.S. petroleum imports and in the economic damages expected to result from climate change. In contrast, other categories of benefits—principally the economic value of future fuel savings projected to result from higher fuel economy—will be experienced exclusively by the initial purchasers and subsequent owners of vehicle models whose fuel economy manufacturers elect to improve as part of their strategies for complying with higher CAFE standards ("private benefits").

Although the economy-wide or "social" benefits from requiring higher fuel economy represent an important share of the total economic benefits from raising CAFE standards, NHTSA estimates that benefits *to vehicle buyers themselves* will significantly exceed the costs of complying with the stricter fuel economy standards this rule establishes, as shown above. Since the agency also assumes that the costs of new technologies manufacturers will employ to improve fuel economy will ultimately be shifted to vehicle buyers in the form of higher purchase prices, NHTSA concludes that the benefits to vehicle buyers from requiring higher fuel efficiency will far outweigh the costs they will be required to pay to obtain it. However, this raises the question of why current purchasing patterns do not already result in higher average fuel economy, and why stricter fuel efficiency standards should be necessary to achieve that goal.

As an illustration, Table IV.G.6–1 reports the agency's estimates of the average lifetime values of fuel savings for MY 2012–2016 passenger cars and light trucks calculated using future retail fuel prices, which are those likely to be used by vehicle buyers to project the value of fuel savings they expect from higher fuel economy. The table compares NHTSA's estimates of the average lifetime value of fuel savings for cars and light trucks to the price increases it projects to result as manufacturers attempt to recover their costs for complying with increased CAFE standards for those model years by increasing vehicle sales prices. As the table shows, the agency's estimates of the present value of lifetime fuel savings (discounted using the OMB-recommended 3% rate) substantially outweigh projected vehicle price increases for both cars and light trucks in every model year, even under the assumption that all of manufacturers' technology outlays are passed on to buyers in the form of higher selling prices for new cars and light trucks. By model year 2016, NHTSA projects that average lifetime fuel savings will exceed the average price increase by more than $2,000 for cars, and by more than $2,700 for light trucks.

TABLE IV.G.6–1—VALUE OF LIFETIME FUEL SAVINGS VS. VEHICLE PRICE INCREASES

Fleet	Measure	Model year				
		2012	2013	2014	2015	2016
Passenger Cars	Value of Fuel Savings	$759	$1,349	$1,914	$2,480	$2,932
	Average Price Increase	505	573	690	799	907
	Difference	255	897	1,264	1,680	2,025
Light Trucks	Value of Fuel Savings	828	1,634	2,277	2,887	3,700
	Average Price Increase	322	416	621	752	961
	Difference	506	1,218	1,656	2,135	2,739

The comparisons above immediately raise the question of why current vehicle purchasing patterns do not already result in average fuel economy levels approaching those that this rule would require, and why stricter CAFE standards should be necessary to increase the fuel economy of new cars and light trucks. They also raise the question of why manufacturers do not elect to provide higher fuel economy even in the absence of increases in CAFE standards, since the comparisons in Table IV.G.6–1 suggest that doing so would increase the value of many new vehicle models by far more than it would raise the cost of producing them (and thus raise their purchase prices), thus presumably increasing sales of new vehicles. More specifically, why would potential buyers of new vehicles hesitate to make investments in higher fuel economy that would produce the substantial economic returns illustrated by the comparisons presented in Table IV.G.6–1? And why would manufacturers voluntarily forego opportunities to increase the attractiveness, value, and competitive positioning of their car and light truck models by improving their fuel economy?

The majority of comments received on this topic answered these questions by pointing out many reasons why the market for vehicle fuel economy does not appear to work perfectly, and accordingly, that properly designed CAFE standards would be expected to increase consumer welfare. Some of these imperfections might stem from standard market failures (such as an absence of adequate information on the part of consumers); some of them might involve findings in behavioral economics (including, for example, a lack of sufficient consumer attention to long-term savings, or a lack of salience, to consumers at the time of purchase, of relevant benefits, including fuel and time savings). Both theoretical and empirical research suggests that many consumers do not make energy-efficient investments even when those investments would pay off in the relatively short-term.[735] This research is in line with related findings that consumers may underweigh benefits and costs that are less salient or that will be realized only in the future.[736]

Existing work provides support for the agency's conclusion that the benefits buyers will receive from requiring manufacturers to increase fuel economy far outweigh the costs they will pay to acquire those benefits, by identifying aspects of normal behavior that may explain buyers' current reluctance to purchase vehicles whose higher fuel economy appears to offer an attractive economic return. For example, consumers' understandable aversion to the prospect of losses ("loss aversion") may produce an exaggerated sense of uncertainty about the value of future fuel savings, making consumers reluctant to purchase a more fuel-efficient vehicle seem unattractive, even when doing so *is* likely to be a sound economic decision. Compare the finding in Greene et al. (2009) to the effect that the expected net present value of increasing the fuel economy of a passenger car from 28 to 35 miles per gallon falls from $405 when calculated using standard net present value calculations, to nearly zero when uncertainty regarding future cost savings is taken into account.[737]

The well-known finding that as gas prices rise, consumers show more willingness to pay for fuel-efficient vehicles is not inconsistent with the possibility that many consumers undervalue gasoline costs and fuel economy at the time of purchase. In ordinary circumstances, such costs may be a relatively "shrouded" attribute in consumers' decisions, in part because the savings are cumulative and extend over a significant period of time. This claim fits well with recent findings to the effect that many consumers are willing to pay less than $1 upfront to obtain a $1 benefit reduction in discounted gasoline costs.[738]

Some research suggests that the consumers' apparent unwillingness to purchase more fuel efficient vehicles stems from their inability to value future fuel savings correctly. For example, Larrick and Soll (2008) find evidence that consumers do not understand how to translate changes in fuel economy, which is denominated in miles per gallon, into resulting changes in fuel consumption, measured in gallons per time period.[739] Sanstad and Howarth (1994) argue that consumers resort to imprecise but convenient rules of thumb to compare vehicles that offer different fuel economy ratings, and that this behavior can cause many buyers to underestimate the value of fuel savings, particularly from significant increases in fuel economy.[740] If the behavior identified in these studies is widespread, then the agency's estimates suggesting that the benefits to vehicle owners from requiring higher fuel economy significantly exceed the costs of providing it are indeed likely to be correct.

Another possible reconciliation of the agency's claim that the *average* vehicle buyer will experience large fuel savings from the higher CAFE standards this rule establishes with the fact that the *average* fuel economy of vehicles currently purchased falls well short of the new standards is that the values of future savings from higher fuel economy vary widely across consumers. As an illustration, one recent review of consumers' willingness to pay for improved fuel economy found estimates that varied from less than 1% to almost ten times the present value of the resulting fuel savings when those are discounted at 7% over the vehicle's expected lifetime.[741] The wide variation in these estimates undoubtedly reflects methodological and measurement differences among the studies surveyed. However, it may also reveal that the expected savings from purchasing a vehicle with higher fuel economy vary widely among individuals, because they travel different amounts, have different driving styles, or simply have varying expectations about future fuel prices.

These differences reflect the possibility that many buyers with high valuations of increased fuel economy *already* purchase vehicle models that offer it, while those with lower values of fuel economy emphasize other vehicle attributes in their purchasing decisions. A related possibility is that because the effects of differing fuel economy levels are relatively modest when compared to those provided by other, more prominent features of new vehicles—passenger and cargo-carrying capacity, performance, safety, etc.—it is simply not in many shoppers' interest to spend the time and effort necessary to determine the economic value of higher fuel economy, attempt to isolate the component of a new vehicle's selling price that is related to its fuel economy, and compare these two. (This possibility is consistent with the view that fuel economy is a relatively "shrouded" attribute.) In either case, the agency's estimates of the *average* value of fuel savings that will result from requiring cars and light trucks to achieve higher fuel economy may be correct, but those savings may not be large enough to lead a sufficient number of buyers to push for vehicles with higher fuel economy to increase average fuel economy from its current levels.

Defects in the market for cars and light trucks could also lead manufacturers to undersupply fuel economy, even in cases where many buyers were willing to pay the increased prices necessary to provide it.

To be sure, the relevant market, taken as a whole, has a great deal of competition. But even in those circumstances, there may not such competition with respect to all vehicle attributes. Incomplete or "asymmetric" access to information on vehicle attributes such as fuel economy—whereby manufacturers of new vehicles or sellers of used cars and light trucks

[735] Jaffe, A. B., and Stavins, R. N. (1994). The Energy Paradox and the Diffusion of Conservation Technology. Resource and Energy Economics, 16(2); see Hunt Alcott and Nathan Wozny, Gasoline Prices, Fuel Economy, and the Energy Paradox (2010, available at *http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf.*

[736] Hossain, Janjim, and John Morgan (2009). "* * * Plus Shipping and Handling: Revenue (Non)Equivalence in Field Experiments on eBay," Advances in Economic Analysis and Policy vol. 6; Barber, Brad, Terrence Odean, and Lu Zheng (2005). "Out of Sight, Out of Mind: The Effects of Expenses on Mutual Fund Flows," Journal of Business vol. 78, no. 6, pp. 2095–2020.

[737] Greene, D., J. German, and M. Delucchi (2009). "Fuel Economy: The Case for Market Failure" in Reducing Climate Impacts in the Transportation Sector, Sperling, D., and J. Cannon, eds. Springer Science. Surprisingly, the authors find that uncertainty regarding the future price of gasoline appears to be less important than uncertainty surrounding the expected lifetimes of new vehicles. (Docket NHTSA–2009–0059–0154).

[738] *See* Alcott and Wozny.

[739] Larrick, R. P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593–1594.

[740] Sanstad, A., and R. Howarth (1994). " 'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811–818.

[741] Greene, David L., "How Consumers Value Fuel Economy: A Literature Review," Draft report to U.S. Environmental Protection Agency, Oak Ridge National Laboratory, December 29, 2009; *see* Table 10, p. 37.

See also David Greene and Jin-Tan Liu (1988). "Automotive Fuel Economy Improvements and Consumers' Surplus." Transportation Research Part A 22A(3): 203–218 (Docket EPA–HQ–OAR–2009–0472–0045). The study actually calculated the willingness to pay for reduced vehicle operating costs, of which vehicle fuel economy is a major component.

have more complete knowledge of the value of purchasing higher fuel economy, than do potential buyers—may also prevents sellers of new or used vehicles from capturing its full value. In this situation, the level of fuel efficiency provided in the markets for new or used vehicles might remain persistently lower than that demanded by potential buyers (at least if they are well-informed).

It is also possible that deliberate decisions by manufacturers of cars and light trucks, rather than constraints on the combinations of fuel economy, carrying capacity, and performance that manufacturers can offer using current technologies, limit the range of fuel economy available to buyers within individual vehicle market segments, such as full-size automobiles, small SUVs, or minivans. As an illustration, once a potential buyer has decided to purchase a minivan, the range of fuel economy among current models extends only from 18 to 24 mpg.[742] Manufacturers might make such decisions if they underestimate the premiums that shoppers in certain market segments are willing to pay for more fuel-efficient versions of the vehicle models they currently offer to prospective buyers within those segments. If this occurs, manufacturers may fail to supply levels of fuel efficiency as high as those buyers are willing to pay for, and the average fuel efficiency of their entire new vehicle fleets could remain below the levels that potential buyers demand and are willing to pay for. (Of course this possibility is most realistic if it is also assumed that buyers are imperfectly informed or if fuel economy savings are not sufficiently salient.) However, other commenters suggested that, if one assumes a perfectly functioning market, there must be unidentified consumer welfare losses that could offset the private fuel savings that consumers are currently foregoing.

One explanation for this apparent paradox is that NHTSA's estimates of benefits and costs from requiring manufacturers to improve the fuel efficiency of their vehicle models do not match potential vehicle buyers' assessment of the likely benefits and costs from requiring higher fuel efficiency. This could occur because the agency's underlying assumptions about some of the factors that affect the value of fuel savings differ from those made by potential buyers, because NHTSA has used different estimates for some components of the benefits from saving fuel than do buyers, or because the agency has failed to account for some potential costs of achieving higher fuel economy.

For example, buyers may not value increased fuel economy as highly as the agencies' calculations suggest, because they have shorter time horizons than the full vehicle lifetimes assumed by NHTSA and EPA, or because, when buying vehicles, they discount future fuel future savings using higher rates than those prescribed by OMB for evaluating Federal regulations. Potential buyers may also anticipate lower fuel prices in the future than those forecast by the Energy Information Administration, or may expect larger differences between vehicles rated and actual on-road MPG levels than the agencies' estimate.

To illustrate the first of these possibilities, Table IV.G.6–2 shows the effect of differing assumptions about vehicle buyers' time horizons for assessing the value of future fuel savings. Specifically, the table compares the average value of fuel savings from purchasing a MY 2016 car or light truck when fuel savings are evaluated over different time horizons to the estimated increase in its price. This table shows that as reported previously in Table IV.G.6–2, when fuel savings are evaluated over the entire expected lifetime of a MY 2016 car (approximately 14 years) or light truck (about 16 years), their discounted present value (using the OMB-recommended 3% discount rate) lifetime fuel savings exceeds the estimated average price increase by more than $2,000 for cars and by more than $2,700 for light trucks.

If buyers are instead assumed to consider fuel savings over a 10-year time horizon, however, the present value of fuel savings exceeds the projected price increase for a MY 2016 car by about $1,300, and by somewhat more than $1,500 for a MY 2016 light truck. Finally, Table VI.G.6–2 shows that under the assumption that buyers consider fuel savings only over the length of time for which they typically finance new car purchases (slightly more than 5 years during 2009), the value of fuel savings exceeds the estimated increase in the price of a MY 2016 car by only about $350, and the corresponding difference is reduced to slightly more than $500 for a MY 2016 light truck.

TABLE IV.G.6–2—VALUE OF FUEL SAVINGS VS. VEHICLE PRICE INCREASES WITH ALTERNATIVE ASSUMPTIONS ABOUT VEHICLE BUYER TIME HORIZONS

Vehicle	Measure	Value over alternative time horizons		
		Expected lifetime [743]	10 years	Average loan term [744]
MY 2016 Passenger Car	Fuel Savings	$2,932	$2,180	$1,254
	Price Increase	907	907	907
	Difference	2,025	1,273	347
MY 2016 Light Truck	Fuel Savings	3,700	2,508	1,484
	Price Increase	961	961	961
	Difference	2,739	1,547	523

Potential vehicle buyers may also discount future fuel future savings using higher rates than those typically used to evaluate Federal regulations. OMB guidance prescribes that future benefits and costs of regulations that mainly

[742] This is the range of combined city and highway fuel economy levels from lowest (Toyota Siena 4WD) to highest (Mazda 5) available for model year 2010; *http://www.fueleconomy.gov/feg/bestworstEPAtrucks.htm* (last accessed February 15, 2010).

[743] Expected lifetimes are approximately 14 years for cars and 16 years for light trucks.

[744] Average term on new vehicle loans made by auto finance companies during 2009 was 62 months; *See* Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.19, Consumer Credit. *Available at http://www.federalreserve.gov/releases/g19/Current* (last accessed March 1, 2010).

affect private consumption decisions, as will be the case if manufacturers' costs for complying with higher fuel economy standards are passed on to vehicle buyers, should be discounted using a consumption rate of time preference.[745] OMB estimates that savers currently discount future consumption at an average real or inflation-adjusted rate of about 3 percent when they face little risk about its likely level, which makes it a reasonable estimate of the consumption rate of time preference. However, vehicle buyers may view the value of future fuel savings that results from purchasing a vehicle with higher fuel economy as risky or uncertain, or they may instead discount future consumption at rates reflecting their costs for financing the higher capital outlays required to purchase more fuel-efficient models. In either case, they may discount future fuel savings at rates well above the 3% assumed in NHTSA's evaluation in their purchase decisions.

Table IV.G.6–3 shows the effects of higher discount rates on vehicle buyers' evaluation of the fuel savings projected to result from the CAFE standards established by this rule, again using MY 2016 passenger cars and light trucks as an example. As Table IV.G.6–1 showed previously, average future fuel savings discounted at the OMB 3% consumer rate exceed the agency's estimated price increases by more than $2,000 for MY 2016 passenger cars and by more than $2,700 for MY 2016 light trucks. If vehicle buyers instead discount future fuel savings at the average new-car loan rate during 2009 (6.7%), however, these differences decline to slightly more than $1,400 for cars and $1,900 for light trucks, as Table IV.G.6–3 illustrates.

This is a potentially plausible alternative assumption, because buyers are likely to finance the increases in purchase prices resulting from compliance with higher CAFE standards as part of the process of financing the vehicle purchase itself. Finally, as the table also shows, discounting future fuel savings using a consumer credit card rate (which averaged 13.4% during 2009) reduces these differences to less than $800 for a MY 2016 passenger car and less than $1,100 for the typical MY 2016 light truck. Note, however, that even at these higher discount rates, the table shows that the private net benefits from purchasing a vehicle with the average level of fuel economy this rule requires remains large.

TABLE IV.G.6–3—VALUE OF FUEL SAVINGS VS. VEHICLE PRICE INCREASES WITH ALTERNATIVE ASSUMPTIONS ABOUT CONSUMER DISCOUNT RATES

Vehicle	Measure	Value over alternative time horizons			
		OMB consumer rate (3%)	New car loan rate (6.7%)[746]	OMB investment rate (7%)	Consumer credit card rate (13.4%)[747]
MY 2016 Passenger Car	Fuel Savings	$2,932	$2,336	$2,300	$1,669
	Price Increase	907	907	907	907
	Difference	2,025	1,429	1,393	762
MY 2016 Light Truck	Fuel Savings	3,700	2,884	2,836	2,030
	Price Increase	961	961	961	961
	Difference	2,739	1,923	1,875	1,069

Combinations of a shorter time horizon and a higher discount rate could further reduce or even eliminate the difference between the value of fuel savings and the agency's estimates of increases in vehicle prices. One plausible combination would be for buyers to discount fuel savings over the term of a new car loan, using the interest rate on that loan as a discount rate. Doing so would reduce the amount by which future fuel savings exceed the estimated increase in the prices of MY 2016 vehicles to about $340 for passenger cars and $570 for light trucks. Some evidence also suggests directly that vehicle buyers may employ combinations of higher discount rates and shorter time horizons for their purchase decisions; for example, consumers surveyed by Kubik (2006) reported that fuel savings would have to be adequate to pay back the additional purchase price of a more fuel-efficient vehicle in less than 3 years to persuade a typical buyer to purchase it.[748] As these comparisons and evidence illustrate, reasonable alternative assumptions about how consumers might evaluate the major benefit from requiring higher fuel economy can significantly affect the benefits they expect to receive when they decide to purchase a new vehicle.

Imaginable combinations of shorter time horizons, higher discount rates, and lower expectations about future fuel prices or annual vehicle use and fuel savings could make potential buyers hesitant or even unwilling to purchase vehicles offering the increased fuel economy levels this rule will require manufacturers to produce. At the same time, they might cause vehicle buyers' collective assessment of the aggregate benefits and costs of this rule to differ from NHTSA's estimates. If consumers' views about critical variables such as future fuel prices or the appropriate discount rate differ sufficiently from the assumptions used by the agency, some or perhaps many potential vehicle buyers might conclude that the value of fuel savings and other benefits they will experience from higher fuel economy are not sufficient to justify the increase in purchase prices they expect to pay. This would explain why their current choices among available models do not result in average fuel economy levels

[745] Office of Management and Budget, Circular A–4, "Regulatory Analysis," September 17, 2003, 33. *Available at http://www.whitehouse.gov/omb/assets/regulatory_matters_pdf/a-4.pdf* (last accessed March 1, 2010).

[746] Average rate on 48-month new vehicle loans made by commercial banks during 2009 was 6.72%; *See* Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.19, Consumer Credit. *Available at http://www.federalreserve.gov/releases/g19/Current* (last accessed March 1, 2010).

[747] Average rate on consumer credit card accounts at commercial banks during 2009 was 13.4%; *See* Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.19, Consumer Credit. *Available at http://www.federalreserve.gov/releases/g19/Current* (last accessed March 1, 2010).

[748] Kubik, M. (2006). Consumer Views on Transportation and Energy. Second Edition. Technical Report: National Renewable Energy Laboratory. *Available at* Docket No. NHTSA–2009–0059–0038.

approaching those this rule would require.

Another possibility is that achieving the fuel economy improvements required by stricter fuel economy standards might mean that manufacturers will forego planned future improvements in performance, carrying capacity, safety, or other features of their vehicle models that represent important sources of utility to vehicle owners. Although the specific economic values that vehicle buyers attach to individual vehicle attributes such as fuel economy, performance, passenger- and cargo-carrying capacity, and other sources of vehicles' utility are difficult to infer from their purchasing decisions and vehicle prices, changes in vehicle attributes can significantly affect the overall utility that vehicles offer to potential buyers. Foregoing future improvements in these or other highly-valued attributes could be viewed by potential buyers as an additional cost of improving fuel economy.

As indicated in its previous discussion of technology costs, NHTSA has approached this potential problem by developing cost estimates for fuel economy-improving technologies that include allowances for any additional manufacturing costs that would be necessary to maintain the reference fleet (or baseline) levels of performance, comfort, capacity, or safety of light-duty vehicle models to which those technologies are applied. In doing so, the agency followed the precedent established by the 2002 NAS Report on improving fuel economy, which estimated "constant performance and utility" costs for technologies that manufacturers could employ to increase the fuel efficiency of cars or light trucks. Although NHTSA has revised its estimates of manufacturers' costs for some technologies significantly for use in this rulemaking, these revised estimates are still intended to represent costs that would allow manufacturers to maintain the performance, safety, carrying capacity, and utility of vehicle models while improving their fuel economy. The adoption of the footprint-based standards also addresses this concern.

Finally, vehicle buyers may simply prefer the choices of vehicle models they now have available to the combinations of price, fuel economy, and other attributes that manufacturers are likely to offer when required to achieve higher overall fuel economy. If this is the case, their choices among models—and even some buyers' decisions about whether to purchase a new vehicle—will respond accordingly, and their responses to these new choices will reduce their overall welfare. Some may buy models with combinations of price, fuel efficiency, and other attributes that they consider less desirable than those they would otherwise have purchased, while others may simply postpone buying a new vehicle. The use of the footprint-based standards, the level of stringency, and the lead time this rule allows manufacturers are all intended to ensure that this does not occur. Although the potential losses in buyers' welfare associated with these responses cannot be large enough to offset the estimated value of fuel savings reported in the agencies' analyses, they might reduce the benefits from requiring manufacturers to achieve higher fuel efficiency, particularly in combination with the other possibilities outlined previously.

As the foregoing discussion suggests, the agency does not have a complete answer to the question of why the apparently large differences between its estimates of benefits from requiring higher fuel economy and the costs of supplying it do not result in higher average fuel economy for new cars and light trucks in the absence of this rule. One explanation is that NHTSA's estimates are reasonable, and that for the reasons outlined above, the market for fuel economy is not operating efficiently. NHTSA believes that the existing literature gives support for the view that because of various market failures (including behavioral factors, such as emphasis on the short-term and a lack of salience), there are likely to be substantial private gains, on net, from the rule, but it will continue to investigate new empirical literature as it becomes available.

NHTSA acknowledges the possibility that it has incorrectly characterized the impact of the CAFE standards this rule establishes on consumers. To recognize this possibility, this section presents an alternative accounting of the benefits and costs of CAFE standards for MYs 2012–2016 passenger cars and light trucks and discusses its implications. Table IV.G.6–4 displays the economic impacts of the rule as viewed from the perspective of potential buyers, and also reconciles the estimated net benefits of the rule as they are likely to be viewed by vehicle buyers with its net benefits to the economy as a whole.

As the table shows, the total benefits to vehicle buyers (line 4) consist of the value of fuel savings at retail fuel prices (line 1), the economic value of vehicle occupants' savings in refueling time (line 2), and the economic benefits from added rebound-effect driving (line 3). As the zero entries in line 5 of the table suggest, the agency's estimate of the retail value of fuel savings reported in line 1 is assumed to be correct, and no losses in consumer welfare from changes in vehicle attributes (other than those from increases in vehicle prices) are assumed to occur. Thus there is no reduction in the total private benefits to vehicle owners, so that net private benefits to vehicle buyers (line 6) are equal to total private benefits (reported previously in line 4).

As Table IV.G.6–4 also shows, the decline in fuel tax revenues (line 7) that results from reduced fuel purchases is in effect a social cost that offsets part of the benefits of fuel savings to vehicle buyers (line 1).[749] Thus the sum of lines 1 and 7 is the savings in fuel production costs that was reported previously as the value of fuel savings at pre-tax prices in the agency's usual accounting of benefits and costs. Lines 8 and 9 of Table IV.G.6–4 report the value of reductions in air pollution and climate-related externalities resulting from lower emissions during fuel production and consumption, while line 10 reports the savings in energy security externalities to the U.S. economy from reduced consumption and imports of crude petroleum and refined fuel. Line 12 reports the costs of increased congestion delays, accidents, and noise that result from additional driving due to the fuel economy rebound effect; net social benefits (line 13) is thus the sum of the change in fuel tax revenues, the reduction in environmental and energy security externalities, and increased costs from added driving.

Line 14 of Table IV.G.6–4 shows manufacturers' technology outlays for meeting higher CAFE standards for passenger cars and light trucks, which represent the principal cost of requiring higher fuel economy. The net total benefits (line 15 of the table) resulting from the rule consist of the sum of private (line 6) and external (line 13) benefits, minus technology costs (line 14); as expected, the figures reported in line 15 of the table are identical to those reported previously in the agency's customary format.

Table IV.G.6–4 highlights several important features of this rule's

[749] Strictly speaking, fuel taxes represent a transfer of resources from consumers of fuel to government agencies and not a use of economic resources. Reducing the volume of fuel purchases simply reduces the value of this transfer, and thus cannot produce a real economic cost or benefit. Representing the change in fuel tax revenues in effect as an economy-wide cost is necessary to offset the portion of fuel savings included in line 1 that represents savings in fuel tax payments by consumers. This prevents the savings in tax revenues from being counted as a benefit from the economy-wide perspective.

economic impacts. First, comparing the rule's net private (line 6) and external (line 13) benefits makes it clear that a substantial majority of the benefits from requiring higher fuel economy are experienced by vehicle buyers, with only a small share distributed throughout the remainder of the U.S. economy. In turn, the vast majority of private benefits stem from fuel savings. External benefits are small because the value of reductions in environmental and energy security externalities is almost exactly offset by the decline in fuel tax revenues and the increased costs associated with added vehicle use via the rebound effect of higher fuel economy. As a consequence, the net economic benefits of the rule mirror closely its benefits to private vehicle buyers and the technology costs for achieving higher fuel economy, again highlighting the importance of accounting for any other effects of the rule on the economic welfare of vehicle buyers.

TABLE IV.G.6–4—PRIVATE, SOCIAL, AND TOTAL BENEFITS AND COSTS OF MY 2012–16 CAFE STANDARDS: PASSENGER CARS PLUS LIGHT TRUCKS

Entry	Model year					
	2012	2013	2014	2015	2016	Total, 2012–2016
1. Value of Fuel Savings (at Retail Fuel Prices)	$10.5	$22.9	$32.9	$42.5	$52.7	$161.6
2. Savings in Refueling Time	0.7	1.4	1.9	2.5	3.0	9.4
3. Consumer Surplus from Added Driving	0.7	1.5	2.2	2.8	3.4	10.5
4. Total Private Benefits (= 1+ 2 + 3)	11.9	25.8	37.0	47.8	59.0	181.5
5. Reduction in Private Benefits	0.0	0.0	0.0	0.0	0.0	0.0
6. Net Private Benefits (= 1 + 2)	11.9	25.8	37.0	47.8	59.0	181.5
7. Change in Fuel Tax Revenues	−1.3	−2.7	−3.8	−4.8	−5.9	−18.5
8. Reduced Health Damages from Criteria Emissions	0.5	0.9	1.3	1.6	2.0	6.4
9. Reduced Climate Damages from CO_2 Emissions	0.9	2.0	2.9	3.8	4.8	14.5
10. Reduced Energy Security Externalities	0.5	1.2	1.6	2.1	2.5	8.0
11. Reduction in Externalities (= 8 + 9 + 10)	1.9	4.1	5.9	7.6	9.3	28.8
12. Increased Costs of Congestion, etc	−0.7	−1.3	−1.9	−2.4	−3.0	−9.4
13. Net Social Benefits (= 7 + 11 + 12)	0.0	0.1	0.1	0.3	0.5	1.0
14. Technology Costs	5.9	7.9	10.5	12.5	14.9	51.7
15. Net Social Benefits (= 6 + 12 − 14)	6.0	17.9	26.6	35.5	44.6	130.7

As discussed in detail previously, NHTSA believes that the aggregate benefits from this rule amply justify its aggregate costs, but it remains possible that the agency has overestimated the value of fuel savings to buyers and subsequent owners of the cars and light trucks to which higher CAFE standards will apply. It is also possible that the agency has failed to identify and value reductions in consumer welfare that could result from buyers' responses to changes in vehicle attributes that manufacturers make as part of their efforts to achieve higher fuel economy. To acknowledge these possibilities, NHTSA examines their potential impact on the rule's benefits and costs, showing the rule's economic impacts for MY 2012–16 passenger cars and light trucks under varying theoretical assumptions about the agency's potential overestimation of private benefits from higher fuel economy and the value of potential changes in other vehicle attributes. See Chapter VIII of the FRIA.

7. What other impacts (quantitative and unquantifiable) will these final standards have?

In addition to the quantified benefits and costs of fuel economy standards, the final standards will have other impacts that we have not quantified in monetary terms. The decision on whether or not to quantify a particular impact depends on several considerations:

Does the impact exist, and can the magnitude of the impact reasonably be attributed to the outcome of this rulemaking?

Would quantification help NHTSA and the public evaluate standards that may be set in rulemaking?

Is the impact readily quantifiable in monetary terms? Do we know how to quantify a particular impact?

If quantified, would the monetary impact likely be material?

Can a quantification be derived with a sufficiently narrow range of uncertainty so that the estimate is useful?

NHTSA expects that this rulemaking will have a number of genuine, material impacts that have not been quantified due to one or more of the considerations listed above. In some cases, further research may yield estimates for future rulemakings.

Technology Forcing

The final rule will improve the fuel economy of the U.S. new vehicle fleet, but it will also increase the cost (and presumably, the price) of new passenger cars and light trucks built during MYs 2012–2016. We anticipate that the cost, scope, and duration of this rule, as well as the steadily rising standards it requires, will cause automakers and suppliers to devote increased attention to methods of improving vehicle fuel economy.

This increased attention will stimulate additional research and engineering, and we anticipate that, over time, innovative approaches to reducing the fuel consumption of light duty vehicles will emerge. Several commenters agreed. These innovative approaches may reduce the cost of the final rule in its later years, and also increase the set of feasible technologies in future years.

We have attempted to estimate the effect of learning on known technologies within the period of the rulemaking. We have not attempted to estimate the extent to which not-yet-invented technologies will appear, either within the time period of the current rulemaking or that might be available after MY 2016.

Effects on Vehicle Maintenance, Operation, and Insurance Costs

Any action that increases the cost of new vehicles will subsequently make such vehicles more costly to maintain, repair, and insure. In general, this effect can be expected to be a positive linear function of vehicle costs. The final rule raises vehicle costs by over $900 by 2016, and for some manufacturers costs will increase by $1,000–$1,800. Depending on the retail price of the vehicle, this could represent a significant increase in the overall vehicle cost and subsequently increase insurance rates, operation costs, and maintenance costs. Comprehensive insurance costs are likely to be directly related to price increases, but liability premiums will go up by a smaller proportion because the bulk of liability coverage reflects the cost of personal injury. The impact on operation and maintenance costs is less clear, because the maintenance burden and useful life of each technology are not known. However, one of the common consequences of using more complex or innovative technologies is a decline in vehicle reliability and an increase in maintenance costs, borne, in part, by the manufacturer (through warranty costs, which are included in the indirect costs of production) and, in part by the vehicle owner. NHTSA believes that this effect is difficult to quantify for purposes of this final rule. The agency will analyze this issue further for future rulemakings to attempt to gauge its impact more completely.

Effects on Vehicle Miles Traveled (VMT)

While NHTSA has estimated the impact of the rebound effect on VMT, we have not estimated how a change in vehicle sales could impact VMT. Since the value of the fuel savings to consumers outweighs the technology costs, new vehicle sales are predicted to increase. A change in vehicle sales will have complicated and a hard-to-quantify effect on vehicle miles traveled given the rebound effect, the trade-in of older vehicles, etc. In general, overall VMT should not be significantly affected.

Effect on Composition of Passenger Car and Light Truck Sales

In addition, manufacturers, to the extent that they pass on costs to customers, may distribute these costs across their motor vehicle fleets in ways that affect the composition of sales by model. To the extent that changes in the composition of sales occur, this could affect fuel savings to some degree. However, NHTSA's view is that the scope for compositional effects is relatively small, since most vehicles will to some extent be impacted by the standards. Compositional effects might be important with respect to compliance costs for individual manufacturers, but are unlikely to be material for the rule as a whole.

NHTSA is continuing to study methods of estimating compositional effects and may be able to develop methods for use in future rulemakings.

Effects on the Used Vehicle Market

The effect of this rule on the use and scrappage of older vehicles will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, and the total sales of new vehicles. Elsewhere in this analysis, NHTSA estimates that vehicle sales will increase. This would occur because the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' costs. Under these circumstances, sales of new vehicles will rise, while scrappage rates of used vehicles will increase slightly. This will cause the "turnover" of the vehicle fleet—that is, the retirement of used vehicles and their replacement by new models—to accelerate slightly, thus accentuating the anticipated effect of the rule on fleet-wide fuel consumption and CO_2 emissions. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles would decline, as would the rate at which used vehicles are retired from service. This effect will slow the replacement of used vehicles by new models, and thus partly offset the anticipated effects of the proposed rules on fuel use and emissions.

Impacts of Changing Fuel Composition on Costs, Benefits, and Emissions

EPAct, as amended by EISA, creates a Renewable Fuels Standard that sets targets for greatly increased usage of renewable fuels over the next decade. The law requires fixed volumes of renewable fuels to be used—volumes that are not linked to actual usage of transportation fuels.

Ethanol and biodiesel (in the required volumes) may increase or decrease the cost of blended gasoline and diesel depending on crude oil prices and tax subsidies. The potential extra cost of renewable fuels would be borne through a cross-subsidy: The price of every gallon of blended gasoline could rise sufficiently to pay for any extra cost of renewable fuels. However, if the price of fuel increases enough, the consumer could actually realize a savings through the increased usage of renewable fuels. The final CAFE rule, by reducing total fuel consumption, could tend to increase any necessary cross-subsidy per gallon of fuel, and hence raise the market price of transportation fuels, while there would be no change in the volume or cost of renewable fuels used.

These effects are indirectly incorporated in NHTSA's analysis of the proposed CAFE rule because they are directly incorporated in EIA's projections of future gasoline and diesel prices in the Annual Energy Outlook, which incorporates in its baseline both a Renewable Fuel Standard and an increasing CAFE standard.

The net effect of incorporating an RFS then might be to slightly reduce the benefits of the rule because affected vehicles might be driven slightly less, and because they emit slightly fewer greenhouse gas emissions per gallon. In addition there might be corresponding losses from the induced reduction in VMT. All of these effects are difficult to estimate, because of uncertainty in future crude oil prices, uncertainty in future tax policy, and uncertainty about how petroleum marketers will actually comply with the RFS, but they are likely to be small, because the cumulative deviation from baseline fuel consumption induced by the final rule will itself be small.

Macroeconomic Impacts of This Rule

The final rule will have a number of consequences that may have short-run and longer-run macroeconomic effects. It is important to recognize, however, that these effects do *not* represent benefits in addition to those resulting directly from reduced fuel consumption and emissions. Instead, they represent the economic effects that occur as these direct impacts filter through the interconnected markets comprising the U.S. economy.

Increasing the cost and quality (in the form of better fuel economy) of new passenger cars and light trucks will have ripple effects through the rest of the economy. Depending on the assumptions made, the rule could generate very small increases or declines in output.

Reducing consumption of imported petroleum should induce an increase in long-run output.

Decreasing the world price of oil should induce an increase in long-run output.

NHTSA has not studied the macroeconomic effects of the final rule, however a discussion of the economy-wide impacts of this rule conducted by EPA is presented in Section III.H and is included in the docket. Although economy-wide models do not capture all of the potential impacts of this rule (*e.g.,* improvements in product quality), these models can provide valuable insights on how this final rule would impact the U.S. economy in ways that extend beyond the transportation sector.

Military Expenditures

This analysis contains quantified estimates for the social cost of petroleum imports based on the risk of oil market disruption. We have not included estimates of monopsony effects or the cost of military expenditures associated with petroleum imports.

Distributional Effects

The final rule analysis provides a national-level distribution of impacts for gas price and similar variables. NHTSA also shows the effects of the EIA high and low gas price forecasts on the aggregate benefits in the sensitivity analysis. Generally, this rule has the greatest impact on those individuals who purchase vehicles. In terms of how the benefits of the rule might accrue differently for different consumers, consumers who drive more than our mean estimates for VMT will see more fuel savings, while those who drive less than our mean VMT estimates will see less fuel savings.

H. Vehicle Classification

Vehicle classification, for purposes of the CAFE program, refers to whether NHTSA considers a vehicle to be a passenger automobile or a light truck, and thus subject to either the passenger automobile or the light truck standards. As NHTSA explained in the MY 2011 rulemaking, EPCA categorizes some light 4-wheeled vehicles as passenger automobiles (cars) and the balance as non-passenger automobiles (light trucks). EPCA defines passenger automobiles as any automobile (other than an automobile capable of off-highway operation) which NHTSA decides by rule is manufactured primarily for use in the transportation of not more than 10 individuals. EPCA 501(2), 89 Stat. 901. NHTSA created regulatory definitions for passenger automobiles and light trucks, found at 49 CFR part 523, to guide the agency and manufacturers in classifying vehicles.

Under EPCA, there are two general groups of automobiles that qualify as non-passenger automobiles or light trucks: (1) Those defined by NHTSA in its regulations as other than passenger automobiles due to their having design features that indicate they were not manufactured "primarily" for transporting up to ten individuals; and (2) those expressly excluded from the passenger category by statute due to their capability for off-highway operation, regardless of whether they might have been manufactured primarily for passenger transportation.[750] NHTSA's classification rule directly tracks those two broad groups of non-passenger automobiles in subsections (a) and (b), respectively, of 49 CFR 523.5.

For the purpose of this NPRM for the MYs 2012–2016 standards, EPA agreed to use NHTSA's regulatory definitions for determining which vehicles would be subject to which CO_2 standards.

In the MY 2011 rulemaking, NHTSA took a fresh look at the regulatory definitions in light of several factors and developments: Its desire to ensure clarity in how vehicles are classified, the passage of EISA, and the Ninth Circuit's decision in *CBD* v. *NHTSA*.[751] NHTSA explained the origin of the current definitions of passenger automobiles and light trucks by tracing them back through the history of the CAFE program, and did not propose to change the definitions themselves at that time, because the agency concluded that the definitions were largely consistent with Congress' intent in separating passenger automobiles and light trucks, but also in part because the agency tentatively concluded that doing so would not lead to increased fuel savings. However, the agency tightened the definitions in § 523.5 to ensure that only vehicles that actually have 4WD will be classified as off-highway vehicles by reason of having 4WD (to prevent 2WD SUVs that also come in a 4WD "version" from qualifying automatically as "off-road capable" simply by reason of the existence of the 4WD version). It also took this action to ensure that manufacturers may only use the "greater cargo-carrying capacity" criterion of 523.5(a)(4) for cargo van-type vehicles, rather than for SUVs with removable second-row seats unless they truly have greater cargo-carrying than passenger-carrying capacity "as sold" to the first retail purchaser. NHTSA concluded that these changes increased clarity, were consistent with EPCA and EISA, and responded to the Ninth Circuit's decision with regard to vehicle classification.

However, NHTSA recognizes that manufacturers may have an incentive to classify vehicles as light trucks if the fuel economy target for light trucks with a given footprint is less stringent than the target for passenger cars with the same footprint. This is often the case given the current fleet, due to the fact that the curves are based on actual fuel economy capabilities of the vehicles to which they apply. Because of characteristics like 4WD and towing and hauling capacity (and correspondingly, although not necessarily, heavier weight), the vehicles in the current light truck fleet are generally less capable of achieving higher fuel economy levels as compared to the vehicles in the passenger car fleet. 2WD SUVs are the vehicles that could be most readily redesigned so that they can be "moved" from the passenger car to the light truck fleet. A manufacturer could do this by adding a third row of seats, for example, or boosting GVWR over 6,000 lbs for a 2WD SUV that already meets the ground clearance requirements for "off-road capability." A change like this may only be possible during a vehicle redesign, but since vehicles are redesigned, on average, every 5 years, at least some manufacturers may choose to make such changes before or during the model years covered by this rulemaking.

In the NPRM, in looking forward to model years beyond 2011 and considering how CAFE should operate in the context of the National Program and previously-received comments as requested by President Obama, NHTSA sought comment on the following potential changes to NHTSA's vehicle classification system, as well as on whether, if any of the changes were to be adopted, they should be applied to any of the model years covered by this rulemaking or whether, due to lead time concerns, they should apply only to MY 2017 and thereafter.

Reclassifying minivans and other "3-row" light trucks as passenger cars (i.e., removing 49 CFR 523.5(a)(5)):

NHTSA has received repeated comments over the course of the last several rulemakings from environmental and consumer groups regarding the classification of minivans as light trucks instead of as passenger cars. Commenters have argued that because minivans generally have three rows of seats, are built on unibody chassis, and are used primarily for transporting passengers, they should be classified as passenger cars. NHTSA did not accept these arguments in the MY 2011 final rule, due to concerns that moving minivans to the passenger car fleet would lower the fuel economy targets for those passenger cars having essentially the same footprint as the minivans, and thus lower the overall fuel average fuel economy level that the

[750] 49 U.S.C. 32901(a)(18). We note that the statute refers both to vehicles that are 4WD and to vehicles over 6,000 lbs GVWR as potential candidates for off-road capability, if they also meet the "significant feature * * * designed for off-highway operation" as defined by the Secretary. NHTSA would consider "AWD" vehicles as 4WD for purposes of this determination—they send power to all wheels of the vehicle all the time, while 4WD vehicles may only do so part of the time, which appears to make them equal candidates for off-road capability given other necessary characteristics.

[751] 538 F.3d 1172 (9th Cir. 2008).

manufacturers would need to meet. However, due to the new methodology for setting standards, the as-yet-unknown fuel-economy capabilities of future minivans and 3-row 2WD SUVs, and the unknown state of the vehicle market (particularly for MYs 2017 and beyond), NHTSA did not feel that it could say with certainty that moving these vehicles could negatively affect potential stringency levels for either passenger cars or light trucks. Thus, although such a change would not be made applicable during the MY 2012–2016 time frame, NHTSA sought comment on why the agency should or should not consider, as part of this rulemaking, reclassifying minivans (and other current light trucks that qualify as such because they have three rows of designated seating positions as standard equipment) for MYs 2017 and after.

Comments received on this issue were split between support and opposition. As perhaps expected, the Alliance, AIAM, NADA, Chrysler, Ford, and Toyota all commented in favor of maintaining 3-row vehicles as light trucks indefinitely. The Alliance and Chrysler stated that the existing definitions for light trucks are consistent with Congressional intent in EPCA and EISA, given that Congress could have changed the 3-row definition in passing EISA but did not do so. The Alliance, AIAM, and Chrysler also argued that the functional characteristics of 3-row vehicles do make them "truck-like," citing their "high load characteristics" and ability to carry cargo if their seats are stowed or removed. Ford and Toyota emphasized the need for stability in the definitions as manufacturers adjust to the recent reclassification of many 2WD SUVs from the truck to the car fleet, and the Alliance argued further that moving the 3-row vehicles to the car fleet would simply deter manufacturers from continuing to provide them, causing consumers to purchase larger full-size vans instead and resulting in less fuel savings and emissions reductions. Toyota stated further that no significant changes have occurred in the marketplace (as in, not all 2WD SUVs suddenly have 3 rows) to trigger additional reclassification beyond that required by the MY 2011 final rule. Hyundai neither supported nor objected to reclassification, but requested ample lead time for the industry if any changes are eventually made.

Other commenters favored reclassification of 3-row vehicles from the truck to the car fleet: NJ DEP expressed general support for reclassifying 3-row vehicles for MYs 2017 and beyond, while the UCSB student commenters seemed to support reclassifying these vehicles for the current rulemaking. The UCSB students stated that EPCA/EISA properly distinguishes light trucks based on their "specialized utility," either their ability to go off-road or to transport material loads, but that 3-row vehicles do not generally have such utility as sold, and are clearly primarily sold and used for transporting passengers. The UCSB students suggested that reclassifying the 3-row vehicles from the truck to the car fleet could help to ensure the anticipated levels of fuel savings by moving the fleet closer to the 67/33 fleet split assumed in the agencies' analysis for MY 2016, and stated that this would increase fuel economy over the long term. The students urged NHTSA to look at the impact on fuel savings from reclassifying these vehicles for the model years covered by the rulemaking.

In response, NHTSA did conduct such an analysis to attempt to consider the impact of moving these vehicles. As previously stated, the agency's hypothesis is that moving 3-row vehicles from the truck to the car fleet will tend to bring the achieved fuel economy levels down in both fleets—the car fleet achieved levels could theoretically fall due to the introduction of many more vehicles that are relatively heavy for their footprint and thus comparatively less fuel economy-capable, while the truck fleet achieved levels could theoretically fall due to the characteristics of the vehicles remaining in the fleet (4WDs and pickups, mainly) that are often comparatively less fuel-economy capable than 3-row vehicles, although more vehicles would be subject to the relatively more stringent passenger car standards, assuming the curves were not refit to the data.

The agency first identified which vehicles should be moved. We identified all of the 3-row vehicles in the baseline (MY 2008) fleet,[752] and then considered whether any could be properly classified as a light truck under a different provision of 49 CFR 523.5—about 40 vehicles were classifiable under § 523.5(b) as off-highway capable.

The agency then transferred those remaining 3-row vehicles from the light truck to the passenger car input sheets for the Volpe model, re-estimated the gap in stringency between the passenger car and light truck standards, shifted the curves to obtain the same overall average required fuel economy as under the final standards, and ran the model to evaluate potential impacts (in terms of costs, fuel savings, etc.) of moving these vehicles. The results of this analysis may be found in the same location on NHTSA's Web site as the results of the analysis of the final standards. In summary, moving the vehicles reduced the stringency of the passenger car standards by approximately 0.8 mpg on average for the five years of the rule, and reduced the stringency of the light truck standards by approximately 0.2 mpg on average for the five years of the rule. It also caused the gap between the car curve and the truck curve to decrease or narrow slightly, by 0.1 mpg. However, the analysis also showed that such a shift in 3-row vehicles could result in approximately 676 million fewer gallons of fuel consumed (equivalent to about 1 percent of the reduction in fuel consumption under the final standards) and 7.1 mmt fewer CO_2 emissions (equivalent to about 1 percent of the reduction in CO_2 emissions under the final standards) over the lifetime of the MYs 2012–2016 vehicles. This result is attributable to slight differences (due to rounding precision) in the overall average required fuel economy levels in MYs 2012–2014, and to the retention of the relatively high lifetime mileage accumulation (compared to "traditional" passenger cars) of the vehicles moved from the light truck fleet to the passenger car fleet.

The changes in overall costs and vehicle price did not necessarily go in the same direction for both fleets, however. Overall costs of applying technology for the passenger car fleet went up approximately $1 billion per year for each of MYs 2012–2016, while overall costs for the light truck fleet went down by an average of approximately $800 million for each year, such that the net effect was approximately $200 million additional spending on technology each year (equivalent to about 2 percent of the average increase in annual technology outlays under the final standards). Assuming manufacturers would pass that cost forward to consumers by increasing vehicle costs, vehicle prices would increase by an average of approximately $13 during MYs 2012–2016.

However, one important point to note in this comparative analysis is that, due to time constraints, the agency did not attempt to refit the respective fleet target curves or to change the intended required stringency in MY 2016 of 34.1 mpg for the combined fleets. If we had refitted curves following the same procedures described above in Section II, considering the vehicles in question, we expect that we might have obtained a somewhat steeper passenger car curve, and a somewhat flatter light truck curve.

[752] Of the 430 light trucks models in the fleet, 175 of these had 3 rows.

If so, this might have increased the gap in between portions of the passenger car and light truck curves.

NHTSA agrees with the industry commenters that some degree of stability in the passenger car and light truck definitions will assist the industry in making the transition to the stringency of the new National Program, and therefore will not reclassify 3-row vehicles to the passenger car fleet for purposes of MYs 2012–2016. Going forward, the real question is how to balance the benefits of regulatory stability against the potential benefits of greater fuel savings if reclassification is determined to lead in that direction. NHTSA believes that this question merits much further analysis before the agency can make a decision for model years beyond MY 2016, and will provide further opportunity for public comment regarding that analysis prior to finalizing any changes in the future.

Classifying "like" vehicles together:

Many commenters objected in the rulemaking for the MY 2011 standards to NHTSA's regulatory separation of "like" vehicles. Industry commenters argued that it was technologically inappropriate for NHTSA to place 4WD and 2WD versions of the same SUV in separate classes. They argued that the vehicles are the same, except for their drivetrain features, thus giving them similar fuel economy improvement potential. They further argued that all SUVs should be classified as light trucks. Environmental and consumer group commenters, on the other hand, argued that 4WD SUVs and 2WD SUVs that are "off-highway capable" by virtue of a GVWR above 6,000 pounds should be classified as passenger cars, since they are primarily used to transport passengers. In the MY 2011 rulemaking, NHTSA rejected both of these sets of arguments. NHTSA concluded that 2WD SUVs that were neither "off-highway capable" nor possessed "truck-like" functional characteristics were appropriately classified as passenger cars. At the same time, NHTSA also concluded that because Congress explicitly designated vehicles with GVWRs over 6,000 pounds as "off-highway capable" (if they meet the ground clearance requirements established by the agency), NHTSA did not have authority to move these vehicles to the passenger car fleet.

With regard to the first argument, that "like" vehicles should be classified similarly (*i.e.,* that 2WD SUVs should be classified as light trucks because, besides their drivetrain, they are "like" the 4WD version that qualifies as a light truck), NHTSA continues to believe that 2WD SUVs that do not meet any part of the existing regulatory definition for light trucks should be classified as passenger cars. However, NHTSA recognizes the additional point raised by industry commenters in the MY 2011 rulemaking that manufacturers may respond to this tighter classification by ceasing to build 2WD versions of SUVs, which could reduce fuel savings. In response to that point, NHTSA stated in the MY 2011 final rule that it expects that manufacturer decisions about whether to continue building 2WD SUVs will be driven in much greater measure by consumer demand than by NHTSA's regulatory definitions. If it appears, in the course of the next several model years, that manufacturers are indeed responding to the CAFE regulatory definitions in a way that reduces overall fuel savings from expected levels, it may be appropriate for NHTSA to review this question again. NHTSA sought comment in the NPRM on how the agency might go about reviewing this question as more information about manufacturer behavior is accumulated, but no commenters really responded to this issue directly, although several cited the possibility that manufacturers might cease to build 2WD SUVs as a way of avoiding the higher passenger car curve targets in arguing that the agencies should implement backstop standards for all fleets. Since NHTSA has already stated above that it will revisit the backstop question as necessary in the future, we may as well add that we will consider the need to classify "like" vehicles together as necessary in the future.

With regard to the second argument, that NHTSA should move vehicles that qualify as "off-highway capable" from the light truck to the passenger car fleet because they are primarily used to transport passengers, NHTSA reiterates that EPCA is clear that certain vehicles are non-passenger automobiles (*i.e.,* light trucks) because of their off-highway capabilities, regardless of how they may be used day-to-day.

However, NHTSA suggested in the NPRM that it could explore additional approaches, although it cautioned that not all could be pursued on current law. Possible alternative legal regimes might include: (a) Classifying vehicles as passenger cars or light trucks based on use alone (rather than characteristics); (b) removing the regulatory distinction altogether and setting standards for the entire fleet of vehicles instead of for separate passenger car and light truck fleets; or (c) dividing the fleet into multiple categories more consistent with current vehicle fleets (*i.e.,* sedans, minivans, SUVs, pickup trucks, etc.). NHTSA sought comment on whether and why it should pursue any of these courses of action.

Some commenters (ICCT, CBD, NESCAUM) did raise the issue of removing the regulatory distinction between cars and trucks and setting standards for the entire fleet of vehicles, but those commenters did not appear to recognize the fact that EPCA/EISA expressly requires that NHTSA set separate standards for passenger cars and light trucks. As the statute is currently written, NHTSA does not believe that a single standard would be appropriate unless the observed relationship between footprint and fuel economy of the two fleets converged significantly over time. Nevertheless, NHTSA will continue to monitor the issue going forward.

Besides these issues in vehicle classification, NHTSA additionally received comments from two manufacturers on issues not raised by NHTSA in the NPRM. VW requested clarification with respect to how the agency evaluates a vehicle for off-road capability under 49 CFR 523.5(b)(2), asking the agency to measure vehicles with "active ride height management" at the "height setting representative of off-road operation if the vehicle has the capability to change ride height." NHTSA issued an interpretation to Porsche in 2004 addressing this issue, when Porsche asked whether a driver-controlled variable ride height suspension system could be used in the "off-road" ride height position to meet the suspension parameters required for an off- road classification determination.[753] Porsche argued that a vehicle should not need to satisfy the four-out-of-five criteria at all ride heights in order to be deemed capable of off-highway operation. NHTSA agreed that 523.5(b)(2) does not require a vehicle to meet four of the five criteria at *all* ride heights, but stated that a vehicle must meet four out of the five criteria in at *least one* ride height. The agency determined that it would be appropriate to measure the vehicle's running clearance with the vehicle's adjustable suspension placed in the position(s) intended for off-road operation under real-world conditions.

Thus, NHTSA clarifies that the agency would consider it appropriate to measure vehicles for off-road capability at the height setting intended for off-road operation under real-world conditions. However, we note that before this question need be asked and answered, the vehicle must first either

[753] *Available at http://isearch.nhtsa.gov/files/porschevrhs.html* (last accessed Mar. 1, 2010).

be equipped with 4WD or be rated at more than 6,000 pounds gross vehicle weight to be eligible for classification as a light truck under 49 CFR 523.5(b).

The final comment on the issue of vehicle classification was received from Honda, who recommended that deformable aero parts, such as strakes, should be excluded from the ride height measurements that determine whether a vehicle qualifies as a truck for off-road capability. The air strakes described by Honda are semi-deformable parts similar to a mud flap that can be used to improve a vehicle's aerodynamics, and thus to improve its fuel economy. Honda argued that NHTSA would deter the application of this technology if it did not agree to measure ride height with the air strakes at their most deformed state, because otherwise a vehicle so equipped would have to be classified as a passenger car and thus be faced with the more stringent standard.

In response, Honda did not provide enough information to the agency for the agency to make a decision with regard to how air strakes should be considered in measuring a vehicle for off-road capability. NHTSA personnel would prefer to directly examine a vehicle equipped with these devices before considering the issue further. The agency will defer consideration of this issue to another time, and no changes will be made in this final rule in response to this comment.

I. Compliance and Enforcement

1. Overview

NHTSA's CAFE enforcement program and the compliance flexibilities available to manufacturers are largely established by statute—unlike the CAA, EPCA and EISA are very prescriptive and leave the agency limited authority to increase the flexibilities available to manufacturers. This was intentional, however. Congress balanced the energy saving purposes of the statute against the benefits of the various flexibilities and incentives it provided and placed precise limits on those flexibilities and incentives. For example, while the Department sought authority for unlimited transfer of credits between a manufacturer's car and light truck fleets, Congress limited the extent to which a manufacturer could raise its average fuel economy for one of its classes of vehicles through credit transfer in lieu of adding more fuel saving technologies. It did not want these provisions to slow progress toward achieving greater energy conservation or other policy goals. In keeping with EPCA's focus on energy conservation, NHTSA has done its best, for example, in crafting the credit transfer and trading regulations authorized by EISA, to ensure that total fuel savings are preserved when manufacturers exercise their compliance flexibilities.

The following sections explain how NHTSA determines whether manufacturers are in compliance with the CAFE standards for each model year, and how manufacturers may address potential non-compliance situations through the use of compliance flexibilities or fine payment.

2. How does NHTSA determine compliance?

a. Manufacturer Submission of Data and CAFE Testing by EPA

NHTSA begins to determine CAFE compliance by considering pre- and mid-model year reports submitted by manufacturers pursuant to 49 CFR part 537, Automotive Fuel Economy Reports.[754] The reports for the current model year are submitted to NHTSA every December and July. As of the time of this final rule, NHTSA has received pre-model year reports from manufacturers for MY 2010, and anticipates receiving mid-model year reports for MY 2010 in July of this year. Although the reports are used for NHTSA's reference only, they help the agency, and the manufacturers who prepare them, anticipate potential compliance issues as early as possible, and help manufacturers plan compliance strategies. Currently, NHTSA receives these reports in paper form. In order to facilitate submission by manufacturers and consistent with the President's electronic government initiatives, NHTSA proposed to amend part 537 to allow for electronic submission of the pre- and mid-model year CAFE reports. The only comments addressing this proposal were from Ferrari, who supported it in the interest of efficiency, and Ford, who did not object as long as CBI was sufficiently protected. Having received no comments objecting, NHTSA is finalizing this change to part 537.

NHTSA makes its ultimate determination of manufacturers' CAFE compliance upon receiving EPA's official certified and reported CAFE data. The EPA certified data is based on vehicle testing and on final model year data submitted by manufacturers to EPA pursuant to 40 CFR 600.512, Model Year Report, no later than 90 days after the end of the calendar year. Pursuant to 49 U.S.C. 32904(e), EPA is responsible for calculating automobile manufacturers' CAFE values so that NHTSA can determine compliance with the CAFE standards. In measuring the fuel economy of passenger cars, EPA is required by EPCA[755] to use the EPA test procedures in place as of 1975 (or procedures that give comparable results), which are the city and highway tests of today, with adjustments for procedural changes that have occurred since 1975. EPA uses similar procedures for light trucks, although, as noted above, EPCA does not require it to do so.

As discussed above in Section III, a number of commenters raised the issue of whether the city and highway test procedures and the calculation are still appropriate or whether they may be outdated. Several commenters argued that the calculation should be more "real-world": For example, ACEEE stated that EPA should use a "correction factor" like the one used for the fuel economy label in the interim until test procedures can be changed, while BorgWarner, Cummins, Honeywell, MECA, and MEMA argued that EPA should change the weighting of the city and highway cycles (to more highway and less city) to reflect current American driving patterns and to avoid biasing the calculation against technologies that provide greater efficiency in highway driving than in city driving. Sierra Club *et al.* commented that the fact that EPA was proposing to allow off-cycle credits indicated that the test procedures and the calculation needed updating. Several commenters (API, James Hyde, MECA, NACAA, and NY DEC) stated that the test procedures should use more "real-world" fuel, like E–10 instead of "indolene clear." The UCSB students also had a number of comments aimed at making the test procedures more thorough and real-world. Several industry-related commenters (AIAM, Ferrari, and Ford) argued to the contrary that existing test procedures and calculations are fine for now, and that any changes would require significant lead time to allow manufacturers to adjust their plans to the new procedures.

Statutorily, the decision to change the test procedures or calculation is within EPA's discretion, so NHTSA will not attempt to answer these comments in detail, see *supra* Section III for EPA's responses. We note simply that the agency recognizes the need for lead time for the industry if test procedures were to change in the future to become more real-world, and will keep it in mind.

One notable shortcoming of the 1975 test procedure is that it does not include

[754] 49 CFR part 537 is authorized by 49 U.S.C. 32907.

[755] 49 U.S.C. 32904(c).

a provision for air conditioner usage during the test cycle. As discussed in Section III above, air conditioner usage increases the load on a vehicle's engine, reducing fuel efficiency and increasing CO_2 emissions. Since the air conditioner is not turned on during testing, equipping a vehicle model with a relatively inefficient air conditioner will not adversely affect that model's measured fuel economy, while equipping a vehicle model with a relatively efficient air conditioner will not raise that model's measured fuel economy. The fuel economy test procedures for light trucks could be amended through rulemaking to provide for air conditioner operation during testing and to take other steps for improving the accuracy and representativeness of fuel economy measurements. In the NPRM, NHTSA sought comment regarding implementing such amendments beginning in MY 2017 and also on the more immediate interim step of providing credits under 49 U.S.C. 32904(c) for light trucks equipped with relatively efficient air conditioners for MYs 2012–2016. NHTSA emphasized that modernizing the passenger car test procedures as well would not be possible under EPCA as currently written.

Comments were split as to whether the test procedure should be changed. Several manufacturers and manufacturer groups (BMW, GM, Toyota, VW, the Alliance) opposed changes to the test procedures to account for A/C usage on the grounds that any changes could create negative unintended consequences. Public Citizen also opposed changes to the test procedure, arguing that the fuel economy information presented to the consumer on the fuel economy label is already confusing, and that further changes to the light truck test procedures when there was no authority to change the passenger car test procedures would simply result in more confusion. In contrast, NJ DEP fully supported changes to the light truck test procedures beginning with MY 2017, and an individual commenter (Weber) also supported the inclusion of A/C in the test procedures to represent real-world "A/C on" time.

However, some of the same commenters—BMW, Toyota, and VW, for example—that opposed changes to the test procedure supported NHTSA allowing credits for A/C. Toyota stated that it supported anything that increased compliance flexibility, while VW emphasized that A/C credits for CAFE would help to address the fact that NHTSA's standards could end up being more stringent than EPA's for manufacturers relying heavily on A/C improvements to meet the GHG standards. NJ DEP also supported interim A/C credits for light trucks, but in contrast to VW, argued that the light truck standards would have to be made more stringent to account for those credits if they were allowed.

Other commenters (Chrysler, Daimler, Ferrari) supported interim A/C credits for light truck CAFE, but stated that such credits could simply be added to EPA's calculation of CAFE under 49 U.S.C. 32904(c) without any change in the test procedure ever being necessary. Daimler stated that the prohibition on changing the test procedure, according to legislative history, was to avoid sudden and dramatic changes and provide consistency for manufacturers in the beginning of the CAFE program, but that nothing indicated that EPA was barred from updating the way a manufacturer's fuel economy is calculated after the test procedures are followed. Daimler emphasized that EPA has broad authority in how it calculates fuel economy, and that adding credits at the end of the calculation would make CAFE more consistent with the GHG program and recognize real-world benefits not measured by the test cycle. Daimler argued that if EPA did not include A/C credits as part of the calculation, it would remove incentives to improve A/C, because those gains could not be used for CAFE compliance and NHTSA has no authority to include A/C in determining stringency, because A/C is a "parasitic load" that does not impact mpg.

Some commenters opposed interim A/C credits. CARB stated that no A/C credits should be given under EPCA unless the test procedures can be changed to fully account for A/C and NHTSA is given clear authority for A/C, while GM stated that NHTSA's authority to create additional types of credits must be limited by the fact that Congress clearly provided in EPCA for some types of CAFE credits but not for A/C-related credits for CAFE.

NHTSA has decided not to implement interim A/C credits for purposes of this final rule and MYs 2012–2016 light trucks. Changes to the test procedure for light trucks will be considered by the agencies in subsequent rulemakings.

While NHTSA agrees with commenters that the EPA authority to consider how fuel economy is calculated is broad, especially as to light trucks, we disagree that credits could simply be added to the CAFE calculation without making parallel changes in CAFE standard stringency to reflect their availability. CAFE stringency is determined, in part, with reference to the technologies available to manufacturers to improve mpg. If a technology draws power from the engine, like A/C, then making that technology more efficient to reduce its load on the engine will conserve fuel, consistent with EPCA's purposes. However, as noted above, some technologies that improve mpg are not accounted for in current CAFE test procedures. NHTSA agrees that the test procedures should be updated to account for the real-world loads on the engine and their impact on fuel economy, but recognizes that manufacturers will need lead-time and advance notice in order to ready themselves for such changes and their impact on CAFE compliance.

Thus, if manufacturers are able to achieve improvements in mpg that are not reflected on the test cycle, then the level of CAFE that they are capable of achieving is higher than that which their performance on the test cycle would otherwise indicate, which suggests, in turn, that a higher stringency is feasible. NHTSA has determined that the current CAFE levels being finalized today are feasible using traditional "tailpipe technologies" alone. If manufacturers are capable of improving fuel economy beyond that level using A/C technologies, and wish to receive credit for doing so, then NHTSA believes that more stringent CAFE standards would need to be established. Not raising CAFE could allow manufacturers to leave tailpipe technology on the table and make cheaper A/C improvements, which would not result in the maximum feasible fuel savings contemplated by EPCA.

Because raising CAFE stringency in conjunction with allowing A/C credits was not a possibility clearly contemplated in the NPRM, NHTSA does not believe that it would be within scope of notice for purposes of this rulemaking. Accordingly, the final rule cannot provide for interim A/C credits. However, if NHTSA were to allow A/C credits in the future, NHTSA believes it would be required to increase standard stringency accordingly, to avoid losses in fuel savings, as stated above. NHTSA will consider this approach further, ensuring that any changes to the treatment of A/C and accompanying changes in CAFE stringency are made with sufficient notice and lead-time.

b. NHTSA Then Analyzes EPA-Certified CAFE Values for Compliance

Determining CAFE compliance is fairly straightforward: After testing, EPA verifies the data submitted by manufacturers and issues final CAFE reports to manufacturers and to NHTSA between April and October of each year (for the previous model year), and NHTSA then identifies the manufacturers' compliance categories (fleets) that do not meet the applicable CAFE fleet standards.

To determine if manufacturers have earned credits that would offset those shortfalls, NHTSA calculates a cumulative credit status for each of a manufacturer's vehicle compliance categories according to 49 U.S.C. 32903. If a manufacturer's compliance category exceeds the applicable fuel economy standard, NHTSA adds credits to the account for that compliance category. If a manufacturer's vehicles in a particular compliance category fall below the standard fuel economy value, NHTSA will provide written notification to the manufacturer that it has not met a particular fleet standard. The manufacturer will be required to confirm the shortfall and must either: Submit a plan indicating it will allocate existing credits, and/or for MY 2011 and later, how it will earn, transfer and/or acquire credits; or pay the appropriate civil penalty. The manufacturer must submit a plan or payment within 60 days of receiving agency notification. The amount of credits are determined by multiplying the number of tenths of a mpg by which a manufacturer exceeds, or falls short of, a standard for a particular category of automobiles by the total volume of automobiles of that category manufactured by the manufacturer for a given model year. Credits used to offset shortfalls are subject to the three and five year limitations as described in 49 U.S.C. 32903(a). Transferred credits are subject to the limitations specified by 49 U.S.C. 32903(g)(3). The value of each credit, when used for compliance, received via trade or transfer is adjusted, using the adjustment factor described in 49 CFR 536.4, pursuant to 49 U.S.C. 32903(f)(1). Credit allocation plans received from the manufacturer will be reviewed and approved by NHTSA. NHTSA will approve a credit allocation plan unless it finds the proposed credits are unavailable or that it is unlikely that the plan will result in the manufacturer earning sufficient credits to offset the subject credit shortfall. If a plan is approved, NHTSA will revise the respective manufacturer's credit account accordingly. If a plan is rejected, NHTSA will notify the respective manufacturer and request a revised plan or payment of the appropriate fine.

In the event that a manufacturer does not comply with a CAFE standard, even after the consideration of credits, EPCA provides for the assessing of civil penalties. The Act specifies a precise formula for determining the amount of civil penalties for such a noncompliance. The penalty, as adjusted for inflation by law, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year multiplied by the total volume of those vehicles in the affected fleet (*i.e.,* import or domestic passenger car, or light truck), manufactured for that model year. The amount of the penalty may not be reduced except under the unusual or extreme circumstances specified in the statute. All penalties are paid to the U.S. Treasury and not to NHTSA itself.[756]

Unlike the National Traffic and Motor Vehicle Safety Act, EPCA does not provide for recall and remedy in the event of a noncompliance. The presence of recall and remedy provisions[757] in the Safety Act and their absence in EPCA is believed to arise from the difference in the application of the safety standards and CAFE standards. A safety standard applies to individual vehicles; that is, each vehicle must possess the requisite equipment or feature which must provide the requisite type and level of performance. If a vehicle does not, it is noncompliant. Typically, a vehicle does not entirely lack an item or equipment or feature. Instead, the equipment or features fails to perform adequately. Recalling the vehicle to repair or replace the noncompliant equipment or feature can usually be readily accomplished.

In contrast, a CAFE standard applies to a manufacturer's entire fleet for a model year. It does not require that a particular individual vehicle be equipped with any particular equipment or feature or meet a particular level of fuel economy. It does require that the manufacturer's fleet, as a whole, comply. Further, although under the attribute-based approach to setting CAFE standards fuel economy targets are established for individual vehicles based on their footprints, the vehicles are not required to comply with those targets on a model-by-model or vehicle-by-vehicle basis. However, as a practical matter, if a manufacturer chooses to design some vehicles so they fall below their target levels of fuel economy, it will need to design other vehicles so they exceed their targets if the manufacturer's overall fleet average is to meet the applicable standard.

Thus, under EPCA, there is no such thing as a noncompliant vehicle, only a noncompliant fleet. No particular vehicle in a noncompliant fleet is any more, or less, noncompliant than any other vehicle in the fleet.

After enforcement letters are sent, NHTSA continues to monitor receipt of credit allocation plans or civil penalty payments that are due within 60 days from the date of receipt of the letter by the vehicle manufacturer, and takes further action if the manufacturer is delinquent in responding.

Several commenters encouraged the agency to increase the transparency of how the agency monitors and enforces CAFE compliance. EDF, Public Citizen, Sierra Club *et al.,* UCS, and Porsche all commented that NHTSA should publish an annual compliance report for manufacturers, and Porsche suggested that it be available online. Sierra Club *et al.* and Porsche stated that this would help clarify manufacturers' credit status (for the benefit of the public and manufacturers looking to purchase credits, respectively) and sales, and Sierra Club *et al.* further stated that the agency should make public all information regarding credits and attained versus projected fleet average mpg levels. EDF similarly urged the agency to provide publicly a compliance report every year that would include any recommended adjustments to the program, enforcement actions, or prospective policy action to ensure the policy objectives are achieved.

In response, NHTSA agrees that there could be substantial benefits to increasing the transparency of information concerning the credit holdings of each credit holder. Along with the MY 2011 final rule, NHTSA issued a new regulation 49 CFR part 536 to implement the new CAFE credit trading and transfer programs authorized by EISA. Paragraph 536.5(e) requires that we periodically publish credit holding information. NHTSA plans to make this information available to the public on the NHTSA Web site. The exact format that will be used to display this information has not been finalized but it is our plan to begin making this information available no later than calendar year 2011 to coincide with MY 2011 when manufacturers may begin utilizing credit trades and transfers.

[756] Honeywell commented that any fines imposed and collected under the CAFE and GHG standards should be appropriated to the development of vehicle technologies that continue to improve fuel economy in the future, and that the direct application of the penalties collected would support the underlying legislative policy and drive innovation. While NHTSA certainly would not oppose such an outcome, it would lie within the hands of Congress and not the agency to direct the use of the fines in that manner.

[757] 49 U.S.C. 30120, Remedies for defects and noncompliance.

3. What compliance flexibilities are available under the CAFE program and how do manufacturers use them?

There are three basic flexibilities permitted by EPCA/EISA that manufacturers can use to achieve compliance with CAFE standards beyond applying fuel economy-improving technologies: (1) Building dual- and alternative-fueled vehicles; (2) banking, trading, and transferring credits earned for exceeding fuel economy standards; and (3) paying fines. We note again that while these flexibility mechanisms will reduce compliance costs to some degree for most manufacturers, 49 U.S.C. 32902(h) expressly prohibits NHTSA from considering the availability of credits (either for building dual- or alternative-fueled vehicles or from accumulated transfers or trades) in determining the level of the standards. Thus, NHTSA may not raise CAFE standards because manufacturers have enough credits to meet higher standards. This is an important difference from EPA's authority under the CAA, which does not contain such a restriction, and which allows EPA to set higher standards as a result.

a. Dual- and Alternative-Fueled Vehicles

As discussed at length in prior rulemakings, EPCA encourages manufacturers to build alternative-fueled and dual- (or flexible-) fueled vehicles by providing special fuel economy calculations for "dedicated" (that is, 100 percent) alternative fueled vehicles and "dual-fueled" (that is, capable of running on either the alternative fuel or gasoline) vehicles. The fuel economy of a dedicated alternative fuel vehicle is determined by dividing its fuel economy in equivalent miles per gallon of gasoline or diesel fuel by 0.15.[758] Thus, a 15 mpg dedicated alternative fuel vehicle would be rated as 100 mpg. For dual-fueled vehicles, the rating is the average of the fuel economy on gasoline or diesel and the fuel economy on the alternative fuel vehicle divided by 0.15.[759]

For example, this calculation procedure turns a dual-fueled vehicle that averages 25 mpg on gasoline or diesel into a 40 mpg vehicle for CAFE purposes. This assumes that (1) the vehicle operates on gasoline or diesel 50 percent of the time and on alternative fuel 50 percent of the time; (2) fuel economy while operating on alternative fuel is 15 mpg (15/.15 = 100 mpg); and (3) fuel economy while operating on gas or diesel is 25 mpg. Thus:

CAFE FE = 1/{0.5/(mpg gas) + 0.5/(mpg alt fuel)} = 1/{0.5/25 + 0.5/100} = 40 mpg

In the case of natural gas, the calculation is performed in a similar manner. The fuel economy is the weighted average while operating on natural gas and operating on gas or diesel. The statute specifies that 100 cubic feet (ft^3) of natural gas is equivalent to 0.823 gallons of gasoline. The gallon equivalency of natural gas is equal to 0.15 (as for other alternative fuels).[760] Thus, if a vehicle averages 25 miles per 100 ft^3 of natural gas, then:

CAFE FE = (25/100) * (100/.823)*(1/0.15) = 203 mpg

Congress extended the incentive in EISA for dual-fueled automobiles through MY 2019, but provided for its phase out between MYs 2015 and 2019.[761] The maximum fuel economy increase which may be attributed to the incentive is thus as follows:

Model year	mpg increase
MYs 1993–2014	1.2
MY 2015	1.0
MY 2016	0.8
MY 2017	0.6
MY 2018	0.4
MY 2019	0.2
After MY 2019	0

49 CFR part 538 implements the statutory alternative-fueled and dual-fueled automobile manufacturing incentive. NHTSA updated part 538 as part of this final rule to reflect the EISA changes extending the incentive to MY 2019, but to the extent that 49 U.S.C. 32906(a) differs from the current version of 49 CFR 538.9, the statute supersedes the regulation, and regulated parties may rely on the text of the statute.

A major difference between EPA's statutory authority and NHTSA's statutory authority is that the CAA contains no specific prescriptions with regard to credits for dual- and alternative-fueled vehicles comparable to those found in EPCA/EISA. As an exercise of that authority, and as discussed in Section III above, EPA is offering similar credits for dual- and alternative-fueled vehicles through MY 2015 for compliance with its CO_2 standards, but for MY 2016 and beyond EPA will establish CO_2 emission levels for alternative fuel vehicles based on measurement of actual CO_2 emissions during testing, plus a manufacturer demonstration that the vehicles are actually being run on the alternative fuel. The manufacturer would then be allowed to weight the gasoline and alternative fuel test results based on the proportion of actual usage of both fuels, as discussed above in Section III. NHTSA has no such authority under EPCA/EISA to require that vehicles manufactured for the purpose of obtaining the credit actually be run on the alternative fuel, but requested comment in the NPRM on whether it should seek legislative changes to revise its authority to address this issue.

NHTSA received only one comment on this issue: VW commented that NHTSA should not seek a change in its authority, because Congress' intent for NHTSA is already clear. VW did, however, encourage NHTSA to include the statutory FFV credit phase-out in Part 538, which the agency is doing.

b. Credit Trading and Transfer

As part of the MY 2011 final rule, NHTSA established Part 536 for credit trading and transfer. Part 536 implements the provisions in EISA authorizing NHTSA to establish by regulation a credit trading program and directing it to establish by regulation a credit transfer program.[762] Since its enactment, EPCA has permitted manufacturers to earn credits for exceeding the standards and to carry those credits backward or forward. EISA extended the "carry-forward" period from three to five model years, and left the "carry-back" period at three model years. Under part 536, credit holders (including, but not limited to, manufacturers) will have credit accounts with NHTSA, and will be able to hold credits, use them to achieve compliance with CAFE standards, transfer them between compliance categories, or trade them. A credit may also be cancelled before its expiry date, if the credit holder so chooses. Traded and transferred credits are subject to an "adjustment factor" to ensure total oil savings are preserved, as required by EISA.[763] EISA also prohibits credits

[758] 49 U.S.C. 32905(a).

[759] 49 U.S.C. 32905(b).

[760] 49 U.S.C. 32905(c).

[761] 49 U.S.C. 32906(a). NHTSA notes that the incentive for dedicated alternative-fuel automobiles, automobiles that run exclusively on an alternative fuel, at 49 U.S.C. 32905(a), was not phased-out by EISA.

[762] Congress required that DOT establish a credit "transferring" regulation, to allow individual manufacturers to move credits from one of their fleets to another (*e.g.*, using a credit earned for exceeding the light truck standard for compliance with the domestic passenger car standard). Congress allowed DOT to establish a credit "trading" regulation, so that credits may be bought and sold between manufacturers and other parties.

[763] Ford and Toyota both commented on NHTSA's use of the adjustment factor: Ford stated that it preferred a streamlined "megagrams"

Continued

earned before MY 2011 from being transferred, so NHTSA has developed several regulatory restrictions on trading and transferring to facilitate Congress' intent in this regard. EISA also establishes a "cap" for the maximum increase in any compliance category attributable to transferred credits: For MYs 2011–2013, transferred credits can only be used to increase a manufacturer's CAFE level in a given compliance category by 1.0 mpg; for MYs 2014–2017, by 1.5 mpg; and for MYs 2018 and beyond, by 2.0 mpg.

NHTSA recognizes that some manufacturers may have to rely on credit transferring for compliance in MYs 2012–2017.[764] As a way to improve the transferring flexibility mechanism for manufacturers, NHTSA interprets EISA not to prohibit the banking of transferred credits for use in later model years. Thus, NHTSA believes that the language of EISA may be read to allow manufacturers to transfer credits from one fleet that has an excess number of credits, within the limits specified, to another fleet that may also have excess credits instead of transferring only to a fleet that has a credit shortfall. This would mean that a manufacturer could transfer a certain number of credits each year and bank them, and then the credits could be carried forward or back "without limit" later if and when a shortfall ever occurred in that same fleet. NHTSA bases this interpretation on 49 U.S.C. 32903(g)(2), which states that transferred credits "are available to be used in the same model years that the manufacturer could have applied such credits under subsections (a), (b), (d), and (e), as well as for the model year in which the manufacturer earned such credits." The EISA limitation applies only to the application of such credits for compliance in particular model years, and not their transfer *per se.* If transferred credits have the same lifespan and may be used in carry-back and carry-forward plans, it seems reasonable that they should be allowed to be stored in any fleet, rather than only in the fleet in which they were earned. Of course, manufacturers could not transfer and bank credits for purposes of achieving the minimum standard for domestically-manufactured passenger cars, as prohibited by 49 U.S.C. 32903(g)(4). Transferred and banked credits would additionally still be subject to the adjustment factor when actually used, which would help to ensure that total oil savings are preserved while still offering greater flexibility to manufacturers. This interpretation of EISA also helps NHTSA, to some extent, to harmonize better with EPA's CO_2 program, which allows unlimited banking and transfer of credits. NHTSA sought comment in the NPRM on this interpretation of EISA.

Only one commenter, VW, commented on NHTSA's interpretation of EISA as allowing the banking of transferred credits, and agreed with it. VW suggested that NHTSA revise part 536 to clarify accordingly, and that NHTSA include the statutory transfer cap in part 536 as well. While NHTSA does not believe that including the statutory transfer cap in the regulation is necessary, NHTSA will revise Part 536 in this final rule by amending the definition of "transfer" as follows (in bold and italics):

Transfer means the application by a manufacturer of credits earned by that manufacturer in one compliance category or credits acquired be trade (and originally earned by another manufacturer in that category) to achieve compliance with fuel economy standards with respect to a different compliance category. For example, a manufacturer may purchase light truck credits from another manufacturer, and transfer them to achieve compliance in the manufacturer's domestically manufactured passenger car fleet. ***Subject to the credit transfer limitations of 49 U.S.C. 32903 (g)(3), credits can also be transferred across compliance categories and banked or saved in that category to be carried forward or backward to address a credit shortfall.***

c. Payment of Fines

If a manufacturer's average miles per gallon for a given compliance category (domestic passenger car, imported passenger car, light truck) falls below the applicable standard, and the manufacturer cannot make up the difference by using credits earned or acquired, the manufacturer is subject to penalties. The penalty, as mentioned, is $5.50 for each tenth of a mpg that a manufacturer's average fuel economy falls short of the standard for a given model year, multiplied by the total volume of those vehicles in the affected fleet, manufactured for that model year. NHTSA has collected $785,772,714.50 to date in CAFE penalties, the largest ever being paid by DaimlerChrysler for its MY 2006 import passenger car fleet, $30,257,920.00. For their MY 2008 fleets, six manufacturers paid CAFE fines for not meeting an applicable standard—Ferrari, Maserati, Mercedes-Benz, Porsche, Chrysler and Fiat—for a total of $12,922,255,50.

NHTSA recognizes that some manufacturers may use the option to pay fines as a CAFE compliance flexibility—presumably, when paying fines is deemed more cost-effective than applying additional fuel economy-improving technology, or when adding fuel economy-improving technology would fundamentally change the characteristics of the vehicle in ways that the manufacturer believes its target consumers would not accept. NHTSA has no authority under EPCA/EISA to prevent manufacturers from turning to fine-payment if they choose to do so. This is another important difference from EPA's authority under the CAA, which allows EPA to revoke a manufacturer's certificate of conformity that permits it to sell vehicles if EPA determines that the manufacturer is in non-compliance, and does not permit manufacturers to pay fines in lieu of compliance with applicable standards.

NHTSA has grappled repeatedly with the issue of whether fines are motivational for manufacturers, and whether raising fines would increase manufacturers' compliance with the standards. EPCA authorizes increasing the civil penalty very slightly up to $10.00, exclusive of inflationary adjustments, if NHTSA decides that the increase in the penalty "will result in, or substantially further, substantial energy conservation for automobiles in the model years in which the increased penalty may be imposed; and will not have a substantial deleterious impact on the economy of the United States, a State, or a region of a State." 49 U.S.C. 32912(c).

To support a decision that increasing the penalty would result in "substantial energy conservation" without having "a substantial deleterious impact on the economy," NHTSA would likely need to provide some reasonably certain quantitative estimates of the fuel that would be saved, and the impact on the economy, if the penalty were raised. Comments received on this issue in the past have not explained in clear quantitative terms what the benefits and drawbacks to raising the penalty might be. Additionally, it may be that the range of possible increase that the statute provides, *i.e.,* up to $10 per tenth of a mpg, is insufficient to result in

approach like EPA was proposing, while Toyota stated that NHTSA and EPA should use consistent VMT estimates for purposes of all analysis and for use in the adjustment factor. In response to Ford, NHTSA is maintaining use of the adjustment factor just finalized last March, which uses mpg rather than gallons or grams and is thus consistent with the rest of the CAFE program. In response to Toyota, NHTSA agrees that consistency of VMT estimates should be maintained and will revise the adjustment factor as necessary.

[764] In contrast, manufacturers stated in comments in NHTSA's MY 2011 rulemaking that they did not anticipate a robust market for credit trading, due to competitive concerns. NHTSA does not yet know whether those concerns will continue to deter manufacturers from exercising the trading flexibility during MYs 2012–2016.

substantial energy conservation, although changing this would require an amendment to the statute by Congress. While NHTSA continues to seek to gain information on this issue to inform a future rulemaking decision, we requested in the NPRM that commenters wishing to address this issue please provide, as specifically as possible, estimates of how raising or not raising the penalty amount will or will not substantially raise energy conservation and impact the economy.

Only Ferrari and Daimler commented on this issue. Both manufacturers argued that raising the penalty would have no impact on fuel savings and would simply hurt the manufacturers forced to pay it. Daimler stated further that the agency's asking for a quantitative analysis ignores the fact that manufacturers pay fines because they cannot increase energy savings any further. Thus, again, the agency finds itself without a clear quantitative explanation of what the benefits and drawbacks to raising the penalty might be, but it continues to appear that the range of possible increase is insufficient to result in additional substantial energy conservation. NHTSA will therefore defer consideration of this issue for purposes of this rulemaking.

4. Other CAFE Enforcement Issues—Variations in Footprint

NHTSA has a standardized test procedure for determining vehicle footprint,[765] which is defined by regulation as follows:

> Footprint is defined as the product of track width (measured in inches, calculated as the average of front and rear track widths, and rounded to the nearest tenth of an inch) times wheelbase (measured in inches and rounded to the nearest tenth of an inch), divided by 144 and then rounded to the nearest tenth of a square foot.[766]

"Track width," in turn, is defined as "the lateral distance between the centerlines of the base tires at ground, including the camber angle." [767] "Wheelbase" is defined as "the longitudinal distance between front and rear wheel centerlines." [768]

NHTSA began requiring manufacturers to submit this information on footprint, wheelbase, and track width as part of their pre-model year reports in MY 2008 for light trucks, and will require manufacturers to submit this information for passenger cars as well beginning in MY 2010. Manufacturers have submitted the required information for their light trucks, but NHTSA has identified several issues with regard to footprint measurement that could affect how required fuel economy levels are calculated for a manufacturer as discussed below.

a. Variations in Track Width

By definition, wheelbase measurement should be very consistent from one vehicle to another of the same model. Track width, in contrast, may vary in two respects: Wheel offset,[769] and camber. Most current vehicles have wheels with positive offset, with technical specifications for offset typically expressed in millimeters. Additionally, for most vehicles, the camber angle of each of a vehicle's wheels is specified as a range, *i.e.,* front axle, left and right within minus 0.9 to plus 0.3 degree and rear axle, left and right within minus 0.9 to plus 0.1 degree. Given the small variations in offset and camber angle dimensions, the potential effects of components (wheels) and vehicle specifications (camber) within existing designs on vehicle footprints are considered insignificant.

However, NHTSA recognizes that manufacturers may change the specifications of and the equipment on vehicles, even those that are not redesigned or refreshed, during a model year and from year to year. There may be opportunity for manufacturers to change specifications for wheel offset and camber to increase a vehicle's track width and footprint, and thus decrease their required fuel economy level. NHTSA believes that this is likely easiest on vehicles that already have sufficient space to accommodate changes without accompanying changes to the body profile and/or suspension component locations.

There may be drawbacks to such a decision, however. Changing from positive offset wheels to wheels with zero or negative offset will move tires and wheels outward toward the fenders. Increasing the negative upper limit of camber will tilt the top of the tire and wheel inward and move the bottom outward, placing the upper portion of the rotating tires and wheels in closer proximity to suspension components. In addition, higher negative camber can adversely affect tire life and the on-road fuel economy of the vehicle. Furthermore, it is likely that most vehicle designs have already used the available space in wheel areas since, by doing so, the vehicle's handling performance is improved. Therefore, it seems unlikely that manufacturers will make significant changes to wheel offset and camber. No comments were received on this issue.

b. How Manufacturers Designate "Base Tires" and Wheels

According to the definition of "track width" in 49 CFR 523.2, manufacturers must determine track width when the vehicle is equipped with "base tires." Section 523.2 defines "base tire," in turn, as "the tire specified as standard equipment by a manufacturer on each configuration of a model type." NHTSA did not define "standard equipment."

In their pre-model year reports required by 49 CFR 537, manufacturers have the option of either (A) reporting a base tire for each model type, or (B) reporting a base tire for each vehicle configuration within a model type, which represents an additional level of specificity. If different vehicle configurations have different footprint values, then reporting the number of vehicles for each footprint will improve the accuracy of the required fuel economy level for the fleet, since the pre-model year report data is part of what manufacturers use to determine their CAFE obligations.

For example, assume a manufacturer's pre-model year report listed five vehicle configurations that comprise one model type. If the manufacturer provides only one vehicle configuration's front and rear track widths, wheelbase, footprint and base tire size to represent the model type, and the other vehicle configurations all have a different tire size specified as standard equipment, the footprint value represented by the manufacturer may not capture the full spectrum of footprint values for that model type. Similarly, the base tires of a model type may be mounted on two or more wheels with different offset dimensions for different vehicle configurations. Of course, if the footprint value for all vehicle configurations is essentially the same, there would be no need to report by vehicle configuration. However, if footprints are different—larger or smaller—reporting for each group with similar footprints or for each vehicle configuration would produce a more

[765] NHTSA TP–537–01, March 30, 2009. *Available at http://www.nhtsa.gov/portal/site/nhtsa/menuitem.b166d5602714f9a73baf3210dba046a0/,* scroll down to "537" (last accessed July 18, 2009).

[766] 49 CFR 523.2.

[767] *Id.*

[768] *Id.*

[769] Offset of a wheel is the distance from its hub mounting surface to the centerline of the wheel, *i.e.,* measured laterally inboard or outboard.

Zero offset—the hub mounting surface is even with the centerline of the wheel.

Positive offset—the hub mounting surface is outboard of the centerline of the wheel (toward street side).

Negative offset—the hub mounting surface is inboard of the centerline of the wheel (away from street side).

accurate result. No comments were received on this issue.

c. Vehicle "Design" Values Reported by Manufacturers

NHTSA understands that the track widths and wheelbase values and the calculated footprint calculated values, as provided in pre-model year reports, are based on vehicle designs. This can lead to inaccurate calculations of required fuel economy level. For example, if the values reported by manufacturers are within an expected range of values, but are skewed to the higher end of the ranges, the required fuel economy level for the fleet will be artificially lower, an inaccurate attribute based value. Likewise, it would be inaccurate for manufacturers to submit values on the lower end of the ranges, but would decrease the likelihood that measured values would be less than the values reported and reduce the likelihood of an agency inquiry. Since not every vehicle is identical, it is also probable that variations between vehicles exist that can affect track width, wheelbase and footprint. As with other self-certifications, each manufacturer must decide how it will report, by model type, vehicle configuration, or a combination, and whether the reported values have sufficient margin to account for variations.

To address this, the agency will be monitoring the track widths, wheelbases and footprints reported by manufacturers, and anticipates measuring vehicles to determine if the reported and measured values are consistent. We will look for year-to-year changes in the reported values. We can compare MY 2008 light truck information and MY 2010 passenger car information to the information reported in subsequent model years. Moreover, under 49 CFR 537.8, manufacturers may make separate reports to explain why changes have occurred or they may be contacted by the agency to explain them. No comments were received on this issue.

d. How Manufacturers Report This Information in Their Pre-Model Year Reports

49 CFR 537.7(c) requires that manufacturers' pre-model year reports include "model type and configuration fuel economy and technical information." The fuel economy of a "model type" is, for many manufacturers, comprised of a number of vehicle configurations. 49 CFR 537.4 states that "model type" and "vehicle configuration" are defined in 40 CFR 600. Under that Part, "model type" includes engine, transmission, and drive configuration (2WD, 4WD, or all-wheel drive), while "vehicle configuration" includes those parameters plus test weight. Model type is important for calculating fuel economy in the new attribute-based system—the required fuel economy level for each of a manufacturer's fleets is calculated using the number of vehicles within each model type and the applicable fuel economy target for each model type.

In MY 2008 and 2009 pre-model year reports for light trucks, manufacturers have expressed information in different ways. Some manufacturers that have many vehicle configurations within a model type have included information for each vehicle configuration's track width, wheelbase and footprint. Other manufacturers reported vehicle configuration information per § 537.7(c)(4), but provided only model type track width, wheelbase and footprint information for subsections 537.7(c)(4)(xvi)(B)(3), (4) and (5). NHTSA believes that these manufacturers may have reported the information this way because the track widths, wheelbase and footprint are essentially the same for each vehicle configuration within each model type. A third group of manufacturers submitted model type information only, presumably because each model type contains only one vehicle configuration.

NHTSA does not believe that this variation in reporting methodology presents an inherent problem, as long as manufacturers follow the specifications in part 537 for reporting format, and as long as pre-model year reports provide information that is accurate and represents each vehicle configuration within a model type. The report may, but need not, be similar to what manufacturers submit to EPA as their end-of-model year report. However, NHTSA sought comment in the NPRM on any potential benefits or drawbacks to requiring a more standardized reporting methodology. NHTSA requested that, if commenters recommend increasing standardization, they provide specific examples of what information should be required and how NHTSA should require it to be provided but no comments were received on this specific issue.

However, on a related topic, Honda and Toyota both commented on the equations and corresponding terms used to calculate the fleet required standards. Both manufacturers indicated that the terms defined for use in the equations could be interpreted differently by vehicle manufacturers. For example, the term "footprint of a vehicle model" could be interpreted to mean that a manufacturer only has to use one representative footprint within a model type or that it is necessary to use all the unique footprints and corresponding fuel economy target standards within a model type when determining a fleet target standard. This issue is discussed in more detail in Section IV.E. above.

5. Other CAFE Enforcement Issues—Miscellaneous

Hyundai commented that 49 CFR 537.9 appeared to contain erroneous references to 40 CFR 600.506 and 600.506(a)(2), which seemed not to exist, and asked the agency to check those references. In response, NHTSA examined the issue and found that 40 CFR 600.506 was, in fact, eliminated by a final rule published on April 6, 1984 (49 FR 13832). That section of 40 CFR originally required manufacturers to submit preliminary CAFE data to EPA prior to submitting the final end of the year data. EPA's primary intent for eliminating the requirement, as stated in the final rule, was to reduce administration burden. To address these inaccurate references, NHTSA is revising part 537 to delete references to 40 CFR 600.506. This will not impact the existing requirements for the pre-model year, mid-model year and supplemental reports manufacturers must submit to NHTSA under part 537.

J. Other Near-Term Rulemakings Mandated by EISA

1. Commercial Medium- and Heavy-Duty On-Highway Vehicles and Work Trucks

EISA added new provisions to 49 U.S.C. 32902 requiring DOT, in consultation with DOE and EPA, to conduct a study regarding a program to require improvements in the fuel efficiency of commercial medium- and heavy-duty on-highway vehicles and work trucks and then to conduct a rulemaking to adopt and implement such a program. In the study, the agency must examine the fuel efficiency of commercial medium- and heavy-duty on-highway vehicles [770] and work trucks [771] and determine the appropriate test procedures and methodologies for measuring their fuel efficiency, as well as the appropriate metric for measuring and expressing their fuel efficiency performance and the range of factors that affect their fuel efficiency. Then the agency must determine in a rulemaking

[770] Defined as an on-highway vehicle with a gross vehicle weight rating of 10,000 pounds or more.

[771] Defined as a vehicle that is both rated at between 8,500 and 10,000 pounds gross vehicle weight; and also is not a medium-duty passenger vehicle (as defined in 40 CFR 86.1803–01, as in effect on the date of EISA's enactment.

proceeding how to implement a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement, and adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for commercial medium- and heavy-duty on-highway vehicles and work trucks. The agency is working closely with EPA on developing a proposal for these standards.

2. Consumer Information on Fuel Efficiency and Emissions

EISA also added a new provision to 49 U.S.C. 32908 requiring DOT, in consultation with DOE and EPA, to develop and implement by rule a program to require manufacturers to label new automobiles sold in the United States with:

(1) Information reflecting an automobile's performance on the basis of criteria that EPA shall develop, not later than 18 months after the date of the enactment of EISA, to reflect fuel economy and greenhouse gas and other emissions over the useful life of the automobile; and

(2) A rating system that would make it easy for consumers to compare the fuel economy and greenhouse gas and other emissions of automobiles at the point of purchase, including a designation of automobiles with the lowest greenhouse gas emissions over the useful life of the vehicles; and with the highest fuel economy.

DOT must also develop and implement by rule a program to require manufacturers to include in the owner's manual for vehicles capable of operating on alternative fuels information that describes that capability and the benefits of using alternative fuels, including the renewable nature and environmental benefits of using alternative fuels.

EISA further requires DOT, in consultation with DOE and EPA, to

> Develop and implement by rule a consumer education program to improve consumer understanding of automobile performance described [by the label to be developed] and to inform consumers of the benefits of using alternative fuel in automobiles and the location of stations with alternative fuel capacity;
>
> Establish a consumer education campaign on the fuel savings that would be recognized from the purchase of vehicles equipped with thermal management technologies, including energy efficient air conditioning systems and glass; and
>
> By rule require a label to be attached to the fuel compartment of vehicles capable of operating on alternative fuels, with the form of alternative fuel stated on the label.

49 U.S.C. 32908(g)(2) and (3).

DOT has 42 months from the date of EISA's enactment (by the end of 2011) to issue final rules under this subsection. Work on developing these standards is also on-going. The agency is working closely with EPA on developing a proposal for these regulations.

Additionally, in preparation for this future rulemaking, NHTSA will consider appropriate metrics for presenting fuel economy-related information on labels. Based on the non-linear relationship between mpg and fuel costs as well as emissions, inclusion of the "gallons per 100 miles" metric on fuel economy labels may be appropriate going forward, although the mpg information is currently required by law. A cost/distance metric may also be useful, as could a CO_2e grams per mile metric to facilitate comparisons between conventional vehicles and alternative fuel vehicles and to incorporate information about air conditioning-related emissions.

K. Record of Decision

On May 19, 2009 President Obama announced a National Fuel Efficiency Policy aimed at both increasing fuel economy and reducing greenhouse gas pollution for all new cars and trucks sold in the United States, while also providing a predictable regulatory framework for the automotive industry. The policy seeks to set harmonized Federal standards to regulate both fuel economy and GHG emissions. The program covers model year 2012 to model year 2016 and ultimately requires the equivalent of an average fuel economy of 35.5 mpg in 2016, if all CO_2 reduction were achieved through fuel economy improvements.

In accordance with President Obama's May 19, 2009 announcement, this final rule promulgates the fuel economy standards for MYs 2012–2016. This final rule constitutes the Record of Decision (ROD) for NHTSA's MYs 2012–2016 CAFE standards, pursuant to the National Environmental Policy Act (NEPA) and the Council on Environmental Quality's (CEQ) implementing regulations.[772] *See* 40 CFR 1505.2.

As required by CEQ regulations, this final rule and ROD sets forth the following: (1) The agency's decision; (2) alternatives considered by NHTSA in reaching its decision, including the environmentally preferable alternative; (3) the factors balanced by NHTSA in making its decision, including considerations of national policy; (4) how these factors and considerations entered into its decision; and (5) the agency's preferences among alternatives based on relevant factors, including economic and technical considerations and agency statutory missions. This final rule also briefly addresses mitigation.

The Agency's Decision

In the DEIS and the FEIS, the agency identified the approximately 4.3-percent average annual increase alternative as NHTSA's Preferred Alternative. After carefully reviewing and analyzing all of the information in the public record including technical support documents, the FEIS, and public and agency comments submitted on the DEIS, the FEIS, and the NPRM, NHTSA has decided to proceed with the Preferred Alternative. The Preferred Alternative requires approximately a 4.3-percent average annual increase in mpg for MYs 2012–2016. This decision results in an estimated required MY 2016 fleetwide 37.8 mpg for passenger cars and 28.7 mpg for light trucks. As stated in the FEIS, the Preferred Alternative results in a combined estimated required fleetwide 34.1 mpg in MY 2016.

Following publication of the FEIS, the Federal government Interagency Working Group on Social Cost of Carbon made public a revised estimate of the Social Cost of Carbon to support Federal regulatory activities where reducing CO_2 emissions is an important potential outcome. NHTSA relied upon the interagency group's interim guidance published in August 2009 for the FEIS analysis. For this final rule NHTSA has updated the analysis and now uses the central SCC value of $21 per metric ton (2010 emissions) identified in the interagency group's revised guidance.[773] See Section IV.C.3.l.iii.

The group's purpose in developing new estimates of the SCC was to allow

[772] NEPA is codified at 42 U.S.C. 4321–47. CEQ NEPA implementing regulations are codified at 40 Code of Federal Regulations (CFR) Parts 1500–08.

[773] The $21/ton estimate is for 2010 emissions and increases over time because of damages resulting from increased GHG concentrations. $21 is the average SCC at the 3 percent discount rate. The other three estimates include: Avg SCC at 5% ($5–$16); Avg SCC at 2.5% ($35–$65); and 95th percentile at 3% ($65–$136).

Federal agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions, as most Federal regulatory actions can be expected to have. The interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. The revised SCC estimates represent the interagency group's consideration of the literature and judgments about how to monetize some of the benefits of GHG mitigation.[774]

Incorporating the revised estimate, NHTSA's analysis indicates that the Agency's Decision will likely result in slightly greater fuel savings and CO_2 emissions reductions than those noted in the EIS. The revised SCC valuation applied for purposes of the final rule resulted in a slightly smaller gap in stringency between the passenger car and light truck standards; the ratio of passenger car stringency (*i.e.,* average required fuel economy) to light truck stringency in MY 2016 shrank from 1.318 to 1.313, or about 0.4 percent. Because manufacturers projected to pay civil penalties (rather than fully complying with CAFE standards) account for a smaller share of the light truck market than of the passenger car market, and because lifetime mileage accumulation is somewhat higher for light trucks than for passenger cars, this slight shift in relative stringency caused average fuel economy levels achieved under the preferred alternative to increase by about 0.02 mpg during MYs 2012–2016, resulted in corresponding lifetime (*i.e.,* over the full useful life of MYs 2012–2016 vehicles) fuel savings increases of about 0.9 percent, and corresponding increases in lifetime CO_2 emission reductions of about 1.1 percent. For environmental impacts associated with NHTSA's Decision, see Section IV.G of this final rule.

The incorporation of the revised interagency estimate of SCC results in minimal changes to the required fleetwide mpg for some model years covered by this final rule. All changes are less than or equal to .1 mpg (but may reflect an increase when rounding up during calculations) and continue to result, on average, in a 4.3 percent annual increase in mpg.[775] *See* Section IV.F for discussion of required annual fleetwide mpg.

For a discussion of the agency's selection of the Preferred Alternative as NHTSA's Decision, see Section IV.F of this final rule.

Alternatives Considered by NHTSA in Reaching Its Decision, Including the Environmentally Preferable Alternative

When preparing an EIS, NEPA requires an agency to compare the potential environmental impacts of its proposed action and a reasonable range of alternatives. NHTSA identified alternative stringencies that represent the spectrum of potential actions the agency could take. The environmental impacts of these alternatives, in turn, represent the spectrum of potential environmental impacts that could result from NHTSA's chosen action in setting CAFE standards. Specifically, the DEIS and FEIS analyzed the impacts of the following eight "action" alternatives: 3-Percent Alternative (Alternative 2), 4-Percent Alternative (Alternative 3), Preferred Alternative (Alternative 4), 5-Percent Alternative (Alternative 5), an alternative that maximizes net benefits (MNB) (Alternative 6), 6-Percent Alternative (Alternative 7), 7-Percent Alternative (Alternative 8), and an alternative under which total cost equals total benefit (TCTB) (Alternative 9). The DEIS and FEIS also analyzed the impacts that would be expected if NHTSA imposed no new requirements (the No Action Alternative). In accordance with CEQ regulations, the agency selected a Preferred Alternative in the DEIS and the FEIS (the approximately 4.3-percent average annual increase alternative).

In response to public comments, the FEIS expanded the analysis to determine how the proposed alternatives were affected by variations in the economic assumptions input into the computer model NHTSA uses to calculate the costs and benefits of various potential CAFE standards (the Volpe model). Variations in economic assumptions can be used to examine the sensitivity of costs and benefits of each of the alternatives, including future fuel prices, the value of reducing CO_2 emissions (referred to as the social cost of carbon or SCC), the magnitude of the rebound effect, and the value of oil import externalities. Different combinations of economic assumptions can also affect the calculation of environmental impacts of the various action alternatives. This occurs partly because some economic inputs to the Volpe model—notably fuel prices and the size of the rebound effect—influence its estimates of vehicle use and fuel consumption, the main factors that determine emissions of GHGs, criteria air pollutants, and airborne toxics. See section 2.4 of the FEIS for a discussion of the sensitivity analysis conducted for the FEIS.

The agency considered and analyzed each of the individual economic assumptions to determine which assumptions most accurately represent future economic conditions. For a discussion of the analysis supporting the selection of the economic assumptions relied on by the agency in this final rule, see Section IV.C.3.

Also in response to comments, the agency conducted a national-scale photochemical air quality modeling and health risk assessment for a subset of the DEIS alternatives to support and confirm the health effects and health-related economic estimates of the EIS. The photochemical air quality study is included as Appendix F to the EIS. The study used air quality modeling and health benefits analysis tools to quantify the air quality and health-related benefits associated with the alternative CAFE standards. Four alternatives from the DEIS were modeled: the No Action Alternative and Alternative 2 (the 3-Percent Alternative) to represent fuel economy requirements at the lower end of the range; Alternative 4 (the Preferred Alternative) and Alternative 8 (the 7-Percent Alternative) to represent fuel economy requirements at the higher end of the range.

The agency compared the potential environmental impacts of alternative mpg levels, analyzing direct, indirect, and cumulative impacts. For a discussion of the environmental impacts associated with each of the alternatives, *see* Chapters 3 and 4 of the FEIS.

Alternative 8 (the 7-Percent Alternative) is the overall Environmentally Preferable Alternative, because it would result in the largest reductions in fuel use and GHG emissions by vehicles produced during MYs 2012–2016 among the alternatives considered. Under each alternative the agency considered, the reduction in fuel consumption resulting from higher fuel economy causes emissions that occur during fuel refining and distribution to decline. For most pollutants, this decline is more than sufficient to offset the increase in tailpipe emissions that results from increased driving due to the fuel economy rebound effect, leading to

[774] The interagency group intends to update these estimates as the science and economic understanding of climate change and its impacts on society improves over time.

[775] There are no "substantial changes to the proposed action" and there are no "significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts." Therefore, consistent with 40 CFR 1502.9(c), no supplement to the EIS is required. Moreover, the environmental impacts of this decision fall within the spectrum of impacts analyzed in the DEIS and the FEIS.

a net reduction in total emissions from fuel production, distribution, and use. Because it leads to the largest reductions in fuel refining, distribution, and consumption among the alternatives considered, Alternative 8 would also lead to the largest net reductions in emissions of CO_2 and other GHGs, most criteria air pollutants,[776] as well as the mobile source air toxics (MSATs) benzene and diesel particulate matter (diesel PM).

However, NHTSA's environmental analysis indicates that emissions of the MSATs acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde would increase under some alternatives, with the largest increases in emissions of these MSATs projected to occur under Alternative 8 in most future years. This occurs because the rates at which these MSATs are emitted during fuel refining and distribution are very low relative to their emission rates during vehicle use. As a consequence, the reductions in their total emissions during fuel refining and distribution that result from lower fuel use are insufficient to offset the increases in emissions that result from additional vehicle use. The amount by which increased tailpipe emissions of these MSATs exceeds the reductions in their emissions during fuel refining and distribution increases for alternatives that require larger improvements in fuel economy, and in most future years is smallest under Alternative 2 (which would increase CAFE standards least rapidly among the action alternatives) and largest under Alternative 8 (which would require the most rapid increase in fuel economy). Thus while Alternative 8 is the environmentally preferable alternative on the basis of CO_2 and other GHGs, most criteria air pollutants, and some MSATs, other alternatives are environmentally preferable from the standpoint of the criteria air pollutants fine particulate matter and sulfur oxides, as well as the MSATs acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde. Overall, however, NHTSA considers Alternative 8 to be the Environmentally Preferable Alternative.

For additional discussion regarding the alternatives considered by the agency in reaching its decision, including the Environmentally Preferable Alternative, *see* Section IV.F of this final rule. For a discussion of the environmental impacts associated with each alternative, *see* Chapters 3 and 4 of the FEIS.

Factors Balanced by NHTSA in Making Its Decision

For discussion of the factors balanced by NHTSA in making its decision, see Sections IV.D. and IV.F of this final rule.

How the Factors and Considerations Balanced by NHTSA Entered Into Its Decision

For discussion of how the factors and considerations balanced by the agency entered into NHTSA's Decision, *see* Section IV.F of this final rule.

The Agency's Preferences Among Alternatives Based on Relevant Factors, Including Economic and Technical Considerations and Agency Statutory Missions

For discussion of the agency's preferences among alternatives based on relevant factors, including economic and technical considerations, *see* Section IV.F of this final rule.

Mitigation

The CEQ regulations specify that a ROD must "state whether all practicable means to avoid or minimize environmental harm from the alternative selected have been adopted, and if not, why they were not." 49 CFR 1505.2(c). The majority of the environmental effects of NHTSA's action are positive, *i.e.,* beneficial environmental impacts, and would not raise issues of mitigation. The only negative environmental impacts are the projected increase in emissions of carbon monoxide and certain air toxics, as discussed above under the Environmentally Preferable Alternative, and in Section 2.6 and Chapter 5 of the FEIS. The agency forecasts these increases because, under all the alternatives analyzed in the EIS, increase in vehicle use due to improved fuel economy is projected to result in growth in total miles traveled by passenger cars and light trucks. This growth is exacerbated by the expected growth in the number of passenger cars and light trucks in use in the United States. The growth in travel outpaces emissions reductions for some pollutants, resulting in projected increases for these pollutants.

NHTSA's authority to promulgate new fuel economy standards is limited and does not allow regulation of vehicle emissions or of factors affecting vehicle emissions, including driving habits. Consequently, under the CAFE program, NHTSA must set standards but is unable to take steps to mitigate the impacts of these standards. However, we note that the Department of Transportation is currently implementing initiatives that work toward the stated Secretarial policy goal of reducing annual vehicle miles traveled. Chapter 5 of the FEIS outlines a number of other initiatives across government that could ameliorate the environmental impacts of motor vehicle use.

L. Regulatory Notices and Analyses

Following is a discussion of regulatory notices and analyses relevant to this rulemaking.

1. Executive Order 12866 and DOT Regulatory Policies and Procedures

Executive Order 12866, "Regulatory Planning and Review" (58 FR 51735, Oct. 4, 1993), provides for making determinations whether a regulatory action is "significant" and therefore subject to OMB review and to the requirements of the Executive Order. The Order defines a "significant regulatory action" as one that is likely to result in a rule that may:

(1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local or Tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

The rulemaking proposed in this NPRM is economically significant. Accordingly, OMB reviewed it under Executive Order 12866. The rule is also significant within the meaning of the Department of Transportation's Regulatory Policies and Procedures.

The benefits and costs of this rule are described above. Because the rule is economically significant under both the Department of Transportation's procedures and OMB guidelines, the agency has prepared a Final Regulatory Impact Analysis (FRIA) and placed it in the docket and on the agency's Web site. Further, pursuant to OMB Circular A–4, we have prepared a formal probabilistic uncertainty analysis for this rule. The

[776] Reductions in emissions of two criteria air pollutants, fine particulate matter ($PM_{2.5}$) and sulfur oxides (SO_X), are forecast to be slightly larger for Alternative 9 (TCTB) than for Alternative 8. Because the estimates of health benefits depend most critically on changes in particulate matter emissions, this causes the health benefits estimates reported in this FEIS to be slightly larger for Alternative 9 than for Alternative 8. *See* Section 3.3 of the FEIS. Nonetheless, for the other reasons explained above, NHTSA considers Alternative 8 to be the overall Environmentally Preferable Alternative.

circular requires such an analysis for complex rules where there are large, multiple uncertainties whose analysis raises technical challenges or where effects cascade and where the impacts of the rule exceed $1 billion. This final rule meets these criteria on all counts.

2. National Environmental Policy Act

Under NEPA, a Federal agency must prepare an Environmental Impact Statement (EIS) on proposed actions that could significantly impact the quality of the human environment. The requirement is designed to serve three major functions: (1) To provide the decisionmaker(s) with a detailed description of the potential environmental impacts of a proposed action prior to its adoption, (2) to rigorously explore and evaluate all reasonable alternatives, and (3) to inform the public of, and allow comment on, such efforts.

In addition, the CEQ regulations emphasize agency cooperation early in the NEPA process, and allow a lead agency (in this case, NHTSA) to request the assistance of other agencies that either have jurisdiction by law or have special expertise regarding issues considered in an EIS.[777] NHTSA invited EPA to be a cooperating agency because of its special expertise in the areas of climate change and air quality. On May 12, 2009, EPA agreed to become a cooperating agency.[778]

NHTSA, in cooperation with EPA, prepared a draft EIS (DEIS), solicited public comments in writing and in a public hearing, and prepared a final EIS (FEIS) responding to those comments. Specifically, in April 2009, NHTSA published an NOI to prepare an EIS for proposed MYs 2012–2016 CAFE standards.[779] *See* 40 CFR 1501.7.

On September 25, 2009, EPA issued its Notice of Availability of the DEIS,[780] triggering the 45-day public comment period. *See* 74 FR 48951. *See* also 40 CFR 1506.10. In accordance with CEQ regulations, the public was invited to submit written comments on the DEIS until November 9, 2009. *See* 40 CFR 1503, *et seq.*

NHTSA mailed (both electronically and through regular U.S. mail) over 500 copies of the DEIS to interested parties, including Federal, State, and local officials and agencies; elected officials, environmental and public interest groups; Native American tribes; and other interested individuals. NHTSA held a public hearing on the DEIS at the National Transportation Safety Board Conference Center in Washington, DC on October 30, 2009.

NHTSA received 11 written comments from interested stakeholders, including Federal agencies, state agencies, environmental advocacy groups, and private citizens. In addition, three interested parties spoke at the public hearing. The transcript from the public hearing and written comments submitted to NHTSA are part of the administrative record, and are available on the Federal Docket, which can be found on the Web at *http://www.regulations.gov,* Reference Docket No. NHTSA–2009–0059.

NHTSA reviewed and analyzed all comments received during the public comment period and revised the FEIS in response to comments on the EIS where appropriate.[781] For a more detailed discussion of NHTSA's scoping and comment periods, *see* Section 1.5 and Chapter 10 of the FEIS.

On February 22, 2010, NHTSA submitted the FEIS to the EPA. NHTSA also mailed (both electronically and through regular U.S. mail) over 500 copies of the FEIS to interested parties and posted the FEIS on its Web site, *http://www.nhtsa.gov/portal/fueleconomy.jsp.* On March 3, 2010, EPA published a Notice of Availability of the FEIS in the **Federal Register.** *See* 75 FR 9596.

The FEIS analyzes and discloses the potential environmental impacts of the proposed MYs 2012–2016 CAFE standards for the total fleet of passenger cars and light trucks and reasonable alternative standards for the NHTSA CAFE Program pursuant to the National Environmental Policy Act (NEPA), the Council on Environmental Quality (CEQ) regulations implementing NEPA, DOT Order 5610.1C, and NHTSA regulations.[782] The FEIS compared the potential environmental impacts of alternative mile per gallon (mpg) levels considered by NHTSA for the final rule. It also analyzed direct, indirect, and cumulative impacts and analyzes impacts in proportion to their significance. See the FEIS and the FEIS Summary for a discussion of the environmental impacts analyzed. Docket Nos. NHTSA–2009–0059–0140, NHTSA–2009–0059–0141.

The MYs 2012–2016 CAFE standards adopted in this final rule have been informed by analyses contained in the *Final Environmental Impact Statement, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2012–2016,* Docket No. NHTSA–2009–0059 (FEIS). For purposes of this rulemaking, the agency referred to an extensive compilation of technical and policy documents available in NHTSA's EIS/Rulemaking docket and EPA's docket. NHTSA's EIS and rulemaking docket and EPA's rulemaking docket can be found on the Web at *http://www.regulations.gov*, Reference Docket Nos.: NHTSA–2009–0059 (EIS and Rulemaking) and EPA–HQ–OAR–2009–0472 (EPA Rulemaking).

Based on the foregoing, the agency concludes that the environmental analysis and public involvement process complies with NEPA implementing regulations issued by CEQ, DOT Order 5610.1C, and NHTSA regulations.[783]

3. Clean Air Act (CAA)

The CAA (42 U.S.C. 7401) is the primary Federal legislation that addresses air quality. Under the authority of the CAA and subsequent amendments, the EPA has established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants, which are relatively commonplace pollutants that can accumulate in the atmosphere as a result of normal levels of human activity. The EPA is required to review the NAAQS every five years and to change the levels of the standards

[777] 40 CFR 1501.6.

[778] Consistent with the National Fuel Efficiency Policy that the President announced on May 19, 2009, EPA and NHTSA published their Notice of Upcoming Joint Rulemaking to ensure a coordinated National Program on GHG emissions and fuel economy for passenger cars, light-duty trucks, and medium-duty passenger vehicles. NHTSA takes no position on whether the EPA proposed rule on GHG emissions could be considered a "connected action" under the CEQ regulation at 40 CFR Section 1508.25. For purposes of the EIS, however, NHTSA decided to treat the EPA proposed rule as if it were a "connected action" under that regulation to improve the usefulness of the EIS for NHTSA decisionmakers and the public. NHTSA is aware that Section 7(c) of the Energy Supply and Environmental Coordination Act of 1974 expressly exempts from NEPA requirements EPA action taken under the CAA. *See* 15 U.S.C. 793(c)(1).

[779] *See* Notice of Intent to Prepare an Environmental Impact Statement for New Corporate Average Fuel Economy Standards, 74 FR 14857 (Apr. 1, 2009).

[780] Also on September 25, 2009, NHTSA published a **Federal Register** Notice of Availability of its DEIS. *See* 74 FR 48894. NHTSA's Notice of Availability also announced the date and location of a public hearing, and invited the public to participate at the hearing on October 30, 2009, in Washington, DC. See *id.*

[781] The agency also changed the FEIS as a result of updated information that became available after issuance of the DEIS.

[782] NEPA is codified at 42 U.S.C. 4321–4347. CEQ NEPA implementing regulations are codified at 40 Code of Federal Regulations (CFR) Parts 1500–1508. NHTSA NEPA implementing regulations are codified at 49 CFR part 520.

[783] NEPA is codified at 42 U.S.C. 4321–4347. CEQ's NEPA implementing regulations are codified at 40 CFR parts 1500–1508, and NHTSA's NEPA implementing regulations are codified at 49 CFR part 520.

if warranted by new scientific information.

The air quality of a geographic region is usually assessed by comparing the levels of criteria air pollutants found in the atmosphere to the levels established by the NAAQS. Concentrations of criteria pollutants within the air mass of a region are measured in parts of a pollutant per million parts of air (ppm) or in micrograms of a pollutant per cubic meter (g/m^3) of air present in repeated air samples taken at designated monitoring locations. These ambient concentrations of each criteria pollutant are compared to the permissible levels specified by the NAAQS in order to assess whether the region's air quality is potentially unhealthful.

When the measured concentrations of a criteria pollutant within a geographic region are below those permitted by the NAAQS, the region is designated by the EPA as an attainment area for that pollutant, while regions where concentrations of criteria pollutants exceed Federal standards are called nonattainment areas (NAAs). Former NAAs that have attained the NAAQS are designated as maintenance areas. Each NAA is required to develop and implement a State Implementation Plan (SIP), which documents how the region will reach attainment levels within time periods specified in the CAA. In maintenance areas, the SIP documents how the State intends to maintain compliance with the NAAQS. When EPA changes a NAAQS, States must revise their SIPs to address how they will attain the new standard.

Section 176(c) of the CAA prohibits Federal agencies from taking actions in nonattainment or maintenance areas that do not "conform" to the State Implementation Plan (SIP). The purpose of this conformity requirement is to ensure that Federal activities do not interfere with meeting the emissions targets in the SIPs, do not cause or contribute to new violations of the NAAQS, and do not impede the ability to attain or maintain the NAAQS. The EPA has issued two sets of regulations to implement CAA Section 176(c):

The Transportation Conformity Rules (40 CFR part 51 subpart T), which apply to transportation plans, programs, and projects funded under title 23 United States Code (U.S.C.) or the Federal Transit Act. Highway and transit infrastructure projects funded by FHWA or the Federal Transit Administration (FTA) usually are subject to transportation conformity.

The General Conformity Rules (40 CFR part 51 subpart W) apply to all other Federal actions not covered under transportation conformity. The General Conformity Rules established emissions thresholds, or *de minimis* levels, for use in evaluating the conformity of a project. If the net emission increases due to the project are less than these thresholds, then the project is presumed to conform and no further conformity evaluation is required. If the emission increases exceed any of these thresholds, then a conformity determination is required. The conformity determination may entail air quality modeling studies, consultation with EPA and State air quality agencies, and commitments to revise the SIP or to implement measures to mitigate air quality impacts.

The CAFE standards and associated program activities are not funded under title 23 U.S.C. or the Federal Transit Act. Further, CAFE standards are established by NHTSA and are not an action undertaken by FHWA or FTA. Accordingly, the CAFE standards are not subject to transportation conformity.

The General Conformity Rules contain several exemptions applicable to "Federal actions," which the conformity regulations define as: "any activity engaged in by a department, agency, or instrumentality of the Federal Government, or any activity that a department, agency or instrumentality of the Federal Government supports in any way, provides financial assistance for, licenses, permits, or approves, other than activities [subject to transportation conformity]." 40 CFR 51.852. "Rulemaking and policy development and issuance" are exempted at 40 CFR 51.853(c)(2)(iii). Since NHTSA's CAFE standards involve a rulemaking process, its action is exempt from general conformity. Also, emissions for which a Federal agency does not have a "continuing program responsibility" are not considered "indirect emissions" subject to general conformity under 40 CFR 51.852. "Emissions that a Federal agency has a continuing program responsibility for means emissions that are specifically caused by an agency carrying out its authorities, and does not include emissions that occur due to subsequent activities, unless such activities are required by the Federal agency." 40 CFR 51.852. Emissions that occur as a result of the final CAFE standards are not caused by NHTSA carrying out its statutory authorities and clearly occur due to subsequent activities, including vehicle manufacturers' production of passenger car and light truck fleets and consumer purchases and driving behavior. Thus, changes in any emissions that result from NHTSA's final CAFE standards are not those for which the agency has a "continuing program responsibility" and NHTSA is confident that a general conformity determination is not required. NHTSA has evaluated the potential impacts of air emissions under NEPA.

4. National Historic Preservation Act (NHPA)

The NHPA (16 U.S.C. 470) sets forth government policy and procedures regarding "historic properties"—that is, districts, sites, buildings, structures, and objects included in or eligible for the National Register of Historic Places (NRHP). *See* also 36 CFR part 800. Section 106 of the NHPA requires Federal agencies to "take into account" the effects of their actions on historic properties. The agency concludes that the NHPA is not applicable to NHTSA's Decision, because it does not directly involve historic properties. The agency has, however, conducted a qualitative review of the related direct, indirect, and cumulative impacts, positive or negative, of the alternatives on potentially affected resources, including historic and cultural resources. *See* Sections 3.5 and 4.5 of the FEIS.

5. Executive Order 12898 (Environmental Justice)

Under Executive Order 12898, Federal agencies are required to identify and address any disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations. NHTSA complied with this order by identifying and addressing the potential effects of the alternatives on minority and low-income populations in Sections 3.5 and 4.5 of the FEIS, where the agency set forth a qualitative analysis of the cumulative effects of the alternatives on these populations.

6. Fish and Wildlife Conservation Act (FWCA)

The FWCA (16 U.S.C. 2900) provides financial and technical assistance to States for the development, revision, and implementation of conservation plans and programs for nongame fish and wildlife. In addition, the Act encourages all Federal agencies and departments to utilize their authority to conserve and to promote conservation of nongame fish and wildlife and their habitats. The agency concludes that the FWCA is not applicable to NHTSA's Decision, because it does not directly involve fish and wildlife.

7. Coastal Zone Management Act (CZMA)

The Coastal Zone Management Act (16 U.S.C. 1450) provides for the preservation, protection, development, and (where possible) restoration and enhancement of the nation's coastal zone resources. Under the statute, States are provided with funds and technical assistance in developing coastal zone management programs. Each participating State must submit its program to the Secretary of Commerce for approval. Once the program has been approved, any activity of a Federal agency, either within or outside of the coastal zone, that affects any land or water use or natural resource of the coastal zone must be carried out in a manner that is consistent, to the maximum extent practicable, with the enforceable policies of the State's program.

The agency concludes that the CZMA is not applicable to NHTSA's Decision, because it does not involve an activity within, or outside of, the nation's coastal zones. The agency has, however, conducted a qualitative review of the related direct, indirect, and cumulative impacts, positive or negative, of the alternatives on potentially affected resources, including coastal zones. *See* Sections 3.5 and 4.5 of the FEIS.

8. Endangered Species Act (ESA)

Under Section 7(a)(2) of the Endangered Species Act (ESA) Federal agencies must ensure that actions they authorize, fund, or carry out are "not likely to jeopardize" federally listed threatened or endangered species or result in the destruction or adverse modification of the designated critical habitat of these species. 16 U.S.C. 1536(a)(2). If a Federal agency determines that an agency action may affect a listed species or designated critical habitat, it must initiate consultation with the appropriate Service—the U.S. Fish and Wildlife Service (FWS) of the Department of the Interior and/or National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries Service) of the Department of Commerce, depending on the species involved—in order to ensure that the action is not likely to jeopardize the species or destroy or adversely modify designated critical habitat. *See* 50 CFR 402.14. Under this standard, the Federal agency taking action evaluates the possible effects of its action and determines whether to initiate consultation. *See* 51 FR 19926, 19949 (Jun. 3, 1986).

NHTSA has reviewed applicable ESA regulations, case law, guidance, and rulings in assessing the potential for impacts to threatened and endangered species from the proposed CAFE standards. NHTSA believes that the agency's action of setting CAFE standards, which will result in nationwide fuel savings and, consequently, emissions reductions from what would otherwise occur in the absence of the agency's CAFE standards, does not require consultation with NOAA Fisheries Service or the FWS under section 7(a)(2) of the ESA. For additional discussion of the agency's rationale, see Appendix G of the FEIS. Accordingly, NHTSA has concluded its review of this action under Section 7 of the ESA.

NHTSA has worked with EPA to assess ESA requirements and develop the agencies' responses to comments addressing this issue. NHTSA notes that EPA has reached the same conclusion as NHTSA, and has determined that ESA consultation is not required for its action taken today pursuant to the Clean Air Act. EPA's determination with regard to ESA is set forth in its response to comments regarding ESA requirements, and can be found in EPA's Response to Comments document, which EPA will place in the EPA docket for this rulemaking (OAR–2009–0472), and on the EPA Web site. As set forth therein, EPA adopts the reasoning of NHTSA's response in Appendix G of the FEIS as applied to EPA's rulemaking action.

9. Floodplain Management (Executive Order 11988 & DOT Order 5650.2)

These Orders require Federal agencies to avoid the long- and short-term adverse impacts associated with the occupancy and modification of floodplains, and to restore and preserve the natural and beneficial values served by floodplains. Executive Order 11988 also directs agencies to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains through evaluating the potential effects of any actions the agency may take in a floodplain and ensuring that its program planning and budget requests reflect consideration of flood hazards and floodplain management. DOT Order 5650.2 sets forth DOT policies and procedures for implementing Executive Order 11988. The DOT Order requires that the agency determine if a proposed action is within the limits of a base floodplain, meaning it is encroaching on the floodplain, and whether this encroachment is significant. If significant, the agency is required to conduct further analysis of the proposed action and any practicable alternatives. If a practicable alternative avoids floodplain encroachment, then the agency is required to implement it.

In this rulemaking, the agency is not occupying, modifying and/or encroaching on floodplains. The agency, therefore, concludes that the Orders are not applicable to NHTSA's Decision. The agency has, however, conducted a review of the alternatives on potentially affected resources, including floodplains. *See* Section 4.5 of the FEIS.

10. Preservation of the Nation's Wetlands (Executive Order 11990 & DOT Order 5660.1a)

These Orders require Federal agencies to avoid, to the extent possible, undertaking or providing assistance for new construction located in wetlands unless the agency head finds that there is no practicable alternative to such construction and that the proposed action includes all practicable measures to minimize harms to wetlands that may result from such use. Executive Order 11990 also directs agencies to take action to minimize the destruction, loss or degradation of wetlands in "conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities." DOT Order 5660.1a sets forth DOT policy for interpreting Executive Order 11990 and requires that transportation projects "located in or having an impact on wetlands" should be conducted to assure protection of the Nation's wetlands. If a project does have a significant impact on wetlands, an EIS must be prepared.

The agency is not undertaking or providing assistance for new construction located in wetlands. The agency, therefore, concludes that these Orders do not apply to NHTSA's Decision. The agency has, however, conducted a review of the alternatives on potentially affected resources, including wetlands. *See* Section 4.5 of the FEIS.

11. Migratory Bird Treaty Act (MBTA), Bald and Golden Eagle Protection Act (BGEPA), Executive Order 13186

The MBTA provides for the protection of migratory birds that are native to the United States by making it illegal for anyone to pursue, hunt, take, attempt to take, kill, capture, collect, possess, buy, sell, trade, ship, import, or export any migratory bird covered under the statute. The statute prohibits both intentional and unintentional acts. Therefore, the statute is violated if an agency acts in a manner that harms a migratory bird, whether it was intended or not. *See, e.g., United States* v. *FMC Corp.,* 572 F.2d 902 (2nd Cir. 1978).

The BGEPA (16 U.S.C. 668) prohibits any form of possession or taking of both bald and golden eagles. Under the BGEPA, violators are subject to criminal and civil sanctions as well as an enhanced penalty provision for subsequent offenses.

Executive Order 13186, "Responsibilities of Federal Agencies to Protect Migratory Birds," helps to further the purposes of the MBTA by requiring a Federal agency to develop a Memorandum of Understanding (MOU) with the Fish and Wildlife Service when it is taking an action that has (or is likely to have) a measurable negative impact on migratory bird populations.

The agency concludes that the MBTA, BGEPA, and Executive Order 13186 do not apply to NHTSA's Decision, because there is no disturbance and/or take involved in NHTSA's Decision.

12. Department of Transportation Act (Section 4(f))

Section 4(f) of the Department of Transportation Act of 1966 (49 U.S.C. 303), as amended by Public Law § 109–59, is designed to preserve publicly owned parklands, waterfowl and wildlife refuges, and significant historic sites. Specifically, Section 4(f) of the Department of Transportation Act provides that DOT agencies cannot approve a transportation program or project that requires the use of any publicly owned land from a significant public park, recreation area, or wildlife and waterfowl refuge, or any land from a significant historic site, unless a determination is made that:

There is no feasible and prudent alternative to the use of land, and

The program or project includes all possible planning to minimize harm to the property resulting from use, or

A transportation use of Section 4(f) property results in a *de minimis* impact.

The agency concludes that the Section 4(f) is not applicable to NHTSA's Decision because this rulemaking does not require the use of any publicly owned land. For a more detailed discussion, *please see* Section 3.5 of the FEIS.

13. Regulatory Flexibility Act

Pursuant to the Regulatory Flexibility Act (5 U.S.C. 601 *et seq.,* as amended by the Small Business Regulatory Enforcement Fairness Act (SBREFA) of 1996), whenever an agency is required to publish a notice of rulemaking for any proposed or final rule, it must prepare and make available for public comment a regulatory flexibility analysis that describes the effect of the rule on small entities (*i.e.,* small businesses, small organizations, and small governmental jurisdictions). The Small Business Administration's regulations at 13 CFR part 121 define a small business, in part, as a business entity "which operates primarily within the United States." 13 CFR 121.105(a). No regulatory flexibility analysis is required if the head of an agency certifies the rule will not have a significant economic impact on a substantial number of small entities.

I certify that this final rule will not have a significant economic impact on a substantial number of small entities. The following is NHTSA's statement providing the factual basis for the certification (5 U.S.C. 605(b)).

The final rule directly affects twenty-one large single stage motor vehicle manufacturers.[784] According to current information, the final rule would also affect two small domestic single stage motor vehicle manufacturers, Saleen and Tesla.[785] According to the Small Business Administration's small business size standards (*see* 13 CFR 121.201), a single stage automobile or light truck manufacturer (NAICS code 336111, Automobile Manufacturing; 336112, Light Truck and Utility Vehicle Manufacturing) must have 1,000 or fewer employees to qualify as a small business. Both Saleen and Tesla have less than 1,000 employees and make less than 1,000 vehicles per year. We believe that the rulemaking would not have a significant economic impact on these small vehicle manufacturers because under part 525, passenger car manufacturers making less than 10,000 vehicles per year can petition NHTSA to have alternative standards set for those manufacturers. Tesla produces only electric vehicles with fuel economy values far above those finalized today, so we would not expect them to need to petition for relief. Saleen modifies a very small number of vehicles produced by one of the 21 large single-stage manufacturers, and currently does not meet the 27.5 mpg passenger car standard, nor is it anticipated to be able to meet the standards proposed today. However, Saleen already petitions the agency for relief. If the standard is raised, it has no meaningful impact on Saleen, because it must still go through the same process to petition for relief. Ferrari commented that NHTSA will not necessarily always grant the petitions of small vehicle manufacturers for alternative standards, and that therefore the relief is not guaranteed.[786] In response, NHTSA notes that the fact that the agency may not grant a petition for an alternative standard for one manufacturer at one time does not mean that the mechanism for handling small businesses is unavailable for all. Thus, given that there already is a mechanism for handling small businesses, which is the purpose of the Regulatory Flexibility Act, a regulatory flexibility analysis was not prepared.

14. Executive Order 13132 (Federalism)

Executive Order 13132 requires NHTSA to develop an accountable process to ensure "meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications." The Order defines the term "Policies that have federalism implications" to include regulations that have "substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government." Under the Order, NHTSA may not issue a regulation that has federalism implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by State and local governments, or NHTSA consults with State and local officials early in the process of developing the proposed regulation. Several state agencies provided comments to the proposed standards.

Additionally, in his January 26 memorandum, the President requested NHTSA to "consider whether any provisions regarding preemption are consistent with the EISA, the Supreme Court's decision in *Massachusetts* v. *EPA* and other relevant provisions of law and the policies underlying them." NHTSA is deferring consideration of the preemption issue. The agency believes that it is unnecessary to address the issue further at this time because of the consistent and coordinated Federal standards that will apply nationally under the National Program.

[784] BMW, Daimler (Mercedes), Chrysler, Ferrari, Ford, Subaru, General Motors, Honda, Hyundai, Kia, Lotus, Maserati, Mazda, Mitsubishi, Nissan, Porsche, Subaru, Suzuki, Tata, Toyota, and Volkswagen.

[785] The Regulatory Flexibility Act only requires analysis of small domestic manufacturers. There are two passenger car manufacturers that we know of, Saleen and Tesla, and no light truck manufacturers.

[786] We note that Ferrari would not currently qualify for such an alternative standard, because it does not manufacture fewer than 10,000 passenger automobiles per year, as required by 49 U.S.C. 32902(d) for exemption from the main passenger car CAFE standard.

15. Executive Order 12988 (Civil Justice Reform)

Pursuant to Executive Order 12988, "Civil Justice Reform,"[787] NHTSA has considered whether this rulemaking would have any retroactive effect. This final rule does not have any retroactive effect.

16. Unfunded Mandates Reform Act

Section 202 of the Unfunded Mandates Reform Act of 1995 (UMRA) requires Federal agencies to prepare a written assessment of the costs, benefits, and other effects of a proposed or final rule that includes a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of more than $100 million in any one year (adjusted for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for 2006 results in $126 million (116.043/92.106 = 1.26). Before promulgating a rule for which a written statement is needed, section 205 of UMRA generally requires NHTSA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows NHTSA to adopt an alternative other than the least costly, most cost-effective, or least burdensome alternative if the agency publishes with the final rule an explanation why that alternative was not adopted.

This final rule will not result in the expenditure by State, local, or tribal governments, in the aggregate, of more than $126 million annually, but it will result in the expenditure of that magnitude by vehicle manufacturers and/or their suppliers. In promulgating this final rule, NHTSA considered a variety of alternative average fuel economy standards lower and higher than those proposed. NHTSA is statutorily required to set standards at the maximum feasible level achievable by manufacturers based on its consideration and balancing of relevant factors and has concluded that the final fuel economy standards are the maximum feasible standards for the passenger car and light truck fleets for MYs 2012–2016 in light of the statutory considerations.

17. Regulation Identifier Number

The Department of Transportation assigns a regulation identifier number (RIN) to each regulatory action listed in the Unified Agenda of Federal Regulations. The Regulatory Information Service Center publishes the Unified Agenda in April and October of each year. You may use the RIN contained in the heading at the beginning of this document to find this action in the Unified Agenda.

18. Executive Order 13045

Executive Order 13045[788] applies to any rule that: (1) Is determined to be economically significant as defined under E.O. 12866, and (2) concerns an environmental, health, or safety risk that NHTSA has reason to believe may have a disproportionate effect on children. If the regulatory action meets both criteria, we must evaluate the environmental health or safety effects of the proposed rule on children, and explain why the proposed regulation is preferable to other potentially effective and reasonably foreseeable alternatives considered by us.

Chapter 4 of NHTSA's FEIS notes that breathing PM can cause respiratory ailments, heart attack, and arrhythmias (Dockery *et al.* 1993, Samet *et al.* 2000, Pope *et al.* 1995, 2002, 2004, Pope and Dockery 2006, Dominici *et al.* 2006, Laden *et al.* 2006, all in Ebi *et al.* 2008).[789] Populations at greatest risk could include children, the elderly, and those with heart and lung disease, diabetes (Ebi *et al.* 2008), and high blood pressure (Künzli *et al.* 2005, in Ebi *et al.* 2008). Chronic exposure to PM could decrease lifespan by 1 to 3 years (Pope 2000, in American Lung Association 2008). Increasing PM concentrations are expected to have a measurable adverse impact on human health (Confalonieri *et al.* 2007).

Additionally, the FEIS notes that substantial morbidity and childhood mortality has been linked to water- and food-borne diseases. Climate change is projected to alter temperature and the hydrologic cycle through changes in precipitation, evaporation, transpiration, and water storage. These changes, in turn, potentially affect water-borne and food-borne diseases, such as salmonellosis, campylobacter, leptospirosis, and pathogenic species of vibrio. They also have a direct impact on surface water availability and water quality. Increased temperatures, greater evaporation, and heavy rain events have been associated with adverse impacts on drinking water through increased waterborne diseases, algal blooms, and toxins (Chorus and Bartram 1999, Levin *et al.* 2002, Johnson and Murphy 2004, all in Epstein *et al.* 2005). A seasonal signature has been associated with waterborne disease outbreaks (EPA 2009b). In the United States, 68 percent of all waterborne diseases between 1948 and 1994 were observed after heavy rainfall events (Curriero *et al.* 2001a, in Epstein *et al.* 2005).

Climate change could further impact a pathogen by directly affecting its life cycle (Ebi *et al.* 2008). The global increase in the frequency, intensity, and duration of red tides could be linked to local impacts already associated with climate change (Harvell *et al.* 1999, in Epstein *et al.* 2005); toxins associated with red tide directly affect the nervous system (Epstein *et al.* 2005).

Many people do not report or seek medical attention for their ailments of water-borne or food-borne diseases; hence, the number of actual cases with these diseases is greater than clinical records demonstrate (Mead *et al.* 1999, in Ebi *et al.* 2008). Many of the gastrointestinal diseases associated with water-borne and food-borne diseases can be self-limiting; however, vulnerable populations include young children, those with a compromised immune system, and the elderly.

Thus, as detailed in the FEIS, NHTSA has evaluated the environmental health and safety effects of agency's action on children.

19. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act (NTTAA) requires NHTA to evaluate and use existing voluntary consensus standards in its regulatory activities unless doing so would be inconsistent with applicable law (*e.g.,* the statutory provisions regarding NHTSA's vehicle safety authority) or otherwise impractical.

Voluntary consensus standards are technical standards developed or adopted by voluntary consensus standards bodies. Technical standards are defined by the NTTAA as "performance-base or design-specific technical specification and related management systems practices." They pertain to "products and processes, such as size, strength, or technical performance of a product, process or material."

Examples of organizations generally regarded as voluntary consensus standards bodies include the American Society for Testing and Materials (ASTM), the Society of Automotive

[787] 61 FR 4729 (Feb. 7, 1996).

[788] 62 FR 19885 (Apr. 23, 1997).

[789] The references referred to in the remainder of this section are detailed in Section 7.4.5 of the FEIS.

Engineers (SAE), and the American National Standards Institute (ANSI). If NHTSA does not use available and potentially applicable voluntary consensus standards, we are required by the Act to provide Congress, through OMB, an explanation of the reasons for not using such standards.

There are currently no voluntary consensus standards relevant to today's final CAFE standards.

20. Executive Order 13211

Executive Order 13211[790] applies to any rule that: (1) Is determined to be economically significant as defined under E.O. 12866, and is likely to have a significant adverse effect on the supply, distribution, or use of energy; or (2) that is designated by the Administrator of the Office of Information and Regulatory Affairs as a significant energy action. If the regulatory action meets either criterion, we must evaluate the adverse energy effects of the final rule and explain why the final regulation is preferable to other potentially effective and reasonably feasible alternatives considered by us.

The final rule seeks to establish passenger car and light truck fuel economy standards that will reduce the consumption of petroleum and will not have any adverse energy effects. Accordingly, this final rulemaking action is not designated as a significant energy action.

21. Department of Energy Review

In accordance with 49 U.S.C. 32902(j)(1), we submitted this final rule to the Department of Energy for review. That Department did not make any comments that we have not addressed.

22. Privacy Act

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an organization, business, labor union, etc.). You may review DOT's complete Privacy Act statement in the **Federal Register** (65 FR 19477–78, April 11, 2000) or you may visit *http://www.dot.gov/privacy.html.*

List of Subjects

40 CFR Part 85

Confidential business information, Imports, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Research, Warranties.

40 CFR Part 86

Administrative practice and procedure, Confidential business information, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements.

40 CFR Part 600

Administrative practice and procedure, Electric power, Fuel economy, Incorporation by reference, Labeling, Reporting and recordkeeping requirements.

49 CFR Part 531 and 533

Fuel economy.

49 CFR Part 536 and 537

Fuel economy, Reporting and recordkeeping requirements.

49 CFR Part 538

Administrative practice and procedure, Fuel economy, Motor vehicles, Reporting and recordkeeping requirements.

Environmental Protection Agency

40 CFR Chapter I

■ Accordingly, EPA amends 40 CFR Chapter I as follows:

PART 85—CONTROL OF AIR POLLUTION FROM MOBILE SOURCES

■ 1. The authority citation for part 85 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

Subpart T—[Amended]

■ 2. Section 85.1902 is amended by revising paragraphs (b) and (d) to read as follows:

§ 85.1902 Definitions.

* * * * *

(b) The phrase *emission-related defect* shall mean:

(1) A defect in design, materials, or workmanship in a device, system, or assembly described in the approved Application for Certification (required by 40 CFR 86.1843–01 and 86.1844–01, and by 40 CFR 86.001–22 and similar provisions of 40 CFR part 86) which affects any parameter or specification enumerated in appendix VIII of this part; or

(2) A defect in the design, materials, or workmanship in one or more emissions control or emission-related parts, components, systems, software or elements of design which must function properly to assure continued compliance with vehicle emission requirements, including compliance with CO_2, CH_4, N_2O, and carbon-related exhaust emission standards;

* * * * *

(d) The phrase *Voluntary Emissions Recall* shall mean a repair, adjustment, or modification program voluntarily initiated and conducted by a manufacturer to remedy any emission-related defect for which direct notification of vehicle or engine owners has been provided, including programs to remedy defects related to emissions standards for CO_2, CH_4, N_2O, and/or carbon-related exhaust emissions.

* * * * *

PART 86—CONTROL OF EMISSIONS FROM NEW AND IN–USE HIGHWAY VEHICLES AND ENGINES

■ 3. The authority citation for part 86 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 4. Section 86.1 is amended by adding paragraphs (b)(2)(xxxix) through (xl) to read as follows:

§ 86.1 Reference materials.

* * * * *

(b) * * *

(2) * * *

(xxxix) SAE J2064, Revised December 2005, R134a Refrigerant Automotive Air-Conditioned Hose, IBR approved for § 86.166–12.

(xl) SAE J2765, October, 2008, Procedure for Measuring System COP [Coefficient of Performance] of a Mobile Air Conditioning System on a Test Bench, IBR approved for § 86.1866–12.

* * * * *

Subpart B—[Amended]

■ 5. Section 86.111–94 is amended by revising paragraph (b) introductory text to read as follows:

§ 86.111–94 Exhaust gas analytical system.

* * * * *

(b) *Major component description.* The exhaust gas analytical system, Figure B94–7, consists of a flame ionization detector (FID) (heated, 235 ±15 F (113 ±8 C) for methanol-fueled vehicles) for the determination of THC, a methane analyzer (consisting of a gas chromatograph combined with a FID) for the determination of CH_4, non-dispersive infrared analyzers (NDIR) for the determination of CO and CO_2, a chemiluminescence analyzer (CL) for the determination of NO_X, and an analyzer meeting the requirements specified in 40 CFR 1065.275 for the determination of N_2O (required for 2015 and later model year vehicles). A heated

[790] 66 FR 28355 (May 18, 2001).

flame ionization detector (HFID) is used for the continuous determination of THC from petroleum-fueled diesel-cycle vehicles (may also be used with methanol-fueled diesel-cycle vehicles), Figure B94–5 (or B94–6). The analytical system for methanol consists of a gas chromatograph (GC) equipped with a flame ionization detector. The analysis for formaldehyde is performed using high-pressure liquid chromatography (HPLC) of 2,4-dinitrophenylhydrazine (DNPH) derivatives using ultraviolet (UV) detection. The exhaust gas analytical system shall conform to the following requirements:

* * * * *

■ 6. Section 86.113–04 is amended by revising the entry for RVP in the table in paragraph (a)(1) to read as follows:

§ 86.113–04 Fuel specifications.

* * * * *

(a) * * *

(1) * * *

Item	ASTM test method No.	Value
* * * * *	*	*
RVP [2, 3]	D 323	8.7–9.2 (60.0–63.4)
* * * * *	*	*

* * * * *

■ 7. A new § 86.127–12 is added to read as follows:

§ 86.127–12 Test procedures; overview.

Applicability. The procedures described in this subpart are used to determine the conformity of vehicles with the standards set forth in subpart A or S of this part (as applicable) for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. Except where noted, the procedures of paragraphs (a) through (d) of this section, and the contents of §§ 86.135–00, 86.136–90, 86.137–96, 86.140–94, 86.142–90, and 86.144–94 are applicable for determining emission results for vehicle exhaust emission systems designed to comply with the FTP emission standards, or the FTP emission element required for determining compliance with composite SFTP standards. Paragraph (e) of this section discusses fuel spitback emissions. Paragraphs (f) and (g) of this section discuss the additional test elements of aggressive driving (US06) and air conditioning (SC03) that comprise the exhaust emission components of the SFTP. Paragraphs (h) and (i) of this section are applicable to all vehicle emission test procedures.

(a) The overall test consists of prescribed sequences of fueling, parking, and operating test conditions. Vehicles are tested for any or all of the following emissions, depending upon the specific test requirements and the vehicle fuel type:

(1) Gaseous exhaust THC, NMHC, NMOG, CO, NO_X, CO_2, N_2O, CH_4, CH_3OH, C_2H_5OH, C_2H_4O, and HCHO.

(2) Particulates.

(3) Evaporative HC (for gasoline-fueled, methanol-fueled and gaseous-fueled vehicles) and CH_3OH (for methanol-fueled vehicles). The evaporative testing portion of the procedure occurs after the exhaust emission test; however, exhaust emissions need not be sampled to complete a test for evaporative emissions.

(4) Fuel spitback (this test is not required for gaseous-fueled vehicles).

(b) The FTP Otto-cycle exhaust emission test is designed to determine gaseous THC, NMHC, NMOG, CO, CO_2, CH_4, NO_X, N_2O, and particulate mass emissions from gasoline-fueled, methanol-fueled and gaseous-fueled Otto-cycle vehicles as well as methanol and formaldehyde from methanol-fueled Otto-cycle vehicles, as well as methanol, ethanol, acetaldehyde, and formaldehyde from ethanol-fueled vehicles, while simulating an average trip in an urban area of approximately 11 miles (approximately 18 kilometers). The test consists of engine start-ups and vehicle operation on a chassis dynamometer through a specified driving schedule (see paragraph (a) of appendix I to this part for the Urban Dynamometer Driving Schedule). A proportional part of the diluted exhaust is collected continuously for subsequent analysis, using a constant volume (variable dilution) sampler or critical flow venturi sampler.

(c) The diesel-cycle exhaust emission test is designed to determine particulate and gaseous mass emissions during the test described in paragraph (b) of this section. For petroleum-fueled diesel-cycle vehicles, diluted exhaust is continuously analyzed for THC using a heated sample line and analyzer; the other gaseous emissions (CH_4, CO, CO_2, N_2O, and NO_X) are collected continuously for analysis as in paragraph (b) of this section. For methanol- and ethanol-fueled vehicles, THC, methanol, formaldehyde, CO, CO_2, CH_4, N_2O, and NO_X are collected continuously for analysis as in paragraph (b) of this section. Additionally, for ethanol-fueled vehicles, ethanol and acetaldehyde are collected continuously for analysis as in paragraph (b) of this section. THC, methanol, ethanol, acetaldehyde, and formaldehyde are collected using heated sample lines, and a heated FID is used for THC analyses. Simultaneous with the gaseous exhaust collection and analysis, particulates from a proportional part of the diluted exhaust are collected continuously on a filter. The mass of particulate is determined by the procedure described in § 86.139. This testing requires a dilution tunnel as well as the constant volume sampler.

(d) The evaporative emission test (gasoline-fueled vehicles, methanol-fueled and gaseous-fueled vehicles) is designed to determine hydrocarbon and methanol evaporative emissions as a consequence of diurnal temperature fluctuation, urban driving and hot soaks following drives. It is associated with a series of events that a vehicle may experience and that may result in hydrocarbon and/or methanol vapor losses. The test procedure is designed to measure:

(1) Diurnal emissions resulting from daily temperature changes (as well as relatively constant resting losses), measured by the enclosure technique (see § 86.133–96);

(2) Running losses resulting from a simulated trip performed on a chassis dynamometer, measured by the enclosure or point-source technique (see § 86.134–96; this test is not required for gaseous-fueled vehicles); and

(3) Hot soak emissions, which result when the vehicle is parked and the hot engine is turned off, measured by the enclosure technique (see § 86.138–96).

(e) Fuel spitback emissions occur when a vehicle's fuel fill neck cannot accommodate dispensing rates. The vehicle test for spitback consists of a short drive followed immediately by a complete refueling event. This test is not required for gaseous-fueled vehicles.

(f) The element of the SFTP for exhaust emissions related to aggressive driving (US06) is designed to determine gaseous THC, NMHC, CO, CO_2, CH_4, and NO_X emissions from gasoline-fueled or diesel-fueled vehicles (see § 86.158–08 Supplemental test procedures; overview, and § 86.159–08 Exhaust emission test procedures for US06 emissions). The test cycle simulates urban driving speeds and accelerations that are not represented by the FTP Urban Dynamometer Driving Schedule simulated trips discussed in paragraph (b) of this section. The test consists of vehicle operation on a chassis dynamometer through a specified driving cycle (see paragraph (g), US06 Dynamometer Driving Schedule, of appendix I to this part). A proportional part of the diluted exhaust is collected continuously for subsequent analysis, using a constant volume (variable dilution) sampler or critical flow venturi sampler.

(g)(1) The element of the SFTP related to the increased exhaust emissions caused by air conditioning operation (SC03) is designed to determine gaseous THC, NMHC, CO, CO_2, CH_4, and NO_X emissions from gasoline-fueled or diesel fueled vehicles related to air conditioning use (see § 86.158–08 Supplemental Federal test procedures; overview and § 86.160–00 Exhaust emission test procedure for SC03 emissions). The test cycle simulates urban driving behavior with the air conditioner operating. The test consists of engine startups and vehicle operation on a chassis dynamometer through specified driving cycles (see paragraph (h), SC03 Dynamometer Driving Schedule, of appendix I to this part). A proportional part of the diluted exhaust is collected continuously for subsequent analysis, using a constant volume (variable dilution) sampler or critical flow venturi sampler. The testing sequence includes an approved preconditioning cycle, a 10 minute soak with the engine turned off, and the SC03 cycle with measured exhaust emissions.

(2) The SC03 air conditioning test is conducted with the air conditioner operating at specified settings and the ambient test conditions of:

(i) Air temperature of 95 F;

(ii) 100 grains of water/pound of dry air (approximately 40 percent relative humidity);

(iii) Simulated solar heat intensity of 850 W/m² (see § 86.161–00(d)); and

(iv) Air flow directed at the vehicle that will provide representative air conditioner system condenser cooling at all vehicle speeds (see § 86.161–00(e)).

(3) Manufacturers have the option of simulating air conditioning operation during testing at other ambient test conditions provided they can demonstrate that the vehicle tail pipe exhaust emissions are representative of the emissions that would result from the SC03 cycle test procedure and the ambient conditions of paragraph (g)(2) of this section. The simulation test procedure must be approved in advance by the Administrator (see §§ 86.162–03 and 86.163–00).

(h) Except in cases of component malfunction or failure, all emission control systems installed on or incorporated in a new motor vehicle shall be functioning during all procedures in this subpart. Maintenance to correct component malfunction or failure shall be authorized in accordance with § 86.007–25 or § 86.1834–01 as applicable.

(i) Background concentrations are measured for all species for which emissions measurements are made. For exhaust testing, this requires sampling and analysis of the dilution air. For evaporative testing, this requires measuring initial concentrations. (When testing methanol-fueled vehicles, manufacturers may choose not to measure background concentrations of methanol and/or formaldehyde, and then assume that the concentrations are zero during calculations.)

■ 8. A new § 86.135–12 is added to read as follows:

§ 86.135–12 Dynamometer procedure.

(a) *Overview.* The dynamometer run consists of two tests, a "cold" start test, after a minimum 12-hour and a maximum 36-hour soak according to the provisions of §§ 86.132 and 86.133, and a "hot" start test following the "cold" start by 10 minutes. Engine startup (with all accessories turned off), operation over the UDDS, and engine shutdown make a complete cold start test. Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test. The exhaust emissions are diluted with ambient air in the dilution tunnel as shown in Figure B94–5 and Figure B94–6. A dilution tunnel is not required for testing vehicles waived from the requirement to measure particulates. Six particulate samples are collected on filters for weighing; the first sample plus backup is collected during the first 505 seconds of the cold start test; the second sample plus backup is collected during the remainder of the cold start test (including shutdown); the third sample plus backup is collected during the hot start test. Continuous proportional samples of gaseous emissions are collected for analysis during each test phase. For gasoline-fueled, natural gas-fueled and liquefied petroleum gas-fueled Otto-cycle vehicles, the composite samples collected in bags are analyzed for THC, CO, CO_2, CH_4, NO_X, and, for 2015 and later model year vehicles, N_2O. For petroleum-fueled diesel-cycle vehicles (optional for natural gas-fueled, liquefied petroleum gas-fueled and methanol-fueled diesel-cycle vehicles), THC is sampled and analyzed continuously according to the provisions of § 86.110–94. Parallel samples of the dilution air are similarly analyzed for THC, CO, CO_2, CH_4, NO_X, and, for 2015 and later model year vehicles, N_2O. For natural gas-fueled, liquefied petroleum gas-fueled and methanol-fueled vehicles, bag samples are collected and analyzed for THC (if not sampled continuously), CO, CO_2, CH_4, NO_X, and, for 2015 and later model year vehicles, N_2O. For methanol-fueled vehicles, methanol and formaldehyde samples are taken for both exhaust emissions and dilution air (a single dilution air formaldehyde sample, covering the total test period may be collected). For ethanol-fueled vehicles, methanol, ethanol, acetaldehyde, and formaldehyde samples are taken for both exhaust emissions and dilution air (a single dilution air formaldehyde sample, covering the total test period may be collected). Parallel bag samples of dilution air are analyzed for THC, CO, CO_2, CH_4, NO_X, and, for 2015 and later model year vehicles, N_2O.

(b) During dynamometer operation, a fixed speed cooling fan shall be positioned so as to direct cooling air to the vehicle in an appropriate manner with the engine compartment cover open. In the case of vehicles with front engine compartments, the fan shall be squarely positioned within 12 inches (30.5 centimeters) of the vehicle. In the case of vehicles with rear engine compartments (or if special designs make the above impractical), the cooling fan shall be placed in a position to provide sufficient air to maintain vehicle cooling. The fan capacity shall normally not exceed 5300 cfm (2.50 m³/sec). However, if the manufacturer can show that during field operation the vehicle receives additional cooling, and that such additional cooling is needed to provide a representative test, the fan capacity may be increased, additional fans used, variable speed fan(s) may be used, and/or the engine compartment cover may be closed, if approved in advance by the Administrator. For example, the hood may be closed to provide adequate air flow to an intercooler through a factory installed hood scoop. Additionally, the Administrator may conduct certification, fuel economy and in-use testing using the additional cooling set-up approved for a specific vehicle.

(c) The vehicle speed as measured from the dynamometer rolls shall be used. A speed vs. time recording, as evidence of dynamometer test validity, shall be supplied on request of the Administrator.

(d) Practice runs over the prescribed driving schedule may be performed at test point, provided an emission sample is not taken, for the purpose of finding the minimum throttle action to maintain the proper speed-time relationship, or to permit sampling system adjustment. **Note:** When using two-roll dynamometers a truer speed-time trace may be obtained by minimizing the rocking of the vehicle in the rolls; the rocking of the vehicle changes the tire rolling radius on each roll. This rocking may be minimized by restraining the vehicle horizontally (or nearly so) by using a cable and winch.

(e) The drive wheel tires may be inflated up to a gauge pressure of 45 psi (310 kPa) in order to prevent tire damage. The drive wheel tire pressure shall be reported with the test results.

(f) If the dynamometer has not been operated during the 2-hour period immediately preceding the test, it shall be warmed up for 15 minutes by operating at 30 mph (48 kph) using a non-test vehicle or as recommended by the dynamometer manufacturer.

(g) If the dynamometer horsepower must be adjusted manually, it shall be set within 1 hour prior to the exhaust emissions test phase. The test vehicle shall not be used to make this adjustment. Dynamometers using automatic control of pre-selectable power settings may be set anytime prior to the beginning of the emissions test.

(h) The driving distance, as measured by counting the number of dynamometer roll or shaft revolutions, shall be determined for the transient cold start, stabilized cold start, and transient hot start phases of the test. The revolutions shall be measured on the same roll or shaft used for measuring the vehicle's speed.

(i) Four-wheel drive and all-wheel drive vehicles may be tested either in a four-wheel drive or a two-wheel drive mode of operation. In order to test in the two-wheel drive mode, four-wheel drive and all-wheel drive vehicles may have one set of drive wheels disengaged; four-wheel and all-wheel drive vehicles which can be shifted to a two-wheel mode by the driver may be tested in a two-wheel drive mode of operation.

■ 9. A new § 86.165–12 is added to subpart B to read as follows:

§ 86.165–12 Air conditioning idle test procedure.

(a) *Applicability.* This section describes procedures for determining air conditioning-related CO_2 emissions from light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. The results of this test are used to qualify for air conditioning efficiency CO_2 credits according to § 86.1866–12(c).

(b) *Overview.* The test consists of a brief period to stabilize the vehicle at idle, followed by a ten-minute period at idle when CO_2 emissions are measured without any air conditioning systems operating, followed by a ten-minute period at idle when CO_2 emissions are measured with the air conditioning system operating. This test is designed to determine the air conditioning-related CO_2 emission value, in grams per minute. If engine stalling occurs during cycle operation, follow the provisions of § 86.136–90 to restart the test. Measurement instruments must meet the specifications described in this subpart.

(c) *Test cell ambient conditions.*

(1) Ambient humidity within the test cell during all phases of the test sequence shall be controlled to an average of 50 ± 5 grains of water/pound of dry air.

(2) Ambient air temperature within the test cell during all phases of the test sequence shall be controlled to 75 ± 2 F on average and 75 ± 5 F as an instantaneous measurement. Air temperature shall be recorded continuously at a minimum of 30 second intervals.

(d) *Test sequence.*

(1) Connect the vehicle exhaust system to the raw sampling location or dilution stage according to the provisions of this subpart. For dilution systems, dilute the exhaust as described in this subpart. Continuous sampling systems must meet the specifications provided in this subpart.

(2) Test the vehicle in a fully warmed-up condition. If the vehicle has soaked for two hours or less since the last exhaust test element, preconditioning may consist of a 505 Cycle, 866 Cycle, US06, or SC03, as these terms are defined in § 86.1803–01, or a highway fuel economy test procedure, as defined in § 600.002–08 of this chapter. For soak periods longer than two hours, precondition the vehicle using one full Urban Dynamometer Driving Schedule. Ensure that the vehicle has stabilized at test cell ambient conditions such that the vehicle interior temperature is not substantially different from the external test cell temperature. Windows may be opened during preconditioning to achieve this stabilization.

(3) Immediately after the preconditioning, turn off any cooling fans, if present, close the vehicle's hood, fully close all the vehicle's windows, ensure that all the vehicle's air conditioning systems are set to full off, start the CO_2 sampling system, and then idle the vehicle for not less than 1 minute and not more than 5 minutes to achieve normal and stable idle operation.

(4) Measure and record the continuous CO_2 concentration for 600 seconds. Measure the CO_2 concentration continuously using raw or dilute sampling procedures. Multiply this concentration by the continuous (raw or dilute) flow rate at the emission sampling location to determine the CO_2 flow rate. Calculate the CO_2 cumulative flow rate continuously over the test interval. This cumulative value is the total mass of the emitted CO_2.

(5) Within 60 seconds after completing the measurement described in paragraph (d)(4) of this section, turn on the vehicle's air conditioning system. Set automatic air conditioning systems to a temperature 9 F (5 C) below the ambient temperature of the test cell. Set manual air conditioning systems to maximum cooling with recirculation turned off, except that recirculation shall be enabled if the air conditioning system automatically defaults to a recirculation mode when set to maximum cooling. Continue idling the vehicle while measuring and recording the continuous CO_2 concentration for 600 seconds as described in paragraph (d)(4) of this section. Air conditioning systems with automatic temperature controls are finished with the test after this 600 second idle period. Manually controlled air conditioning systems must complete one additional idle period as described in paragraph (d)(6) of this section.

(6) This paragraph (d)(6) applies only to manually controlled air conditioning systems. Within 60 seconds after completing the measurement described in paragraph (d)(5) of this section, leave the vehicle's air conditioning system on and set as described in paragraph (d)(5) of this section but set the fan speed to the lowest setting that continues to provide air flow. Recirculation shall be turned off except that if the system defaults to a recirculation mode when set to maximum cooling and maintains

recirculation with the low fan speed, then recirculation shall continue to be enabled. After the fan speed has been set, continue idling the vehicle while measuring and recording the continuous CO_2 concentration for a total of 600 seconds as described in paragraph (d)(4) of this section.

(e) *Calculations.* (1) For the measurement with no air conditioning operation, calculate the CO_2 emissions (in grams per minute) by dividing the total mass of CO_2 from paragraph (d)(4) of this section by 10.0 (the duration in minutes for which CO_2 is measured). Round this result to the nearest tenth of a gram per minute.

(2)(i) For the measurement with air conditioning in operation for automatic air conditioning systems, calculate the CO_2 emissions (in grams per minute) by dividing the total mass of CO_2 from paragraph (d)(5) of this section by 10.0. Round this result to the nearest tenth of a gram per minute.

(ii) For the measurement with air conditioning in operation for manually controlled air conditioning systems, calculate the CO_2 emissions (in grams per minute) by summing the total mass of CO_2 from paragraphs (d)(5) and (d)(6) of this section and dividing by 20.0. Round this result to the nearest tenth of a gram per minute.

(3) Calculate the increased CO_2 emissions due to air conditioning (in grams per minute) by subtracting the results of paragraph (e)(1) of this section from the results of paragraph (e)(2)(i) or (ii) of this section, whichever is applicable.

(f) The Administrator may prescribe procedures other than those in this section for air conditioning systems and/or vehicles that may not be susceptible to satisfactory testing by the procedures and methods in this section. For example, the Administrator may prescribe alternative air conditioning system settings for systems with controls that are not able to meet the requirements in this section.

■ 10. A new § 86.166–12 is added to subpart B to read as follows:

§ 86.166–12 Method for calculating emissions due to air conditioning leakage.

This section describes procedures used to determine a refrigerant leakage rate in grams per year from vehicle-based air conditioning units. The results of this test are used to determine air conditioning leakage credits according to § 86.1866–12(b).

(a) *Emission totals.* Calculate an annual rate of refrigerant leakage from an air conditioning system using the following equation:

$$\text{Grams/YR}_{TOT} = \text{Grams/YR}_{RP} + \text{Grams/YR}_{SP} + \text{Grams/YR}_{FH} + \text{Grams/YR}_{MC} + \text{Grams/YR}_{C}$$

Where:

Grams/YR_{TOT} = Total air conditioning system emission rate in grams per year and rounded to the nearest tenth of a gram per year.

Grams/YR_{RP} = Emission rate for rigid pipe connections as described in paragraph (b) of this section.

Grams/YR_{SP} = Emission rate for service ports and refrigerant control devices as described in paragraph (c) of this section.

Grams/YR_{FH} = Emission rate for flexible hoses as described in paragraph (d) of this section.

Grams/YR_{MC} = Emission rate for heat exchangers, mufflers, receiver/driers, and accumulators as described in paragraph (e) of this section.

Grams/YR_{C} = Emission rate for compressors as described in paragraph (f) of this section.

(b) *Rigid pipe connections.* Determine the grams per year emission rate for rigid pipe connections using the following equation:

$$\text{Grams/YR}_{RP} = 0.00522 \times [(125 \times SO) + (75 \times SCO) + (50 \times MO) + (10 \times SW) + (5 \times SWO) + (MG)]$$

Where:

Grams/YR_{RP} = Total emission rate for rigid pipe connections in grams per year.

SO = The number of single O-ring connections.

SCO = The number of single captured O-ring connections.

MO = The number of multiple O-ring connections.

SW = The number of seal washer connections.

SWO = The number of seal washer with O-ring connections.

MG = The number of metal gasket connections.

(c) *Service ports and refrigerant control devices.* Determine the grams per year emission rate for service ports and refrigerant control devices using the following equation:

$$\text{Grams/YR}_{SP} = 0.522 \times [(0.3 \times HSSP) + (0.2 \times LSSP) + (0.2 \times STV) + (0.2 \times TXV)]$$

Where:

Grams/YR_{SP} = The emission rate for service ports and refrigerant control devices, in grams per year.

HSSP = The number of high side service ports.

LSSP = The number of low side service ports.

STV = The total number of switches, transducers, and pressure relief valves.

TXV = The number of refrigerant control devices.

(d) *Flexible hoses.* Determine the permeation emission rate in grams per year for each segment of flexible hose using the following equation, and then sum the values for all hoses in the system to calculate a total flexible hose emission rate for the system. Hose end connections shall be included in the calculations in paragraph (b) of this section.

$$\text{Grams/YR}_{FH} = 0.00522 \times (3.14159 \times ID \times L \times ER)$$

Where:

Grams/YR_{FH} = Emission rate for a segment of flexible hose in grams per year.

ID = Inner diameter of hose, in millimeters.

L = Length of hose, in millimeters.

ER = Emission rate per unit internal surface area of the hose, in g/mm^2. Select the appropriate value for ER from the following table:

Material/configuration	ER	
	High-pressure side	Low-pressure side
All rubber hose	0.0216	0.0144
Standard barrier or veneer hose	0.0054	0.0036
Ultra-low permeation barrier or veneer hose	0.00225	0.00167

(e) *Heat exchangers, mufflers, receiver/driers, and accumulators.* Use an emission rate of 0.261 grams per year as a combined value for all heat exchangers, mufflers, receiver/driers, and accumulators (Grams/YR_{MC}).

(f) *Compressors.* Determine the emission rate for compressors using the following equation, except that the final term in the equation ("1500/SSL") is not applicable to electric (or semi-hermetic) compressors:

$$\text{Grams/YR}_{C} = 0.00522 \times [(300 \times OHS) + (200 \times MHS) + (150 \times FAP) + (100 \times GHS) + (1500/SSL)]$$

Where:

Grams/YR_{C} = The emission rate for the compressors in the air conditioning system, in grams per year.

OHS = The number of O-ring housing seals.
MHS = The number of molded housing seals.
FAP = The number of fitting adapter plates.
GHS = The number of gasket housing seals.
SSL = The number of lips on shaft seal (for belt-driven compressors only).

(g) *Definitions.* The following definitions apply to this section:

(1) *All rubber hose* means a Type A or Type B hose as defined by SAE J2064 with a permeation rate not greater than 15 kg/m²/year when tested according to SAE J2064. SAE J2064 is incorporated by reference; see § 86.1.

(2) *Standard barrier or veneer hose* means a Type C, D, E, or F hose as defined by SAE J2064 with a permeation rate not greater than 5 kg/m²/year when tested according to SAE J2064. SAE J2064 is incorporated by reference; see § 86.1.

(3) *Ultra-low permeation barrier or veneer hose* means a hose with a permeation rate not greater than 1.5 kg/m²/year when tested according to SAE J2064. SAE J2064 is incorporated by reference; see § 86.1.

Subpart S—[Amended]

■ 11. A new § 86.1801–12 is added to read as follows:

§ 86.1801–12 Applicability.

(a) *Applicability.* Except as otherwise indicated, the provisions of this subpart apply to new light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, and Otto-cycle complete heavy-duty vehicles, including multi-fueled, alternative fueled, hybrid electric, plug-in hybrid electric, and electric vehicles. These provisions also apply to new incomplete light-duty trucks below 8,500 Gross Vehicle Weight Rating. In cases where a provision applies only to a certain vehicle group based on its model year, vehicle class, motor fuel, engine type, or other distinguishing characteristics, the limited applicability is cited in the appropriate section of this subpart.

(b) *Aftermarket conversions.* The provisions of this subpart apply to aftermarket conversion systems, aftermarket conversion installers, and aftermarket conversion certifiers, as those terms are defined in 40 CFR 85.502, of all model year light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, and complete Otto-cycle heavy-duty vehicles.

(c) *Optional applicability.*

(1) [Reserved]

(2) A manufacturer may request to certify any incomplete Otto-cycle heavy-duty vehicle of 14,000 pounds Gross Vehicle Weight Rating or less in accordance with the provisions for complete heavy-duty vehicles. Heavy-duty engine or heavy-duty vehicle provisions of subpart A of this part do not apply to such a vehicle.

(3) [Reserved]

(4) Upon preapproval by the Administrator, a manufacturer may optionally certify an aftermarket conversion of a complete heavy-duty vehicle greater than 10,000 pounds Gross Vehicle Weight Rating and of 14,000 pounds Gross Vehicle Weight Rating or less under the heavy-duty engine or heavy-duty vehicle provisions of subpart A of this part. Such preapproval will be granted only upon demonstration that chassis-based certification would be infeasible or unreasonable for the manufacturer to perform.

(5) A manufacturer may optionally certify an aftermarket conversion of a complete heavy-duty vehicle greater than 10,000 pounds Gross Vehicle Weight Rating and of 14,000 pounds Gross Vehicle Weight Rating or less under the heavy-duty engine or heavy-duty vehicle provisions of subpart A of this part without advance approval from the Administrator if the vehicle was originally certified to the heavy-duty engine or heavy-duty vehicle provisions of subpart A of this part.

(d) *Small volume manufacturers.* Special certification procedures are available for any manufacturer whose projected or actual combined sales in all states and territories of the United States of light-duty vehicles, light-duty trucks, heavy-duty vehicles, and heavy-duty engines in its product line (including all vehicles and engines imported under the provisions of 40 CFR 85.1505 and 85.1509) are fewer than 15,000 units for the model year in which the manufacturer seeks certification. The small volume manufacturer's light-duty vehicle and light-duty truck certification procedures are described in § 86.1838–01.

(e)–(g) [Reserved]

(h) *Applicability of provisions of this subpart to light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, and heavy-duty vehicles.* Numerous sections in this subpart provide requirements or procedures applicable to a "vehicle" or "vehicles." Unless otherwise specified or otherwise determined by the Administrator, the term "vehicle" or "vehicles" in those provisions apply equally to light-duty vehicles (LDVs), light-duty trucks (LDTs), medium-duty passenger vehicles (MDPVs), and heavy-duty vehicles (HDVs), as those terms are defined in § 86.1803–01.

(i) *Applicability of provisions of this subpart to exhaust greenhouse gas emissions.* Numerous sections in this subpart refer to requirements relating to "exhaust emissions." Unless otherwise specified or otherwise determined by the Administrator, the term "exhaust emissions" refers at a minimum to emissions of all pollutants described by emission standards in this subpart, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

(j) *Exemption from greenhouse gas emission standards for small businesses.* Manufacturers that qualify as a small business under the Small Business Administration regulations in 13 CFR part 121 are exempt from the greenhouse gas emission standards specified in § 86.1818–12 and in associated provisions in this part and in part 600 of this chapter. Both U.S.-based and non-U.S.-based businesses are eligible for this exemption. The following categories of businesses (with their associated NAICS codes) may be eligible for exemption based on the Small Business Administration size standards in 13 CFR 121.201.

(1) Vehicle manufacturers (NAICS code 336111).

(2) Independent commercial importers (NAICS codes 811111, 811112, 811198, 423110, 424990, and 441120).

(3) Alternate fuel vehicle converters (NAICS codes 335312, 336312, 336322, 336399, 454312, 485310, and 811198).

(k) *Conditional exemption from greenhouse gas emission standards.* Manufacturers meeting the eligibility requirements described in paragraph (k)(1) and (2) of this section may request a conditional exemption from compliance with the emission standards described in § 86.1818–12 paragraphs (c) through (e) and associated provisions in this part and in part 600 of this chapter. The terms "sales" and "sold" as used in this paragraph (k) shall mean vehicles produced and delivered for sale (or sold) in the states and territories of the United States. For the purpose of determining eligibility the sales of related companies shall be aggregated according to the provisions of § 86.1838–01(b)(3).

(1) *Eligibility requirements.* Eligibility as determined in this paragraph (k) shall be based on the total sales of combined passenger automobiles and light trucks. Manufacturers must meet one of the requirements in paragraph (k)(1)(i) or (ii) of this section to initially qualify for this exemption.

(i) A manufacturer with 2008 or 2009 model year sales of more than zero and fewer than 5,000 is eligible for a conditional exemption from the greenhouse gas emission standards described in § 86.1818–12 paragraphs (c) through (e).

(ii) A manufacturer with 2008 or 2009 model year sales of more than zero and fewer than 5,000 while under the control of another manufacturer, where those 2008 or 2009 model year vehicles bore the brand of the producing manufacturer but were sold by or otherwise under the control of another manufacturer, and where the manufacturer producing the vehicles became independent no later than December 31, 2010, is eligible for a conditional exemption from the greenhouse gas emission standards described in § 86.1818–12 paragraphs (c) through (e).

(2) *Maintaining eligibility for exemption from greenhouse gas emission standards.* To remain eligible for exemption under this paragraph (k) the manufacturer's average sales for the three most recent consecutive model years must remain below 5,000. If a manufacturer's average sales for the three most recent consecutive model years exceeds 4999, the manufacturer will no longer be eligible for exemption and must meet applicable emission standards according to the provisions in this paragraph (k)(2).

(i) If a manufacturer's average sales for three consecutive model years exceeds 4999, and if the increase in sales is the result of corporate acquisitions, mergers, or purchase by another manufacturer, the manufacturer shall comply with the emission standards described in § 86.1818–12 paragraphs (c) through (e), as applicable, beginning with the first model year after the last year of the three consecutive model years.

(ii) If a manufacturer's average sales for three consecutive model years exceeds 4999 and is less than 50,000, and if the increase in sales is solely the result of the manufacturer's expansion in vehicle production, the manufacturer shall comply with the emission standards described in § 86.1818–12 paragraphs (c) through (e), as applicable, beginning with the second model year after the last year of the three consecutive model years.

(iii) If a manufacturer's average sales for three consecutive model years exceeds 49,999, the manufacturer shall comply with the emission standards described in § 86.1818–12 paragraphs (c) through (e), as applicable, beginning with the first model year after the last year of the three consecutive model years.

(3) *Requesting the conditional exemption from standards.* To be exempted from the standards described in § 86.1818–12(c) through (e), the manufacturer must submit a declaration to EPA containing a detailed written description of how the manufacturer qualifies under the provisions of this paragraph (k). The declaration must describe eligibility information that includes the following: model year 2008 and 2009 sales, sales volumes for each of the most recent three model years, detailed information regarding ownership relationships with other manufacturers, details regarding the application of the provisions of § 86.1838–01(b)(3) regarding the aggregation of sales of related companies, and documentation of good-faith efforts made by the manufacturer to purchase credits from other manufacturers. This declaration must be signed by a chief officer of the company, and must be made prior to each model year for which the exemption is requested. The declaration must be submitted to EPA at least 30 days prior to the introduction into commerce of any vehicles for each model year for which the exemption is requested, but not later than December of the calendar year prior to the model year for which exemption is requested. A conditional exemption will be granted when EPA approves the exemption declaration. The declaration must be sent to the Environmental Protection Agency at the following address: Director, Compliance and Innovative Strategies Division, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, Michigan 48105.

■ 12. Section 86.1803–01 is amended as follows:

■ a. By adding the definition for "Air conditioning idle test."

■ b. By adding the definition for "Air conditioning system."

■ c. By revising the definition for "Banking."

■ d. By adding the definition for "Base level."

■ e. By adding the definition for "Base tire."

■ f. By adding the definition for "Base vehicle."

■ g. By revising the definition for "Basic engine."

■ h. By adding the definition for "Carbon-related exhaust emissions."

■ i. By adding the definition for "Combined CO_2."

■ j. By adding the definition for "Combined CREE."

■ k. By adding the definition for "Electric vehicle."

■ l. By revising the definition for "Engine code."

■ m. By adding the definition for "Ethanol fueled vehicle."

■ n. By revising the definition for "Flexible fuel vehicle."

■ o. By adding the definition for "Footprint."

■ p. By adding the definition for "Fuel cell electric vehicle."

■ q. By adding the definition for "Highway fuel economy test procedure."

■ r. By adding the definition for "Hybrid electric vehicle."

■ s. By adding the definition for "Interior volume index."

■ t. By revising the definition for "Model type."

■ u. By adding the definition for "Motor vehicle."

■ v. By adding the definition for "Multi-fuel vehicle."

■ w. By adding the definition for "Petroleum equivalency factor."

■ x. By adding the definition for "Petroleum-equivalent fuel economy."

■ y. By adding the definition for "Petroleum powered accessory."

■ z. By adding the definition for "Plug-in hybrid electric vehicle."

■ aa. By adding the definition for "Production volume."

■ bb. By revising the definition for "Round, rounded, or rounding."

■ cc. By adding the definition for "Subconfiguration."

■ dd. By adding the definition for "Track width."

■ ee. By revising the definition for "Transmission class."

■ ff. By revising the definition for "Transmission configuration."

■ gg. By adding the definition for "Wheelbase."

§ 86.1803–01 Definitions.

* * * * *

Air Conditioning Idle Test means the test procedure specified in § 86.165–12.

Air conditioning system means a unique combination of air conditioning and climate control components, including: compressor type (*e.g.*, belt, gear, or electric-driven, or a combination of compressor drive mechanisms); compressor refrigerant capacity; the number and type of rigid pipe and flexible hose connections; the number of high side service ports; the number of low side service ports; the number of switches, transducers, and expansion valves; the number of TXV refrigerant control devices; the number and type of heat exchangers, mufflers, receiver/dryers, and accumulators; and the length and type of flexible hose (*e.g.*, rubber, standard barrier or veneer, ultra-low permeation).

* * * * *

Banking means one of the following:

(1) The retention of NO_X emission credits for complete heavy-duty vehicles by the manufacturer generating the emission credits, for use in future model year certification programs as permitted by regulation.

(2) The retention of cold temperature non-methane hydrocarbon (NMHC) emission credits for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles by the manufacturer generating the emission credits, for use in future model year certification programs as permitted by regulation.

(3) The retention of NO_X emission credits for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles for use in future model year certification programs as permitted by regulation.

(4) The retention of CO_2 emission credits for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles for use in future model year certification programs as permitted by regulation.

Base level has the meaning given in § 600.002–08 of this chapter.

Base tire has the meaning given in § 600.002–08 of this chapter.

Base vehicle has the meaning given in § 600.002–08 of this chapter.

Basic engine has the meaning given in § 600.002–08 of this chapter.

* * * * *

Carbon-related exhaust emissions (CREE) has the meaning given in § 600.002–08 of this chapter.

* * * * *

Combined CO_2 means the CO_2 value determined for a vehicle (or vehicles) by averaging the city and highway CO_2 values, weighted 0.55 and 0.45 respectively.

Combined CREE means the CREE value determined for a vehicle (or vehicles) by averaging the city and highway fuel CREE values, weighted 0.55 and 0.45 respectively.

* * * * *

Electric vehicle means a motor vehicle that is powered solely by an electric motor drawing current from a rechargeable energy storage system, such as from storage batteries or other portable electrical energy storage devices, including hydrogen fuel cells, provided that:

(1) The vehicle is capable of drawing recharge energy from a source off the vehicle, such as residential electric service; and

(2) The vehicle must be certified to the emission standards of Bin #1 of Table S04–1 in § 86.1811–09(c)(6).

(3) The vehicle does not have an onboard combustion engine/generator system as a means of providing electrical energy.

* * * * *

Engine code means a unique combination within a test group of displacement, fuel injection (or carburetor) calibration, choke calibration, distributor calibration, auxiliary emission control devices, and other engine and emission control system components specified by the Administrator. For electric vehicles, engine code means a unique combination of manufacturer, electric traction motor, motor configuration, motor controller, and energy storage device.

* * * * *

Ethanol-fueled vehicle means any motor vehicle or motor vehicle engine that is engineered and designed to be operated using ethanol fuel (*i.e.,* a fuel that contains at least 50 percent ethanol (C_2H_5OH) by volume) as fuel.

* * * * *

Flexible fuel vehicle means any motor vehicle engineered and designed to be operated on a petroleum fuel and on a methanol or ethanol fuel, or any mixture of the petroleum fuel and methanol or ethanol. Methanol-fueled and ethanol-fueled vehicles that are only marginally functional when using gasoline (*e.g.,* the engine has a drop in rated horsepower of more than 80 percent) are not flexible fuel vehicles.

Footprint is the product of track width (measured in inches, calculated as the average of front and rear track widths, and rounded to the nearest tenth of an inch) and wheelbase (measured in inches and rounded to the nearest tenth of an inch), divided by 144 and then rounded to the nearest tenth of a square foot.

Fuel cell vehicle means an electric vehicle propelled solely by an electric motor where energy for the motor is supplied by an electrochemical cell that produces electricity via the non-combustion reaction of a consumable fuel, typically hydrogen.

* * * * *

Highway Fuel Economy Test Procedure (HFET) has the meaning given in § 600.002–08 of this chapter.

* * * * *

Hybrid electric vehicle (HEV) means a motor vehicle which draws propulsion energy from onboard sources of stored energy that are both an internal combustion engine or heat engine using consumable fuel, and a rechargeable energy storage system such as a battery, capacitor, hydraulic accumulator, or flywheel, where recharge energy for the energy storage system comes solely from sources on board the vehicle.

* * * * *

Interior volume index has the meaning given in § 600.315–08 of this chapter.

* * * * *

Model type has the meaning given in § 600.002–08 of this chapter.

* * * * *

Motor vehicle has the meaning given in § 85.1703 of this chapter.

* * * * *

Multi-fuel vehicle means any motor vehicle capable of operating on two or more different fuel types, either separately or simultaneously.

* * * * *

Petroleum equivalency factor means the value specified in 10 CFR 474.3(b), which incorporates the parameters listed in 49 U.S.C. 32904(a)(2)(B) and is used to calculate petroleum-equivalent fuel economy.

Petroleum-equivalent fuel economy means the value, expressed in miles per gallon, that is calculated for an electric vehicle in accordance with 10 CFR 474.3(a), and reported to the Administrator of the Environmental Protection Agency for use in determining the vehicle manufacturer's corporate average fuel economy.

* * * * *

Petroleum-powered accessory means a vehicle accessory (*e.g.,* a cabin heater, defroster, and/or air conditioner) that:

(1) Uses gasoline or diesel fuel as its primary energy source; and

(2) Meets the requirements for fuel, operation, and emissions in § 88.104–94(g) of this chapter.

Plug-in hybrid electric vehicle (PHEV) means a hybrid electric vehicle that has the capability to charge the battery from an off-vehicle electric source, such that the off-vehicle source cannot be connected to the vehicle while the vehicle is in motion.

* * * * *

Production volume has the meaning given in § 600.002–08 of this chapter.

* * * * *

Round, rounded or *rounding* means, unless otherwise specified, that numbers will be rounded according to ASTM–E29–93a, which is incorporated by reference in this part pursuant to § 86.1.

* * * * *

Subconfiguration has the meaning given in § 600.002–08 of this chapter.

* * * * *

Track width is the lateral distance between the centerlines of the base tires at ground, including the camber angle.

* * * * *

Transmission class has the meaning given in § 600.002–08 of this chapter.

Transmission configuration has the meaning given in § 600.002–08 of this chapter.

* * * * *

Wheelbase is the longitudinal distance between front and rear wheel centerlines.

* * * * *

■ 13. A new § 86.1805–12 is added to read as follows:

§ 86.1805–12 Useful life.

(a) Except as permitted under paragraph (b) of this section or required under paragraphs (c) and (d) of this section, the full useful life for all LDVs and LLDTs is a period of use of 10 years or 120,000 miles, whichever occurs first. The full useful life for all HLDTs, MDPVs, and complete heavy-duty vehicles is a period of 11 years or 120,000 miles, whichever occurs first. These full useful life values apply to all exhaust, evaporative and refueling emission requirements except for standards which are specified to only be applicable at the time of certification. These full useful life requirements also apply to all air conditioning leakage credits, air conditioning efficiency credits, and other credit programs used by the manufacturer to comply with the fleet average CO_2 emission standards in § 86.1818–12.

(b) Manufacturers may elect to optionally certify a test group to the Tier 2 exhaust emission standards for 150,000 miles to gain additional NO_X credits, as permitted in § 86.1860–04(g), or to opt out of intermediate life standards as permitted in § 86.1811–04(c). In such cases, useful life is a period of use of 15 years or 150,000 miles, whichever occurs first, for all exhaust, evaporative and refueling emission requirements except for cold CO standards and standards which are applicable only at the time of certification.

(c) Where intermediate useful life exhaust emission standards are applicable, such standards are applicable for five years or 50,000 miles, whichever occurs first.

(d) Where cold CO standards are applicable, the useful life requirement for compliance with the cold CO standard only, is 5 years or 50,000 miles, whichever occurs first.

■ 14. Section 86.1806–05 is amended by revising paragraph (a)(1) to read as follows:

§ 86.1806–05 On-board diagnostics for vehicles less than or equal to 14,000 pounds GVWR.

(a) * * *

(1) Except as provided by paragraph (a)(2) of this section, all light-duty vehicles, light-duty trucks and complete heavy-duty vehicles weighing 14,000 pounds GVWR or less (including MDPVs) must be equipped with an onboard diagnostic (OBD) system capable of monitoring all emission-related powertrain systems or components during the applicable useful life of the vehicle. All systems and components required to be monitored by these regulations must be evaluated periodically, but no less frequently than once per applicable certification test cycle as defined in paragraphs (a) and (d) of Appendix I of this part, or similar trip as approved by the Administrator. Emissions of CO_2, CH_4, and N_2O are not required to be monitored by the OBD system.

* * * * *

■ 15. A new § 86.1809–12 is added to read as follows:

§ 86.1809–12 Prohibition of defeat devices.

(a) No new light-duty vehicle, light-duty truck, medium-duty passenger vehicle, or complete heavy-duty vehicle shall be equipped with a defeat device.

(b) The Administrator may test or require testing on any vehicle at a designated location, using driving cycles and conditions that may reasonably be expected to be encountered in normal operation and use, for the purposes of investigating a potential defeat device.

(c) For cold temperature CO and cold temperature NMHC emission control, the Administrator will use a guideline to determine the appropriateness of the CO and NMHC emission control at ambient temperatures between 25 F (the upper bound of the FTP test temperature range) and 68 F (the lower bound of the FTP test temperature range). The guideline for CO emission congruity across the intermediate temperature range is the linear interpolation between the CO standard applicable at 25 F and the CO standard applicable at 68 F. The guideline for NMHC emission congruity across the intermediate temperature range is the linear interpolation between the NMHC FEL pass limit (*e.g.* 0.3499 g/mi for a 0.3 g/mi FEL) applicable at 20 F and the Tier 2 NMOG standard to which the vehicle was certified at 68 F, where the intermediate temperature NMHC level is rounded to the nearest hundredth for comparison to the interpolated line. For vehicles that exceed this CO emissions guideline or this NMHC emissions guideline upon intermediate temperature cold testing:

(1) If the CO emission level is greater than the 20 F emission standard, the vehicle will automatically be considered to be equipped with a defeat device without further investigation. If the intermediate temperature NMHC emission level, rounded to the nearest hundredth, is greater than the 20 F FEL pass limit, the vehicle will be presumed to have a defeat device unless the manufacturer provides evidence to EPA's satisfaction that the cause of the test result in question is not due to a defeat device.

(2) If the CO emission level does not exceed the 20 F emission standard, the Administrator may investigate the vehicle design for the presence of a defeat device under paragraph (d) of this section. If the intermediate temperature NMHC emission level, rounded to the nearest hundredth, does not exceed the 20 F FEL pass limit the Administrator may investigate the vehicle design for the presence of a defeat device under paragraph (d) of this section.

(d) The following provisions apply for vehicle designs designated by the Administrator to be investigated for possible defeat devices:

(1) The manufacturer must show to the satisfaction of the Administrator that the vehicle design does not incorporate strategies that unnecessarily reduce emission control effectiveness exhibited during the Federal Test Procedure or Supplemental Federal Test Procedure (FTP or SFTP) or the Highway Fuel Economy Test Procedure (described in subpart B of 40 CFR part 600), or the Air Conditioning Idle Test (described in § 86.165–12), when the vehicle is operated under conditions that may reasonably be expected to be encountered in normal operation and use.

(2) The following information requirements apply:

(i) Upon request by the Administrator, the manufacturer must provide an explanation containing detailed information regarding test programs, engineering evaluations, design specifications, calibrations, on-board computer algorithms, and design strategies incorporated for operation both during and outside of the Federal emission test procedures.

(ii) For purposes of investigations of possible cold temperature CO or cold temperature NMHC defeat devices under this paragraph (d), the manufacturer must provide an explanation to show, to the satisfaction of the Administrator, that CO emissions and NMHC emissions are reasonably controlled in reference to the linear guideline across the intermediate temperature range.

(e) For each test group the manufacturer must submit, with the Part II certification application, an engineering evaluation demonstrating to the satisfaction of the Administrator that a discontinuity in emissions of non-methane organic gases, carbon monoxide, carbon dioxide, oxides of nitrogen, nitrous oxide, methane, and formaldehyde measured on the Federal Test Procedure (subpart B of this part) and on the Highway Fuel Economy Test Procedure (subpart B of 40 CFR part 600) does not occur in the temperature range of 20 to 86 F. For diesel vehicles, the engineering evaluation must also include particulate emissions.

■ 16. Section 86.1810–09 is amended by revising paragraph (f) to read as follows:

§ 86.1810–09 General standards; increase in emissions; unsafe condition; waivers.

* * * * *

(f) *Altitude requirements.* (1) All emission standards apply at low altitude conditions and at high altitude conditions, except for the following standards, which apply only at low altitude conditions:

(i) The supplemental exhaust emission standards as described in § 86.1811–04(f);

(ii) The cold temperature NMHC emission standards as described in § 86.1811–10(g);

(iii) The evaporative emission standards as described in § 86.1811–09(e).

(2) For vehicles that comply with the cold temperature NMHC standards described in § 86.1811–10(g) and the CO_2, N_2O, and CH_4 exhaust emission standards described in § 86.1818–12, manufacturers must submit an engineering evaluation indicating that common calibration approaches are utilized at high altitudes. Any deviation from low altitude emission control practices must be included in the auxiliary emission control device (AECD) descriptions submitted at certification. Any AECD specific to high altitude must require engineering emission data for EPA evaluation to quantify any emission impact and validity of the AECD.

* * * * *

■ 17. A new § 86.1818–12 is added to read as follows:

§ 86.1818–12 Greenhouse gas emission standards for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles.

(a) *Applicability.* This section contains standards and other regulations applicable to the emission of the air pollutant defined as the aggregate group of six greenhouse gases: Carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. This section applies to 2012 and later model year LDVs, LDTs and MDPVs, including multi-fuel vehicles, vehicles fueled with alternative fuels, hybrid electric vehicles, plug-in hybrid electric vehicles, electric vehicles, and fuel cell vehicles. Unless otherwise specified, multi-fuel vehicles must comply with all requirements established for each consumed fuel. The provisions of this section also apply to aftermarket conversion systems, aftermarket conversion installers, and aftermarket conversion certifiers, as those terms are defined in 40 CFR 85.502, of all model year light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. Manufacturers that qualify as a small business according to the requirements of § 86.1801–12(j) are exempt from the emission standards in this section. Manufacturers that have submitted a declaration for a model year according to the requirements of § 86.1801–12(k) for which approval has been granted by the Administrator are conditionally exempt from the emission standards in paragraphs (c) through (e) of this section for the approved model year.

(b) *Definitions.* For the purposes of this section, the following definitions shall apply:

(1) *Passenger automobile* means a motor vehicle that is a passenger automobile as that term is defined in 49 CFR 523.4.

(2) *Light truck* means a motor vehicle that is a non-passenger automobile as that term is defined in 49 CFR 523.5.

(c) *Fleet average CO_2 standards for passenger automobiles and light trucks.* (1) For a given individual model year's production of passenger automobiles and light trucks, manufacturers must comply with a fleet average CO_2 standard calculated according to the provisions of this paragraph (c). Manufacturers must calculate separate fleet average CO_2 standards for their passenger automobile and light truck fleets, as those terms are defined in this section. Each manufacturer's fleet average CO_2 standards determined in this paragraph (c) shall be expressed in whole grams per mile, in the model year specified as applicable. Manufacturers eligible for and choosing to participate in the Temporary Leadtime Allowance Alternative Standards for qualifying manufacturers specified in paragraph (e) of this section shall not include vehicles subject to the Temporary Leadtime Allowance Alternative Standards in the calculations of their primary passenger automobile or light truck standards determined in this paragraph (c). Manufacturers shall demonstrate compliance with the applicable standards according to the provisions of § 86.1865–12.

(2) *Passenger automobiles*—(i) *Calculation of CO_2 target values for passenger automobiles.* A CO_2 target value shall be determined for each passenger automobile as follows:

(A) For passenger automobiles with a footprint of less than or equal to 41 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	244.0
2013	237.0
2014	228.0
2015	217.0
2016 and later	206.0

(B) For passenger automobiles with a footprint of greater than 56 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	315.0
2013	307.0
2014	299.0
2015	288.0
2016 and later	277.0

(C) For passenger automobiles with a footprint that is greater than 41 square feet and less than or equal to 56 square feet, the gram/mile CO_2 target value shall be calculated using the following equation and rounded to the nearest 0.1 grams/mile:

$$\text{Target } CO_2 = [4.72 \times f] + b$$

Where:

f is the vehicle footprint, as defined in § 86.1803; and

b is selected from the following table for the appropriate model year:

Model year	*b*
2012	50.5
2013	43.3
2014	34.8
2015	23.4
2016 and later	12.7

(ii) *Calculation of the fleet average CO_2 standard for passenger automobiles.* In each model year manufacturers must comply with the CO_2 exhaust emission standard for their passenger automobile fleet, calculated for that model year as follows:

(A) A CO_2 target value shall be determined according to paragraph (c)(2)(i) of this section for each unique combination of model type and footprint value.

(B) Each CO_2 target value, determined for each unique combination of model type and footprint value, shall be multiplied by the total production of that model type/footprint combination for the appropriate model year.

(C) The resulting products shall be summed, and that sum shall be divided by the total production of passenger automobiles in that model year. The result shall be rounded to the nearest whole gram per mile. This result shall be the applicable fleet average CO_2 standard for the manufacturer's passenger automobile fleet.

(3) *Light trucks*—(i) *Calculation of CO_2 target values for light trucks.* A CO_2 target value shall be determined for each light truck as follows:

(A) For light trucks with a footprint of less than or equal to 41 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	294.0
2013	284.0
2014	275.0
2015	261.0
2016 and later	247.0

(B) For light trucks with a footprint of greater than 66 square feet, the gram/mile CO_2 target value shall be selected for the appropriate model year from the following table:

Model year	CO_2 target value (grams/mile)
2012	395.0
2013	385.0
2014	376.0
2015	362.0
2016 and later	348.0

(C) For light trucks with a footprint that is greater than 41 square feet and less than or equal to 66 square feet, the gram/mile CO_2 target value shall be calculated using the following equation and rounded to the nearest 0.1 grams/mile:

$$\text{Target } CO_2 = (4.04 \times f) + b$$

Where:

f is the footprint, as defined in § 86.1803; and
b is selected from the following table for the appropriate model year:

Model year	b
2012	128.6
2013	118.7
2014	109.4
2015	95.1
2016 and later	81.1

(ii) *Calculation of fleet average CO_2 standards for light trucks.* In each model year manufacturers must comply with the CO_2 exhaust emission standard for their light truck fleet, calculated for that model year as follows:

(A) A CO_2 target value shall be determined according to paragraph (c)(3)(i) of this section for each unique combination of model type and footprint value.

(B) Each CO_2 target value, which represents a unique combination of model type and footprint value, shall be multiplied by the total production of that model type/footprint combination for the appropriate model year.

(C) The resulting products shall be summed, and that sum shall be divided by the total production of light trucks in that model year. The result shall be rounded to the nearest whole gram per mile. This result shall be the applicable fleet average CO_2 standard for the manufacturer's light truck fleet.

(d) *In-use CO_2 exhaust emission standards.* The in-use exhaust CO_2 emission standard shall be the combined city/highway carbon-related exhaust emission value calculated for the appropriate vehicle carline/subconfiguration according to the provisions of § 600.113–08(g)(4) of this chapter multiplied by 1.1 and rounded to the nearest whole gram per mile. For in-use vehicle carlines/subconfigurations for which a combined city/highway carbon-related exhaust emission value was not determined under § 600.113(g)(4) of this chapter, the in-use exhaust CO_2 emission standard shall be the combined city/highway carbon-related exhaust emission value calculated according to the provisions of § 600.208–12 of this chapter for the vehicle model type (except that total model year production data shall be used instead of sales projections) multiplied by 1.1 and rounded to the nearest whole gram per mile. For vehicles that are capable of operating on multiple fuels, including but not limited to alcohol dual fuel, natural gas dual fuel and plug-in hybrid electric vehicles, a separate in-use standard shall be determined for each fuel that the vehicle is capable of operating on. These standards apply to in-use testing performed by the manufacturer pursuant to regulations at § 86.1845–04 and 86.1846–01 and to in-use testing performed by EPA.

(e) *Temporary Lead Time Allowance Alternative Standards.* (1) The interim fleet average CO_2 standards in this paragraph (e) are optionally applicable to each qualifying manufacturer, where the terms "sales" or "sold" as used in this paragraph (e) means vehicles produced and delivered for sale (or sold) in the states and territories of the United States.

(i) A qualifying manufacturer is a manufacturer with sales of 2009 model year combined passenger automobiles and light trucks of greater than zero and less than 400,000 vehicles.

(A) If a manufacturer sold less than 400,000 but more than zero 2009 model year combined passenger automobiles and light trucks while under the control of another manufacturer, where those 2009 model year passenger automobiles and light trucks bore the brand of the producing manufacturer, and where the producing manufacturer became independent no later than December 31, 2010, the producing manufacturer is a qualifying manufacturer.

(B) In the case where two or more qualifying manufacturers combine as the result of merger or the purchase of 50 percent or more of one or more companies by another company, and if the combined 2009 model year sales of the merged or combined companies is less than 400,000 but more than zero (combined passenger automobiles and light trucks), the corporate entity formed by the combination of two or more qualifying manufacturers shall continue to be a qualifying manufacturer. The total number of vehicles that the corporate entity is allowed to include under the Temporary Leadtime Allowance Alternative Standards shall be determined by paragraph (e)(2) or (e)(3) of this section where sales is the total combined 2009 model year sales of all of the merged or combined companies. Vehicles sold by the companies that combined by merger/acquisition to form the corporate entity that were subject to the Temporary Leadtime Allowance Alternative Standards in paragraph (e)(4) of this section prior to the merger/acquisition shall be combined to determine the remaining number of vehicles that the corporate entity may include under the Temporary Leadtime Allowance Alternative Standards in this paragraph (e).

(C) In the case where two or more manufacturers combine as the result of merger or the purchase of 50 percent or more of one or more companies by another company, and if the combined 2009 model year sales of the merged or combined companies is equal to or greater than 400,000 (combined passenger automobiles and light trucks), the new corporate entity formed by the combination of two or more manufacturers is not a qualifying manufacturer. Such a manufacturer shall meet the emission standards in paragraph (c) of this section beginning with the model year that is numerically two years greater than the calendar year in which the merger/acquisition(s) took place.

(ii) For the purposes of making the determination in paragraph (e)(1)(i) of this section, "manufacturer" shall mean that term as defined at 49 CFR 531.4 and as that definition was applied to the 2009 model year for the purpose of determining compliance with the 2009 corporate average fuel economy standards at 49 CFR parts 531 and 533.

(iii) A qualifying manufacturer may not use these Temporary Leadtime Allowance Alternative Standards until they have used all available banked credits and/or credits available for transfer accrued under § 86.1865–12(k). A qualifying manufacturer with a net positive credit balance calculated under § 86.1865–12(k) in any model year after considering all available credits either generated, carried forward from a prior model year, transferred from other averaging sets, or obtained from other manufacturers, may not use these Temporary Leadtime Allowance Alternative Standards in such model year.

(2) Qualifying manufacturers may select any combination of 2012 through 2015 model year passenger automobiles and/or light trucks to include under the Temporary Leadtime Allowance Alternative Standards determined in this paragraph (e) up to a cumulative total of 100,000 vehicles. Vehicles selected to comply with these standards shall not be included in the calculations of the manufacturer's fleet average standards under paragraph (c) of this section.

(3) Qualifying manufacturers with sales of 2009 model year combined passenger automobiles and light trucks in the United States of greater than zero and less than 50,000 vehicles may select any combination of 2012 through 2015 model year passenger automobiles and/or light trucks to include under the Temporary Leadtime Allowance Alternative Standards determined in this paragraph (e) up to a cumulative total of 200,000 vehicles, and additionally may select up to 50,000 2016 model year vehicles to include under the Temporary Leadtime Allowance Alternative Standards determined in this paragraph (e). To be eligible for the provisions of this paragraph (e)(3) qualifying manufacturers must provide annual documentation of good-faith efforts made by the manufacturer to purchase credits from other manufacturers. Without such documentation, the manufacturer may use the Temporary Leadtime Allowance Alternative Standards according to the provisions of paragraph (e)(2) of this section, and the provisions of this paragraph (e)(3) shall not apply. Vehicles selected to comply with these standards shall not be included in the calculations of the manufacturer's fleet average standards under paragraph (c) of this section.

(4) To calculate the applicable Temporary Leadtime Allowance Alternative Standards, qualifying manufacturers shall determine the fleet average standard separately for the passenger automobiles and light trucks selected by the manufacturer to be subject to the Temporary Leadtime Allowance Alternative Standards, subject to the limitations expressed in paragraphs (e)(1) through (3) of this section.

(i) The Temporary Leadtime Allowance Alternative Standard applicable to qualified passenger automobiles as defined in § 600.002–08 of this chapter shall be the standard calculated using the provisions of paragraph (c)(2)(ii) of this section for the appropriate model year multiplied by 1.25 and rounded to the nearest whole gram per mile. For the purposes of applying paragraph (c)(2)(ii) of this section to determine the standard, the passenger automobile fleet shall be limited to those passenger automobiles subject to the Temporary Leadtime Allowance Alternative Standard.

(ii) The Temporary Leadtime Allowance Alternative Standard applicable to qualified light trucks (*i.e.* non-passenger automobiles as defined in § 600.002–08 of this chapter) shall be the standard calculated using the provisions of paragraph (c)(3)(ii) of this section for the appropriate model year multiplied by 1.25 and rounded to the nearest whole gram per mile. For the purposes of applying paragraph (c)(3)(ii) of this section to determine the standard, the light truck fleet shall be limited to those light trucks subject to the Temporary Leadtime Allowance Alternative Standard.

(5) Manufacturers choosing to optionally apply these standards are subject to the restrictions on credit banking and trading specified in § 86.1865–12.

(f) *Nitrous oxide (N_2O) and methane (CH_4) exhaust emission standards for passenger automobiles and light trucks.* Each manufacturer's fleet of combined passenger automobile and light trucks must comply with N_2O and CH_4 standards using either the provisions of paragraph (f)(1) of this section or the provisions of paragraph (f)(2) of this section. The manufacturer may not use the provisions of both paragraphs (f)(1) and (f)(2) of this section in a model year. For example, a manufacturer may not use the provisions of paragraph (f)(1) of this section for their passenger automobile fleet and the provisions of paragraph (f)(2) for their light truck fleet in the same model year.

(1) *Standards applicable to each test group.*

(i) Exhaust emissions of nitrous oxide (N_2O) shall not exceed 0.010 grams per mile at full useful life, as measured according to the Federal Test Procedure (FTP) described in subpart B of this part.

(ii) Exhaust emissions of methane (CH_4) shall not exceed 0.030 grams per mile at full useful life, as measured according to the Federal Test Procedure (FTP) described in subpart B of this part.

(2) *Including N_2O and CH_4 in fleet averaging program.* Manufacturers may elect to not meet the emission standards in paragraph (f)(1) of this section. Manufacturers making this election shall include N_2O and CH_4 emissions in the determination of their fleet average carbon-related exhaust emissions, as calculated in subpart F of part 600 of this chapter. Manufacturers using this option must include both N_2O and CH_4 full useful life values in the fleet average calculations for passenger automobiles and light trucks. Use of this option will account for N_2O and CH_4 emissions within the carbon-related exhaust emission value determined for each model type according to the provisions part 600 of this chapter. This option requires the determination of full useful life emission values for both the Federal Test Procedure and the Highway Fuel Economy Test.

■ 18. Section 86.1823–08 is amended by adding paragraph (m) to read as follows:

§ 86.1823–08 Durability demonstration procedures for exhaust emissions.

* * * * *

(m) *Durability demonstration procedures for vehicles subject to the greenhouse gas exhaust emission standards specified in § 86.1818–12.*

(1) *CO_2.* (i) Unless otherwise specified under paragraph (m)(1)(ii) of this section, manufacturers may use a multiplicative CO_2 deterioration factor of one or an additive deterioration factor of zero.

(ii) Based on an analysis of industry-wide data, EPA may periodically establish and/or update the deterioration factor for CO_2 emissions including air conditioning and other credit related emissions. Deterioration factors established and/or updated under this paragraph (m)(1)(ii) will provide adequate lead time for manufacturers to plan for the change.

(iii) Alternatively, manufacturers may use the whole-vehicle mileage accumulation procedures in § 86.1823–08 paragraphs (c) or (d)(1) to determine CO_2 deterioration factors. In this case, each FTP test performed on the durability data vehicle selected under § 86.1822–01 of this part must also be accompanied by an HFET test, and combined FTP/HFET CO_2 results determined by averaging the city (FTP) and highway (HFET) CO_2 values, weighted 0.55 and 0.45 respectively. The deterioration factor will be determined for this combined CO_2 value. Calculated multiplicative deterioration factors that are less than one shall be set to equal one, and calculated additive deterioration factors that are less than zero shall be set to zero.

(iv) If, in the good engineering judgment of the manufacturer, the deterioration factors determined according to paragraphs (m)(1)(i), (m)(1)(ii), or (m)(1)(iii) of this section do not adequately account for the expected CO_2 emission deterioration over the vehicle's useful life, the manufacturer may petition EPA to request a more appropriate deterioration factor.

(2) *N_2O and CH_4.* (i) For manufacturers complying with the emission standards for N_2O and CH_4 specified in § 86.1818–12(f)(1), deterioration factors for N_2O and CH_4 shall be determined according to the provisions of paragraphs (a) through (l) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2), separate deterioration factors shall be determined for the FTP and HFET test cycles. Therefore each FTP test performed on the durability data vehicle selected under § 86.1822–01 of this part must also be accompanied by an HFET test.

(iii) For the 2012 through 2014 model years only, manufacturers may use alternative deterioration factors. For N_2O, the alternative deterioration factor to be used to adjust FTP and HFET emissions is the deterioration factor determined for NO_X emissions according to the provisions of this section. For CH_4, the alternative deterioration factor to be used to adjust FTP and HFET emissions is the deterioration factor determined for NMOG or NMHC emissions according to the provisions of this section.

(3) *Other carbon-related exhaust emissions.* Deterioration factors shall be determined according to the provisions of paragraphs (a) through (l) of this section. Optionally, in lieu of determining emission-specific FTP and HFET deterioration factors for CH_3OH (methanol), HCHO (formaldehyde), C_2H_5OH (ethanol), and C_2H_4O (acetaldehyde), manufacturers may use the deterioration factor determined for NMOG or NMHC emissions according to the provisions of this section.

(4) *Air Conditioning leakage and efficiency or other emission credit requirements to comply with exhaust CO_2 standards.* Manufactures will attest to the durability of components and systems used to meet the CO_2 standards. Manufacturers may submit engineering data to provide durability demonstration.

■ 19. Section 86.1827–01 is amended by revising paragraph (a)(5) and by adding paragraph (f) to read as follows:

§ 86.1827–01 Test group determination.

* * * * *

(a) * * *

(5) Subject to the same emission standards (except for CO_2), or FEL in the case of cold temperature NMHC standards, except that a manufacturer may request to group vehicles into the same test group as vehicles subject to more stringent standards, so long as all the vehicles within the test group are certified to the most stringent standards applicable to any vehicle within that test group. Light-duty trucks and light-duty vehicles may be included in the same test group if all vehicles in the test group are subject to the same emission standards, with the exception of the CO_2 standard and/or the total HC standard.

* * * * *

(f) Unless otherwise approved by the Administrator, a manufacturer of electric vehicles must create separate test groups based on the type of battery technology, the capacity and voltage of the battery, and the type and size of the electric motor.

■ 20. Section 86.1829–01 is amended by revising paragraph (b)(1)(i) and by adding paragraph (b)(1)(iii)(G) to read as follows:

§ 86.1829–01 Durability and emission testing requirements; waivers.

* * * * *

(b) * *

(1) * * *

(i) *Testing at low altitude.* One EDV shall be tested in each test group for exhaust emissions using the FTP and SFTP test procedures of subpart B of this part and the HFET test procedure of subpart B of part 600 of this chapter. The configuration of the EDV will be determined under the provisions of § 86.1828–01 of this subpart.

* * * * *

(iii) * * *

(G) For the 2012 through 2014 model years only, in lieu of testing a vehicle for N_2O emissions, a manufacturer may provide a statement in its application for certification that such vehicles comply with the applicable standards. Such a statement must be based on previous emission tests, development tests, or other appropriate information and good engineering judgment.

* * * * *

■ 21. Section 86.1835–01 is amended as follows:

■ a. By revising paragraph (a)(4).

■ b. By revising paragraph (b)(1) introductory text.

■ c. By adding paragraph (b)(1)(vi).

■ d. By revising paragraph (b)(3).

■ e. By revising paragraph (c)(1)(ii).

§ 86.1835–01 Confirmatory certification testing.

(a) * * *

(4) Retesting for fuel economy reasons or for compliance with greenhouse gas exhaust emission standards in § 86.181–12 may be conducted under the provisions of § 600.008–08 of this chapter.

(b) * * *

(1) If the Administrator determines not to conduct a confirmatory test under the provisions of paragraph (a) of this section, manufacturers of light-duty vehicles, light-duty trucks, and/or medium-duty passenger vehicles will conduct a confirmatory test at their facility after submitting the original test data to the Administrator whenever any of the conditions listed in paragraphs (b)(1)(i) through (vi) of this section exist, and complete heavy-duty vehicles manufacturers will conduct a confirmatory test at their facility after submitting the original test data to the Administrator whenever the conditions listed in paragraph (b)(1)(i) or (b)(1)(ii) of this section exist, as follows:

* * * * *

(vi) The exhaust carbon-related exhaust emissions of the test as measured in accordance with the procedures in 40 CFR part 600 are lower than expected based on procedures approved by the Administrator.

* * * * *

(3) For light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles the manufacturer shall conduct a retest of the FTP or highway test if the difference between the fuel economy of the confirmatory test and the original manufacturer's test equals or exceeds three percent (or such lower percentage to be applied consistently to all manufacturer conducted confirmatory testing as requested by the manufacturer and approved by the Administrator).

(i) For use in the fuel economy and exhaust greenhouse gas fleet averaging program described in 40 CFR parts 86 and 600, the manufacturer may, in lieu of conducting a retest, accept as official the lower of the original and confirmatory test fuel economy results, and by doing so will also accept as official the calculated CREE value associated with the lower fuel economy test results.

(ii) The manufacturer shall conduct a second retest of the FTP or highway test if the fuel economy difference between the second confirmatory test and the original manufacturer test equals or exceeds three percent (or such lower percentage as requested by the manufacturer and approved by the Administrator) and the fuel economy difference between the second confirmatory test and the first confirmatory test equals or exceeds three percent (or such lower percentage as requested by the manufacturer and approved by the Administrator). In lieu of conducting a second retest, the manufacturer may accept as official (for use in the fuel economy program and the exhaust greenhouse gas fleet averaging program) the lowest fuel economy of the original test, the first confirmatory test, and the second confirmatory test fuel economy results, and by doing so will also accept as official the calculated CREE value associated with the lowest fuel economy test results.

(c) * * *

(1) * * *

(ii) Official test results for fuel economy and exhaust CO_2 emission purposes are determined in accordance with the provisions of § 600.008–08 of this chapter.

* * * * *

■ 22. Section 86.1841–01 is amended by adding paragraph (a)(3) and revising paragraph (b) to read as follows:

§ 86.1841–01 Compliance with emission standards for the purpose of certification.

(a) * * *

(3) Compliance with CO_2 exhaust emission standards shall be demonstrated at certification by the certification levels on the FTP and HFET tests for carbon-related exhaust emissions determined according to § 600.113–08 of this chapter.

* * * * *

(b) To be considered in compliance with the standards for the purposes of certification, the certification levels for the test vehicle calculated in paragraph (a) of this section shall be less than or equal to the standards for all emission constituents to which the test group is subject, at both full and intermediate useful life as appropriate for that test group.

* * * * *

■ 23. Section 86.1845–04 is amended as follows:

■ a. By revising paragraph (a)(1).

■ b. By revising paragraph (b)(5)(i).

■ c. By revising paragraph (c)(5)(i).

§ 86.1845–04 Manufacturer in-use verification testing requirements.

(a) * * *

(1) A manufacturer of LDVs, LDTs, MDPVs and/or complete HDVs must test, or cause to have tested, a specified number of LDVs, LDTs, MDPVs and complete HDVs. Such testing must be conducted in accordance with the provisions of this section. For purposes of this section, the term vehicle includes light-duty vehicles, light-duty trucks and medium-duty passenger vehicles.

* * * * *

(b) * * *

(5) * * *

(i) Each test vehicle of a test group shall be tested in accordance with the Federal Test Procedure and the US06 portion of the Supplemental Federal Test Procedure as described in subpart B of this part, when such test vehicle is tested for compliance with applicable exhaust emission standards under this subpart. Test vehicles subject to applicable exhaust CO_2 emission standards under this subpart shall also be tested in accordance with the highway fuel economy test as described in part 600, subpart B of this chapter.

* * * * *

(c) * * *

(5) * * *

(i) Each test vehicle shall be tested in accordance with the Federal Test Procedure and the US06 portion of the Supplemental Federal Test Procedure as described in subpart B of this part when such test vehicle is tested for compliance with applicable exhaust emission standards under this subpart. Test vehicles subject to applicable exhaust CO_2 emission standards under this subpart shall also be tested in accordance with the highway fuel economy test as described in part 600, subpart B of this chapter. The US06 portion of the SFTP is not required to be performed on vehicles certified in accordance with the National LEV provisions of subpart R of this part. One test vehicle from each test group shall receive a Federal Test Procedure at high altitude. The test vehicle tested at high altitude is not required to be one of the same test vehicles tested at low altitude. The test vehicle tested at high altitude is counted when determining the compliance with the requirements shown in Table S04–06 and Table S04–07 in paragraph (b)(3) of this section or the expanded sample size as provided for in this paragraph (c).

* * * * *

■ 24. Section 86.1846–01 is amended by revising paragraphs (a)(1) and (b) introductory text to read as follows:

§ 86.1846–01 Manufacturer in-use confirmatory testing requirements.

(a) * * *

(1) A manufacturer of LDVs, LDTs and/or MDPVs must test, or cause testing to be conducted, under this section when the emission levels shown by a test group sample from testing under §§ 86.1845–01 or 86.1845–04, as applicable, exceeds the criteria specified in paragraph (b) of this section. The testing required under this section applies separately to each test group and at each test point (low and high mileage) that meets the specified criteria. The testing requirements apply separately for each model year starting with model year 2001. These provisions do not apply to heavy-duty vehicles or heavy-duty engines prior to the 2007 model year. These provisions do not apply to emissions of CO_2, CH_4, and N_2O.

* * * * *

(b) *Criteria for additional testing.* A manufacturer shall test a test group or a subset of a test group as described in paragraph (j) of this section when the results from testing conducted under §§ 86.1845–01 and 86.1845–04, as applicable, show mean emissions for that test group of any pollutant(s) (except CO_2, CH_4, and N_2O) to be equal to or greater than 1.30 times the applicable in-use standard and a failure rate, among the test group vehicles, for the corresponding pollutant(s) of fifty percent or greater.

* * * * *

■ 25. Section 86.1848–10 is amended by adding paragraph (c)(9) to read as follows:

§ 86.1848–10 Certification.

* * * * *

(c) * * *

(9) For 2012 and later model year LDVs, LDTs, and MDPVs, all certificates of conformity issued are conditional upon compliance with all provisions of § 86.1818–12 and § 86.1865–12 both during and after model year production. The manufacturer bears the burden of establishing to the satisfaction of the Administrator that the terms and conditions upon which the certificate(s) was (were) issued were satisfied. For recall and warranty purposes, vehicles not covered by a certificate of

conformity will continue to be held to the standards stated or referenced in the certificate that otherwise would have applied to the vehicles.

(i) Failure to meet the fleet average CO_2 requirements will be considered a failure to satisfy the terms and conditions upon which the certificate(s) was (were) issued and the vehicles sold in violation of the fleet average CO_2 standard will not be covered by the certificate(s). The vehicles sold in violation will be determined according to § 86.1865–12(k)(7).

(ii) Failure to comply fully with the prohibition against selling credits that are not generated or that are not available, as specified in § 86.1865–12, will be considered a failure to satisfy the terms and conditions upon which the certificate(s) was (were) issued and the vehicles sold in violation of this prohibition will not be covered by the certificate(s).

* * * * *

■ 26. A new § 86.1854–12 is added to read as follows:

§ 86.1854–12 Prohibited acts.

(a) The following acts and the causing thereof are prohibited:

(1) In the case of a manufacturer, as defined by § 86.1803, of new motor vehicles or new motor vehicle engines for distribution in commerce, the sale, or the offering for sale, or the introduction, or delivery for introduction, into commerce, or (in the case of any person, except as provided by regulation of the Administrator), the importation into the United States of any new motor vehicle or new motor vehicle engine subject to this subpart, unless such vehicle or engine is covered by a certificate of conformity issued (and in effect) under regulations found in this subpart (except as provided in Section 203(b) of the Clean Air Act (42 U.S.C. 7522(b)) or regulations promulgated thereunder).

(2)(i) For any person to fail or refuse to permit access to or copying of records or to fail to make reports or provide information required under Section 208 of the Clean Air Act (42 U.S.C. 7542) with regard to vehicles.

(ii) For a person to fail or refuse to permit entry, testing, or inspection authorized under Section 206(c) (42 U.S.C. 7525(c)) or Section 208 of the Clean Air Act (42 U.S.C. 7542) with regard to vehicles.

(iii) For a person to fail or refuse to perform tests, or to have tests performed as required under Section 208 of the Clean Air Act (42 U.S.C. 7542) with regard to vehicles.

(iv) For a person to fail to establish or maintain records as required under §§ 86.1844, 86.1862, 86.1864, and 86.1865 with regard to vehicles.

(v) For any manufacturer to fail to make information available as provided by regulation under Section 202(m)(5) of the Clean Air Act (42 U.S.C. 7521(m)(5)) with regard to vehicles.

(3)(i) For any person to remove or render inoperative any device or element of design installed on or in a vehicle or engine in compliance with regulations under this subpart prior to its sale and delivery to the ultimate purchaser, or for any person knowingly to remove or render inoperative any such device or element of design after such sale and delivery to the ultimate purchaser.

(ii) For any person to manufacture, sell or offer to sell, or install, any part or component intended for use with, or as part of, any vehicle or engine, where a principal effect of the part or component is to bypass, defeat, or render inoperative any device or element of design installed on or in a vehicle or engine in compliance with regulations issued under this subpart, and where the person knows or should know that the part or component is being offered for sale or installed for this use or put to such use.

(4) For any manufacturer of a vehicle or engine subject to standards prescribed under this subpart:

(i) To sell, offer for sale, introduce or deliver into commerce, or lease any such vehicle or engine unless the manufacturer has complied with the requirements of Section 207(a) and (b) of the Clean Air Act (42 U.S.C. 7541(a), (b)) with respect to such vehicle or engine, and unless a label or tag is affixed to such vehicle or engine in accordance with Section 207(c)(3) of the Clean Air Act (42 U.S.C. 7541(c)(3)).

(ii) To fail or refuse to comply with the requirements of Section 207 (c) or (e) of the Clean Air Act (42 U.S.C. 7541(c) or (e)).

(iii) Except as provided in Section 207(c)(3) of the Clean Air Act (42 U.S.C. 7541(c)(3)), to provide directly or indirectly in any communication to the ultimate purchaser or any subsequent purchaser that the coverage of a warranty under the Clean Air Act is conditioned upon use of any part, component, or system manufactured by the manufacturer or a person acting for the manufacturer or under its control, or conditioned upon service performed by such persons.

(iv) To fail or refuse to comply with the terms and conditions of the warranty under Section 207(a) or (b) of the Clean Air Act (42 U.S.C. 7541(a) or (b)).

(b) For the purposes of enforcement of this subpart, the following apply:

(1) No action with respect to any element of design referred to in paragraph (a)(3) of this section (including any adjustment or alteration of such element) shall be treated as a prohibited act under paragraph (a)(3) of this section if such action is in accordance with Section 215 of the Clean Air Act (42 U.S.C. 7549);

(2) Nothing in paragraph (a)(3) of this section is to be construed to require the use of manufacturer parts in maintaining or repairing a vehicle or engine. For the purposes of the preceding sentence, the term "manufacturer parts" means, with respect to a motor vehicle engine, parts produced or sold by the manufacturer of the motor vehicle or motor vehicle engine;

(3) Actions for the purpose of repair or replacement of a device or element of design or any other item are not considered prohibited acts under paragraph (a)(3) of this section if the action is a necessary and temporary procedure, the device or element is replaced upon completion of the procedure, and the action results in the proper functioning of the device or element of design;

(4) Actions for the purpose of a conversion of a motor vehicle or motor vehicle engine for use of a clean alternative fuel (as defined in title II of the Clean Air Act) are not considered prohibited acts under paragraph (a) of this section if:

(i) The vehicle complies with the applicable standard when operating on the alternative fuel; and

(ii) In the case of engines converted to dual fuel or flexible use, the device or element is replaced upon completion of the conversion procedure, and the action results in proper functioning of the device or element when the motor vehicle operates on conventional fuel.

■ 27. A new § 86.1865–12 is added to subpart S to read as follows:

§ 86.1865–12 How to comply with the fleet average CO_2 standards.

(a) *Applicability.* (1) Unless otherwise exempted under the provisions of § 86.1801–12(j), CO_2 fleet average exhaust emission standards apply to:

(i) 2012 and later model year passenger automobiles and light trucks.

(ii) Aftermarket conversion systems as defined in 40 CFR 85.502.

(iii) Vehicles imported by ICIs as defined in 40 CFR 85.1502.

(2) The terms "passenger automobile" and "light truck" as used in this section have the meanings as defined in § 86.1818–12.

(b) *Useful life requirements.* Full useful life requirements for CO_2 standards are defined in § 86.1818–12. There is not an intermediate useful life standard for CO_2 emissions.

(c) *Altitude.* Altitude requirements for CO_2 standards are provided in § 86.1810–09(f).

(d) *Small volume manufacturer certification procedures.* Certification procedures for small volume manufacturers are provided in § 86.1838–01. Small businesses meeting certain criteria may be exempted from the greenhouse gas emission standards in § 86.1818–12 according to the provisions of § 86.1801–12(j).

(e) *CO_2 fleet average exhaust emission standards.* The fleet average standards referred to in this section are the corporate fleet average CO_2 standards for passenger automobiles and light trucks set forth in § 86.1818–12(c) and (e). The fleet average CO_2 standards applicable in a given model year are calculated separately for passenger automobiles and light trucks for each manufacturer and each model year according to the provisions in § 86.1818–12. Each manufacturer must comply with the applicable CO_2 fleet average standard on a production-weighted average basis, for each separate averaging set, at the end of each model year, using the procedure described in paragraph (j) of this section.

(f) *In-use CO_2 standards.* In-use CO_2 exhaust emission standards applicable to each model type are provided in § 86.1818–12(d).

(g) *Durability procedures and method of determining deterioration factors (DFs).* Deterioration factors for CO_2 exhaust emission standards are provided in § 86.1823–08(m).

(h) *Vehicle test procedures.* (1) The test procedures for demonstrating compliance with CO_2 exhaust emission standards are contained in subpart B of this part and subpart B of part 600 of this chapter.

(2) Testing of all passenger automobiles and light trucks to determine compliance with CO_2 exhaust emission standards set forth in this section must be on a loaded vehicle weight (LVW) basis, as defined in § 86.1803–01.

(3) Testing for the purpose of providing certification data is required only at low altitude conditions. If hardware and software emission control strategies used during low altitude condition testing are not used similarly across all altitudes for in-use operation, the manufacturer must include a statement in the application for certification, in accordance with § 86.1844–01(d)(11) and § 86.1810–09(f), stating what the different strategies are and why they are used.

(i) *Calculating the fleet average carbon-related exhaust emissions.* (1) Manufacturers must compute separate production-weighted fleet average carbon-related exhaust emissions at the end of the model year for passenger automobiles and light trucks, using actual production, where production means vehicles produced and delivered for sale, and certifying model types to standards as defined in § 86.1818–12. The model type carbon-related exhaust emission results determined according to 40 CFR part 600 subpart F (in units of grams per mile rounded to the nearest whole number) become the certification standard for each model type.

(2) Manufacturers must separately calculate production-weighted fleet average carbon-related exhaust emissions levels for the following averaging sets according to the provisions of part 600 subpart F of this chapter:

(i) Passenger automobiles subject to the fleet average CO_2 standards specified in § 86.1818–12(c)(2);

(ii) Light trucks subject to the fleet average CO_2 standards specified in § 86.1818–12(c)(3);

(iii) Passenger automobiles subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e), if applicable; and

(iv) Light trucks subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e), if applicable.

(j) *Certification compliance and enforcement requirements for CO_2 exhaust emission standards.* (1) Compliance and enforcement requirements are provided in § 86.1864–10 and § 86.1848–10(c)(9).

(2) The certificate issued for each test group requires all model types within that test group to meet the in-use emission standards to which each model type is certified as outlined in § 86.1818–12(d).

(3) Each manufacturer must comply with the applicable CO_2 fleet average standard on a production-weighted average basis, at the end of each model year, using the procedure described in paragraph (i) of this section.

(4) Each manufacturer must comply on an annual basis with the fleet average standards as follows:

(i) Manufacturers must report in their annual reports to the Agency that they met the relevant corporate average standard by showing that their production-weighted average CO_2 emissions levels of passenger automobiles and light trucks, as applicable, are at or below the applicable fleet average standard; or

(ii) If the production-weighted average is above the applicable fleet average standard, manufacturers must obtain and apply sufficient CO_2 credits as authorized under paragraph (k)(8) of this section. A manufacturer must show that they have offset any exceedence of the corporate average standard via the use of credits. Manufacturers must also include their credit balances or deficits in their annual report to the Agency.

(iii) If a manufacturer fails to meet the corporate average CO_2 standard for four consecutive years, the vehicles causing the corporate average exceedence will be considered not covered by the certificate of conformity (*see* paragraph (k)(8) of this section). A manufacturer will be subject to penalties on an individual-vehicle basis for sale of vehicles not covered by a certificate.

(iv) EPA will review each manufacturer's production to designate the vehicles that caused the exceedence of the corporate average standard. EPA will designate as nonconforming those vehicles in test groups with the highest certification emission values first, continuing until reaching a number of vehicles equal to the calculated number of noncomplying vehicles as determined in paragraph (k)(8) of this section. In a group where only a portion of vehicles would be deemed nonconforming, EPA will determine the actual nonconforming vehicles by counting backwards from the last vehicle produced in that test group. Manufacturers will be liable for penalties for each vehicle sold that is not covered by a certificate.

(k) *Requirements for the CO_2 averaging, banking and trading (ABT) program.* (1) A manufacturer whose CO_2 fleet average emissions exceed the applicable standard must complete the calculation in paragraph (k)(4) of this section to determine the size of its CO_2 deficit. A manufacturer whose CO_2 fleet average emissions are less than the applicable standard must complete the calculation in paragraph (k)(4) of this section to generate CO_2 credits. In either case, the number of credits or debits must be rounded to the nearest whole number.

(2) There are no property rights associated with CO_2 credits generated under this subpart. Credits are a limited authorization to emit the designated amount of emissions. Nothing in this part or any other provision of law should be construed to limit EPA's authority to terminate or limit this authorization through a rulemaking.

(3) Each manufacturer must comply with the reporting and recordkeeping

requirements of paragraph (l) of this section for CO_2 credits, including early credits. The averaging, banking and trading program is enforceable through the certificate of conformity that allows the manufacturer to introduce any regulated vehicles into commerce.

(4) Credits are earned on the last day of the model year. Manufacturers must calculate, for a given model year and separately for passenger automobiles and light trucks, the number of credits or debits it has generated according to the following equation, rounded to the nearest megagram:

CO_2 Credits or Debits (Mg) = [(CO_2 Standard—Manufacturer's Production-Weighted Fleet Average CO_2 Emissions) × (Total Number of Vehicles Produced) × (Vehicle Lifetime Miles)] 1,000,000

Where:

CO_2 Standard = the applicable standard for the model year as determined by § 86.1818–12;

Manufacturer's Production-Weighted Fleet Average CO_2 Emissions = average calculated according to paragraph (i) of this section;

Total Number of Vehicles Produced = The number of vehicles domestically produced plus those imported as defined in § 600.511–80 of this chapter; and

Vehicle Lifetime Miles is 195,264 for passenger automobiles and 225,865 for light trucks.

(5) Total credits or debits generated in a model year, maintained and reported separately for passenger automobiles and light trucks, shall be the sum of the credits or debits calculated in paragraph (k)(4) of this section and any of the following credits, if applicable:

(i) Air conditioning leakage credits earned according to the provisions of § 86.1866–12(b);

(ii) Air conditioning efficiency credits earned according to the provisions of § 86.1866–12(c);

(iii) Off-cycle technology credits earned according to the provisions of § 86.1866–12(d).

(6) Unused CO_2 credits shall retain their full value through the five subsequent model years after the model year in which they were generated. Credits available at the end of the fifth model year after the year in which they were generated shall expire.

(7) Credits may be used as follows:

(i) Credits generated and calculated according to the method in paragraph (k)(4) of this section may not be used to offset deficits other than those deficits accrued with respect to the standard in § 86.1818–12. Credits may be banked and used in a future model year in which a manufacturer's average CO_2 level exceeds the applicable standard. Credits may be exchanged between the passenger automobile and light truck fleets of a given manufacturer. Credits may also be traded to another manufacturer according to the provisions in paragraph (k)(8) of this section. Before trading or carrying over credits to the next model year, a manufacturer must apply available credits to offset any deficit, where the deadline to offset that credit deficit has not yet passed.

(ii) The use of credits shall not change Selective Enforcement Auditing or in-use testing failures from a failure to a non-failure. The enforcement of the averaging standard occurs through the vehicle's certificate of conformity. A manufacturer's certificate of conformity is conditioned upon compliance with the averaging provisions. The certificate will be void ab initio if a manufacturer fails to meet the corporate average standard and does not obtain appropriate credits to cover its shortfalls in that model year or subsequent model years (see deficit carry-forward provisions in paragraph (k)(8) of this section).

(iii) *Special provisions for manufacturers using the Temporary Leadtime Allowance Alternative Standards.* (A) Credits generated by vehicles subject to the fleet average CO_2 standards specified in § 86.1818–12(c) may only be used to offset a deficit generated by vehicles subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e).

(B) Credits generated by a passenger automobile or light truck averaging set subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e)(4)(i) or (ii) of this section may be used to offset a deficit generated by an averaging set subject to the Temporary Leadtime Allowance Alternative Standards through the 2015 model year, except that manufacturers qualifying under the provisions of § 86.1818–12(e)(3) may use such credits to offset a deficit generated by an averaging set subject to the Temporary Leadtime Allowance Alternative Standards through the 2016 model year .

(C) Credits generated by an averaging set subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e)(4)(i) or (ii) of this section may not be used to offset a deficit generated by an averaging set subject to the fleet average CO_2 standards specified in § 86.1818–12(c)(2) or (3) or otherwise transferred to an averaging set subject to the fleet average CO_2 standards specified in § 86.1818–12(c)(2) or (3).

(D) Credits generated by vehicles subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e)(4)(i) or (ii) may be banked for use in a future model year (to offset a deficit generated by an averaging set subject to the Temporary Leadtime Allowance Alternative Standards). All such credits shall expire at the end of the 2015 model year, except that manufacturers qualifying under the provisions of § 86.1818–12(e)(3) may use such credits to offset a deficit generated by an averaging set subject to the Temporary Leadtime Allowance Alternative Standards through the 2016 model year.

(E) A manufacturer with any vehicles subject to the Temporary Leadtime Allowance Alternative Standards specified in § 86.1818–12(e)(4)(i) or (ii) of this section in a model year in which that manufacturer also generates credits with vehicles subject to the fleet average CO_2 standards specified in § 86.1818–12(c) may not trade or bank credits earned against the fleet average standards in § 86.1818–12(c) for use in a future model year.

(8) The following provisions apply if debits are accrued:

(i) If a manufacturer calculates that it has negative credits (also called "debits" or a "credit deficit") for a given model year, it may carry that deficit forward into the next three model years. Such a carry-forward may only occur after the manufacturer exhausts any supply of banked credits. At the end of the third model year, the deficit must be covered with an appropriate number of credits that the manufacturer generates or purchases. Any remaining deficit is subject to a voiding of the certificate ab initio, as described in this paragraph (k)(8). Manufacturers are not permitted to have a credit deficit for four consecutive years.

(ii) If debits are not offset within the specified time period, the number of vehicles not meeting the fleet average CO_2 standards (and therefore not covered by the certificate) must be calculated.

(A) Determine the gram per mile quantity of debits for the noncompliant vehicle category by multiplying the total megagram deficit by 1,000,000 and then dividing by the vehicle lifetime miles for the vehicle category (passenger automobile or light truck) specified in paragraph (k)(4) of this section.

(B) Divide the result by the fleet average standard applicable to the model year in which the debits were first incurred and round to the nearest whole number to determine the number of vehicles not meeting the fleet average CO_2 standards.

(iii) EPA will determine the vehicles not covered by a certificate because the condition on the certificate was not satisfied by designating vehicles in those test groups with the highest CO_2 emission values first and continuing until reaching a number of vehicles equal to the calculated number of noncomplying vehicles as determined in paragraph (k)(7) of this section. If this calculation determines that only a portion of vehicles in a test group contribute to the debit situation, then EPA will designate actual vehicles in that test group as not covered by the certificate, starting with the last vehicle produced and counting backwards.

(iv)(A) If a manufacturer ceases production of passenger cars and light trucks, the manufacturer continues to be responsible for offsetting any debits outstanding within the required time period. Any failure to offset the debits will be considered a violation of paragraph (k)(7)(i) of this section and may subject the manufacturer to an enforcement action for sale of vehicles not covered by a certificate, pursuant to paragraphs (k)(7)(ii) and (iii) of this section.

(B) If a manufacturer is purchased by, merges with, or otherwise combines with another manufacturer, the controlling entity is responsible for offsetting any debits outstanding within the required time period. Any failure to offset the debits will be considered a violation of paragraph (k)(7)(i) of this section and may subject the manufacturer to an enforcement action for sale of vehicles not covered by a certificate, pursuant to paragraphs (k)(7)(ii) and (iii) of this section.

(v) For purposes of calculating the statute of limitations, a violation of the requirements of paragraph (k)(7)(i) of this section, a failure to satisfy the conditions upon which a certificate(s) was issued and hence a sale of vehicles not covered by the certificate, all occur upon the expiration of the deadline for offsetting debits specified in paragraph (k)(7)(i) of this section.

(9) The following provisions apply to CO_2 credit trading:

(i) EPA may reject CO_2 credit trades if the involved manufacturers fail to submit the credit trade notification in the annual report.

(ii) A manufacturer may not sell credits that are not available for sale pursuant to the provisions in paragraph (k)(6) of this section.

(iii) In the event of a negative credit balance resulting from a transaction, both the buyer and seller are liable. EPA may void ab initio the certificates of conformity of all test groups participating in such a trade.

(iv) (A) If a manufacturer trades a credit that it has not generated pursuant to paragraph (k) of this section or acquired from another party, the manufacturer will be considered to have generated a debit in the model year that the manufacturer traded the credit. The manufacturer must offset such debits by the deadline for the annual report for that same model year.

(B) Failure to offset the debits within the required time period will be considered a failure to satisfy the conditions upon which the certificate(s) was issued and will be addressed pursuant to paragraph (k)(7) of this section.

(v) A manufacturer may only trade credits that it has generated pursuant to paragraph (k)(4) of this section or acquired from another party.

(l) *Maintenance of records and submittal of information relevant to compliance with fleet average CO_2 standards*—(1) *Maintenance of records.* (i) Manufacturers producing any light-duty vehicles, light-duty trucks, or medium-duty passenger vehicles subject to the provisions in this subpart must establish, maintain, and retain all the following information in adequately organized records for each model year:

(A) Model year.

(B) Applicable fleet average CO_2 standards for each averaging set as defined in paragraph (i) of this section.

(C) The calculated fleet average CO_2 value for each averaging set as defined in paragraph (i) of this section.

(D) All values used in calculating the fleet average CO_2 values.

(ii) Manufacturers producing any passenger cars or light trucks subject to the provisions in this subpart must establish, maintain, and retain all the following information in adequately organized records for each passenger car or light truck subject to this subpart:

(A) Model year.

(B) Applicable fleet average CO_2 standard.

(C) EPA test group.

(D) Assembly plant.

(E) Vehicle identification number.

(F) Carbon-related exhaust emission standard to which the passenger car or light truck is certified.

(G) In-use carbon-related exhaust emission standard.

(H) Information on the point of first sale, including the purchaser, city, and state.

(iii) Manufacturers must retain all required records for a period of eight years from the due date for the annual report. Records may be stored in any format and on any media, as long as manufacturers can promptly send EPA organized written records in English if requested by the Administrator. Manufacturers must keep records readily available as EPA may review them at any time.

(iv) The Administrator may require the manufacturer to retain additional records or submit information not specifically required by this section.

(v) Pursuant to a request made by the Administrator, the manufacturer must submit to the Administrator the information that the manufacturer is required to retain.

(vi) EPA may void ab initio a certificate of conformity for vehicles certified to emission standards as set forth or otherwise referenced in this subpart for which the manufacturer fails to retain the records required in this section or to provide such information to the Administrator upon request, or to submit the reports required in this section in the specified time period.

(2) *Reporting.* (i) Each manufacturer must submit an annual report. The annual report must contain for each applicable CO_2 standard, the calculated fleet average CO_2 value, all values required to calculate the CO_2 emissions value, the number of credits generated or debits incurred, all the values required to calculate the credits or debits, and the resulting balance of credits or debits.

(ii) For each applicable fleet average CO_2 standard, the annual report must also include documentation on all credit transactions the manufacturer has engaged in since those included in the last report. Information for each transaction must include all of the following:

(A) Name of credit provider.

(B) Name of credit recipient.

(C) Date the trade occurred.

(D) Quantity of credits traded in megagrams.

(E) Model year in which the credits were earned.

(iii) Manufacturers calculating early air conditioning leakage and/or efficiency credits under paragraph § 86.1867–12(b) of this section shall include in the 2012 report, the following information for each model year separately for passenger automobiles and light trucks and for each air conditioning system used to generate credits:

(A) A description of the air conditioning system.

(B) The leakage credit value and all the information required to determine this value.

(C) The total credits earned for each averaging set, model year, and region, as applicable.

(iv) Manufacturers calculating early advanced technology vehicle credits under paragraph § 86.1867–12(c) shall include in the 2012 report, separately for each model year and separately for passenger automobiles and light trucks, the following information:

(A) The number of each model type of eligible vehicle sold.

(B) The cumulative model year production of eligible vehicles starting with the 2009 model year.

(C) The carbon-related exhaust emission value by model type and model year.

(v) Manufacturers calculating early off-cycle technology credits under paragraph § 86.1867–12(d) shall include in the 2012 report, for each model year and separately for passenger automobiles and light trucks, all test results and data required for calculating such credits.

(vi) Unless a manufacturer reports the data required by this section in the annual production report required under § 86.1844–01(e) or the annual report required under § 600.512–12 of this chapter, a manufacturer must submit an annual report for each model year after production ends for all affected vehicles produced by the manufacturer subject to the provisions of this subpart and no later than May 1 of the calendar year following the given model year. Annual reports must be submitted to: Director, Compliance and Innovative Strategies Division, U.S. Environmental Protection Agency, 2000 Traverwood, Ann Arbor, Michigan 48105.

(vii) Failure by a manufacturer to submit the annual report in the specified time period for all vehicles subject to the provisions in this section is a violation of section 203(a)(1) of the Clean Air Act (42 U.S.C. 7522 (a)(1)) for each applicable vehicle produced by that manufacturer.

(viii) If EPA or the manufacturer determines that a reporting error occurred on an annual report previously submitted to EPA, the manufacturer's credit or debit calculations will be recalculated. EPA may void erroneous credits, unless traded, and will adjust erroneous debits. In the case of traded erroneous credits, EPA must adjust the selling manufacturer's credit balance to reflect the sale of such credits and any resulting credit deficit.

(3) *Notice of opportunity for hearing.* Any voiding of the certificate under paragraph (l)(1)(vi) of this section will be made only after EPA has offered the affected manufacturer an opportunity for a hearing conducted in accordance with § 86.614–84 for light-duty vehicles or § 86.1014–84 for light-duty trucks and, if a manufacturer requests such a hearing, will be made only after an initial decision by the Presiding Officer.

■ 28. A new § 86.1866–12 is added to subpart S to read as follows:

§ 86.1866–12 CO_2 fleet average credit programs.

(a) *Incentive for certification of advanced technology vehicles.* Electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles, as those terms are defined in § 86.1803–01, that are certified and produced in the 2012 through 2016 model years may be eligible for a reduced CO_2 emission value under the provisions of this paragraph (a) and under the provisions of part 600 of this chapter.

(1) Electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles may use a value of zero (0) grams/mile of CO_2 to represent the proportion of electric operation of a vehicle that is derived from electricity that is generated from sources that are not onboard the vehicle.

(2) The use of zero (0) grams/mile CO_2 is limited to the first 200,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2012 through 2016 model years, except that a manufacturer that produces and delivers for sale 25,000 or more such vehicles in the 2012 model year shall be subject to a limitation on the use of zero (0) grams/mile CO_2 to the first 300,000 combined electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles produced and delivered for sale by a manufacturer in the 2012 through 2016 model years.

(b) *Credits for reduction of air conditioning refrigerant leakage.* Manufacturers may generate credits applicable to the CO_2 fleet average program described in § 86.1865–12 by implementing specific air conditioning system technologies designed to reduce air conditioning refrigerant leakage over the useful life of their passenger cars and/or light trucks. Credits shall be calculated according to this paragraph (b) for each air conditioning system that the manufacturer is using to generate CO_2 credits. Manufacturers may also generate early air conditioning refrigerant leakage credits under this paragraph (b) for the 2009 through 2011 model years according to the provisions of § 86.1867–12(b).

(1) The manufacturer shall calculate an annual rate of refrigerant leakage from an air conditioning system in grams per year according to the provisions of § 86.166–12.

(2) The CO_2-equivalent gram per mile leakage reduction to be used to calculate the total credits generated by the air conditioning system shall be determined according to the following formulae, rounded to the nearest tenth of a gram per mile:

(i) Passenger automobiles:

$$\text{Leakage credit} = MaxCredit \times \left[1 - \left(\frac{Leakage}{16.6}\right) \times \left(\frac{GWP_{REF}}{GWP_{HFC134a}}\right)\right]$$

Where:

MaxCredit is 12.6 (grams CO_2-equivalent/mile) for air conditioning systems using HFC–134a, and 13.8 (grams CO_2-equivalent/mile) for air conditioning systems using a refrigerant with a lower global warming potential.

Leakage means the annual refrigerant leakage rate determined according to the provisions of § 86.166–12(a), except if the calculated rate is less than 8.3 grams/year (4.1 grams/year for systems using electric compressors) the rate for the purpose of this formula shall be 8.3 grams/year (4.1 grams/year for systems using electric compressors);

The constant 16.6 is the average passenger car impact of air conditioning leakage in units of grams/year;

GWP_{REF} means the global warming potential of the refrigerant as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator;

$GWP_{HFC134a}$ means the global warming potential of HFC–134a as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator.

(ii) Light trucks:

$$Leakage\ credit = MaxCredit \times \left[1 - \left(\frac{Leakage}{20.7}\right) \times \left(\frac{GWP_{REF}}{GWP_{HFC134a}}\right)\right]$$

Where:

MaxCredit is 15.6 (grams CO_2-equivalent/mile) for air conditioning systems using HFC–134a, and 17.2 (grams CO_2-equivalent/mile) for air conditioning systems using a refrigerant with a lower global warming potential.

Leakage means the annual refrigerant leakage rate determined according to the provisions of § 86.166–12(a), except if the calculated rate is less than 10.4 grams/year (5.2 grams/year for systems using electric compressors) the rate for the purpose of this formula shall be 10.4 grams/year (5.2 grams/year for systems using electric compressors);

The constant 20.7 is the average passenger car impact of air conditioning leakage in units of grams/year;

GWP_{REF} means the global warming potential of the refrigerant as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator;

GWP_{R134a} means the global warming potential of HFC–134a as indicated in paragraph (b)(5) of this section or as otherwise determined by the Administrator.

(3) The total leakage reduction credits generated by the air conditioning system shall be calculated separately for passenger cars and light trucks according to the following formula:

Total Credits (megagrams) = (Leakage × Production × VLM)   1,000,000

Where:

Leakage = the CO_2-equivalent leakage credit value in grams per mile determined in paragraph (b)(2) of this section.

Production = The total number of passenger cars or light trucks, whichever is applicable, produced with the air conditioning system to which to the leakage credit value from paragraph (b)(2) of this section applies.

VLM = vehicle lifetime miles, which for passenger cars shall be 195,264 and for light trucks shall be 225,865.

(4) The results of paragraph (b)(3) of this section, rounded to the nearest whole number, shall be included in the manufacturer's credit/debit totals calculated in § 86.1865–12(k)(5).

(5) The following values for refrigerant global warming potential (GWP_{REF}), or alternative values as determined by the Administrator, shall be used in the calculations of this paragraph (b). The Administrator will determine values for refrigerants not included in this paragraph (b)(5) upon request by a manufacturer.

(i) For HFC–134a, GWP_{REF} = 1430;

(ii) For HFC–152a, GWP_{REF} = 124;

(iii) For HFO–1234yf,: GWP_{REF} = 4;

(iv) For CO_2, GWP_{REF} = 1.

(c) *Credits for improving air conditioning system efficiency.* Manufacturers may generate credits applicable to the CO_2 fleet average program described in § 86.1865–12 by implementing specific air conditioning system technologies designed to reduce air conditioning-related CO_2 emissions over the useful life of their passenger cars and/or light trucks. Credits shall be calculated according to this paragraph (c) for each air conditioning system that the manufacturer is using to generate CO_2 credits. Manufacturers may also generate early air conditioning efficiency credits under this paragraph (c) for the 2009 through 2011 model years according to the provisions of § 86.1867–12(b). For model years 2012 and 2013 the manufacturer may determine air conditioning efficiency credits using the requirements in paragraphs (c)(1) through (4) of this section. For model years 2014 and later the eligibility requirements specified in paragraph (c)(5) of this section must be met before an air conditioning system is allowed to generate credits.

(1) Air conditioning efficiency credits are available for the following technologies in the gram per mile amounts indicated:

(i) Reduced reheat, with externally-controlled, variable-displacement compressor (*e.g.* a compressor that controls displacement based on temperature setpoint and/or cooling demand of the air conditioning system control settings inside the passenger compartment): 1.7 g/mi.

(ii) Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor (*e.g.* a compressor that controls displacement based on conditions within, or internal to, the air conditioning system, such as head pressure, suction pressure, or evaporator outlet temperature): 1.1 g/mi.

(iii) Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 F or higher: 1.7 g/mi. Air conditioning systems that operated with closed-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.

(iv) Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature is 75 F or higher: 1.1 g/mi. Air conditioning systems that operate with open-loop control of the air supply at different temperatures may receive credits by submitting an engineering analysis to the Administrator for approval.

(v) Blower motor controls which limit wasted electrical energy (*e.g.* pulse width modulated power controller): 0.9 g/mi.

(vi) Internal heat exchanger (*e.g.* a device that transfers heat from the high-pressure, liquid-phase refrigerant entering the evaporator to the low-pressure, gas-phase refrigerant exiting the evaporator): 1.1 g/mi.

(vii) Improved condensers and/or evaporators with system analysis on the component(s) indicating a coefficient of performance improvement for the system of greater than 10% when compared to previous industry standard designs): 1.1 g/mi.

(viii) Oil separator: 0.6 g/mi. The manufacturer must submit an engineering analysis demonstrating the increased improvement of the system relative to the baseline design, where the baseline component for comparison is the version which a manufacturer most recently had in production on the same vehicle design or in a similar or related vehicle model. The characteristics of the baseline component shall be compared to the new component to demonstrate the improvement.

(2) Air conditioning efficiency credits are determined on an air conditioning system basis. For each air conditioning system that is eligible for a credit based on the use of one or more of the items listed in paragraph (c)(1) of this section, the total credit value is the sum of the gram per mile values listed in paragraph (c)(1) of this section for each item that applies to the air conditioning system. If the sum of those values for an air conditioning system is greater than 5.7 grams per mile, the total credit value is deemed to be 5.7 grams per mile.

(3) The total efficiency credits generated by an air conditioning system shall be calculated separately for passenger cars and light trucks according to the following formula:

Total Credits (Megagrams) = (Credit × Production × VLM)   1,000,000

Where:

Credit = the CO_2 efficiency credit value in grams per mile determined in paragraph (c)(2) or (c)(5) of this section, whichever is applicable.

Production = The total number of passenger cars or light trucks, whichever is applicable, produced with the air conditioning system to which to the efficiency credit value from paragraph (c)(2) of this section applies.

VLM = vehicle lifetime miles, which for passenger cars shall be 195,264 and for light trucks shall be 225,865.

(4) The results of paragraph (c)(3) of this section, rounded to the nearest whole number, shall be included in the manufacturer's credit/debit totals calculated in § 86.1865–12(k)(5).

(5) Use of the Air Conditioning Idle Test Procedure is required after the 2013 model year as specified in this paragraph (c)(5).

(i) After the 2013 model year, for each air conditioning system selected by the manufacturer to generate air conditioning efficiency credits, the manufacturer shall perform the Air Conditioning Idle Test Procedure specified in § 86.165–14 of this part.

(ii) Using good engineering judgment, the manufacturer must select the vehicle configuration to be tested that is expected to result in the greatest increased CO_2 emissions as a result of the operation of the air conditioning system for which efficiency credits are being sought. If the air conditioning system is being installed in passenger automobiles and light trucks, a separate determination of the quantity of credits for passenger automobiles and light trucks must be made, but only one test vehicle is required to represent the air conditioning system, provided it represents the worst-case impact of the system on CO_2 emissions.

(iii) For an air conditioning system to be eligible to generate credits in the 2014 and later model years, the increased CO_2 emissions as a result of the operation of that air conditioning system determined according to the Idle Test Procedure in § 86.165–14 must be less than 21.3 grams per minute.

(A) If the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–14 is less than or equal to 14.9 grams/minute, the total credit value for use in paragraph (c)(3) of this section shall be as determined in paragraph (c)(2) of this section.

(B) If the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–14 is greater than 14.9 grams/minute and less than 21.3 grams/minute, the total credit value for use in paragraph (c)(3) of this section shall be as determined according to the following formula:

$$TCV = TCV_1 \times \left[1 - \left(\frac{ITP - 14.9}{6.4}\right)\right]$$

Where:

TCV = The total credit value for use in paragraph (c)(3) of this section;

TCV_1 = The total credit value determined according to paragraph (c)(2) of this section; and

ITP = the increased CO_2 emissions determined from the Idle Test Procedure in § 86.165–14.

(iv) Air conditioning systems with compressors that are solely powered by electricity shall submit Air Conditioning Idle Test Procedure data to be eligible to generate credits in the 2014 and later model years, but such systems are not required to meet a specific threshold to be eligible to generate such credits, as long as the engine remains off for a period of at least 2 minutes during the air conditioning on portion of the Idle Test Procedure in § 86.165–12(d).

(6) The following definitions apply to this paragraph (c):

(i) *Reduced reheat, with externally-controlled, variable displacement compressor* means a system in which compressor displacement is controlled via an electronic signal, based on input from sensors (*e.g.,* position or setpoint of interior temperature control, interior temperature, evaporator outlet air temperature, or refrigerant temperature) and air temperature at the outlet of the evaporator can be controlled to a level at 41 F, or higher.

(ii) *Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor* means a system in which the output of either compressor is controlled by cycling the compressor clutch off-and-on via an electronic signal, based on input from sensors (*e.g.,* position or setpoint of interior temperature control, interior temperature, evaporator outlet air temperature, or refrigerant temperature) and air temperature at the outlet of the evaporator can be controlled to a level at 41 F, or higher.

(iii) *Default to recirculated air mode* means that the default position of the mechanism which controls the source of air supplied to the air conditioning system shall change from outside air to recirculated air when the operator or the automatic climate control system has engaged the air conditioning system (*i.e.,* evaporator is removing heat), except under those conditions where dehumidification is required for visibility (*i.e.,* defogger mode). In vehicles equipped with interior air quality sensors (*e.g.,* humidity sensor, or carbon dioxide sensor), the controls may determine proper blend of air supply sources to maintain freshness of the cabin air and prevent fogging of windows while continuing to maximize the use of recirculated air. At any time, the vehicle operator may manually select the non-recirculated air setting during vehicle operation but the system must default to recirculated air mode on subsequent vehicle operations (*i.e.,* next vehicle start). The climate control system may delay switching to recirculation mode until the interior air temperature is less than the outside air temperature, at which time the system must switch to recirculated air mode.

(iv) *Blower motor controls which limit waste energy* means a method of controlling fan and blower speeds which does not use resistive elements to decrease the voltage supplied to the motor.

(v) *Improved condensers and/or evaporators* means that the coefficient of performance (COP) of air conditioning system using improved evaporator and condenser designs is 10 percent higher, as determined using the bench test procedures described in SAE J2765 "Procedure for Measuring System COP of a Mobile Air Conditioning System on a Test Bench," when compared to a system using standard, or prior model year, component designs. SAE J2765 is incorporated by reference; see § 86.1. The manufacturer must submit an engineering analysis demonstrating the increased improvement of the system relative to the baseline design, where the baseline component(s) for comparison is the version which a manufacturer most recently had in production on the same vehicle design or in a similar or related vehicle model. The dimensional characteristics (*e.g.,* tube configuration/thickness/spacing, and fin density) of the baseline component(s) shall be compared to the new component(s) to demonstrate the improvement in coefficient of performance.

(vi) *Oil separator* means a mechanism which removes at least 50 percent of the oil entrained in the oil/refrigerant mixture exiting the compressor and returns it to the compressor housing or compressor inlet, or a compressor design which does not rely on the circulation of an oil/refrigerant mixture for lubrication.

(d) *Credits for CO_2-reducing technologies where the CO_2 reduction is not captured on the Federal Test Procedure or the Highway Fuel Economy Test.* With prior EPA approval, manufacturers may optionally generate credits applicable to the CO_2 fleet average program described in § 86.1865–12 by implementing innovative technologies that have a measurable, demonstrable, and verifiable real-world CO_2 reduction. These optional credits are referred to as "off-cycle" credits and may be earned through the 2016 model year.

(1) *Qualification criteria.* To qualify for this credit, the criteria in this paragraph (d)(1) must be met as determined by the Administratory:

(i) The technology must be an innovative and novel vehicle- or engine-based approach to reducing greenhouse gas emissions, and not in widespread use.

(ii) The *CO_2*-reducing impact of the technology must not be significantly measurable over the Federal Test Procedure and the Highway Fuel Economy Test. The technology must improve *CO_2* emissions beyond the driving conditions of those tests.

(iii) The technology must be able to be demonstrated to be effective for the full useful life of the vehicle. Unless the manufacturer demonstrates that the technology is not subject to in-use deterioration, the manufacturer must account for the deterioration in their analysis.

(2) *Quantifying the CO_2 reductions of an off-cycle technology.* The manufacturer may use one of the two options specified in this paragraph (d)(2) to measure the *CO_2*-reducing potential of an innovative off-cycle technology. The option described in paragraph (d)(2)(ii) of this section may be used only with EPA approval, and to use that option the manufacturer must be able to justify to the Administrator why the 5-cycle option described in paragraph (d)(2)(i) of this section insufficiently characterizes the effectiveness of the off-cycle technology. The manufacturer should notify EPA in their pre-model year report of their intention to generate any credits under paragraph (d) of this section.

(i) *Technology demonstration using EPA 5-cycle methodology.* To demonstrate an off-cycle technology and to determine a *CO_2* credit using the EPA 5-cycle methodology, the manufacturer shall determine 5-cycle city/highway combined carbon-related exhaust emissions both with the technology installed and operating and without the technology installed and/or operating. The manufacturer shall conduct the following steps, both with the off-cycle technology installed and operating and without the technology operating or installed.

(A) Determine carbon-related exhaust emissions over the FTP, the HFET, the US06, the SC03, and the cold temperature FTP test procedures according to the test procedure provisions specified in 40 CFR part 600 subpart B and using the calculation procedures specified in § 600.113–08 of this chapter.

(B) Calculate 5-cycle city and highway carbon-related exhaust emissions using data determined in paragraph (d)(2)(i)(A) of this section according to the calculation procedures in paragraphs (d) through (f) of § 600.114–08 of this chapter.

(C) Calculate a 5-cycle city/highway combined carbon-related exhaust emission value using the city and highway values determined in paragraph (d)(2)(i)(B) of this section.

(D) Subtract the 5-cycle city/highway combined carbon-related exhaust emission value determined with the off-cycle technology operating from the 5-cycle city/highway combined carbon-related exhaust emission value determined with the off-cycle technology not operating. The result is the gram per mile credit amount assigned to the technology.

(ii) *Technology demonstration using alternative EPA-approved methodology.* In cases where the EPA 5-cycle methodology described in paragraph (d)(2)(i) of this section cannot adequately measure the emission reduction attributable to an innovative off-cycle technology, the manufacturer may develop an alternative approach. Prior to a model year in which a manufacturer intends to seek these credits, the manufacturer must submit a detailed analytical plan to EPA. EPA will work with the manufacturer to ensure that an analytical plan will result in appropriate data for the purposes of generating these credits. The alternative demonstration program must be approved in advance by the Administrator and should:

(A) Use modeling, on-road testing, on-road data collection, or other approved analytical or engineering methods;

(B) Be robust, verifiable, and capable of demonstrating the real-world emissions benefit with strong statistical significance;

(C) Result in a demonstration of baseline and controlled emissions over a wide range of driving conditions and number of vehicles such that issues of data uncertainty are minimized;

(D) Result in data on a model type basis unless the manufacturer demonstrates that another basis is appropriate and adequate.

(iii) *Calculation of total off-cycle credits.* Total off-cycle credits in Megagrams of CO_2 (rounded to the nearest whole number) shall be calculated separately for passenger automobiles and light trucks according to the following formula:

Total Credits (Megagrams) = (Credit × Production × VLM) 1,000,000

Where:

Credit = the 5-cycle credit value in grams per mile determined in paragraph (d)(2)(i)(D) or (d)(2)(ii) of this section.

Production = The total number of passenger cars or light trucks, whichever is applicable, produced with the off-cycle technology to which to the credit value determined in paragraph (d)(2)(i)(D) or (d)(2)(ii) of this section applies.

VLM = vehicle lifetime miles, which for passenger cars shall be 195,264 and for light trucks shall be 225,865.

(3) *Notice and opportunity for public comment.* The Administrator will publish a notice of availability in the **Federal Register** notifying the public of a manufacturer's proposed alternative off-cycle credit calculation methodology. The notice will include details regarding the proposed methodology, but will not include any Confidential Business Information. The notice will include instructions on how to comment on the methodology. The Administrator will take public comments into consideration in the final determination, and will notify the public of the final determination. Credits may not be accrued using an approved methodology until the model year following the final approval.

■ 29. A new § 86.1867–12 is added to subpart S to read as follows:

§ 86.1867–12 Optional early CO_2 credit programs.

Manufacturers may optionally generate CO_2 credits in the 2009 through 2011 model years for use in the 2012 and later model years subject to EPA approval and to the provisions of this section. Manufacturers may generate early fleet average credits, air conditioning leakage credits, air conditioning efficiency credits, early advanced technology credits, and early off-cycle technology credits. Manufacturers generating any credits under this section must submit an early credits report to the Administrator as required in this section. The terms "sales" and "sold" as used in this section shall mean vehicles produced and delivered for sale in the states and territories of the United States.

(a) *Early fleet average CO_2 reduction credits.* Manufacturers may optionally generate credits for reductions in their fleet average CO_2 emissions achieved in the 2009 through 2011 model years. To generate early fleet average CO_2 reduction credits, manufacturers must select one of the four pathways described in paragraphs (a)(1) through (4) of this section. The manufacturer may select only one pathway, and that pathway must remain in effect for the 2009 through 2011 model years. Fleet average credits (or debits) must be calculated and reported to EPA for each model year under each selected pathway. Early credits are subject to five year carry-forward restrictions based on the model year in which the credits are generated.

(1) *Pathway 1.* To earn credits under this pathway, the manufacturer shall calculate an average carbon-related exhaust emission value to the nearest one gram per mile for the classes of motor vehicles identified in this paragraph (a)(1), and the results of such calculations will be reported to the Administrator for use in determining compliance with the applicable CO_2 early credit threshold values.

(i) An average carbon-related exhaust emission value calculation will be made for the combined LDV/LDT1 averaging set.

(ii) An average carbon-related exhaust emission value calculation will be made for the combined LDT2/HLDT/MDPV averaging set.

(iii) Average carbon-related exhaust emission values shall be determined according to the provisions of § 600.510–12 of this chapter, except that:

(A) Total U.S. model year sales data will be used, instead of production data.

(B) The average carbon-related exhaust emissions for alcohol fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(ii)(B) of this chapter, without the use of the 0.15 multiplicative factor.

(C) The average carbon-related exhaust emissions for natural gas fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(iii)(B) of this chapter, without the use of the 0.15 multiplicative factor.

(D) The average carbon-related exhaust emissions for alcohol dual fueled model types shall be the value measured using gasoline or diesel fuel, as applicable, and shall be calculated according to the provisions of § 600.510–12(j)(2)(vi) of this chapter, without the use of the 0.15 multiplicative factor and with F = 0. For the 2010 and 2011 model years only, if the California Air Resources Board has approved a manufacturer's request to use a non-zero value of F, the manufacturer may use such an approved value.

(E) The average carbon-related exhaust emissions for natural gas dual fueled model types shall be the value measured using gasoline or diesel fuel, as applicable, and shall be calculated according to the provisions of § 600.510–12(j)(2)(vii) of this chapter, without the use of the 0.15 multiplicative factor and with F = 0. For the 2010 and 2011 model years only, if the California Air Resources Board has approved a manufacturer's request to use a non-zero value of F, the manufacturer may use such an approved value.

(F) Carbon-related exhaust emission values for electric, fuel cell, and plug-in hybrid electric model types shall be included in the fleet average determined under paragraph (a)(1) of this section only to the extent that such vehicles are not being used to generate early advanced technology vehicle credits under paragraph (c) of this section.

(iv) Fleet average CO_2 credit threshold values.

Model year	LDV/LDT1	LDT2/HLDT/MDPV
2009	323	439
2010	301	420
2011	267	390

(v) Credits are earned on the last day of the model year. Manufacturers must calculate, for a given model year, the number of credits or debits it has generated according to the following equation, rounded to the nearest megagram:

CO_2 Credits or Debits (Mg) = [(CO_2 Credit Threshold − Manufacturer's Sales Weighted Fleet Average CO_2 Emissions) × (Total Number of Vehicles Sold) × (Vehicle Lifetime Miles)] 1,000,000

Where:

CO_2 Credit Threshold = the applicable credit threshold value for the model year and vehicle averaging set as determined by paragraph (a)(1)(iv) of this section;

Manufacturer's Sales Weighted Fleet Average CO_2 Emissions = average calculated according to paragraph (a)(1)(iii) of this section;

Total Number of Vehicles Sold = The number of vehicles domestically sold as defined in § 600.511–80 of this chapter; and

Vehicle Lifetime Miles is 195,264 for the LDV/LDT1 averaging set and 225,865 for the LDT2/HLDT/MDPV averaging set.

(vi) Deficits generated against the applicable CO_2 credit threshold values in paragraph (a)(1)(iv) of this section in any averaging set for any of the 2009–2011 model years must be offset using credits accumulated by any averaging set in any of the 2009–2011 model years before determining the number of credits that may be carried forward to the 2012. Deficit carry forward and credit banking provisions of § 86.1865–12 apply to early credits earned under this paragraph (a)(1), except that deficits may not be carried forward from any of the 2009–2011 model years into the 2012 model year, and credits earned in the 2009 model year may not be traded to other manufacturers.

(2) *Pathway 2.* To earn credits under this pathway, manufacturers shall calculate an average carbon-related exhaust emission value to the nearest one gram per mile for the classes of motor vehicles identified in paragraph (a)(1) of this section, and the results of such calculations will be reported to the Administrator for use in determining compliance with the applicable CO_2 early credit threshold values.

(i) Credits under this pathway shall be calculated according to the provisions of paragraph (a)(1) of this section, except credits may only be generated by vehicles sold in a model year in California and in states with a section 177 program in effect in that model year. For the purposes of this section, "section 177 program" means State regulations or other laws that apply to vehicle emissions from any of the following categories of motor vehicles: Passenger cars, light-duty trucks up through 6,000 pounds GVWR, and medium-duty vehicles from 6,001 to 14,000 pounds GVWR, as these categories of motor vehicles are defined in the California Code of Regulations, Title 13, Division 3, Chapter 1, Article 1, Section 1900.

(ii) A deficit in any averaging set for any of the 2009–2011 model years must be offset using credits accumulated by any averaging set in any of the 2009–2011 model years before determining the number of credits that may be carried forward to the 2012 model year. Deficit carry forward and credit banking provisions of § 86.1865–12 apply to early credits earned under this paragraph (a)(1), except that deficits may not be carried forward from any of the 2009–2011 model years into the 2012 model year, and credits earned in the 2009 model year may not be traded to other manufacturers.

(3) *Pathway 3.* Pathway 3 credits are those credits earned under Pathway 2 as described in paragraph (a)(2) of this section in California and in the section 177 states determined in paragraph (a)(2)(i) of this section, combined with additional credits earned in the set of states that does not include California and the section 177 states determined in paragraph (a)(2)(i) of this section and calculated according to this paragraph (a)(3).

(i) Manufacturers shall earn additional credits under Pathway 3 by calculating an average carbon-related exhaust emission value to the nearest one gram per mile for the classes of motor vehicles identified in this paragraph (a)(3). The results of such calculations will be reported to the Administrator for use in determining compliance with the applicable CO_2 early credit threshold values.

(ii) An average carbon-related exhaust emission value calculation will be made for the passenger automobile averaging set. The term "passenger automobile" shall have the meaning given by the Department of Transportation at 49 CFR 523.4 for the specific model year for which the calculation is being made.

(iii) An average carbon-related exhaust emission value calculation will be made for the light truck averaging set. The term "light truck" shall have the meaning given by the Department of Transportation at 49 CFR 523.5 for the specific model year for which the calculation is being made.

(iv) Average carbon-related exhaust emission values shall be determined according to the provisions of § 600.510–12 of this chapter, except that:

(A) Total model year sales data will be used, instead of production data, except that vehicles sold in the section 177 states determined in paragraph (a)(2)(i) of this section shall not be included.

(B) The average carbon-related exhaust emissions for alcohol fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(ii)(B) of this chapter, without the use of the 0.15 multiplicative factor.

(C) The average carbon-related exhaust emissions for natural gas fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(iii)(B) of this chapter, without the use of the 0.15 multiplicative factor.

(D) The average carbon-related exhaust emissions for alcohol dual fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(vi) of this chapter, without the use of the 0.15 multiplicative factor and with F = 0.

(E) The average carbon-related exhaust emissions for natural gas dual fueled model types shall be calculated according to the provisions of § 600.510–12(j)(2)(vii) of this chapter, without the use of the 0.15 multiplicative factor and with F = 0.

(F) Section 600.510–12(j)(3) of this chapter shall not apply. Electric, fuel cell, and plug-in hybrid electric model type carbon-related exhaust emission values shall be included in the fleet average determined under paragraph (a)(1) of this section only to the extent that such vehicles are not being used to generate early advanced technology vehicle credits under paragraph (c) of this section.

(v) Pathway 3 fleet average CO_2 credit threshold values.

(A) For 2009 and 2010 model year passenger automobiles, the fleet average CO_2 credit threshold value is 323 grams/mile.

(B) For 2009 model year light trucks the fleet average CO_2 credit threshold value is 381 grams/mile, or, if the manufacturer chose to optionally meet an alternative manufacturer-specific light truck fuel economy standard calculated under 49 CFR 533.5 for the 2009 model year, the gram per mile fleet average CO_2 credit threshold shall be the CO_2 value determined by dividing 8887 by that alternative manufacturer-specific fuel economy standard and rounding to the nearest whole gram per mile.

(C) For 2010 model year light trucks the fleet average CO_2 credit threshold value is 376 grams/mile, or, if the manufacturer chose to optionally meet an alternative manufacturer-specific light truck fuel economy standard calculated under 49 CFR 533.5 for the 2010 model year, the gram per mile fleet average CO_2 credit threshold shall be the CO_2 value determined by dividing 8887 by that alternative manufacturer-specific fuel economy standard and rounding to the nearest whole gram per mile.

(D) For 2011 model year passenger automobiles the fleet average CO_2 credit threshold value is the value determined by dividing 8887 by the manufacturer-specific passenger automobile fuel economy standard for the 2011 model year determined under 49 CFR 531.5 and rounding to the nearest whole gram per mile.

(E) For 2011 model year light trucks the fleet average CO_2 credit threshold value is the value determined by dividing 8887 by the manufacturer-specific light truck fuel economy standard for the 2011 model year determined under 49 CFR 533.5 and rounding to the nearest whole gram per mile.

(vi) Credits are earned on the last day of the model year. Manufacturers must calculate, for a given model year, the number of credits or debits it has generated according to the following equation, rounded to the nearest megagram:

$$CO_2 \text{ Credits or Debits (Mg)} = [(CO_2 \text{ Credit Threshold} - \text{Manufacturer's Sales Weighted Fleet Average } CO_2 \text{ Emissions}) \times (\text{Total Number of Vehicles Sold}) \times (\text{Vehicle Lifetime Miles})] \quad 1{,}000{,}000$$

Where:

CO_2 Credit Threshold = the applicable credit threshold value for the model year and vehicle averaging set as determined by paragraph (a)(3)(vii) of this section;

Manufacturer's Sales Weighted Fleet Average CO_2 Emissions = average calculated according to paragraph (a)(3)(vi) of this section;

Total Number of Vehicles Sold = The number of vehicles domestically sold as defined in § 600.511–80 of this chapter except that vehicles sold in the section 177 states determined in paragraph (a)(2)(i) of this section shall not be included; and

Vehicle Lifetime Miles is 195,264 for the LDV/LDT1 averaging set and 225,865 for the LDT2/HLDT/MDPV averaging set.

(vii) Deficits in any averaging set for any of the 2009–2011 model years must be offset using credits accumulated by any averaging set in any of the 2009–2011 model years before determining the number of credits that may be carried forward to the 2012. Deficit carry forward and credit banking provisions of § 86.1865–12 apply to early credits earned under this paragraph (a)(3), except that deficits may not be carried forward from any of the 2009–2011 model years into the 2012 model year, and credits earned in the 2009 model year may not be traded to other manufacturers.

(4) *Pathway 4.* Pathway 4 credits are those credits earned under Pathway 3 as described in paragraph (a)(3) of this section in the set of states that does not include California and the section 177 states determined in paragraph (a)(2)(i) of this section and calculated according to paragraph (a)(3) of this section. Credits may only be generated by vehicles sold in the set of states that does not include the section 177 states determined in paragraph (a)(2)(i) of this section.

(b) *Early air conditioning leakage and efficiency credits.* (1) Manufacturers may optionally generate air conditioning refrigerant leakage credits according to the provisions of § 86.1866–12(b) and/or air conditioning efficiency credits according to the provisions of § 86.1866–12(c) in model years 2009 through 2011. The early credits are subject to five year carry forward limits based on the model year in which the credits are generated. Credits must be tracked by model type and model year.

(2) Manufacturers that are required to comply with California greenhouse gas requirements in model years 2009–2011 (for California and section 177 states) may not generate early air conditioning credits for vehicles sold in California and the section 177 states as determined in paragraph (a)(2)(i) of this section.

(c) *Early advanced technology vehicle incentive.* Vehicles eligible for this incentive are electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles, as those terms are defined in § 86.1803–01. If a manufacturer chooses to not include electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles in their fleet averages calculated under any of the early credit pathways described in paragraph (a) of this section, the manufacturer may generate early advanced technology vehicle credits pursuant to this paragraph (c).

(1) The manufacturer shall record the sales and carbon-related exhaust emission values of eligible vehicles by model type and model year for model years 2009 through 2011 and report these values to the Administrator under paragraph (e) of this section.

(2) Manufacturers may use the 2009 through 2011 eligible vehicles in their fleet average calculations starting with the 2012 model year, subject to a five-year carry-forward limitation.

(i) Eligible 2009 model year vehicles may be used in the calculation of a manufacturer's fleet average carbon-related exhaust emissions in the 2012 through 2014 model years.

(ii) Eligible 2010 model year vehicles may be used in the calculation of a manufacturer's fleet average carbon-related exhaust emissions in the 2012 through 2015 model years.

(iii) Eligible 2011 model year vehicles may be used in the calculation of a manufacturer's fleet average carbon-related exhaust emissions in the 2012 through 2016 model years.

(3)(i) To use the advanced technology vehicle incentive, the manufacturer will apply the 2009, 2010, and/or 2011 model type sales volumes and their model type emission levels to the manufacturer's fleet average calculation.

(ii) The early advanced technology vehicle incentive must be used to offset a deficit in one of the 2012 through 2016 model years, as appropriate under paragraph (c)(2) of this section.

(iii) The advanced technology vehicle sales and emission values may be included in a fleet average calculation for passenger automobiles or light trucks, but may not be used to generate credits in the model year in which they are included or in the averaging set in which they are used. Use of early advanced technology vehicle credits is limited to offsetting a deficit that would otherwise be generated without the use of those credits. Manufacturers shall report the use of such credits in their model year report for the model year in which the credits are used.

(4) Manufacturers may use zero grams/mile to represent the carbon-related exhaust emission values for the electric operation of 2009 through 2011 model year electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles subject to the limitations in § 86.1866–12(a). The 2009 through 2011 model year vehicles using zero grams per mile shall count against the 200,000 or 300,000 caps on use of this credit value, whichever is applicable under § 86.1866–12(a).

(d) *Early off-cycle technology credits.* Manufacturers may optionally generate credits for the implementation of certain CO_2-reducing technologies according to the provisions of § 86.1866–12(d) in model years 2009 through 2011. The early credits are subject to five year carry forward limits based on the model year in which the credits are generated. Credits must be tracked by model type and model year.

(e) *Early credit reporting requirements.* Each manufacturer shall submit a report to the Administrator, known as the early credits report, that reports the credits earned in the 2009 through 2011 model years under this section.

(1) The report shall contain all information necessary for the calculation of the manufacturer's early credits in each of the 2009 through 2011 model years.

(2) The early credits report shall be in writing, signed by the authorized representative of the manufacturer and shall be submitted no later than 90 days after the end of the 2011 model year.

(3) Manufacturers using one of the optional early fleet average CO_2 reduction credit pathways described in paragraph (a) of this section shall report the following information separately for the appropriate averaging sets (*e.g.* LDV/LDT1 and LDT2/HLDT/MDPV averaging sets for pathways 1 and 2; LDV, LDT/2011 MDPV, LDV/LDT1 and LDT2/HLDT/MDPV averaging sets for Pathway 3; LDV and LDT/2011 MDPV averaging sets for Pathway 4):

(i) The pathway that they have selected (1, 2, 3, or 4).

(ii) A carbon-related exhaust emission value for each model type of the manufacturer's product line calculated according to paragraph (a) of this section.

(iii) The manufacturer's average carbon-related exhaust emission value calculated according to paragraph (a) of this section for the applicable averaging set and region and all data required to complete this calculation.

(iv) The credits earned for each averaging set, model year, and region, as applicable.

(4) Manufacturers calculating early air conditioning leakage and/or efficiency credits under paragraph (b) of this section shall report the following information for each model year separately for passenger automobiles and light trucks and for each air conditioning system used to generate credits:

(i) A description of the air conditioning system.

(ii) The leakage credit value and all the information required to determine this value.

(iii) The total credits earned for each averaging set, model year, and region, as applicable.

(5) Manufacturers calculating early advanced technology vehicle credits under paragraph (c) of this section shall report, for each model year and separately for passenger automobiles and light trucks, the following information:

(i) The number of each model type of eligible vehicle sold.

(ii) The carbon-related exhaust emission value by model type and model year.

(6) Manufacturers calculating early off-cycle technology credits under paragraph (d) of this section shall report, for each model year and separately for passenger automobiles and light trucks, all test results and data required for calculating such credits.

PART 600—FUEL ECONOMY AND CARBON-RELATED EXHAUST EMISSIONS OF MOTOR VEHICLES

■ 30. The authority citation for part 600 continues to read as follows:

Authority: 49 U.S.C. 32901–23919q, Pub. L. 109–58.

■ 31. The heading for part 600 is revised as set forth above.

Subpart A—Fuel Economy and Carbon-Related Exhaust Emission Regulations for 1977 and Later Model Year Automobiles—General Provisions

■ 32. The heading for subpart A is revised as set forth above.

■ 33. A new § 600.001–12 is added to subpart A to read as follows:

§ 600.001–12 General applicability.

(a) The provisions of this subpart are applicable to 2012 and later model year automobiles and to the manufacturers of 2012 and later model year automobiles.

(b) *Fuel economy and related emissions data.* Unless stated otherwise, references to fuel economy or fuel economy data in this subpart shall also be interpreted to mean the related exhaust emissions of CO_2, HC, and CO, and where applicable for alternative fuel vehicles, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC and CH_4. References to average fuel economy shall be interpreted to also mean average carbon-related exhaust emissions. References to fuel economy data vehicles shall also be meant to refer to vehicles tested for carbon-related exhaust emissions for the purpose of demonstrating compliance with fleet average CO_2 standards in § 86.1818–12 of this chapter.

■ 34. Section 600.002–08 is amended as follows:

■ a. By adding the definition for "Base tire."

■ b. By adding the definition for "Carbon-related exhaust emissions."

■ c. By adding the definition for "Electric vehicle."

■ d. By adding the definition for "Footprint."

■ e. By adding the definition for "Fuel cell."

■ f. By adding the definition for "Fuel cell vehicle."

■ g. By adding the definition for "Hybrid electric vehicle."

■ h. By revising the definition for "Non-passenger automobile."

■ i. By revising the definition for "Passenger automobile."

■ j. By adding the definition for "Plug-in hybrid electric vehicle."

■ k. By adding the definition for "Track width."

■ l. By adding the definition for "Wheelbase."

§ 600.002–08 Definitions.

* * * * *

Base tire means the tire specified as standard equipment by the manufacturer.

* * * * *

Carbon-related exhaust emissions (CREE) means the summation of the carbon-containing constituents of the exhaust emissions, with each constituent adjusted by a coefficient representing the carbon weight fraction of each constituent relative to the CO_2 carbon weight fraction, as specified in § 600.113–08. For example, carbon-related exhaust emissions (weighted 55 percent city and 45 percent highway) are used to demonstrate compliance with fleet average CO_2 emission standards outlined in § 86.1818(c) of this chapter.

* * * * *

Electric vehicle has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Footprint has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Fuel cell has the meaning given in § 86.1803–01 of this chapter.

Fuel cell vehicle has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Hybrid electric vehicle (HEV) has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Non-passenger automobile has the meaning given by the Department of Transportation at 49 CFR 523.5. This term is synonymous with "light truck."

* * * * *

Passenger automobile has the meaning given by the Department of Transportation at 49 CFR 523.4.

* * * * *

Plug-in hybrid electric vehicle (PHEV) has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Track width has the meaning given in § 86.1803–01 of this chapter.

* * * * *

Wheelbase has the meaning given in § 86.1803–01 of this chapter.

* * * * *

■ 35. Section 600.006–08 is amended as follows:

■ a. By revising the section heading.

■ b. By revising paragraph (b)(2)(ii).

■ c. By revising paragraph (b)(2)(iv).

■ d. By revising paragraph (c) introductory text.

■ e. By adding paragraph (c)(5).

■ f. By revising paragraph (e).

■ g. By revising paragraph (g)(3).

§ 600.006–08 Data and information requirements for fuel economy data vehicles.

* * * * *

(b) * * *

(2) * * *

(ii) In the case of electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles, a description of all maintenance to electric motor, motor controller, battery configuration, or other components performed within 2,000 miles prior to fuel economy testing.

* * * * *

(iv) In the case of electric vehicles, plug-in hybrid electric vehicles, and hybrid electric vehicles, a copy of calibrations for the electric motor, motor controller, battery configuration, or other components on the test vehicle as well as the design tolerances.

* * * * *

(c) The manufacturer shall submit the following fuel economy data:

* * * * *

(5) Starting with the 2012 model year, the data submitted according to paragraphs (c)(1) through (c)(4) of this section shall include total HC, CO, CO_2, and, where applicable for alternative fuel vehicles, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC and CH_4. Manufacturers incorporating N_2O and CH_4 emissions in their fleet average carbon-related exhaust emissions as allowed under § 86.1818(f)(2) of this chapter shall also submit N_2O and CH_4 emission data where applicable. The fuel economy and CO_2 emission test results shall be adjusted in accordance with paragraph (g) of this section.

* * * * *

(e) In lieu of submitting actual data from a test vehicle, a manufacturer may provide fuel economy and carbon-related exhaust emission values derived from a previously tested vehicle, where the fuel economy and carbon-related exhaust emissions are expected to be equivalent (or less fuel-efficient and with higher carbon-related exhaust emissions). Additionally, in lieu of submitting actual data from a test vehicle, a manufacturer may provide fuel economy and carbon-related exhaust emission values derived from an analytical expression, *e.g.*, regression analysis. In order for fuel economy and carbon-related exhaust emission values derived from analytical methods to be accepted, the expression (form and coefficients) must have been approved by the Administrator.

* * * * *

(g) * * *

(3)(i) The manufacturer shall adjust all fuel economy test data generated by vehicles with engine-drive system combinations with more than 6,200 miles by using the following equation:

$$FE_{4,000mi} = FE_T[0.979 + 5.25 \times 10^{-6}(mi)]^{-1}$$

Where:

$FE_{4,000mi}$ = Fuel economy data adjusted to 4,000-mile test point rounded to the nearest 0.1 mpg.

FE_T = Tested fuel economy value rounded to the nearest 0.1 mpg.

mi = System miles accumulated at the start of the test rounded to the nearest whole mile.

(ii)(A) The manufacturer shall adjust all carbon-related exhaust emission (CREE) test data generated by vehicles with engine-drive system combinations with more than 6,200 miles by using the following equation:

$$CREE_{4,000mi} = CREE_T[0.979 + 5.25 \times 10^{-6}(mi)]$$

Where:

$CREE_{4,000mi}$ = CREE emission data adjusted to 4,000-mile test point.

$CREE_T$ = Tested emissions value of CREE in grams per mile.

mi = System miles accumulated at the start of the test rounded to the nearest whole mile.

(B) Emissions test values and results used and determined in the calculations in paragraph (g)(3)(ii) of this section shall be rounded in accordance with § 86.1837–01 of this chapter as applicable. CREE values shall be rounded to the nearest gram per mile.

* * * * *

■ 36. Section 600.007–08 is amended as follows:

■ a. By revising paragraph (b)(4) through (6).

■ b. By revising paragraph (c).

■ c. By revising paragraph (f) introductory text.

§ 600.007–08 Vehicle acceptability.

* * * * *

(b) * * *

(4) Each fuel economy data vehicle must meet the same exhaust emission standards as certification vehicles of the respective engine-system combination during the test in which the city fuel economy test results are generated. This may be demonstrated using one of the following methods:

(i) The deterioration factors established for the respective engine-system combination per § 86.1841–01 of this chapter as applicable will be used; or

(ii) The fuel economy data vehicle will be equipped with aged emission control components according to the provisions of § 86.1823–08 of this chapter.

(5) The calibration information submitted under § 600.006(b) must be representative of the vehicle configuration for which the fuel economy and carbon-related exhaust emissions data were submitted.

(6) Any vehicle tested for fuel economy or carbon-related exhaust emissions purposes must be representative of a vehicle which the manufacturer intends to produce under the provisions of a certificate of conformity.

* * * * *

(c) If, based on review of the information submitted under § 600.006(b), the Administrator determines that a fuel economy data vehicle meets the requirements of this section, the fuel economy data vehicle will be judged to be acceptable and fuel economy and carbon-related exhaust emissions data from that fuel economy data vehicle will be reviewed pursuant to § 600.008.

* * * * *

(f) All vehicles used to generate fuel economy and carbon-related exhaust emissions data, and for which emission standards apply, must be covered by a certificate of conformity under part 86 of this chapter before:

* * * * *

■ 37. Section 600.008–08 is amended by revising the section heading and paragraph (a)(1) to read as follows:

§ 600.008–08 Review of fuel economy and carbon-related exhaust emission data, testing by the Administrator.

(a) *Testing by the Administrator.* (1)(i) The Administrator may require that any one or more of the test vehicles be submitted to the Agency, at such place or places as the Agency may designate, for the purposes of conducting fuel economy tests. The Administrator may specify that such testing be conducted at the manufacturer's facility, in which case instrumentation and equipment specified by the Administrator shall be made available by the manufacturer for test operations. The tests to be performed may comprise the FTP, highway fuel economy test, US06, SC03, or Cold temperature FTP or any combination of those tests. Any testing conducted at a manufacturer's facility pursuant to this paragraph shall be scheduled by the manufacturer as promptly as possible.

(ii) Starting with the 2012 model year, evaluations, testing, and test data described in this section pertaining to fuel economy shall also be performed for carbon-related exhaust emissions, except that carbon-related exhaust emissions shall be arithmetically averaged instead of harmonically averaged, and in cases where the manufacturer selects the lowest of several fuel economy results to represent the vehicle, the manufacturer shall select the carbon-related exhaust emissions value from the test results associated with the lowest fuel economy results.

* * * * *

■ 38. Section 600.010–08 is amended by revising paragraph (d) to read as follows:

§ 600.010–08 Vehicle test requirements and minimum data requirements.

* * * * *

(d) *Minimum data requirements for the manufacturer's average fuel economy and average carbon-related exhaust emissions.* For the purpose of calculating the manufacturer's average fuel economy and average carbon-related exhaust emissions under § 600.510, the manufacturer shall submit FTP (city) and HFET (highway) test data representing at least 90 percent of the manufacturer's actual model year production, by configuration, for each category identified for calculation under § 600.510–08(a).

■ 39. Section 600.011–93 is amended to read as follows:

§ 600.011–93 Reference materials.

(a) *Incorporation by reference.* The documents referenced in this section have been incorporated by reference in this part. The incorporation by reference was approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. Copies may be inspected at the U.S. Environmental Protection Agency, Office of Air and Radiation, 1200 Pennsylvania Ave., NW., Washington, DC 20460, phone (202) 272–0167, or at the National Archives and Records Administration (NARA). For information on the availability of this material at NARA, call 202–741–6030, or go to: *http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html* and is available from the sources listed below:

(b) *ASTM.* The following material is available from the American Society for Testing and Materials. Copies of these materials may be obtained from American Society for Testing and Materials, ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428–2959, phone 610–832–9585. *http://www.astm.org/.*

(1) ASTM E 29–67 (Reapproved 1973) Standard Recommended Practice for Indicating Which Places of Figures Are To Be Considered Significant in Specified Limiting Values, IBR approved for §§ 600.002–93 and 600.002–08.

(2) ASTM D 1298–85 (Reapproved 1990) Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method, IBR approved for §§ 600.113–93, 600.510–93, 600.113–08, 600.510–08, and 600.510–12.

(3) ASTM D 3343–90 Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels, IBR approved for §§ 600.113–93 and 600.113–08.

(4) ASTM D 3338–92 Standard Test Method for Estimation of Net Heat of Combustion of Aviation Fuels, IBR approved for §§ 600.113–93 and 600.113–08.

(5) ASTM D 240–92 Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter, IBR approved for §§ 600.113–93, 600.510–93, 600.113–08, and 600.510–08.

(6) ASTM D975–04c Standard Specification for Diesel Fuel Oils, IBR approved for § 600.107–08.

(7) ASTM D 1945–91 Standard Test Method for Analysis of Natural Gas By Gas Chromatography, IBR approved for §§ 600.113–93, 600.113–08.

(c) *SAE Material.* The following material is available from the Society of

Automotive Engineers. Copies of these materials may be obtained from Society of Automotive Engineers World Headquarters, 400 Commonwealth Dr., Warrendale, PA 15096–0001, phone (877) 606–7323 (U.S. and Canada) or (724) 776–4970 (outside the U.S. and Canada), or at *http://www.sae.org.*

(1) Motor Vehicle Dimensions—Recommended Practice SAE 1100a (Report of Human Factors Engineering Committee, Society of Automotive Engineers, approved September 1973 as revised September 1975), IBR approved for §§ 600.315–08 and 600.315–82.

(2) [Reserved]

Subpart B—Fuel Economy and Carbon-Related Exhaust Emission Regulations for 1978 and Later Model Year Automobiles—Test Procedures

■ 40. The heading for subpart B is revised as set forth above.

■ 41. A new § 600.101–12 is added to subpart B to read as follows:

§ 600.101–12 General applicability.

(a) The provisions of this subpart are applicable to 2012 and later model year automobiles and to the manufacturers of 2012 and later model year automobiles.

(b) *Fuel economy and carbon-related emissions data.* Unless stated otherwise, references to fuel economy or fuel economy data in this subpart shall also be interpreted to mean the related exhaust emissions of CO_2, HC, and CO, and where applicable for alternative fuel vehicles, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC and CH_4. References to average fuel economy shall be interpreted to also mean average carbon-related exhaust emissions.

■ 42. Section 600.111–08 is amended by revising paragraph (f) to read as follows:

§ 600.111–08 Test procedures.

* * * * *

(f) *Special Test Procedures.* The Administrator may prescribe test procedures, other than those set forth in this Subpart B, for any vehicle which is not susceptible to satisfactory testing and/or testing results by the procedures set forth in this part. For example, special test procedures may be used for advanced technology vehicles, including, but not limited to battery electric vehicles, fuel cell vehicles, plug-in hybrid electric vehicles and vehicles equipped with hydrogen internal combustion engines. Additionally, the Administrator may conduct fuel economy and carbon-related exhaust emission testing using the special test procedures approved for a specific vehicle.

■ 43. A new § 600.113–12 is added to subpart B to read as follows:

§ 600.113–12 Fuel economy and carbon-related exhaust emission calculations for FTP, HFET, US06, SC03 and cold temperature FTP tests.

The Administrator will use the calculation procedure set forth in this paragraph for all official EPA testing of vehicles fueled with gasoline, diesel, alcohol-based or natural gas fuel. The calculations of the weighted fuel economy and carbon-related exhaust emission values require input of the weighted grams/mile values for total hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2); and, additionally for methanol-fueled automobiles, methanol (CH_3OH) and formaldehyde (HCHO); and, additionally for ethanol-fueled automobiles, methanol (CH_3OH), ethanol (C_2H_5OH), acetaldehyde (C_2H_4O), and formaldehyde (HCHO); and additionally for natural gas-fueled vehicles, non-methane hydrocarbons (NMHC) and methane (CH_4). For manufacturers selecting the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter the calculations of the carbon-related exhaust emissions require the input of grams/mile values for nitrous oxide (N_2O) and methane (CH_4). Emissions shall be determined for the FTP, HFET, US06, SC03 and cold temperature FTP tests. Additionally, the specific gravity, carbon weight fraction and net heating value of the test fuel must be determined. The FTP, HFET, US06, SC03 and cold temperature FTP fuel economy and carbon-related exhaust emission values shall be calculated as specified in this section. An example fuel economy calculation appears in Appendix II of this part.

(a) Calculate the FTP fuel economy.

(1) Calculate the weighted grams/mile values for the FTP test for CO_2, HC, and CO, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 as specified in § 86.144(b) of this chapter. Measure and record the test fuel's properties as specified in paragraph (f) of this section.

(2) Calculate separately the grams/mile values for the cold transient phase, stabilized phase and hot transient phase of the FTP test. For vehicles with more than one source of propulsion energy, one of which is a rechargeable energy storage system, or vehicles with special features that the Administrator determines may have a rechargeable energy source, whose charge can vary during the test, calculate separately the grams/mile values for the cold transient phase, stabilized phase, hot transient phase and hot stabilized phase of the FTP test.

(b) Calculate the HFET fuel economy.

(1) Calculate the mass values for the highway fuel economy test for HC, CO and CO_2, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 as specified in § 86.144(b) of this chapter. Measure and record the test fuel's properties as specified in paragraph (f) of this section.

(2) Calculate the grams/mile values for the highway fuel economy test for HC, CO and CO_2, and where applicable CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 by dividing the mass values obtained in paragraph (b)(1) of this section, by the actual distance traveled, measured in miles, as specified in § 86.135(h) of this chapter.

(c) Calculate the cold temperature FTP fuel economy.

(1) Calculate the weighted grams/mile values for the cold temperature FTP test for HC, CO and CO_2, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 as specified in § 86.144(b) of this chapter. For 2008 through 2010 diesel-fueled vehicles, HC measurement is optional.

(2) Calculate separately the grams/mile values for the cold transient phase, stabilized phase and hot transient phase of the cold temperature FTP test in § 86.244 of this chapter.

(3) Measure and record the test fuel's properties as specified in paragraph (f) of this section.

(d) Calculate the US06 fuel economy.

(1) Calculate the total grams/mile values for the US06 test for HC, CO and CO_2, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 as specified in § 86.144(b) of this chapter.

(2) Calculate separately the grams/mile values for HC, CO and CO_2, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4, for both the US06 City phase and the US06 Highway phase of the US06 test as specified in § 86.164 of this chapter. In lieu of directly measuring the emissions of the separate city and highway phases of the US06 test according to the provisions of § 86.159 of this chapter, the manufacturer may, with the advance approval of the Administrator and using good engineering judgment, optionally analytically determine the grams/mile values for the city and highway phases of the US06 test. To analytically determine US06 City and US06 Highway phase emission results, the manufacturer shall multiply the US06 total grams/mile values determined in paragraph (d)(1) of this section by the estimated proportion of fuel use for the city and highway phases relative to the total US06 fuel use. The manufacturer may estimate the proportion of fuel use

for the US06 City and US06 Highway phases by using modal CO_2, HC, and CO emissions data, or by using appropriate OBD data (*e.g.,* fuel flow rate in grams of fuel per second), or another method approved by the Administrator.

(3) Measure and record the test fuel's properties as specified in paragraph (f) of this section.

(e) Calculate the SC03 fuel economy.

(1) Calculate the grams/mile values for the SC03 test for HC, CO and CO_2, and where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O and CH_4 as specified in § 86.144(b) of this chapter.

(2) Measure and record the test fuel's properties as specified in paragraph (f) of this section.

(f) *Fuel property determination and analysis.*

(1) Gasoline test fuel properties shall be determined by analysis of a fuel sample taken from the fuel supply. A sample shall be taken after each addition of fresh fuel to the fuel supply. Additionally, the fuel shall be resampled once a month to account for any fuel property changes during storage. Less frequent resampling may be permitted if EPA concludes, on the basis of manufacturer-supplied data, that the properties of test fuel in the manufacturer's storage facility will remain stable for a period longer than one month. The fuel samples shall be analyzed to determine the following fuel properties:

(i) Specific gravity measured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

(ii) Carbon weight fraction measured using ASTM D 3343–90 "Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels" (incorporated by reference at § 600.011–93).

(iii) Net heating value (Btu/lb) determined using ASTM D 3338–92 "Standard Test Method for Estimation of Net Heat of Combustion of Aviation Fuels" (incorporated by reference at § 600.011–93).

(2) Methanol test fuel shall be analyzed to determine the following fuel properties:

(i) Specific gravity using either:

(A) ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93) for the blend, or:

(B) ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93) for the gasoline fuel component and also for the methanol fuel component and combining as follows:

$$SG = SGg \times \text{volume fraction gasoline} + SGm \times \text{volume fraction methanol.}$$

(ii)(A) Carbon weight fraction using the following equation:

$$CWF = CWFg \times MFg + 0.375 \times MFm$$

Where:

CWFg = Carbon weight fraction of gasoline portion of blend measured using ASTM D 3343–90 "Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels" (incorporated by reference at § 600.011–93).

MFg = Mass fraction gasoline = $(G \times SGg)/(G \times SGg + M \times SGm)$

MFm = Mass fraction methanol = $(M \times SGm)/(G \times SGg + M \times SGm)$

Where:

G = Volume fraction gasoline.

M = Volume fraction methanol.

SGg = Specific gravity of gasoline as measured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

SGm = Specific gravity of methanol as measured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

(B) Upon the approval of the Administrator, other procedures to measure the carbon weight fraction of the fuel blend may be used if the manufacturer can show that the procedures are superior to or equally as accurate as those specified in this paragraph (f)(2)(ii).

(3) Natural gas test fuel shall be analyzed to determine the following fuel properties:

(i) Fuel composition measured using ASTM D 1945–91 "Standard Test Method for Analysis of Natural Gas By Gas Chromatography" (incorporated by reference at § 600.011–93).

(ii) Specific gravity measured as based on fuel composition per ASTM D 1945–91 "Standard Test Method for Analysis of Natural Gas by Gas Chromatography" (incorporated by reference at § 600.011–93).

(iii) Carbon weight fraction, based on the carbon contained only in the hydrocarbon constituents of the fuel. This equals the weight of carbon in the hydrocarbon constituents divided by the total weight of fuel.

(iv) Carbon weight fraction of the fuel, which equals the total weight of carbon in the fuel (i.e, includes carbon contained in hydrocarbons and in CO_2) divided by the total weight of fuel.

(4) Ethanol test fuel shall be analyzed to determine the following fuel properties:

(i) Specific gravity using either:

(A) ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93) for the blend. or:

(B) ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93) for the gasoline fuel component and also for the methanol fuel component and combining as follows.

$$SG = SGg \times \text{volume fraction gasoline} + SGm \times \text{volume fraction ethanol.}$$

(ii)(A) Carbon weight fraction using the following equation:

$$CWF = CWFg \times MFg + 0.521 \times MFe$$

Where:

CWFg = Carbon weight fraction of gasoline portion of blend measured using ASTM D 3343–90 "Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels" (incorporated by reference at § 600.011–93).

MFg = Mass fraction gasoline = $(G \times SGg)/(G \times SGg + E \times SGm)$

MFe = Mass fraction ethanol = $(E \times SGm)/(G \times SGg + E \times SGm)$

Where:

G = Volume fraction gasoline.

E = Volume fraction ethanol.

SGg = Specific gravity of gasoline as measured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

SGm = Specific gravity of ethanol as measured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

(B) Upon the approval of the Administrator, other procedures to measure the carbon weight fraction of the fuel blend may be used if the manufacturer can show that the procedures are superior to or equally as accurate as those specified in this paragraph (f)(2)(ii).

(g) Calculate separate FTP, highway, US06, SC03 and Cold temperature FTP fuel economy and carbon-related exhaust emissions from the grams/mile values for total HC, CO, CO_2 and, where applicable, CH_3OH, C_2H_5OH, C_2H_4O, HCHO, NMHC, N_2O, and CH_4, and the test fuel's specific gravity, carbon weight fraction, net heating value, and additionally for natural gas, the test fuel's composition.

(1) *Emission values for fuel economy calculations.* The emission values (obtained per paragraph (a) through (e) of this section, as applicable) used in the calculations of fuel economy in this section shall be rounded in accordance with §§ 86.094–26(a)(6)(iii) or 86.1837–01 of this chapter as applicable. The CO_2 values (obtained per this section, as applicable) used in each calculation of fuel economy in this section shall be rounded to the nearest gram/mile.

(2) Emission values for carbon-related exhaust emission calculations.

(i) If the emission values (obtained per paragraph (a) through (e) of this section, as applicable) were obtained from testing with aged exhaust emission control components as allowed under § 86.1823–08 of this chapter, then these test values shall be used in the calculations of carbon-related exhaust emissions in this section.

(ii) If the emission values (obtained per paragraph (a) through (e) of this section, as applicable) were not obtained from testing with aged exhaust emission control components as allowed under § 86.1823–08 of this chapter, then these test values shall be adjusted by the appropriate deterioration factor determined according to § 86.1823–08 of this chapter before being used in the calculations of carbon-related exhaust emissions in this section. For vehicles within a test group, the appropriate NMOG deterioration factor may be used in lieu of the deterioration factors for CH_3OH, C_2H_5OH, and/or C_2H_4O emissions.

(iii) The emission values determined in paragraph (g)(2)(A) or (B) of this section shall be rounded in accordance with § 86.094–26(a)(6)(iii) or § 86.1837–01 of this chapter as applicable. The CO_2 values (obtained per this section, as applicable) used in each calculation of carbon-related exhaust emissions in this section shall be rounded to the nearest gram/mile.

(iv) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, N_2O and CH_4 emission values for use in the calculation of carbon-related exhaust emissions in this section shall be the values determined according to paragraph (g)(2)(iv)(A), (B), or (C) of this section.

(A) The FTP and HFET test values as determined for the emission data vehicle according to the provisions of § 86.1835–01 of this chapter. These values shall apply to all vehicles tested under this section that are included in the test group represented by the emission data vehicle and shall be adjusted by the appropriate deterioration factor determined according to § 86.1823–08 of this chapter before being used in the calculations of carbon-related exhaust emissions in this section.

(B) The FTP and HFET test values as determined according to testing conducted under the provisions of this subpart. These values shall be adjusted by the appropriate deterioration factor determined according to § 86.1823–08 of this chapter before being used in the calculations of carbon-related exhaust emissions in this section.

(C) For the 2012 through 2014 model years only, manufacturers may use an assigned value of 0.010 g/mi for N_2O FTP and HFET test values. This value is not required to be adjusted by a deterioration factor.

(3) The specific gravity and the carbon weight fraction (obtained per paragraph (f) of this section) shall be recorded using three places to the right of the decimal point. The net heating value (obtained per paragraph (f) of this section) shall be recorded to the nearest whole Btu/lb.

(4) For the purpose of determining the applicable in-use emission standard under § 86.1818–12(d) of this chapter, the combined city/highway carbon-related exhaust emission value for a vehicle subconfiguration is calculated by arithmetically averaging the FTP-based city and HFET-based highway carbon-related exhaust emission values, as determined in § 600.113(a) and (b) of this section for the subconfiguration, weighted 0.55 and 0.45 respectively, and rounded to the nearest tenth of a gram per mile.

(h)(1) For gasoline-fueled automobiles tested on test fuel specified in § 86.113–04(a) of this chapter, the fuel economy in miles per gallon is to be calculated using the following equation and rounded to the nearest 0.1 miles per gallon:

$$mpg = (5174 \times 10^4 \times CWF \times SG)/[((CWF \times HC) + (0.429 \times CO) + (0.273 \times CO_2)) \times ((0.6 \times SG \times NHV) + 5471)]$$

Where:

HC = Grams/mile HC as obtained in paragraph (g) of this section.
CO = Grams/mile CO as obtained in paragraph (g) of this section.
CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.
CWF = Carbon weight fraction of test fuel as obtained in paragraph (g) of this section.
NHV = Net heating value by mass of test fuel as obtained in paragraph (g) of this section.
SG = Specific gravity of test fuel as obtained in paragraph (g) of this section.

(2)(i) For 2012 and later model year gasoline-fueled automobiles tested on test fuel specified in § 86.113–04(a) of this chapter, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (CWF/0.273 \times HC) + (1.571 \times CO) + CO_2$$

Where:

CREE means the carbon-related exhaust emissions as defined in § 600.002–08.
HC = Grams/mile HC as obtained in paragraph (g) of this section.
CO = Grams/mile CO as obtained in paragraph (g) of this section.
CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.
CWF = Carbon weight fraction of test fuel as obtained in paragraph (g) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year gasoline-fueled automobiles tested on test fuel specified in § 86.113–04(a) of this chapter is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = [(CWF/0.273) \times NMHC] + (1.571 \times CO) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$$

Where:

CREE means the carbon-related exhaust emissions as defined in § 600.002–08.
NMHC = Grams/mile NMHC as obtained in paragraph (g) of this section.
CO = Grams/mile CO as obtained in paragraph (g) of this section.
CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.
N_2O = Grams/mile N_2O as obtained in paragraph (g) of this section.
CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.
CWF = Carbon weight fraction of test fuel as obtained in paragraph (g) of this section.

(i)(1) For diesel-fueled automobiles, calculate the fuel economy in miles per gallon of diesel fuel by dividing 2778 by the sum of three terms and rounding the quotient to the nearest 0.1 mile per gallon:

(i)(A) 0.866 multiplied by HC (in grams/miles as obtained in paragraph (g) of this section), or

(B) Zero, in the case of cold FTP diesel tests for which HC was not collected, as permitted in § 600.113–08(c);

(ii) 0.429 multiplied by CO (in grams/mile as obtained in paragraph (g) of this section); and

(iii) 0.273 multiplied by CO_2 (in grams/mile as obtained in paragraph (g) of this section).

(2)(i) For 2012 and later model year diesel-fueled automobiles, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (3.172 \times HC) + (1.571 \times CO) + CO_2$$

Where:

CREE means the carbon-related exhaust emissions as defined in § 600.002–08.

HC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year diesel-fueled automobiles is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (3.172 \times NMHC) + (1.571 \times CO) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$$

Where:

CREE means the carbon-related exhaust emissions as defined in § 600.002–08.

NMHC = Grams/mile NMHC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g) of this section.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.

(j)(1) For methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol, the fuel economy in miles per gallon is to be calculated using the following equation:

$$mpg = (CWF \times SG \times 3781.8)/((CWF_{exHC} \times HC) + (0.429 \times CO) + (0.273 \times CO_2) + (0.375 \times CH_3OH) + (0.400 \times HCHO))$$

Where:

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(2)(ii) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(2)(i) of this section.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in paragraph (f)(2)(ii) of this section (for M100 fuel, CWF_{exHC} = 0.866).

HC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

(2)(i) For 2012 and later model year methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (CWF_{exHC}/0.273 \times HC) + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in (f)(2)(ii) of this section (for M100 fuel, CWF_{exHC} = 0.866).

HC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = [(CWF_{exHC}/0.273) \times NMHC] + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in (f)(2)(ii) of this section (for M100 fuel, CWF_{exHC} = 0.866).

NMHC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g) of this section.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.

(k)(1) For automobiles fueled with natural gas, the fuel economy in miles per gallon of natural gas is to be calculated using the following equation:

$$mpg_e = \frac{CWF_{HC/NG} \times D_{NG} \times 121.5}{(0.749 \times CH_4) + (CWF_{NMHC} \times NMHC) + (0.429 \times CO) + (0.273 \times (CO_2 - CO_{2NG}))}$$

Where:

mpg_e = miles per equivalent gallon of natural gas.

$CWF_{HC/NG}$ = carbon weight fraction based on the hydrocarbon constituents in the natural gas fuel as obtained in paragraph (g) of this section.

D_{NG} = density of the natural gas fuel [grams/ft^3 at 68 F (20 C) and 760 mm Hg (101.3 kPa)] pressure as obtained in paragraph (g) of this section.

CH_4, NMHC, CO, and CO_2 = weighted mass exhaust emissions [grams/mile] for methane, non-methane HC, carbon monoxide, and carbon dioxide as calculated in § 600.113.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section.

CO_{2NG} = grams of carbon dioxide in the natural gas fuel consumed per mile of travel.

$$CO_{2NG} = FC_{NG} \times D_{NG} \times WF_{CO2}$$

Where:

$$FC_{NG} = \frac{(0.749 \times CH_4) + (CWF_{NMHC} \times NMHC) + (0.429 \times CO) + (0.273 \times CO_2)}{CWF_{NG} \times D_{NG}}$$

= cubic feet of natural gas fuel consumed per mile

Where:

CWF_{NG} = the carbon weight fraction of the natural gas fuel as calculated in paragraph (f) of this section.

WF_{CO2} = weight fraction carbon dioxide of the natural gas fuel calculated using the mole fractions and molecular weights of the natural gas fuel constituents per ASTM D 1945–91 "Standard Test Method for Analysis of Natural Gas by Gas Chromatography" (incorporated by reference at § 600.011–93).

(2)(i) For automobiles fueled with natural gas, the carbon-related exhaust emissions in grams per mile is to be calculated for 2012 and later model year vehicles using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = 2.743 \times CH_4 + CWF_{NMHC}/0.273 \times NMHC + 1.571 \times CO + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.

NMHC = Grams/mile NMHC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year automobiles fueled with natural gas is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (25 \times CH_4) + [(CWF_{NMHC}/0.273) \times NMHC] + (1.571 \times CO) + CO_2 + (298 \times N_2O)$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.

NMHC = Grams/mile NMHC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel composition per paragraph (f)(3) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g) of this section.

(l)(1) For ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol, the fuel economy in miles per gallon is to be calculated using the following equation:

$$mpg = (CWF \times SG \times 3781.8)/((CWF_{exHC} \times HC) + (0.429 \times CO) + (0.273 \times CO_2) + (0.375 \times CH_3OH) + (0.400 \times HCHO) + (0.521 \times C_2H_5OH) + (0.545 \times C_2H_4O))$$

Where:

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(4) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(4) of this section.

CWF_{exHC}= Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in (f)(4) of this section.

HC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO_2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (d) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (d) of this section.

(2)(i) For 2012 and later model year ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = (CWF_{exHC}/0.273 \times HC) + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + (1.911 \times C_2H_5OH) + (1.998 \times C_2H_4O) + CO_2$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in (f)(4) of this section.

HC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (d) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (d) of this section.

(ii) For manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter, the carbon-related exhaust emissions in grams per mile for 2012 and later model year ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol is to be calculated using the following equation and rounded to the nearest 1 gram per mile:

$$CREE = [(CWF_{exHC}/0.273) \times NMHC] + (1.571 \times CO) + (1.374 \times CH_3OH) + (1.466 \times HCHO) + (1.911 \times C_2H_5OH) + (1.998 \times C_2H_4O) + CO_2 + (298 \times N_2O) + (25 \times CH_4)$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF_g as determined in paragraph (f)(4) of this section.

NMHC = Grams/mile HC as obtained in paragraph (g) of this section.

CO = Grams/mile CO as obtained in paragraph (g) of this section.

CO_2 = Grams/mile CO2 as obtained in paragraph (g) of this section.

CH_3OH = Grams/mile CH_3OH (methanol) as obtained in paragraph (d) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g) of this section.

C_2H_5OH = Grams/mile C_2H_5OH (ethanol) as obtained in paragraph (d) of this section.

C_2H_4O = Grams/mile C_2H_4O (acetaldehyde) as obtained in paragraph (d) of this section.

N_2O = Grams/mile N_2O as obtained in paragraph (g) of this section.

CH_4 = Grams/mile CH_4 as obtained in paragraph (g) of this section.

(m) *Carbon-related exhaust emissions for electric vehicles, fuel cell vehicles and plug-in hybrid electric vehicles.* Manufacturers shall determine carbon-related exhaust emissions for electric vehicles, fuel cell vehicles, and plug-in hybrid electric vehicles according to the provisions of this paragraph (m). Subject to the limitations described in § 86.1866–12(a) of this chapter, the manufacturer may be allowed to use a value of 0 grams/mile to represent the emissions of fuel cell vehicles and the proportion of electric operation of electric vehicles and plug-in hybrid electric vehicles that is derived from electricity that is generated from sources that are not onboard the vehicle, as described in paragraphs (m)(1) through (3) of this section.

(1) For 2012 and later model year electric vehicles, but not including fuel cell vehicles, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest one gram per mile:

$$CREE = CREE_{UP} - CREE_{GAS}$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08, which may be set equal to zero for eligible 2012 through 2016 model year electric vehicles as described in § 86.1866–12(a) of this chapter.

$$CREE_{UP} = 0.7670 \times EC, \text{ and}$$
$$CREE_{GAS} = 0.2485 \times TargetCO_2,$$

Where:

EC = The vehicle energy consumption in watt-hours per mile, determined according to procedures established by the Administrator under § 600.111–08(f).

$TargetCO_2$ = The CO_2 Target Value determined according to § 86.1818–12(c)(2) of this chapter for passenger automobiles and according to § 86.1818–12(c)(3) of this chapter for light trucks.

(2) For 2012 and later model year plug-in hybrid electric vehicles, the carbon-related exhaust emissions in grams per mile is to be calculated using the following equation and rounded to the nearest one gram per mile:

$$CREE = CREE_{CD} + CREE_{CS},$$

Where:

CREE means the carbon-related exhaust emission value as defined in § 600.002–08.

$CREE_{CS}$ = The carbon-related exhaust emissions determined for charge-sustaining operation according to procedures established by the Administrator under § 600.111–08(f); and

$$CREE_{CD} = (ECF \times CREE_{CDEC}) + [(1 - ECF) \times CREE_{CDGAS}]$$

Where:

$CREE_{CD}$ = The carbon-related exhaust emissions determined for charge-depleting operation determined according to the provisions of this section for the applicable fuel and according to procedures established by the Administrator under § 600.111–08(f);

$CREE_{CDEC}$ = The carbon-related exhaust emissions determined for electricity consumption during charge-depleting operation, which shall be determined using the method specified in paragraph (m)(1) of this section and according to procedures established by the Administrator under § 600.111–08(f), and which may be set equal to zero for eligible 2012 through 2016 model year vehicles as described in § 86.1866–12(a) of this chapter;

$CREE_{CDGAS}$ = The carbon-related exhaust emissions determined for charge-depleting operation determined according to the provisions of this section for the applicable fuel and according to procedures established by the Administrator under § 600.111–08(f); and

ECF = Electricity consumption factor as determined by the Administrator under § 600.111–08(f).

(3) For 2012 and later model year fuel cell vehicles, the carbon-related exhaust emissions in grams per mile shall be calculated using the method specified in paragraph (m)(1) of this section, except that $CREE_{UP}$ shall be determined according to procedures established by the Administrator under § 600.111–08(f). As described in § 86.1866–12(a) of this chapter the value of CREE may be set equal to zero for eligible 2012 through 2016 model year fuel cell vehicles.

(n) Equations for fuels other than those specified in paragraphs (h) through (l) of this section may be used with advance EPA approval. Alternate calculation methods for fuel economy and carbon-related exhaust emissions may be used in lieu of the methods described in this section if shown to yield equivalent or superior results and if approved in advance by the Administrator.

■ 44. Section 600.114–08 is amended as follows:

■ a. By revising the section heading.

■ b. By revising the introductory text.

■ c. By adding paragraphs (d) through (f).

§ 600.114–08 Vehicle-specific 5-cycle fuel economy and carbon-related exhaust emission calculations.

Paragraphs (a) through (c) of this section apply to data used for fuel economy labeling under Subpart D of this part. Paragraphs (d) through (f) of this section are used to calculate 5-cycle carbon-related exhaust emissions values for the purpose of determining optional technology-based CO_2 emissions credits under the provisions of paragraph (d) of § 86.1866–12 of this chapter.

* * * * *

(d) *City carbon-related exhaust emission value.* For each vehicle tested, determine the 5-cycle city carbon-related exhaust emissions using the following equation:

(1) $CityCREE = 0.905 \times (StartCREE + RunningCREE)$

Where:

(i) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times StartCREE_{75} + 0.24 \times StartCREE_{20})}{4.1} \right)$$

Where:

$StartCREE_X = 3.6 \times (Bag1CREE_X - Bag3CREE_X)$

Where:

Bag Y $CREE_X$ = the carbon-related exhaust emissions in grams per mile during the specified bag of the FTP test conducted at an ambient temperature of 75 F or 20 F.

(ii) Running CREE =

$0.82 \times [(0.48 \times Bag2_{75}CREE) + (0.41 \times BAG3_{75}CREE) + (0.11 \times US06\ CityCREE)] +$

$0.18 \times [(0.5 \times Bag2_{20}CREE) + (0.5 \times Bag3_{20}CREE)] +$

$0.144 \times [SC03\ CREE - ((0.61 \times Bag3_{75}CREE) + (0.39 \times Bag2_{75}CREE))]$

Where:

$BagY_XCREE$ = carbon-related exhaust emissions in grams per mile over Bag Y at temperature X.

US06 City CREE = carbon-related exhaust emissions in grams per mile over the "city" portion of the US06 test.

SC03 CREE = carbon-related exhaust emissions in grams per mile over the SC03 test.

(e) *Highway carbon-related exhaust emissions.* For each vehicle tested, determine the 5-cycle highway carbon-related exhaust emissions using the following equation:

HighwayCREE = 0.905 × (StartCREE + RunningCREE)

Where:

(1) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times \text{StartCREE}_{75} + 0.24 \times \text{StartCREE}_{20})}{60} \right)$$

Where:

$\text{StartCREE}_X = 3.6 \times (\text{BagCREE}_X - \text{Bag3CREE}_X)$

(2) Running CREE =

$1.007 \times [(0.79 \times \textit{US06 Highway CREE}) + (0.21 \times \textit{HFET CREE})] + 0.045 \times [\textit{SC03 CREE} - ((0.61 \times \textit{Bag3}_{75}\textit{CREE}) + (0.39 \times \textit{Bag2}_{75}\textit{CREE}))]$

Where:

BagY_XCREE = carbon-related exhaust emissions in grams per mile over Bag Y at temperature X,

US06 Highway CREE = carbon-related exhaust emissions in grams per mile over the highway portion of the US06 test,

HFET CREE = carbon-related exhaust emissions in grams per mile over the HFET test,

SC03 CREE = carbon-related exhaust emissions in grams per mile over the SC03 test.

(f) *Carbon-related exhaust emissions calculations for hybrid electric vehicles.* Hybrid electric vehicles shall be tested according to California test methods which require FTP emission sampling for the 75 F FTP test over four phases (bags) of the UDDS (cold-start, transient, warm-start, transient). Optionally, these four phases may be combined into two phases (phases 1 + 2 and phases 3 + 4). Calculations for these sampling methods follow.

(1) *Four-bag FTP equations.* If the 4-bag sampling method is used, manufacturers may use the equations in paragraphs (a) and (b) of this section to determine city and highway carbon-related exhaust emissions values. If this method is chosen, it must be used to determine both city and highway carbon-related exhaust emissions. Optionally, the following calculations may be used, provided that they are used to determine both city and highway carbon-related exhaust emissions values:

(i) *City carbon-related exhaust emissions.*

CityCREE = 0.905 × (StartCREE + RunningCREE)

Where:

(A) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times \text{StartCREE}_{75} + 0.24 \times \text{StartCREE}_{20})}{4.1} \right)$$

Where:

(*1*) $\textit{StartCREE}_{75}$ =

$3.6 \times (\text{Bag1}\textit{CREE}_{75} - \textit{Bag3CREE}_{75}) + 3.9 \times (\textit{Bag2CREE}_{75} - \textit{Bag4CREE}_{75})$

and

(*2*) StartCREE_{20} =

$3.6 \times (\textit{Bag1CREE}_{20} - \textit{Bag3CREE}_{20})$

(B) RunningCREE =

$0.82 \times [(0.48 \times \textit{Bag4}_{75}\textit{CREE}) + (0.41 \times \textit{Bag3}_{75}\textit{CREE}) + (0.11 \times \textit{US06 City CREE})] + 0.18 \times [(0.5 \times \textit{Bag2}_{20}\textit{CREE}) + (0.5 \times \textit{Bag3}_{20}\textit{CREE})] + 0.144 \times [\textit{SC03 CREE} - ((0.61 \times \textit{Bag3}_{75}\textit{CREE}) + (0.39 \times \textit{Bag4}_{75}\textit{CREE}))]$

Where:

US06 Highway CREE = carbon-related exhaust emissions in grams per mile over the city portion of the US06 test.

US06 Highway CREE = carbon-related exhaust emissions in miles per gallon over the Highway portion of the US06 test.

HFET CREE = carbon-related exhaust emissions in grams per mile over the HFET test.

SC03 CREE = carbon-related exhaust emissions in grams per mile over the SC03 test.

(ii) *Highway carbon-related exhaust emissions.*

HighwayCREE = 0.905 × (StartCREE + RunningCREE)

Where:

(A) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times \text{StartCREE}_{75} + 0.24 \times \text{StartCREE}_{20})}{60} \right)$$

Where:

$\text{StartCREE}_{75} = 3.6 \times (\text{Bag1CREE}_{75} - \text{Bag3CREE}^{75}) + 3.9 \times (\text{Bag2CREE}_{75} - \text{Bag4CREE}_{75})$

and

$\text{StartCREE}_{20} = 3.6 \times (\text{Bag1CREE}_{20} - \text{Bag3CREE}_{20})$

(B) RunningCREE =

$1.007 \times [(0.79 \times \textit{US06 Highway CREE}) + (0.21 \times \textit{HFET CREE})] + 0.045 \times [\textit{SC03 CREE} - ((0.61 \times \textit{Bag3}_{75}\textit{CREE}) + (0.39 \times \textit{Bag4}_{75}\textit{CREE}))]$

Where:

US06 Highway CREE = carbon-related exhaust emissions in grams per mile over the Highway portion of the US06 test,

HFET CREE = carbon-related exhaust emissions in grams per mile over the HFET test,

SC03 CREE = carbon-related exhaust emissions in grams per mile over the SC03 test.

(2) *Two-bag FTP equations.* If the 2-bag sampling method is used for the 75 F FTP test, it must be used to determine both city and highway carbon-related exhaust emissions. The following calculations must be used to determine both city and highway carbon-related exhaust emissions:

(i) *City carbon-related exhaust emissions.*

CityCREE = 0.905 × (StartCREE + RunningCREE)

Where:

(A) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times \text{StartCREE}_{75} + 0.24 \times \text{StartCREE}_{20})}{4.1} \right)$$

Where:

Start $CREE_{75}$ = 3.6 × (Bag ½ $CREE_{75}$ − Bag ¾ $CREE_{75}$)

and

Start $CREE_{20}$ = 3.6 × (Bag1$CREE_{20}$ − Bag3$CREE_{20}$)

Where:

Bag Y FE_{20} = the carbon-related exhaust emissions in grams per mile of fuel during Bag 1 or Bag 3 of the 20 F FTP test, and

Bag X/Y FE_{75} = carbon-related exhaust emissions in grams per mile of fuel during combined phases 1 and 2 or phases 3 and 4 of the FTP test conducted at an ambient temperature of 75 F.

(B) RunningCREE =

0.82 × [(0.90 × Bag¾$_{75}$CREE) + (0.10 × US06 City CREE)] + 0.18 × [(0.5 × Bag2$_{20}$CREE) + (0.5 × Bag3$_{20}$CREE)] + 0.144 × [SC03 CREE − (Bag¾$_{75}$CREE)]

Where:

US06 City CREE = carbon-related exhaust emissions in grams per mile over the city portion of the US06 test, and

SC03 CREE = carbon-related exhaust emissions in grams per mile over the SC03 test, and

Bag X/Y FE_{75} = carbon-related exhaust emissions in grams per mile of fuel during combined phases 1 and 2 or phases 3 and 4 of the FTP test conducted at an ambient temperature of 75 F.

(ii) *Highway carbon-related exhaust emissions.*

HighwayCREE = 0.905 × (StartCREE + RunningCREE)

Where:

(A) StartCREE =

$$0.33 \times \left(\frac{(0.76 \times \text{StartCREE}_{75} + 0.24 \times \text{StartCREE}_{20})}{60} \right)$$

Where:

Start $CREE_{75}$ = 7.5 × (Bag½$CREE_{75}$ − Bag¾$CREE_{75}$)

and

Start $CREE_{20}$ = 3.6 × (Bag1$CREE_{20}$ − Bag3$CREE_{20}$)

(B) RunningCREE =

1.007 × [(0.79 × US06 Highway CREE) + (0.21 × HFET CREE)] + 0.045 × [SC03 CREE − Bag¾$_{75}$CREE]

Where:

US06 Highway CREE = carbon-related exhaust emissions in grams per mile over the city portion of the US06 test, and

SC03 CREE = carbon-related exhaust emissions in gram per mile over the SC03 test, and

Bag Y FE_{20} = the carbon-related exhaust emissions in grams per mile of fuel during Bag 1 or Bag 3 of the 20 F FTP test, and

Bag X/Y FE_{75} = carbon-related exhaust emissions in grams per mile of fuel during phases 1 and 2 or phases 3 and 4 of the FTP test conducted at an ambient temperature of 75 F.

Subpart C—Procedures for Calculating Fuel Economy and Carbon-Related Exhaust Emission Values for 1977 and Later Model Year Automobiles

■ 45. The heading for subpart C is revised as set forth above.

■ 46. A new § 600.201–12 is added to subpart C to read as follows:

§ 600.201–12 General applicability.

The provisions of this subpart are applicable to 2012 and later model year automobiles and to the manufacturers of 2012 and later model year automobiles.

■ 47. A new § 600.206–12 is added to subpart C to read as follows:

§ 600.206–12 Calculation and use of FTP-based and HFET-based fuel economy and carbon-related exhaust emission values for vehicle configurations.

(a) Fuel economy and carbon-related exhaust emissions values determined for each vehicle under § 600.113(a) and (b) and as approved in § 600.008–08(c), are used to determine FTP-based city, HFET-based highway, and combined FTP/Highway-based fuel economy and carbon-related exhaust emission values for each vehicle configuration for which data are available.

(1) If only one set of FTP-based city and HFET-based highway fuel economy values is accepted for a vehicle configuration, these values, rounded to the nearest tenth of a mile per gallon, comprise the city and highway fuel economy values for that configuration. If only one set of FTP-based city and HFET-based highway carbon-related exhaust emission values is accepted for a vehicle configuration, these values, rounded to the nearest gram per mile, comprise the city and highway carbon-related exhaust emission values for that configuration.

(2) If more than one set of FTP-based city and HFET-based highway fuel economy and/or carbon-related exhaust emission values are accepted for a vehicle configuration:

(i) All data shall be grouped according to the subconfiguration for which the data were generated using sales projections supplied in accordance with § 600.208–12(a)(3).

(ii) Within each group of data, all fuel economy values are harmonically averaged and rounded to the nearest 0.0001 of a mile per gallon and all carbon-related exhaust emission values are arithmetically averaged and rounded to the nearest tenth of a gram per mile in order to determine FTP-based city and HFET-based highway fuel economy and carbon-related exhaust emission values for each subconfiguration at which the vehicle configuration was tested.

(iii) All FTP-based city fuel economy and carbon-related exhaust emission values and all HFET-based highway fuel economy and carbon-related exhaust emission values calculated in paragraph (a)(2)(ii) of this section are (separately for city and highway) averaged in proportion to the sales fraction (rounded to the nearest 0.0001) within the vehicle configuration (as provided to the Administrator by the manufacturer) of vehicles of each tested subconfiguration. Fuel economy values shall be harmonically averaged and carbon-related exhaust emission values shall be arithmetically averaged. The resultant fuel economy values, rounded to the nearest 0.0001 mile per gallon, are the FTP-based city and HFET-based highway fuel economy values for the vehicle configuration. The resultant carbon-related exhaust emission values, rounded to the nearest tenth of a gram per mile, are the FTP-based city and HFET-based highway carbon-related exhaust emission values for the vehicle configuration.

(3)(i) For the purpose of determining average fuel economy under § 600.510–08, the combined fuel economy value for a vehicle configuration is calculated by harmonically averaging the FTP-based city and HFET-based highway fuel economy values, as determined in paragraph (a)(1) or (2) of this section, weighted 0.55 and 0.45 respectively, and rounded to the nearest 0.0001 mile per gallon. A sample of this calculation appears in Appendix II of this part.

(ii) For the purpose of determining average carbon-related exhaust emissions under § 600.510–08, the combined carbon-related exhaust emission value for a vehicle configuration is calculated by arithmetically averaging the FTP-based city and HFET-based highway carbon-related exhaust emission values, as determined in paragraph (a)(1) or (2) of this section, weighted 0.55 and 0.45 respectively, and rounded to the nearest tenth of gram per mile.

(4) For alcohol dual fuel automobiles and natural gas dual fuel automobiles the procedures of paragraphs (a)(1) or (2) of this section, as applicable, shall be used to calculate two separate sets of FTP-based city, HFET-based highway, and combined fuel economy and carbon-related exhaust emission values for each configuration.

(i) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using gasoline or diesel test fuel.

(ii) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using alcohol or natural gas test fuel.

(b) If only one equivalent petroleum-based fuel economy value exists for an electric vehicle configuration, that value, rounded to the nearest tenth of a mile per gallon, will comprise the petroleum-based fuel economy for that configuration.

(c) If more than one equivalent petroleum-based fuel economy value exists for an electric vehicle configuration, all values for that vehicle configuration are harmonically averaged and rounded to the nearest 0.0001 mile per gallon for that configuration.

■ 48. A new § 600.208–12 is added to subpart C to read as follows:

§ 600.208–12 Calculation of FTP-based and HFET-based fuel economy and carbon-related exhaust emission values for a model type.

(a) Fuel economy and carbon-related exhaust emission values for a base level are calculated from vehicle configuration fuel economy and carbon-related exhaust emission values as determined in § 600.206–12(a), (b), or (c) as applicable, for low-altitude tests.

(1) If the Administrator determines that automobiles intended for sale in the State of California are likely to exhibit significant differences in fuel economy and carbon-related exhaust emission values from those intended for sale in other states, she will calculate fuel economy and carbon-related exhaust emission values for each base level for vehicles intended for sale in California and for each base level for vehicles intended for sale in the rest of the states.

(2) In order to highlight the fuel efficiency and carbon-related exhaust emission values of certain designs otherwise included within a model type, a manufacturer may wish to subdivide a model type into one or more additional model types. This is accomplished by separating subconfigurations from an existing base level and placing them into a new base level. The new base level is identical to the existing base level except that it shall be considered, for the purposes of this paragraph, as containing a new basic engine. The manufacturer will be permitted to designate such new basic engines and base level(s) if:

(i) Each additional model type resulting from division of another model type has a unique car line name and that name appears on the label and on the vehicle bearing that label;

(ii) The subconfigurations included in the new base levels are not included in any other base level which differs only by basic engine (*i.e.,* they are not included in the calculation of the original base level fuel economy values); and

(iii) All subconfigurations within the new base level are represented by test data in accordance with § 600.010–08(c)(1)(ii).

(3) The manufacturer shall supply total model year sales projections for each car line/vehicle subconfiguration combination.

(i) Sales projections must be supplied separately for each car line-vehicle subconfiguration intended for sale in California and each car line/vehicle subconfiguration intended for sale in the rest of the states if required by the Administrator under paragraph (a)(1) of this section.

(ii) Manufacturers shall update sales projections at the time any model type value is calculated for a label value.

(iii) The provisions of paragraph (a)(3) of this section may be satisfied by providing an amended application for certification, as described in § 86.1844–01 of this chapter.

(4) Vehicle configuration fuel economy and carbon-related exhaust emission values, as determined in § 600.206–12 (a), (b) or (c), as applicable, are grouped according to base level.

(i) If only one vehicle configuration within a base level has been tested, the fuel economy and carbon-related exhaust emission values from that vehicle configuration will constitute the fuel economy and carbon-related exhaust emission values for that base level.

(ii) If more than one vehicle configuration within a base level has been tested, the vehicle configuration fuel economy values are harmonically averaged in proportion to the respective sales fraction (rounded to the nearest 0.0001) of each vehicle configuration and the resultant fuel economy value rounded to the nearest 0.0001 mile per gallon; and the vehicle configuration carbon-related exhaust emission values are arithmetically averaged in proportion to the respective sales fraction (rounded to the nearest 0.0001) of each vehicle configuration and the resultant carbon-related exhaust emission value rounded to the nearest gram per mile.

(5) The procedure specified in paragraph (a)(1) through (4) of this section will be repeated for each base level, thus establishing city, highway, and combined fuel economy and carbon-related exhaust emission values for each base level.

(6) For the purposes of calculating a base level fuel economy or carbon-related exhaust emission value, if the only vehicle configuration(s) within the base level are vehicle configuration(s) which are intended for sale at high altitude, the Administrator may use fuel economy and carbon-related exhaust emission data from tests conducted on these vehicle configuration(s) at high altitude to calculate the fuel economy or carbon-related exhaust emission value for the base level.

(7) For alcohol dual fuel automobiles and natural gas dual fuel automobiles, the procedures of paragraphs (a)(1) through (6) of this section shall be used to calculate two separate sets of city, highway, and combined fuel economy and carbon-related exhaust emission values for each base level.

(i) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using gasoline or diesel test fuel.

(ii) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using alcohol or natural gas test fuel.

(b) For each model type, as determined by the Administrator, a city, highway, and combined fuel economy value and a carbon-related exhaust emission value will be calculated by using the projected sales and fuel economy and carbon-related exhaust emission values for each base level within the model type. Separate model type calculations will be done based on the vehicle configuration fuel economy and carbon-related exhaust emission values as determined in § 600.206–12 (a), (b) or (c), as applicable.

(1) If the Administrator determines that automobiles intended for sale in the State of California are likely to exhibit significant differences in fuel economy and carbon-related exhaust emission values from those intended for sale in other states, she will calculate fuel economy and carbon-related exhaust emission values for each model type for vehicles intended for sale in California and for each model type for vehicles intended for sale in the rest of the states.

(2) The sales fraction for each base level is calculated by dividing the projected sales of the base level within the model type by the projected sales of the model type and rounding the quotient to the nearest 0.0001.

(3)(i) The FTP-based city fuel economy values of the model type (calculated to the nearest 0.0001 mpg) are determined by dividing one by a sum of terms, each of which corresponds to a base level and which is a fraction determined by dividing:

(A) The sales fraction of a base level; by

(B) The FTP-based city fuel economy value for the respective base level.

(ii) The FTP-based city carbon-related exhaust emission value of the model type (calculated to the nearest gram per mile) are determined by a sum of terms, each of which corresponds to a base level and which is a product determined by multiplying:

(A) The sales fraction of a base level; by

(B) The FTP-based city carbon-related exhaust emission value for the respective base level.

(4) The procedure specified in paragraph (b)(3) of this section is repeated in an analogous manner to determine the highway and combined fuel economy and carbon-related exhaust emission values for the model type.

(5) For alcohol dual fuel automobiles and natural gas dual fuel automobiles, the procedures of paragraphs (b)(1) through (4) of this section shall be used to calculate two separate sets of city, highway, and combined fuel economy values and two separate sets of city, highway, and combined carbon-related exhaust emission values for each model type.

(i) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using gasoline or diesel test fuel.

(ii) Calculate the city, highway, and combined fuel economy and carbon-related exhaust emission values from the tests performed using alcohol or natural gas test fuel.

Subpart D—[Amended]

■ 49. A new § 600.301–12 is added to subpart D to read as follows:

§ 600.301–12 General applicability.

(a) Unless otherwise specified, the provisions of this subpart are applicable to 2012 and later model year automobiles.

(b) [Reserved]

Subpart F—Fuel Economy Regulations for Model Year 1978 Passenger Automobiles and for 1979 and Later Model Year Automobiles (Light Trucks and Passenger Automobiles)—Procedures for Determining Manufacturer's Average Fuel Economy and Manufacturer's Average Carbon-Related Exhaust Emissions

■ 50. The heading for subpart F is revised as set forth above.

■ 51. A new § 600.501–12 is added to subpart F to read as follows:

§ 600.501–12 General applicability.

The provisions of this subpart are applicable to 2012 and later model year passenger automobiles and light trucks and to the manufacturers of 2012 and later model year passenger automobiles and light trucks. The provisions of this subpart are applicable to medium-duty passenger vehicles and to manufacturers of such vehicles.

■ 52. A new § 600.507–12 is added to subpart F to read as follows:

§ 600.507–12 Running change data requirements.

(a) Except as specified in paragraph (d) of this section, the manufacturer shall submit additional running change fuel economy and carbon-related exhaust emissions data as specified in paragraph (b) of this section for any running change approved or implemented under §§ 86.079–32, 86.079–33, 86.082–34, or 86.1842–01 of this chapter, as applicable, which:

(1) Creates a new base level or,

(2) Affects an existing base level by:

(i) Adding an axle ratio which is at least 10 percent larger (or, optionally, 10 percent smaller) than the largest axle ratio tested.

(ii) Increasing (or, optionally, decreasing) the road-load horsepower for a subconfiguration by 10 percent or more for the individual running change or, when considered cumulatively, since original certification (for each cumulative 10 percent increase using the originally certified road-load horsepower as a base).

(iii) Adding a new subconfiguration by increasing (or, optionally, decreasing) the equivalent test weight for any previously tested subconfiguration in the base level.

(iv) Revising the calibration of an electric vehicle, fuel cell vehicle, hybrid electric vehicle, plug-in hybrid electric vehicle or other advanced technology vehicle in such a way that the city or highway fuel economy of the vehicle (or the energy consumption of the vehicle, as may be applicable) is expected to become less fuel efficient (or optionally, more fuel efficient) by 4.0 percent or more as compared to the original fuel economy label values for fuel economy and/or energy consumption, as applicable.

(b)(1) The additional running change fuel economy and carbon-related exhaust emissions data requirement in paragraph (a) of this section will be determined based on the sales of the vehicle configurations in the created or affected base level(s) as updated at the time of running change approval.

(2) Within each newly created base level as specified in paragraph (a)(1) of this section, the manufacturer shall submit data from the highest projected total model year sales subconfiguration within the highest projected total model year sales configuration in the base level.

(3) Within each base level affected by a running change as specified in paragraph (a)(2) of this section, fuel economy and carbon-related exhaust emissions data shall be submitted for the vehicle configuration created or affected by the running change which has the highest total model year projected sales. The test vehicle shall be of the subconfiguration created by the running change which has the highest projected total model year sales within the applicable vehicle configuration.

(c) The manufacturer shall submit the fuel economy data required by this section to the Administrator in accordance with § 600.314(b).

(d) For those model types created under § 600.208–12(a)(2), the manufacturer shall submit fuel economy and carbon-related exhaust emissions data for each subconfiguration added by a running change.

■ 53. A new § 600.509–12 is added to subpart F to read as follows:

§ 600.509–12 Voluntary submission of additional data.

(a) The manufacturer may optionally submit data in addition to the data required by the Administrator.

(b) Additional fuel economy and carbon-related exhaust emissions data may be submitted by the manufacturer for any vehicle configuration which is to be tested as required in § 600.507 or for which fuel economy and carbon-related exhaust emissions data were previously submitted under paragraph (c) of this section.

(c) Within a base level, additional fuel economy and carbon-related exhaust emissions data may be submitted by the manufacturer for any vehicle configuration which is not required to be tested by § 600.507.

■ 54. A new § 600.510–12 is added to subpart F to read as follows:

§ 600.510–12 Calculation of average fuel economy and average carbon-related exhaust emissions.

(a)(1) Average fuel economy will be calculated to the nearest 0.1 mpg for the categories of automobiles identified in this section, and the results of such calculations will be reported to the Secretary of Transportation for use in determining compliance with the applicable fuel economy standards.

(i) An average fuel economy calculation will be made for the category of passenger automobiles as determined by the Secretary of Transportation. For example, categories may include, but are not limited to domestically manufactured and/or non-domestically manufactured passenger automobiles as determined by the Secretary of Transportation.

(ii) [Reserved]

(iii) An average fuel economy calculation will be made for the category of trucks as determined by the Secretary of Transportation. For example, categories may include, but are not limited to domestically manufactured trucks, non-domestically manufactured trucks, light-duty trucks, medium-duty passenger vehicles, and/or heavy-duty trucks as determined by the Secretary of Transportation.

(iv) [Reserved]

(2) Average carbon-related exhaust emissions will be calculated to the nearest one gram per mile for the categories of automobiles identified in this section, and the results of such calculations will be reported to the Administrator for use in determining compliance with the applicable CO_2 emission standards.

(i) An average carbon-related exhaust emissions calculation will be made for passenger automobiles.

(ii) An average carbon-related exhaust emissions calculation will be made for light trucks.

(b) For the purpose of calculating average fuel economy under paragraph (c) of this section and for the purpose of calculating average carbon-related exhaust emissions under paragraph (j) of this section:

(1) All fuel economy and carbon-related exhaust emissions data submitted in accordance with § 600.006(e) or § 600.512(c) shall be used.

(2) The combined city/highway fuel economy and carbon-related exhaust emission values will be calculated for each model type in accordance with § 600.208–12 of this section except that:

(i) Separate fuel economy values will be calculated for model types and base levels associated with car lines for each category of passenger automobiles and light trucks as determined by the Secretary of Transportation pursuant to paragraph (a)(1) of this section.

(ii) Total model year production data, as required by this subpart, will be used instead of sales projections;

(iii) [Reserved]

(iv) The fuel economy value will be rounded to the nearest 0.1 mpg;

(v) The carbon-related exhaust emission value will be rounded to the nearest gram per mile; and

(vi) At the manufacturer's option, those vehicle configurations that are self-compensating to altitude changes may be separated by sales into high-altitude sales categories and low-altitude sales categories. These separate sales categories may then be treated (only for the purpose of this section) as separate configurations in accordance with the procedure of § 600.208–12(a)(4)(ii).

(3) The fuel economy and carbon-related exhaust emission values for each vehicle configuration are the combined fuel economy and carbon-related exhaust emissions calculated according to § 600.206–08(a)(3) except that:

(i) Separate fuel economy values will be calculated for vehicle configurations associated with car lines for each category of passenger automobiles and light trucks as determined by the Secretary of Transportation pursuant to paragraph (a)(1) of this section.

(ii) Total model year production data, as required by this subpart will be used instead of sales projections; and

(iii) The fuel economy value of diesel-powered model types will be multiplied by the factor 1.0 to convert gallons of diesel fuel to equivalent gallons of gasoline.

(c) Except as permitted in paragraph (d) of this section, the average fuel economy will be calculated individually for each category identified in paragraph (a)(1) of this section as follows:

(1) Divide the total production volume of that category of automobiles; by

(2) A sum of terms, each of which corresponds to a model type within that category of automobiles and is a fraction determined by dividing the number of automobiles of that model type produced by the manufacturer in the model year; by

(i) For gasoline-fueled and diesel-fueled model types, the fuel economy calculated for that model type in accordance with paragraph (b)(2) of this section; or

(ii) For alcohol-fueled model types, the fuel economy value calculated for that model type in accordance with paragraph (b)(2) of this section divided by 0.15 and rounded to the nearest 0.1 mpg; or

(iii) For natural gas-fueled model types, the fuel economy value calculated for that model type in accordance with paragraph (b)(2) of this section divided by 0.15 and rounded to the nearest 0.1 mpg; or

(iv) For alcohol dual fuel model types, for model years 1993 through 2019, the harmonic average of the following two terms; the result rounded to the nearest 0.1 mpg:

(A) The combined model type fuel economy value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type fuel economy value for operation on alcohol fuel as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of § 600.510(g) are met; or

(v) For natural gas dual fuel model types, for model years 1993 through 2019, the harmonic average of the following two terms; the result rounded to the nearest 0.1 mpg:

(A) The combined model type fuel economy value for operation on gasoline or diesel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type fuel economy value for operation on natural gas as determined in § 600.208–12(b)(5)(ii) divided by 0.15 provided the requirements of paragraph (g) of this section are met.

(d) The Administrator may approve alternative calculation methods if they are part of an approved credit plan under the provisions of 15 U.S.C. 2003.

(e) For passenger automobile categories identified in paragraph (a)(1) of this section, the average fuel economy calculated in accordance with paragraph (c) of this section shall be adjusted using the following equation:

$$AFE_{adj} = AFE[((0.55 \times a \times c) + (0.45 \times c) + (0.5556 \times a) + 0.4487)/((0.55 \times a) + 0.45)] + IW$$

Where:

AFE_{adj} = Adjusted average combined fuel economy, rounded to the nearest 0.1 mpg;

AFE = Average combined fuel economy as calculated in paragraph (c) of this section, rounded to the nearest 0.0001 mpg;

a = Sales-weight average (rounded to the nearest 0.0001 mpg) of all model type highway fuel economy values (rounded to the nearest 0.1 mpg) divided by the sales-weighted average (rounded to the nearest 0.0001 mpg) of all model type city fuel economy values (rounded to the nearest 0.1 mpg). The quotient shall be rounded to 4 decimal places. These average fuel economies shall be determined using the methodology of paragraph (c) of this section.

c = 0.0014;

$IW = (9.2917 \times 10^{-3} \times SF_{3IWC} \times FE_{3IWC}) - (3.5123 \times 10^{-3} \times SF_{4ETW} \times FE_{4IWC})$.

Note: Any calculated value of IW less than zero shall be set equal to zero.

SF_{3IWC} = The 3000 lb. inertia weight class sales divided by total sales. The quotient shall be rounded to 4 decimal places.

SF_{4ETW} = The 4000 lb. equivalent test weight category sales divided by total sales. The quotient shall be rounded to 4 decimal places.

FE_{4IWC} = The sales-weighted average combined fuel economy of all 3000 lb. inertia weight class base levels in the compliance category. Round the result to the nearest 0.0001 mpg.

FE_{4IWC} = The sales-weighted average combined fuel economy of all 4000 lb. inertia weight class base levels in the compliance category. Round the result to the nearest 0.0001 mpg.

(f) The Administrator shall calculate and apply additional average fuel economy adjustments if, after notice and opportunity for comment, the Administrator determines that, as a result of test procedure changes not previously considered, such correction is necessary to yield fuel economy test results that are comparable to those obtained under the 1975 test procedures. In making such determinations, the Administrator must find that:

(1) A directional change in measured fuel economy of an average vehicle can be predicted from a revision to the test procedures;

(2) The magnitude of the change in measured fuel economy for any vehicle or fleet of vehicles caused by a revision to the test procedures is quantifiable from theoretical calculations or best available test data;

(3) The impact of a change on average fuel economy is not due to eliminating the ability of manufacturers to take advantage of flexibility within the existing test procedures to gain measured improvements in fuel economy which are not the result of actual improvements in the fuel economy of production vehicles;

(4) The impact of a change on average fuel economy is not solely due to a greater ability of manufacturers to reflect in average fuel economy those design changes expected to have comparable effects on in-use fuel economy;

(5) The test procedure change is required by EPA or is a change initiated by EPA in its laboratory and is not a change implemented solely by a manufacturer in its own laboratory.

(g)(1) Alcohol dual fuel automobiles and natural gas dual fuel automobiles must provide equal or greater energy efficiency while operating on alcohol or natural gas as while operating on gasoline or diesel fuel to obtain the CAFE credit determined in paragraphs (c)(2)(iv) and (v) of this section or to obtain the carbon-related exhaust emissions credit determined in paragraphs (j)(2)(ii) and (iii). The following equation must hold true:

E_{alt}/E_{pet}> or = 1

Where:

$E_{alt} = [FE_{alt}/(NHV_{alt} \times D_{alt})] \times 10^6$ = energy efficiency while operating on alternative fuel rounded to the nearest 0.01 miles/million BTU.

$E_{pet} = [FE_{pet}/(NHV_{pet} \times D_{pet})] \times 10^6$ = energy efficiency while operating on gasoline or diesel (petroleum) fuel rounded to the nearest 0.01 miles/million BTU.

FE_{alt} is the fuel economy [miles/gallon for liquid fuels or miles/100 standard cubic feet for gaseous fuels] while operated on the alternative fuel as determined in § 600.113–08(a) and (b);

FE_{pet} is the fuel economy [miles/gallon] while operated on petroleum fuel (gasoline or diesel) as determined in § 600.113(a) and (b);

NHV_{alt} is the net (lower) heating value [BTU/lb] of the alternative fuel;

NHV_{pet} is the net (lower) heating value [BTU/lb] of the petroleum fuel;

D_{alt} is the density [lb/gallon for liquid fuels or lb/100 standard cubic feet for gaseous fuels] of the alternative fuel;

D_{pet} is the density [lb/gallon] of the petroleum fuel.

(i) The equation must hold true for both the FTP city and HFET highway fuel economy values for each test of each test vehicle.

(ii)(A) The net heating value for alcohol fuels shall be premeasured using a test method which has been approved in advance by the Administrator.

(B) The density for alcohol fuels shall be premeasured using ASTM D 1298–85 (Reapproved 1990) "Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method" (incorporated by reference at § 600.011–93).

(iii) The net heating value and density of gasoline are to be determined by the manufacturer in accordance with § 600.113(f).

(2) [Reserved]

(3) Alcohol dual fuel passenger automobiles and natural gas dual fuel passenger automobiles manufactured during model years 1993 through 2019 must meet the minimum driving range requirements established by the Secretary of Transportation (49 CFR part 538) to obtain the CAFE credit determined in paragraphs (c)(2)(iv) and (v) of this section.

(h) For model years 1993 and later, and for each category of automobile identified in paragraph (a)(1) of this section, the maximum increase in average fuel economy determined in paragraph (c) of this section attributable to alcohol dual fuel automobiles and natural gas dual fuel automobiles shall be as follows:

Model year	Maximum increase (mpg)
1993–2014	1.2
2015	1.0
2016	0.8
2017	0.6
2018	0.4
2019	0.2
2020 and later	0.0

(1) The Administrator shall calculate the increase in average fuel economy to determine if the maximum increase provided in paragraph (h) of this section has been reached. The Administrator shall calculate the average fuel economy for each category of automobiles specified in paragraph (a)(1) of this section by subtracting the average fuel economy values calculated in accordance with this section by assuming all alcohol dual fuel and natural gas dual fuel automobiles are operated exclusively on gasoline (or diesel) fuel from the average fuel economy values determined in paragraph (c) of this section. The difference is limited to the maximum increase specified in paragraph (h) of this section.

(2) [Reserved]

(i) For model years 2012 through 2015, and for each category of automobile identified in paragraph (a)(1) of this section, the maximum decrease in average carbon-related exhaust emissions determined in paragraph (j) of this section attributable to alcohol dual fuel automobiles and natural gas dual fuel automobiles shall be calculated using the following formula, and rounded to the nearest tenth of a gram per mile:

$$\text{Maximum Decrease} = \frac{8887}{\left[\dfrac{8887}{FltAvg} - MPG_{MAX}\right]} - FltAvg$$

Where:

FltAvg = The fleet average CREE value for passenger automobiles or light trucks determined for the applicable model year according to paragraph (j) of this section, except by assuming all alcohol dual fuel and natural gas dual fuel automobiles are operated exclusively on gasoline (or diesel) fuel.

MPG_{MAX} = The maximum increase in miles per gallon determined for the appropriate model year in paragraph (h) of this section.

(1) The Administrator shall calculate the decrease in average carbon-related exhaust emissions to determine if the maximum decrease provided in this paragraph (i) has been reached. The Administrator shall calculate the average carbon-related exhaust emissions for each category of automobiles specified in paragraph (a) of this section by subtracting the average carbon-related exhaust emission values determined in paragraph (j) of this section from the average carbon-related exhaust emission values calculated in accordance with this section by assuming all alcohol dual fuel and natural gas dual fuel automobiles are operated exclusively on gasoline (or diesel) fuel. The difference is limited to the maximum decrease specified in paragraph (i) of this section.

(2) [Reserved]

(j) The average carbon-related exhaust emissions will be calculated individually for each category identified in paragraph (a)(1) of this section as follows:

(1) Divide the total production volume of that category of automobiles into:

(2) A sum of terms, each of which corresponds to a model type within that category of automobiles and is a product determined by multiplying the number of automobiles of that model type produced by the manufacturer in the model year by:

(i) For gasoline-fueled and diesel-fueled model types, the carbon-related exhaust emissions value calculated for that model type in accordance with paragraph (b)(2) of this section; or

(ii)(A) For alcohol-fueled model types, for model years 2012 through 2015, the carbon-related exhaust emissions value calculated for that model type in accordance with paragraph (b)(2) of this section multiplied by 0.15 and rounded to the nearest gram per mile, except that manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter must perform this calculation such that N_2O and CH_4 values are not multiplied by 0.15; or

(B) For alcohol-fueled model types, for model years 2016 and later, the carbon-related exhaust emissions value calculated for that model type in accordance with paragraph (b)(2) of this section; or

(iii)(A) For natural gas-fueled model types, for model years 2012 through 2015, the carbon-related exhaust emissions value calculated for that model type in accordance with paragraph (b)(2) of this section multiplied by 0.15 and rounded to the nearest gram per mile, except that manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter must perform this calculation such that N_2O and CH_4 values are not multiplied by 0.15; or

(B) For natural gas-fueled model types, for model years 2016 and later, the carbon-related exhaust emissions value calculated for that model type in accordance with paragraph (b)(2) of this section; or

(iv) For alcohol dual fuel model types, for model years 2012 through 2015, the arithmetic average of the following two terms, the result rounded to the nearest gram per mile:

(A) The combined model type carbon-related exhaust emissions value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type carbon-related exhaust emissions value for operation on alcohol fuel as determined in § 600.208–12(b)(5)(ii) multiplied by 0.15 provided the requirements of paragraph (g) of this section are met, except that manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter must perform this calculation such that N_2O and CH_4 values are not multiplied by 0.15; or

(v) For natural gas dual fuel model types, for model years 2012 through 2015, the arithmetic average of the following two terms; the result rounded to the nearest gram per mile:

(A) The combined model type carbon-related exhaust emissions value for operation on gasoline or diesel as determined in § 600.208–12(b)(5)(i); and

(B) The combined model type carbon-related exhaust emissions value for operation on natural gas as determined in § 600.208–12(b)(5)(ii) multiplied by 0.15 provided the requirements of paragraph (g) of this section are met, except that manufacturers complying with the fleet averaging option for N_2O and CH_4 as allowed under § 86.1818–12(f)(2) of this chapter must perform this calculation such that N_2O and CH_4 values are not multiplied by 0.15.

(vi) For alcohol dual fuel model types, for model years 2016 and later, the combined model type carbon-related exhaust emissions value determined according to the following formula and rounded to the nearest gram per mile:

$$CREE = (F \times CREE_{alt}) + ((1 - F) \times CREE_{gas})$$

Where:

F = 0.00 unless otherwise approved by the Administrator according to the provisions of paragraph (k) of this section;

$CREE_{alt}$ = The combined model type carbon-related exhaust emissions value for operation on alcohol fuel as determined in § 600.208–12(b)(5)(ii); and

$CREE_{gas}$ = The combined model type carbon-related exhaust emissions value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i).

(vii) For natural gas dual fuel model types, for model years 2016 and later, the combined model type carbon-related exhaust emissions value determined according to the following formula and rounded to the nearest gram per mile:

$$CREE = (F \times CREE_{alt}) + ((1 - F) \times CREE_{gas})$$

Where:

F = 0.00 unless otherwise approved by the Administrator according to the provisions of paragraph (k) of this section;

$CREE_{alt}$ = The combined model type carbon-related exhaust emissions value for operation on natural gas as determined in § 600.208–12(b)(5)(ii); and

$CREE_{gas}$ = The combined model type carbon-related exhaust emissions value for operation on gasoline or diesel fuel as determined in § 600.208–12(b)(5)(i).

(k) *Alternative in-use weighting factors for dual fuel model types.* Using one of the methods in either paragraph (k)(1) or (2) of this section, manufacturers may request the use of alternative values for the weighting factor F in the equations in paragraphs (j)(2)(vi) and (vii) of this section. Unless otherwise approved by the Administrator, the manufacturer must use the value of F that is in effect in paragraphs (j)(2)(vi) and (vii) of this section.

(1) Upon written request from a manufacturer, the Administrator will determine and publish by written guidance an appropriate value of F for each requested alternative fuel based on the Administrator's assessment of real-world use of the alternative fuel. Such published values would be available for any manufacturer to use. The Administrator will periodically update these values upon written request from a manufacturer.

(2) The manufacturer may optionally submit to the Administrator its own demonstration regarding the real-world use of the alternative fuel in their vehicles and its own estimate of the appropriate value of F in the equations in paragraphs (j)(2)(vi) and (vii) of this section. Depending on the nature of the analytical approach, the manufacturer could provide estimates of F that are model type specific or that are generally applicable to the manufacturer's dual fuel fleet. The manufacturer's analysis could include use of data gathered from on-board sensors and computers, from dual fuel vehicles in fleets that are centrally fueled, or from other sources. The analysis must be based on sound statistical methodology and must account for analytical uncertainty. Any approval by the Administrator will pertain to the use of values of F for the model types specified by the manufacturer.

■ 55. A new § 600.512–12 is added to subpart F to read as follows:

§ 600.512–12 Model year report.

(a) For each model year, the manufacturer shall submit to the Administrator a report, known as the model year report, containing all information necessary for the calculation of the manufacturer's average fuel economy and all information necessary for the calculation of the manufacturer's average carbon-related exhaust emissions.

(1) The results of the manufacturer calculations and summary information of model type fuel economy values which are contained in the average fuel economy calculation shall also be submitted to the Secretary of the Department of Transportation, National Highway and Traffic Safety Administration.

(2) The results of the manufacturer calculations and summary information of model type carbon-related exhaust emission values which are contained in the average calculation shall be submitted to the Administrator.

(b)(1) The model year report shall be in writing, signed by the authorized representative of the manufacturer and shall be submitted no later than 90 days after the end of the model year.

(2) The Administrator may waive the requirement that the model year report be submitted no later than 90 days after the end of the model year. Based upon a request by the manufacturer, if the Administrator determines that 90 days is insufficient time for the manufacturer to provide all additional data required as determined in § 600.507, the Administrator shall establish an alternative date by which the model year report must be submitted.

(3) Separate reports shall be submitted for passenger automobiles and light trucks (as identified in § 600.510).

(c) The model year report must include the following information:

(1)(i) All fuel economy data used in the FTP/HFET-based model type calculations under § 600.208–12, and subsequently required by the Administrator in accordance with § 600.507;

(ii) All carbon-related exhaust emission data used in the FTP/HFET-based model type calculations under § 600.208–12, and subsequently required by the Administrator in accordance with § 600.507;

(2)(i) All fuel economy data for certification vehicles and for vehicles tested for running changes approved under § 86.1842–01 of this chapter;

(ii) All carbon-related exhaust emission data for certification vehicles and for vehicles tested for running changes approved under § 86.1842–01 of this chapter;

(3) Any additional fuel economy and carbon-related exhaust emission data submitted by the manufacturer under § 600.509;

(4)(i) A fuel economy value for each model type of the manufacturer's product line calculated according to § 600.510(b)(2);

(ii) A carbon-related exhaust emission value for each model type of the manufacturer's product line calculated according to § 600.510(b)(2);

(5)(i) The manufacturer's average fuel economy value calculated according to § 600.510(c);

(ii) The manufacturer's average carbon-related exhaust emission value calculated according to § 600.510(j);

(6) A listing of both domestically and nondomestically produced car lines as determined in § 600.511 and the cost information upon which the determination was made; and

(7) The authenticity and accuracy of production data must be attested to by the corporation, and shall bear the signature of an officer (a corporate executive of at least the rank of vice-president) designated by the corporation. Such attestation shall constitute a representation by the manufacturer that the manufacturer has established reasonable, prudent procedures to ascertain and provide production data that are accurate and authentic in all material respects and that these procedures have been followed by employees of the manufacturer involved in the reporting process. The signature of the designated officer shall constitute a representation by the required attestation.

(8) For 2008–2010 light truck model year reports, the average fuel economy standard or the "required fuel economy level" pursuant to 49 CFR part 533, as applicable. Model year reports for light trucks meeting required fuel economy levels pursuant to 49 CFR 533.5(g) and (h) shall include information in sufficient detail to verify the accuracy of the calculated required fuel economy level. Such information is expected to include but is not limited to, production information for each unique footprint within each model type contained in the model year report and the formula used to calculate the required fuel economy level. Model year reports for required fuel economy levels shall include a statement that the method of measuring vehicle track width, measuring vehicle wheelbase and calculating vehicle footprint is accurate and complies with applicable Department of Transportation requirements.

(9) For 2011 and later model year reports, the "required fuel economy level" pursuant to 49 CFR parts 531 or 533, as applicable. Model year reports shall include information in sufficient detail to verify the accuracy of the calculated required fuel economy level, including but is not limited to, production information for each unique footprint within each model type contained in the model year report and the formula used to calculate the required fuel economy level. Model year reports shall include a statement that the method of measuring vehicle track

width, measuring vehicle wheelbase and calculating vehicle footprint is accurate and complies with applicable Department of Transportation requirements.

(10) For 2012 and later model year reports, the "required fuel economy level" pursuant to 49 CFR parts 531 or 533 as applicable, and the applicable fleet average CO_2 emission standards. Model year reports shall include information in sufficient detail to verify the accuracy of the calculated required fuel economy level and fleet average CO_2 emission standards, including but is not limited to, production information for each unique footprint within each model type contained in the model year report and the formula used to calculate the required fuel economy level and fleet average CO_2 emission standards. Model year reports shall include a statement that the method of measuring vehicle track width, measuring vehicle wheelbase and calculating vehicle footprint is accurate and complies with applicable Department of Transportation and EPA requirements.

(11) For 2012 and later model year reports, a detailed (but easy to understand) list of vehicle models and the applicable in-use CREE emission standard. The list of models shall include the applicable carline/subconfiguration parameters (including carline, equivalent test weight, road-load horsepower, axle ratio, engine code, transmission class, transmission configuration and basic engine); the test parameters (ETW and a, b, c, dynamometer coefficients) and the associated CREE emission standard. The manufacturer shall provide the method of identifying EPA engine code for applicable in-use vehicles.

■ 56. A new § 600.514–12 is added to subpart F to read as follows:

§ 600.514–12 Reports to the Environmental Protection Agency.

This section establishes requirements for automobile manufacturers to submit reports to the Environmental Protection Agency regarding their efforts to reduce automotive greenhouse gas emissions.

(a) *General Requirements.* (1) For each model year, each manufacturer shall submit a pre-model year report.

(2) The pre-model year report required by this section for each model year must be submitted before the model year begins and before the certification of any test group, no later than December 31 of the calendar year two years before the model year. For example the pre-model year report for the 2012 model year must be submitted no later than December 31, 2010.

(3) Each report required by this section must:

(i) Identify the report as a pre-model year report;

(ii) Identify the manufacturer submitting the report;

(iii) State the full name, title, and address of the official responsible for preparing the report;

(iv) Be submitted to: Director, Compliance and Innovative Strategies Division, U.S. Environmental Protection Agency, 2000 Traverwood, Ann Arbor, Michigan 48105;

(v) Identify the current model year;

(vi) Be written in the English language; and

(vii) Be based upon all information and data available to the manufacturer approximately 30 days before the report is submitted to the Administrator.

(b) *Content of pre-model year reports.* (1) Each pre-model year report must include the following information for each compliance category for the applicable future model year and to the extent possible, two model years into the future:

(i) The manufacturer's estimate of its footprint-based fleet average CO_2 standards (including temporary lead time allowance alternative standards, if applicable);

(ii) Projected total and model-level production volumes for each applicable standard category;

(iii) Projected fleet average CO_2 compliance level for each applicable standard category; and the model-level CO_2 emission values which form the basis of the projection;

(iv) Projected fleet average CO_2 credit/debit status for each applicable standard category;

(v) A description of the various credit, transfer and trading options that will be used to comply with each applicable standard category, including the amount of credit the manufacturer intends to generate for air conditioning leakage, air conditioning efficiency, off-cycle technology, and various early credit programs;

(vi) A description of the method which will be used to calculate the carbon-related exhaust emissions for any electric vehicles, fuel cell vehicles and plug-in hybrid vehicles;

(vii) A summary by model year (beginning with the 2009 model year) of the number of electric vehicles, fuel cell vehicles and plug-in hybrid vehicles using (or projected to use) the advanced technology vehicle incentives program;

(viii) The methodology which will be used to comply with N_2O and CH_4 emission standards; and

(ix) Other information requested by the Administrator.

(2) Manufacturers must submit, in the pre-model year report for each model year in which a credit deficit is generated (or projected to be generated), a compliance plan demonstrating how the manufacturer will comply with the fleet average CO_2 standard by the end of the third year after the deficit occurred.

Department of Transportation

49 CFR Chapter V

In consideration of the foregoing, under the authority of 49 U.S.C. 32901, 32902, 32903, and 32907, and delegation of authority at 49 CFR 1.50, NHTSA amends 49 CFR Chapter V as follows:

PART 531—PASSENGER AUTOMOBILE AVERAGE FUEL ECONOMY STANDARDS

■ 1. The authority citation for part 531 continues to read as follows:

Authority: 49 U.S.C. 32902; delegation of authority at 49 CFR 1.50.

■ 2. Amend § 531.5 as follows:

■ a. By revising paragraph (a) introductory text.

■ b. By revising paragraph (c).

■ c. By redesignating paragraph (d) as paragraph (e).

■ d. By adding a new paragraph (d).

§ 531.5 Fuel economy standards.

(a) Except as provided in paragraph (e) of this section, each manufacturer of passenger automobiles shall comply with the average fuel economy standards in Table I, expressed in miles per gallon, in the model year specified as applicable:

* * * * *

(c) For model years 2012–2016, a manufacturer's passenger automobile fleet shall comply with the fuel economy level calculated for that model year according to Figure 2 and the appropriate values in Table III.

Figure 2 :

$$CAFE_{required} = \frac{\sum_i Production_i}{\sum_i \frac{Production_i}{TARGET_i}}$$

Where:

$CAFE_{required}$ is the required level for a given fleet (domestic passenger automobiles or import passenger automobiles),

Subscript i is a designation of multiple groups of automobiles, where each group's designation, *i.e.,* i = 1, 2, 3, etc., represents automobiles that share a unique model type and footprint within the applicable fleet, either domestic passenger automobiles or import passenger automobiles.

$Production_i$ is the number of passenger automobiles produced for sale in the United States within each ith designation, *i.e.,* which shares the same model type and footprint.

$TARGET_i$ is the fuel economy target in miles per gallon (mpg) applicable to the footprint of passenger automobiles within each ith designation, *i.e.,* which shares the same model type and footprint, calculated according to Figure 3 and rounded to the nearest hundredth of a mpg, *i.e.,* 35.455 = 35.46 mpg, and the summations in the numerator and denominator are both performed over all models in the fleet in question.

Figure 3 :

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Where:

TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet),

Parameters *a, b, c,* and *d* are defined in Table III, and

The *MIN* and *MAX* functions take the minimum and maximum, respectively, of the included values.

TABLE III—PARAMETERS FOR THE PASSENGER AUTOMOBILE FUEL ECONOMY TARGETS

Model year	Parameters			
	a	*b*	*c*	*d*
2012	35.95	27.95	0.0005308	0.006057
2013	36.80	28.46	0.0005308	0.005410
2014	37.75	29.03	0.0005308	0.004725
2015	39.24	29.90	0.0005308	0.003719
2016	41.09	30.96	0.0005308	0.002573

(d) In addition to the requirement of paragraphs (b) and (c) of this section, each manufacturer shall also meet the minimum standard for domestically manufactured passenger automobiles expressed in Table IV:

TABLE IV

Model year	Minimum standard
2011	27.8
2012	30.7
2013	31.4
2014	32.1
2015	33.3
2016	34.7

* * * * *

■ 3. Add Appendix A to Part 531 to read as follows:

Appendix A to Part 531—Example of Calculating Compliance Under § 531.5(c)

Assume a hypothetical manufacturer (Manufacturer X) produces a fleet of domestic passenger automobiles in MY 2012 as follows:

Appendix A, Table 1

Model type				Description	Actual measured fuel economy (mpg)	Volume
Group	Carline name	Basic engine (L)	Transmission class			
1	PC A FWD	1.8	A5	2-door sedan	34.0	1,500
2	PC A FWD	1.8	M6	2-door sedan	34.6	2,000
3	PC A FWD	2.5	A6	4-door wagon	33.8	2,000
4	PC A AWD	1.8	A6	4-door wagon	34.4	1,000
5	PC A AWD	2.5	M6	2-door hatchback	32.9	3,000
6	PC B RWD	2.5	A6	4-door wagon	32.2	8,000
7	PC B RWD	2.5	A7	4-door sedan	33.1	2,000
8	PC C AWD	3.2	A7	4-door sedan	30.6	5,000
9	PC C FWD	3.2	M6	2-door coupe	28.5	3,000
Total						27,500

Note to Appendix A, Table 1. Manufacturer X's required corporate average fuel economy level standard under § 531.5(c) would first be calculated by determining the fuel economy targets applicable to each unique model type and footprint combination for model type groups 1–9 as illustrated in Appendix A, Table 2:

Appendix A, Table 2

Manufacturer X calculates a fuel economy target standard for each unique model type and footprint combination.

Model type				Description	Base tire size	Wheel-base (inches)	Track width F&R average (inches)	Footprint (ft^2)	Volume	Fuel economy target standard (mpg)
Group	Carline name	Basic engine (L)	Trans-mission class							
1a	PC A FWD	1.8	A5	2-door sedan	205/75R14	99.8	61.2	42.4	900	35.01
1b	PC A FWD	1.8	A5	2-door sedan	215/70R15	99.8	60.9	42.2	600	35.14
2	PC A FWD	1.8	M6	2-door sedan	215/70R15	99.8	60.9	42.2	2,000	35.14
3	PC A FWD	2.5	A6	4-door wagon	215/70R15	100.0	60.9	42.3	2,000	35.08
4	PC A AWD	1.8	A6	4-door wagon	235/60R15	100.0	61.2	42.5	1,000	35.95
5	PC A AWD	2.5	M6	2-door hatchback.	225/65R16	99.6	59.5	41.2	3,000	35.81
6a	PC B RWD	2.5	A6	4-door wagon	235/65R16	109.2	67.2	51.0	4,000	30.19
6b	PC B RWD	2.5	A6	4-door wagon	265/55R18	109.2	66.8	50.7	4,000	30.33
7	PC B RWD	2.5	A7	4-door sedan	235/65R17	109.2	67.8	51.4	2,000	29.99
8	PC C AWD	3.2	A7	4-door sedan	265/55R18	111.3	67.8	52.4	5,000	29.52
9	PC C FWD	3.2	M6	2-door coupe	225/65R16	111.3	67.2	51.9	3,000	29.76
Total									27,500	

Note to Appendix A, Table 2. With the appropriate fuel economy targets determined for each unique model type and footprint combination, Manufacturer X's required fuel economy target standard would be calculated as illustrated in Appendix A, Figure 1.

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Appendix A, Figure 1

Calculation of Manufacturer X's target fuel economy standard

(Manufacturer's Domestic Passenger Automobile Production for Applicable Model Year) / ((Group 1a Volume / Group 1a Target) + ((Group 1b Volume / Group 1b Target) + … + (Group 9 Volume / Group 9 Target)) =

27500 / (900/35.01 + 600/35.14 + 2000/35.14 + 2000/35.08 + 1000/34.95 + 3000/35.81 + 4000/30.19 + 4000/30.33 + 2000/29.99 + 5000/25.52 + 3000/29.76) = 31.6

$$\frac{\text{Manufacturer's Domestic Passenger Automobile Production for Applicable Model Year}}{\left[\frac{\begin{array}{c}\text{Group1a}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group1a}\\\text{Target}\end{array}}+\frac{\begin{array}{c}\text{Group1b}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group1b}\\\text{Target}\end{array}}+\frac{\begin{array}{c}\text{Group2}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group2}\\\text{Target}\end{array}}+\frac{\begin{array}{c}\text{Group3}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group3}\\\text{Target}\end{array}}+\cdots+\frac{\begin{array}{c}\text{Group7}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group7}\\\text{Target}\end{array}}+\frac{\begin{array}{c}\text{Group8}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group8}\\\text{Target}\end{array}}+\frac{\begin{array}{c}\text{Group9}\\\text{Volume}\end{array}}{\begin{array}{c}\text{Group9}\\\text{Target}\end{array}}\right]}$$

$$\frac{27{,}500}{\left[\frac{900}{35.27}+\frac{600}{35.40}+\frac{2000}{35.40}+\frac{2000}{35.35}+\frac{1000}{35.21}+\frac{3000}{36.12}+\frac{4000}{30.40}+\frac{4000}{30.55}+\frac{2000}{30.18}+\frac{5000}{29.71}+\frac{3000}{29.93}\right]}$$

Fleet's target fuel economy standard = 31.6 mpg

Appendix A, Figure 2

Calculation of Manufacturer X's actual fuel economy value.

(Manufacturer's Domestic Passenger Automobile Production for Applicable Model Year) / ((Group 1 Volume / Group 1 Fuel Economy) + ((Group 2 Volume / Group 2 Fuel Economy) + … + (Group 9 Volume / Group 9 Fuel Economy)) =

27500 / (1500/34.0 + 2000/34.6 + 2000/33.8 + 1000/34.4 + 3000/32.9 + 8000/32.2 + 2000/33.1 + 5000/30.6 + 3000/28.5) = 32.0

$$\frac{\text{Manufacturer's Domestic Passenger Automobile Production for Applicable Model Year}}{\left[\frac{\text{Group1 Volume}}{\text{Group1 FuelEcon}}+\frac{\text{Group2 Volume}}{\text{Group2 FuelEcon}}+\frac{\text{Group3 Volume}}{\text{Group3 FuelEcon}}+\frac{\text{Group4 Volume}}{\text{Group4 FuelEcon}}+\frac{\text{Group5 Volume}}{\text{Group5 FuelEcon}}+\frac{\text{Group6 Volume}}{\text{Group6 FuelEcon}}+\frac{\text{Group7 Volume}}{\text{Group7 FuelEcon}}+\frac{\text{Group8 Volume}}{\text{Group8 FuelEcon}}+\frac{\text{Group9 Volume}}{\text{Group9 FuelEcon}}\right]}$$

$$\frac{27{,}500}{\left[\frac{1500}{34.0}+\frac{2000}{34.6}+\frac{2000}{33.8}+\frac{1000}{34.4}+\frac{3000}{32.9}+\frac{8000}{32.2}+\frac{2000}{33.1}+\frac{5000}{30.6}+\frac{3000}{28.5}\right]}$$

Fleet's actual fuel economy = 32.0 mpg

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Note to Appendix A, Figure 2. Since the actual average fuel economy of Manufacturer X's fleet is 32.0 mpg, as compared to its required fuel economy level of 31.8 mpg, Manufacturer X complied with the CAFE standard for MY 2012 as set forth in § 531.5(c).

PART 533—LIGHT TRUCK FUEL ECONOMY STANDARDS

■ 4. The authority citation for part 533 continues to read as follows:

Authority: 49 U.S.C. 32902; delegation of authority at 49 CFR 1.50.

■ 5. Amend § 533.5 by adding Figures 2 and 3 and Table VI at the end of paragraph (a), and adding paragraph (i), to read as follows:

§ 533.5 Requirements.

(a) * * *

* * * * *

Figure 2 :

$$CAFE_{required} = \frac{\sum_i Production_i}{\sum_i \frac{Production_i}{TARGET_i}}$$

Where:

$CAFE_{required}$ is the required level for a given fleet,

Subscript i is a designation of multiple groups of light trucks, where each group's designation, *i.e.,* i = 1, 2, 3, etc., represents light trucks that share a unique model type and footprint within the applicable fleet.

Production$_i$ is the number of units of light trucks produced for sale in the United States within each ith designation, *i.e.,* which share the same model type and footprint.

TARGET$_i$ is the fuel economy target in miles per gallon (mpg) applicable to the footprint of light trucks within each ith designation, *i.e.,* which shares the same model type and footprint, calculated according to Figure 3 and rounded to the nearest hundredth of a mpg, *i.e.,* 35.455 = 35.46 mpg, and the summations in the numerator and denominator are both performed over all models in the fleet in question.

Figure 3:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Where:

TARGET is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT,* in square feet),

Parameters *a, b, c,* and *d* are defined in Table VI, and

The *MIN* and *MAX* functions take the minimum and maximum, respectively of the included values.

TABLE VI—PARAMETERS FOR THE LIGHT TRUCK FUEL ECONOMY TARGETS

Model year	Parameters			
	a	*b*	*c*	*d*
2012	29.82	22.27	0.0004546	0.014900
2013	30.67	22.74	0.0004546	0.013968
2014	31.38	23.13	0.0004546	0.013225
2015	32.72	23.85	0.0004546	0.011920
2016	34.42	24.74	0.0004546	0.010413

* * * * *

(i) For model years 2012–2016, a manufacturer's light truck fleet shall comply with the fuel economy level calculated for that model year according to Figures 2 and 3 and the appropriate values in Table VI.

■ 6. Amend Appendix A to Part 533 by revising Tables 1 and 2 and Figures 1 and 2 to read as follows:

Appendix A to Part 533—Example of Calculating Compliance Under § 533.5(i)

Assume a hypothetical manufacturer (Manufacturer X) produces a fleet of light trucks in MY 2012 as follows:

Appendix A, Table 1

Model type				Description	Actual measured fuel economy (mpg)	Volume
Group	Carline name	Basic engine (L)	Transmission class			
1	Pickup A 2WD	4	A5	Reg cab, MB	27.1	800
2	Pickup B 2WD	4	M5	Reg cab, MB	27.6	200
3	Pickup C 2WD	4.5	A5	Reg cab, LB	23.9	300
4	Pickup C 2WD	4	M5	Ext cab, MB	23.7	400
5	Pickup C 4WD	4.5	A5	Crew cab, SB	23.5	400
6	Pickup D 2WD	4.5	A6	Crew cab, SB	23.6	400
7	Pickup E 2WD	5	A6	Ext cab, LB	22.7	500
8	Pickup E 2WD	5	A6	Crew cab, MB	22.5	500
9	Pickup F 2WD	4.5	A5	Reg cab, LB	22.5	1,600
10	Pickup F 4WD	4.5	A5	Ext cab, MB	22.3	800
11	Pickup F 4WD	4.5	A5	Crew cab, SB	22.2	800
Total						6,700

Note to Appendix A, Table 1. Manufacturer X's required corporate average fuel economy level under § 533.5(i) would first be calculated by determining the fuel economy targets applicable to each unique model type and footprint combination for model type groups (1–11) illustrated in Appendix A, Table 2:

Appendix A, Table 2

Manufacturer X calculates a fuel economy target standard value for each unique model type and footprint combination.

Model type				Description	Base tire size	Wheel-base (inches)	Track width F&R average (inches)	Footprint (ft^2)	Volume	Fuel economy target standard (mpg)
Group	Carline name	Basic engine (L)	Transmission class							
1	Pickup A 2WD	4	A5	Reg cab, MB	235/75R15	100.0	68.8	47.8	800	27.30
2a	Pickup B 2WD	4	M5	Reg cab, MB	235/75R15	100.0	68.2	47.4	100	27.44
2b	Pickup B 2WD	4	M5	Reg cab, MB	235/70R16	100.0	68.4	47.5	100	27.40
3	Pickup C 2WD	4.5	A5	Reg cab, LB	255/70R17	125.0	68.8	59.7	300	23.79
4	Pickup C 2WD	4	M5	Ext cab, MB	255/70R17	125.0	68.8	59.7	400	23.79
5	Pickup C 4WD	4.5	A5	Crew cab, SB	275/70R17	150.0	69.0	71.9	400	22.27
6a	Pickup D 2WD	4.5	A6	Crew cab, SB	255/70R17	125.0	68.8	59.7	200	23.79
6b	Pickup D 2WD	4.5	A6	Crew cab, SB	285/70R17	125.0	69.2	60.1	200	23.68
7	Pickup E 2WD	5	A6	Ext cab, LB	255/70R17	125.0	68.8	59.7	500	23.79
8	Pickup E 2WD	5	A6	Crew cab, MB.	285/70R17	125.0	69.2	60.1	500	23.68
9	Pickup F 2WD	4.5	A5	Reg cab, LB	255/70R17	125.0	68.9	59.8	1,600	23.76
10	Pickup F 4WD	4.5	A5	Ext cab, MB	275/70R17	150.0	69.0	71.9	800	22.27
11	Pickup F 4WD	4.5	A5	Crew cab, SB	285/70R17	150.0	69.2	72.1	800	22.27
Total									6,700	

Note to Appendix A, Table 2. With the appropriate fuel economy targets determined for each unique model type and footprint combination, Manufacturer X's required fuel economy target standard would be calculated as illustrated in Appendix A, Figure 1.

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Appendix A, Figure 1

Calculation of Manufacturer X's target fuel economy standard value.

(Manufacturer's Light Truck Production for Applicable Model Year) / ((Group 1 Volume / Group 1 Target) + ((Group 2a Volume / Group 2a Target) + … + (Group 11 Volume / Group 11 Target)) =

6700/ (800/27.30 + 100/27.44 + 100/27.40 + 300/23.79 + 400/23.79 + 400/22.27 + 200/23.79 + 200/23.68 + 500/23.79 + 500/23.68 + 1600/23.76 + 800/22.27 + 800/22.27)

= 23.7

$$\frac{\text{Manufacturer's Light Truck Production for Applicable Model Year}}{\left[\frac{\text{Group1 Volume}}{\text{Group1 Target}}+\frac{\text{Group2a Volume}}{\text{Group2a Target}}+\frac{\text{Group2b Volume}}{\text{Group2b Target}}+\frac{\text{Group3 Volume}}{\text{Group3 Target}}+\cdots+\frac{\text{Group9 Volume}}{\text{Group9 Target}}+\frac{\text{Group10 Volume}}{\text{Group10 Target}}+\frac{\text{Group11 Volume}}{\text{Group11 Target}}\right]}$$

$$\frac{6{,}700}{\left[\frac{800}{26.99}+\frac{100}{27.13}+\frac{100}{27.08}+\frac{300}{23.54}+\frac{400}{23.54}+\frac{400}{22.06}+\frac{200}{23.54}+\frac{200}{23.45}+\frac{500}{23.54}+\frac{500}{23.45}+\frac{1600}{23.52}+\frac{800}{22.06}+\frac{800}{22.06}\right]}$$

Fleet's target fuel economy standard = 23.7 mpg

Appendix A, Figure 2

Calculation of Manufacturer X's actual fuel economy value.

(Manufacturer's Light Truck Production for Applicable Model Year) / ((Group 1 Volume / Group 1 Fuel Economy) + ((Group 2 Volume / Group 2 Fuel Economy) + … + (Group 11 Volume / Group 11 Fuel Economy)) =

6700 / (800/27.1 + 200/27.6 + 300/23.9 + 400/23.7 + 400/23.5 + 400/23.6 + 500/22.7 + 500/22.5 + 1600/22.5 + 800/22.3 + 800/22.2) = 23.3

$$\frac{\text{Manufacturer's Light Truck Production for Applicable Model Year}}{\left[\frac{\text{Group1 Volume}}{\text{Group1 FuelEcon}}+\frac{\text{Group2 Volume}}{\text{Group2 FuelEcon}}+\frac{\text{Group3 Volume}}{\text{Group3 FuelEcon}}+\frac{\text{Group4 Volume}}{\text{Group4 FuelEcon}}+\frac{\text{Group5 Volume}}{\text{Group5 FuelEcon}}+\frac{\text{Group6 Volume}}{\text{Group6 FuelEcon}}+\frac{\text{Group7 Volume}}{\text{Group7 FuelEcon}}+\frac{\text{Group8 Volume}}{\text{Group8 FuelEcon}}+\frac{\text{Group9 Volume}}{\text{Group9 FuelEcon}}+\frac{\text{Group10 Volume}}{\text{Group10 FuelEcon}}+\frac{\text{Group11 Volume}}{\text{Group11 FuelEcon}}\right]}$$

$$\frac{6{,}700}{\left[\frac{800}{27.1}+\frac{200}{27.6}+\frac{300}{23.9}+\frac{400}{23.7}+\frac{400}{23.5}+\frac{400}{23.6}+\frac{500}{22.7}+\frac{500}{22.5}+\frac{1600}{22.5}+\frac{800}{22.3}+\frac{800}{22.2}\right]}$$

Fleet's actual fuel economy value = 23.3 mpg

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Note to Appendix A, Figure 2. Since the actual average fuel economy of Manufacturer X's fleet is 23.3 mpg, as compared to its required fuel economy level of 23.5 mpg, Manufacturer X did not comply with the CAFE standard for MY 2012 as set forth in section 533.5(i).

PART 536—TRANSFER AND TRADING OF FUEL ECONOMY CREDITS

■ 7. The authority citation for part 563 continues to read as follows:

Authority: Sec. 104, Pub. L. 110–140 (49 U.S.C. 32903); delegation of authority at 49 CFR 1.50.

■ 8. Amend § 536.3 by revising the definition of "Transfer" in paragraph (b) to read as follows:

§ 536.3 Definitions.

* * * * *

(b) * * *

Transfer means the application by a manufacturer of credits earned by that manufacturer in one compliance category or credits acquired be trade (and originally earned by another manufacturer in that category) to achieve compliance with fuel economy standards with respect to a different compliance category. For example, a manufacturer may purchase light truck credits from another manufacturer, and transfer them to achieve compliance in the manufacturer's domestically manufactured passenger car fleet. Subject to the credit transfer limitations of 49 U.S.C. 32903(g)(3), credits can also be transferred across compliance categories and banked or saved in that category to be carried forward or backwards later to address a credit shortfall.

* * * * *

■ 9. Amend § 536.4 by revising the values for the terms *VMTe* and *VMTu* in paragraph (c) to read as follows:

§ 536.4 Credits.

* * * * *

(c) * * *

VMTe = Lifetime vehicle miles traveled as provided in the following table for the model year and compliance category in which the credit was earned.

VMTu = Lifetime vehicle miles traveled as provided in the following table for the model year and compliance category in which the credit is used for compliance.

Model year	Lifetime Vehicle Miles Traveled (VMT)				
	2012	2013	2014	2015	2016
Passenger Cars	177,238	177,366	178,652	180,497	182,134
Light Trucks	208,471	208,537	209,974	212,040	213,954

* * * * *

PART 537—AUTOMOTIVE FUEL ECONOMY REPORTS

■ 10. The authority citation for part 537 continues to read as follows:

Authority: 49 U.S.C. 32907, delegation of authority at 49 CFR 1.50.

■ 11. Amend § 537.5 by revising paragraph (c)(4) to read as follows:

§ 537.5 General requirements for reports.

* * * * *

(c) * * *

(4) Be submitted in 5 copies to: Administrator, National Highway Traffic Safety Administration, 1200 New Jersey Avenue, SE., Washington, DC 20590, or submitted electronically to the following secure e-mail address: *cafe@dot.gov.* Electronic submissions should be provided in a pdf format.

* * * * *

§ 537.6 [Amended]

■ 12. Amend § 537.6 by removing paragraph (c)(1) and redesignating paragraph (c)(2) as paragraph (c).

■ 13. Amend § 537.7 by revising paragraphs (c)(4)(xvi)(A)(*4*) and (c)(4)(xvi)(B)(*4*) to read as follows:

§ 537.7 Pre-model year and mid-model year reports.

* * * * *

(c) * * *

(4) * * *

(xvi)(*A*) * * *

(*4*) Beginning model year 2010, front axle, rear axle and average track width as defined in 49 CFR 523.2,

* * * * *

(*B*) * * *

(*4*) Beginning model year 2010, front axle, rear axle and average track width as defined in 49 CFR 523.2,

* * * * *

■ 14. Amend § 537.8 by revising paragraph (c)(1) and removing and reserving paragraph (c)(2) to read as follows:

§ 537.8 Supplementary reports.

* * * * *

(c)(1) Each report required by paragraph (a)(1), (2), or (3) of this section must be submitted in accordance with § 537.5(c) not more than 45 days after the date on which the manufacturer determined, or could have determined with reasonable diligence, that a report is required under paragraph (a)(1), (2), or (3) of this section.

(2) [Reserved]

* * * * *

■ 15. Amend § 537.9 by revising paragraph (c) to read as follows:

§ 537.9 Determination of fuel economy values and average fuel economy.

* * * * *

(c) *Average fuel economy.* Average fuel economy must be based upon fuel economy values calculated under paragraph (b) of this section for each model type and must be calculated in accordance with subpart F of 40 CFR part 600, except that fuel economy values for running changes and for new base levels are required only for those changes made or base levels added before the average fuel economy is required to be submitted under this part.

* * * * *

PART 538—MANUFACTURING INCENTIVES FOR ALTERNATIVE FUEL VEHICLES

■ 16. The authority citation for part 538 continues to read as follows:

Authority: 49 U.S.C. 32901, 32905, and 32906; delegation of authority at 49 CFR 1.50.

■ 17. Revise § 538.1 to read as follows:

§ 538.1 Scope.

This part establishes minimum driving range criteria to aid in identifying passenger automobiles that are dual-fueled automobiles. It also establishes gallon equivalent measurements for gaseous fuels other than natural gas.

■ 18. Revise § 538.2 to read as follows:

§ 538.2 Purpose.

The purpose of this part is to specify one of the criteria in 49 U.S.C. chapter 329 "Automobile Fuel Economy" for identifying dual-fueled passenger automobiles that are manufactured in model years 1993 through 2019. The fuel economy of a qualifying vehicle is calculated in a special manner so as to encourage its production as a way of facilitating a manufacturer's compliance with the Corporate Average Fuel Economy standards set forth in part 531 of this chapter. The purpose is also to establish gallon equivalent measurements for gaseous fuels other than natural gas.

■ 19. Amend § 538.7 by revising paragraph (b)(1) to read as follows:

§ 538.7 Petitions for reduction of minimum driving range.

* * * * *

(b) * * *

(1) Be addressed to: Administrator, National Highway Traffic Safety Administration, 1200 New Jersey Avenue, SE., Washington, DC 20590.

* * * * *

Dated: April 1, 2010.

Ray LaHood,

Secretary, Department of Transportation.

Dated: April 1, 2010.

Lisa P. Jackson,

Administrator, Environmental Protection Agency.

[FR Doc. 2010–8159 Filed 5–6–10; 8:45 am]

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ASSESSMENT OF FUEL ECONOMY TECHNOLOGIES FOR LIGHT-DUTY VEHICLES

Committee on the Assessment of Technologies for Improving
Light-Duty Vehicle Fuel Economy

Board on Energy and Environmental Systems

Division on Engineering and Physical Sciences

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[1]National Academy of Engineering.
[2]National Academy of Sciences.

DEDICATION

This report is dedicated to Dr. Patrick Flynn, a very active and contributing committee member and a member of the National Academy of Engineering, who passed away on August 21, 2008, while this report was being prepared.

Acknowledgments

As a result of the considerable time and effort contributed by the members of the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, whose biographies are presented in Appendix A, this report identifies and estimates the effectiveness of technologies for improving fuel economy in light-duty vehicles, and the related costs. The committee's statement of task (Appendix B) clearly presented substantial challenges, which the committee confronted with fair and honest discussion supported with data from the National Highway Traffic Safety Administration (NHTSA), the Environmental Protection Agency (EPA), and the DOT-Volpe Research Laboratory. I appreciate the members' efforts, especially those who chaired the subgroups and led the compilation of the various chapters.

The data and conclusions presented in the report have benefited from a substantial amount of information provided by global automobile manufacturers, suppliers, and others in the regulatory communities and in non-governmental organizations. Appendix C lists the presentations provided to the committee. Members of the committee also visited industry organizations in North America, Europe, and Japan. In addition, the National Research Council contracted with outside organizations to develop and evaluate a number of technological opportunities.

The committee greatly appreciates and thanks the dedicated and committed staff of the National Research Council (NRC), and specifically the Board on Energy and Environmental Systems (BEES) under the direction of James Zucchetto (director of BEES). The committee particularly wishes to recognize the outstanding leadership of K. John Holmes, study director, and his staff. Thanks and recognition are due to the following BEES staff: Alan Crane, senior program officer; Madeline Woodruff, senior program officer; LaNita Jones, administrative coordinator; Jonathan Yanger, senior program assistant; and Aaron Greco, Mirzayan Policy Fellow, as well as consultants K.G. Duleep of Energy and Environmental Analysis, Inc.; Ricardo, Inc.; and IBIS, Inc. The committee also thanks Christopher Baillie, FEV, Inc., an unpaid consultant to the committee, for his many efforts, dedication, and hard work.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the NRC. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report:

Tom Austin, Sierra Research Corporation,
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Orron Kee, National Highway Traffic Safety Administration (retired),
Steven Plotkin, Argonne National Laboratory,
Priyaranjan Prasad, Prasad Consulting, and
Lee Schipper, Berkeley Transportation Center.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Elisabeth M. Drake, Massachusetts Institute of Technology (retired), and Dale Stein, Michigan Technological University (retired). Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Trevor O. Jones, *Chair*
Committee on the Assessment of Technologies
for Improving Light-Duty Vehicle Fuel Economy

Contents

APPENDIXES

Summary

In 2007 the National Highway Traffic Safety Administration (NHTSA) requested that the National Academies provide an objective and independent update of the technology assessments for fuel economy improvements and incremental costs contained in the 2002 National Research Council (NRC) report *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards.* The NHTSA also asked that the NRC add to its assessment technologies that have emerged since that report was prepared. To address this request, the NRC formed the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy. The statement of task, shown in Appendix B, directed the committee to estimate the efficacy, cost, and applicability of technologies that might be used over the next 15 years.

FINDINGS AND RECOMMENDATIONS

Overarching Finding

A significant number of technologies exist that can reduce the fuel consumption of light-duty vehicles while maintaining similar performance, safety, and utility. Each technology has its own characteristic fuel consumption benefit and estimated cost. Although these technologies are often considered independently, there can be positive and negative interactions among individual technologies, and so the technologies must be integrated effectively into the full vehicle system. Integration requires that other components of the vehicle be added or modified to produce a competitive vehicle that can be marketed successfully. Thus, although the fuel consumption benefits and costs discussed here are compared against those of representative base vehicles, the actual costs and benefits will vary by specific model. Further, the benefits of some technologies are not completely represented in the tests used to estimate corporate average fuel economy (CAFE). The estimate of such benefits will be more realistic using the new five-cycle tests that display fuel economy data on new vehicles' labels, but improvements to test procedures and additional analysis are warranted. Given that the ultimate energy savings are directly related to the amount of fuel consumed, as opposed to the distance that a vehicle travels on a gallon of fuel, consumers also will be helped by addition to the label of explicit information that specifies the number of gallons typically used by the vehicle to travel 100 miles.

Technologies for Reducing Fuel Consumption

Tables S.1 and S.2 show the committee's estimates of fuel consumption benefits and costs for technologies that are commercially available and can be implemented within 5 years. The cost estimates represent estimates for the current (2009/2010) time period to about 5 years in the future. The committee based these estimates on a variety of sources, including recent reports from regulatory agencies and other sources on the costs and benefits of technologies; estimates obtained from suppliers on the costs of components; discussions with experts at automobile manufacturers and suppliers; detailed teardown studies of piece costs for individual technologies; and comparisons of the prices for and amount of fuel consumed by similar vehicles with and without a particular technology.

Some longer-term technologies have also demonstrated the potential to reduce fuel consumption, although further development is required to determine the degree of improvement, cost-effectiveness, and expected durability. These technologies include camless valve trains, homogeneous-charge compression ignition, advanced diesel, plug-in hybrids, diesel hybrids, electric vehicles, fuel cell vehicles, and advanced materials and body designs. Although some of these technologies will see at least limited commercial introduction over the next several years, it is only in the 5- to 15-year time frame and beyond that they are expected to find widespread commercial application. Further, it will not be possible for some of these technologies to become solutions for significant technical and economic challenges, and thus some of these technologies will remain perennially 10 to 15 years out beyond a moving reference. Among its provisions,

TABLE S.1 Committee's Estimates of Effectiveness (shown as a percentage) of Near-Term Technologies in Reducing Vehicle Fuel Consumption

Technologies		Incremental values - A preceding technology must be included								
		I4			V6			V8		
Spark Ignition Techs	Abbreviation	Low	High	AVG	Low	High	AVG	Low	High	AVG
Low Friction Lubricants	LUB	0.5	0.5	**0.5**	0.5	0.5	**0.5**	0.5	0.5	**0.5**
Engine Friction Reduction	EFR	0.5	2.0	**1.3**	0.5	2.0	**1.3**	1.0	2.0	**1.5**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.5	3.0	**2.3**	1.5	3.0	**2.3**	2.0	3.0	**2.5**
Cylinder Deactivation, SOHC	DEAC	NA	NA	NA	4.0	6.0	**5.0**	5.0	10.0	**7.5**
VVT - In take Cam Phasing (ICP)	ICP	1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.5	2.0	**1.8**
VVT - Dual Cam Phasing (DCP)	DCP	1.5	2.5	**2.0**	1.5	3.0	**2.3**	1.5	3.0	**2.3**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Continuously Variable Valve Lift (CVVL)	CVVL	3.5	6.0	**4.8**	3.5	6.5	**5.0**	4.0	6.5	**5.3**
Cylinder Deactivation, OHV	DEAC	NA	NA	NA	4.0	6.0	**5.0**	5.0	10.0	**7.5**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	1.5	2.5	**2.0**	1.5	3.0	**2.3**	2.0	3.0	**2.5**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.5	3.0	**2.3**	1.5	3.0	**2.3**	1.5	3.0	**2.3**
Turbocharging and Downsizing	TRBDS	2.0	5.0	**3.5**	4.0	6.0	**5.0**	4.0	6.0	**5.0**
Diesel Techs										
Conversion to Diesel	DSL	15.0	35.0	**25.0**	15.0	35.0	**25.0**	NA	NA	NA
Conversion to Advanced Diesel	ADSL	7.0	13.0	**10.0**	7.0	13.0	**10.0**	22.0	38.0	**30.0**
Electrification/Accessory Techs										
Electric Power Steering (EPS)	EPS	1.0	3.0	**2.0**	1.0	3.0	**2.0**	1.0	3.0	**2.0**
Improved Accessories	IACC	0.5	1.5	**1.0**	0.5	1.5	**1.0**	0.5	1.5	**1.0**
Higher Voltage/Improved Alternato	HVIA	0.0	0.5	**0.3**	0.0	0.5	**0.3**	0.0	0.5	**0.3**
Transmission Techs										
Continuously Variable Transmission (CVT)	CVT	1.0	7.0	**4.0**	1.0	7.0	**4.0**	1.0	7.0	**4.0**
5-spd Auto. Trans. w/ Improved Internals		2.0	3.0	**2.5**	2.0	3.0	**2.5**	2.0	3.0	**2.5**
6-spd Auto. Trans. w/ Improved Internals		1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.0	2.0	**1.5**
7-spd Auto. Trans. w/ Improved Internals		2.0		**2.0**	2.0		**2.0**	2.0		**2.0**
8-spd Auto. Trans. w/ Improved Internals		1.0		**1.0**	1.0		**1.0**	1.0		**1.0**
6/7/8-spd Auto. Trans. w/ Improved Internals	NAUTO	3.0	8.0	**5.5**	3.0	8.0	**5.5**	3.0	8.0	**5.5**
6/7-spd DCT from 4-spd AT	DCT	6.0	9.0	**7.5**	6.0	9.0	**7.5**	6.0	9.0	**7.5**
6/7-spd DCT from 6-spd AT	DCT	3.0	4.0	**3.5**	3.0	4.0	**3.5**	3.0	4.0	**3.5**
Hybrid Techs										
12V BAS Micro-Hybrid	MHEV	2.0	4.0	**3.0**	2.0	4.0	**3.0**	2.0	4.0	**3.0**
Integrated Starter Generator	ISG	29.0	39.0	**34.0**	29.0	39.0	**34.0**	29.0	39.0	**34.0**
Power Split Hybrid	PSHEV	24.0	50.0	**37.0**	24.0	50.0	**37.0**	24.0	50.0	**37.0**
2-Mode Hybrid	2MHEV	25.0	45.0	**35.0**	25.0	45.0	**35.0**	25.0	45.0	**35.0**
Plug-in hybric	PHEV	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vehicle Techs										
Mass Reduction - 1%	MR1	0.3		**0.3**	0.3		**0.3**	0.3		**0.3**
Mass Reduction - 2%	MR2	1.4		**1.4**	1.4		**1.4**	1.4		**1.4**
Mass Reduction - 5%	MR5	3.0	3.5	**3.3**	3.0	3.5	**3.3**	3.0	3.5	**3.3**
Mass Reduction - 10%	MR10	6.0	7.0	**6.5**	6.0	7.0	**6.5**	6.0	7.0	**6.5**
Mass Reduction - 20%	MR20	11.0	13.0	**12.0**	11.0	13.0	**12.0**	11.0	13.0	**12.0**
Low Rolling Resistance Tires	ROLL	1.0	3.0	**2.0**	1.0	3.0	**2.0**	1.0	3.0	**2.0**
Low Drag Brakes	LDB	1.0		**1.0**	1.0		**1.0**	1.0		**1.0**
Aero Drag Reduction 10%	AERC	1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.0	2.0	**1.5**

NOTE: Some of the benefits (highlighted in green) are incremental to those obtained with preceding technologies shown in the technology pathways described in Chapter 9.

the Energy Independence and Security Act (EISA) of 2007 requires periodic assessments by the NRC of automobile vehicle fuel economy technologies, including how such technologies might be used to meet new fuel economy standards. Follow-on NRC committees will be responsible for responding to the EISA mandates, including the periodic evaluation of emerging technologies.

Testing and Reporting of Vehicle Fuel Use

Fuel economy is a measure of how far a vehicle will travel with a gallon of fuel, whereas fuel consumption is the amount of fuel consumed in driving a given distance. Although each is simply the inverse of the other, fuel consumption is the fundamental metric by which to judge absolute improvements in fuel efficiency, because what is important is gallons of fuel saved in the vehicle fleet. The amount of fuel saved directly relates not only to dollars saved on fuel purchases but also to quantities of carbon dioxide emissions avoided. Fuel economy data cause consumers to undervalue small increases (1-4 mpg) in fuel economy for vehicles in the 15-30 mpg range, where large decreases in fuel consumption can be realized with small increases in fuel economy. The percentage decrease in fuel consumption is approximately

TABLE S.2 Committee's Estimates of Technology Costs in U.S. Dollars (2008)

NRC 2009 Costs													
Technologies		Incremental Values - A preceding technology must be included											
		I4				V6				V8			
Spark Ignition Techs	Abbreviation	Low	High	AVG	AVG w/1.5 RPE	Low	High	AVG	AVG w/1.5 RPE	Low	High	AVG	AVG w/1.5 RPE
Low Friction Lubricants	LUB	3	5	**4**	**6**	3	5	**4**	**6**	3	5	**4**	**6**
Engine Friction Reduction	EFR	32.0	52.0	**42**	**63**	48	78	**63**	**94.5**	64	104	**84**	**126**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	130	160	**145**	**217.5**	180	210	**195**	**292.5**	280	320	**300**	**450**
Cylinder Deactivation, SOHC	DEAC	NA	NA	**NA**	**NA**	340	400	**370**	**555**	357	420	**388.5**	**582.75**
VVT - In take Cam Phasing (ICP)	ICP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
VVT - Dual Cam Phasing (DCP)	DCP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	130	160	**145**	**217.5**	180	220	**200**	**300**	260	300	**280**	**420**
Continuously Variable Valve Lift (CVVL)	CVVL	159	205	**182**	**273**	290	310	**300**	**450**	350	390	**370**	**555**
Cylinder Deactivation, OHV	DEAC	NA	NA	**NA**	**NA**	220	250	**235**	**352.5**	255		**255**	**382.5**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	35		**35**	**52.5**	35		**35**	**52.5**	35		**35**	**52.5**
Discrete Variable Valve Lift (DVVL), OH\	DVVL	130	160	**145**	**218**	210	240	**225**	**338**	280	320	**300**	**450**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	117	195	**156**	**234**	169	256	**213**	**319**	295	351	**323**	**485**
Turbocharging and Downsizing	TRBDS	370	490	**430**	**645**	-144	205	**31**	**46**	525	790	**658**	**986**
Diesel Techs													
Conversion to Diesel	DSL	2154	2632	**2393**	**3590**	2857	3491	**3174**	**4761**	NA	NA	**NA**	**NA**
Conversion to Advanced Diese	ADSL	520	520	**520**	**780**	683	683	**683**	**1025**	3513	4293	**3903**	**5855**
Electrification/Accessory Techs													
Electric Power Steering (EPS)	EPS	70	120	**95**	**143**	70	120	**95**	**143**	70	120	**95**	**143**
Improved Accessories	IACC	70	90	**80**	**120**	70	90	**80**	**120**	70	90	**80**	**120**
Higher Voltage/Improved Alternator	HVIA	15	55	**35**	**53**	15	55	**35**	**53**	15	55	**35**	**53**
Transmission Techs													
Continuously Variable Transmission (CVT)	CVT	150	170	**160**	**240**	243	263	**253**	**380**	243	263	**253**	**380**
5-spd Auto. Trans. w/ Improved Internals		133		**133**	**200**	133		**133**	**200**	133		**133**	**200**
6-spd Auto. Trans. w/ Improved Internals		133	215	**174**	**262**	133	215	**174**	**262**	133	215	**174**	**262**
7-spd Auto. Trans. w/ Improved Internals		170	300	**235**	**353**	170	300	**235**	**353**	170	300	**235**	**353**
8-spd Auto. Trans. w/ Improved Internals		425		**425**	**638**	425		**425**	**638**	425		**425**	**638**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	137	425	**281**	**422**	137	425	**281**	**422**	137	425	**281**	**422**
6/7-spd DCT from 6-spd AT	DCT	-147	185	**19**	**29**	-147	185	**19**	**29**	-147	185	**19**	**29**
6/7-spd DCT from 4-spd AT	DCT	-14	400	**193**	**290**	-14	400	**193**	**290**	-14	400	**193**	**290**
Hybrid Techs													
12V BAS Micro-Hybrid	MHEV	450	550	**500**	**665**	585	715	**650**	**865**	720	880	**800**	**1064**
Integrated Starter Generator	ISG	1760	2640	**2200**	**2926**	2000	3000	**2500**	**3325**	3200	4800	**4000**	**5320**
Power Split Hybrid	PSHEV	2708	4062	**3385**	**4502**	3120	4680	**3900**	**5187**	4000	6000	**5000**	**6650**
2-Mode Hybrid	2MHEV	5200	7800	**6500**	**8645**	5200	7800	**6500**	**8645**	5200	7800	**6500**	**8645**
Series PHEV 40	PHEV	8000	12000	**10000**	**13300**	9600	14400	**12000**	**15960**	13600	20400	**17000**	**22610**
Vehicle Techs													
Mass Reduction - 1%	MR1	37	45	**41**	**61**	48	58	**53**	**80**	68	82	**75**	**113**
Mass Reduction - 2%	MR2	77	93	**85**	**127**	100	121	**111**	**166**	142	170	**156**	**234**
Mass Reduction - 5%	MR5	217	260	**239**	**358**	283	339	**311**	**467**	399	479	**439**	**659**
Mass Reduction - 10%	MR10	520	624	**572**	**859**	679	815	**747**	**1120**	958	1150	**1054**	**1581**
Mass Reduction - 20%	MR20	1600	1700	**1650**	**2475**	1600	1800	**1700**	**2550**	1600	1900	**1750**	**2625**
Low Rolling Resistance Tires	ROLL	30	40	**35**	**53**	30	40	**35**	**53**	30	40	**35**	**53**
Aero Drag Reduction 10%	AERO	40	50	**45**	**68**	40	50	**45**	**68**	40	50	**45**	**68**

equal to the percentage increase in fuel economy for values less than 10 percent (for example, a 9.1 percentage decrease in fuel consumption equals a 10 percent increase in fuel economy), but the differences increase progressively: for example, a 33.3 percent decrease in fuel consumption equals a 50 percent increase in fuel economy.

Recommendation: Because differences in the fuel consumption of vehicles relate directly to fuel savings, the labeling on new cars and light-duty trucks should include information on the gallons of fuel consumed per 100 miles traveled in addition to the already-supplied data on fuel economy so that consumers can become familiar with fuel consumption as a fundamental metric for calculating fuel savings.

Fuel consumption and fuel economy are evaluated by the U.S. Environmental Protection Agency (EPA) for the two driving cycles: the urban dynamometer driving schedule (city cycle) and the highway dynamometer driving schedule (highway cycle). In the opinion of the committee, the schedules used to compute CAFE should be modified so that vehicle test data better reflect actual fuel consumption. Excluding some driving conditions and accessory loads in determining CAFE discourages the introduction of certain technologies into the vehicle fleet. The three additional schedules recently adopted by the EPA for vehicle labeling purposes—ones that capture the effects of higher speed and acceleration, air conditioner use, and cold weather—represent a positive step forward, but further study is needed to assess to what degree the new test procedures can fully characterize changes in in-use vehicle fuel consumption.

Recommendation: The NHTSA and the EPA should review and revise fuel economy test procedures so that they better reflect in-use vehicle operating conditions and also provide the proper incentives to manufacturers to produce vehicles that reduce fuel consumption.

Cost Estimation

Large differences in technology cost estimates can result from differing assumptions. These assumptions include whether costs are long- or short-term costs; whether learning by doing is included in the cost estimate; whether the cost estimate represents direct in-house manufacturing costs or the cost of purchasing a component from a supplier; and which of the other changes in vehicle design that are required to maintain vehicle quality have been included in the cost estimate. Cost estimates also depend greatly on assumed production volumes.

In the committee's judgment, the concept of incremental retail price equivalent (RPE) is the most appropriate indicator of cost for the NHTSA's purposes because it best represents the full, long-run economic costs of decreasing fuel consumption. The RPE represents the average additional price consumers would pay for a fuel economy technology. It is intended to reflect long-run, substantially learned, industry-average production costs that incorporate rates of profit and overhead expenses. A critical issue is choice of the RPE markup factor, which represents the ratio of total cost of a component, taking into account the full range of costs of doing business, to only the direct cost of the fully manufactured component. For fully manufactured components purchased from a Tier 1 supplier,[1] a reasonable average RPE markup factor is 1.5. For in-house manufactured components, a reasonable average RPE markup factor over variable manufacturing costs is 2.0. In addition to the costs of materials and labor and the fixed costs of manufacturing, the RPE factor for components from Tier 1 suppliers includes profit, warranty, corporate overhead, and amortization of certain fixed costs, such as research and development. The RPE factor for in-house manufactured components from automobile manufacturers includes the analogous components of the Tier 1 markup for the manufacturing operations, plus additional fixed costs for vehicle integration design and vehicle installation, corporate overhead for assembly operations, additional product warranty costs, transportation, marketing, dealer costs, and profits. RPE markup factors clearly vary depending on the complexity of the task of integrating a component into a vehicle system, the extent of the changes required to other components, the novelty of the technology, and other factors. However, until empirical data derived via rigorous estimation methods are available, the committee prefers the use of average markup factors.

Available cost estimates are based on a variety of sources: component cost estimates obtained from suppliers, discussions with experts at automobile manufacturers and suppliers, publicly available transaction prices, and comparisons of the prices of similar vehicles with and without a particular technology. However, there is a need for cost estimates based on a teardown of all the elements of a technology and a detailed accounting of materials and capital costs and labor time for all fabrication and assembly processes. Such teardown studies are costly and are not feasible for advanced technologies whose designs are not yet finalized and/or whose system integration impacts are not yet fully understood. Estimates based on the more rigorous method of teardown analysis would increase confidence in the accuracy of the costs of reducing fuel consumption.

Technology cost estimates are provided by the committee for each fuel economy technology discussed in this report. Except as indicated, the cost estimates represent the price an automobile manufacturer would pay a supplier for a finished component. Thus, on average, the RPE multiplier of 1.5 would apply to the direct, fully manufactured cost to obtain the average additional price consumers would pay for a technology. Again, except where indicated otherwise, the

[1] A Tier 1 supplier is one that contracts directly with automobile manufacturers to supply technologies.

cost estimates provided are based on current conditions and do not attempt to estimate economic conditions and hence predict prices 5, 10, or 15 years into the future.

Spark-Ignition Gasoline Engine Technologies

Spark-ignition (SI) engines are expected to continue to be the primary source of propulsion for light-duty vehicles in the United States over the time frame of this report. There have been and continue to be significant improvements in reducing the fuel consumption of SI engines in the areas of friction reduction, reduced pumping losses through advanced valve-event modulation, thermal efficiency improvements, cooled exhaust gas recirculation, and improved overall engine architecture, including downsizing. An important attribute of improvements in SI engine technologies is that they offer a means of reducing fuel consumption in relatively small, incremental steps. This approach allows automobile manufacturers to create packages of technologies that can be tailored to meet specific cost and effectiveness targets, as opposed to developing diesel or full hybrid alternatives that offer a single large benefit, but at a significant cost increase. Because of the flexibility offered by this approach, and given the size of the SI engine-powered fleet, the implementation of SI engine technologies will continue to play a large role in reducing fuel consumption.

Of the technologies currently available, cylinder deactivation is one of the more effective in reducing fuel consumption. This feature is most cost-effective when applied to six-cylinder (V6) and eight-cylinder (V8) overhead valve engines, and typically reduces fuel consumption by 4 to 10 percent at an incremental RPE increase of about $550. Stoichiometric direct injection typically affords a 1.5 to 3 percent reduction in fuel consumption at an incremental RPE increase of $230 to $480, depending on cylinder count and noise abatement requirements. Turbocharging and downsizing can also yield fuel consumption reductions. Downsizing—reducing engine displacement while maintaining vehicle performance—is an important strategy applicable in combination with technologies that increase engine torque, such as turbocharging or supercharging. Downsizing simultaneously reduces throttling and friction losses because downsized engines generally have smaller bearings and either fewer cylinders or smaller cylinder bore friction surfaces. Reductions in fuel consumption can range from 2 to 6 percent with turbocharging and downsizing, depending on many details of implementation. This technology combination is assumed to be added after direct injection, and its fuel consumption benefits are incremental to those from direct injection. Based primarily on an EPA teardown study, the committee's estimates of the costs for turbocharging and downsizing range from close to zero additional cost, when converting from a V6 to a four-cylinder (I4) engine, to almost $1,000, when converting from a V8 to a V6 engine. Valve-event modulation (VEM) can further reduce fuel consumption and can also cause a slight increase in engine performance, which offers a potential opportunity for engine downsizing. There are many different implementations of VEM, and the costs and benefits depend on the specific engine architecture. Fuel consumption reduction can range from 1 percent with only intake cam phasing, to about 7 percent with a continuously variable valve lift and timing setup. The incremental RPE increase for valve-event modulation ranges from about $50 to $550, with the amount depending on the implementation technique and the engine architecture.

Variable compression ratio, camless valve trains, and homogeneous-charge compression ignition were all given careful consideration during the course of this study. Because of questionable benefits, major implementation issues, or uncertain costs, it is uncertain whether any of these technologies will have any significant market penetration in the next 10 to 15 years.

Compression-Ignition Diesel Engine Technologies

Light-duty compression-ignition (CI) engines operating on diesel fuels have efficiency advantages over the more common SI gasoline engines. Although light-duty diesel vehicles are common in Europe, concerns over the ability of such engines to meet emission standards for nitrogen oxides and particulates have slowed their introduction in the United States. However, a joint effort between automobile manufacturers and suppliers has resulted in new emissions control technologies that enable a wide range of light-duty CI engine vehicles to meet federal and California emissions standards. The committee found that replacing a 2007 model year SI gasoline power train with a base-level CI diesel engine with an advanced 6-speed dual-clutch automated manual transmission (DCT) and more efficient accessories packages can reduce fuel consumption by about 33 percent on an equivalent vehicle performance basis. The estimated incremental RPE cost of conversion to the CI engine is about $3,600 for a four-cylinder engine and $4,800 for a six-cylinder engine. Advanced-level CI diesel engines, which are expected to reach market in the 2011-2014 time frame, with DCT (7/8 speed) could reduce fuel consumption by about an additional 13 percent for larger vehicles and by about 7 percent for small vehicles. Part of the gain from advanced-level CI diesel engines comes from downsizing. The estimated incremental RPE cost of the conversion to the package of advanced diesel technologies is about $4,600 for small passenger cars and $5,900 for intermediate and large passenger cars.

An important characteristic of CI diesel engines is that they provide reductions in fuel consumption over the entire vehicle operating range, including city driving, highway driving, hill climbing, and towing. This attribute of CI diesel engines is an advantage when compared with other technology options that in most cases provide fuel consumption benefits for only part of the vehicle operating range.

The market penetration of CI diesel engines will be strongly influenced by both the incremental cost of CI diesel power trains above the cost of SI gasoline power trains and by diesel and gasoline fuel prices. Further, while technology improvements to CI diesel engines are expected to reach market in the 2011-2014 time frame, technology improvements to SI gasoline and hybrid engines will also enter the market. Thus, competition between these power train systems will continue with respect to reductions in fuel consumption and to cost. For the period 2014-2020, further potential reductions in fuel consumption by CI diesel engines may be offset by increases in fuel consumption as a result of changes in engines and emissions systems required to meet potentially stricter emissions standards.

Hybrid Vehicle Technologies

Because of their potential to eliminate energy consumption when the vehicle is stopped, permit braking energy to be recovered, and allow more efficient use of the internal combustion engine, hybrid technologies are one of the most active areas of research and deployment. The degree of hybridization can vary from minor stop-start systems with low incremental costs and modest reductions in fuel consumption to complete vehicle redesign and downsizing of the SI gasoline engine at a high incremental cost but with significant reductions in fuel consumption. For the most basic systems that reduce fuel consumption by turning off the engine while the vehicle is at idle, the fuel consumption benefit may be up to about 4 percent at an estimated incremental RPE increase of $670 to $1,100. The fuel consumption benefit of a full hybrid may be up to about 50 percent at an estimated incremental RPE cost of $3,000 to $9,000 depending on vehicle size and specific hybrid technology. A significant part of the improved fuel consumption of full hybrid vehicles comes from the complete vehicle redesign that can incorporate modifications such as low-rolling-resistance tires, improved aerodynamics, and the use of smaller, more efficient SI engines.

In the next 10 to 15 years, improvements in hybrid vehicles will occur primarily as a result of reduced costs for hybrid power train components and improvements in battery performance such as higher power per mass and volume, increased number of lifetime charges, and wider allowable state-of-charge ranges. During the past decade, significant advances have been made in lithium-ion battery technology. When the cost and safety issues associated with them are resolved, lithium-ion batteries will replace nickel-metal-hydride batteries in hybrid electric vehicles and plug-in hybrid electric vehicles. A number of different lithium-ion chemistries are being studied, and it is not yet clear which ones will prove most beneficial. Given the high level of activity in lithium-ion battery development, plug-in hybrid electric vehicles will be commercially viable and will soon enter at least limited production. The practicality of full-performance battery electric vehicles (i.e., with driving range, trunk space, volume, and acceleration comparable to those of vehicles powered with internal-combustion engines) depends on a battery cost breakthrough that the committee does not anticipate within the time horizon considered in this study. However, it is clear that small, limited-range, but otherwise full-performance battery electric vehicles will be marketed within that time frame. Although there has been significant progress in fuel cell technology, it is the committee's opinion that fuel cell vehicles will not represent a significant fraction of on-road light-duty vehicles within the next 15 years.

Non-engine Technologies for Reducing Vehicle Fuel Consumption

There is a range of non-engine technologies with varying costs and impacts. Many of these technologies are continually being introduced to new vehicle models based on the timing of the product development process. Coordinating the introduction of many technologies with the product development process is critical to maximizing impact and minimizing cost. Relatively minor changes that do not involve reengineering the vehicle or that require recertification for fuel economy, emissions, and/or safety can be implemented within a 2- to 4-year time frame. These changes could include minor reductions in mass (achieved by substitution of materials), improving aerodynamics, or switching to low-rolling-resistance tires. More substantive changes, which require longer-term coordination with the product development process because of the need for reengineering and integration with other subsystems, could include resizing the engine and transmission or aggressively reducing vehicle mass, such as by changing the body structure. The time frame for substantive changes for a single model is approximately 4 to 8 years.

Two important technologies impacting fuel consumption are those for light-weighting and for improving transmissions. Light-weighting has significant potential because vehicles can be made very light with exotic materials, albeit at potentially high cost. The incremental cost to reduce a pound of mass from the vehicle tends to increase as the total amount of reduced mass increases, leading to diminishing returns. About 10 percent of vehicle mass can be eliminated at a cost of roughly $800 to $1,600 and can provide a fuel consumption benefit of about 6 to 7 percent. Reducing mass much beyond 10 percent requires attention to body structure design, such as considering an aluminum-intensive car, which increases the cost per pound. A 10 percent reduction in mass over the next 5 to 10 years appears to be within reach for the typical automobile.

Transmission technologies have improved significantly and, like other vehicle technologies, show a similar trend of diminishing returns. Planetary-based automatic transmissions can have 5, 6, 7, and 8 speeds, but with incremental costs increasing faster than reductions in fuel consumption. DCTs are in production by some automobile manufacturers, and new production capacity for this transmission type has been announced. It is expected that the predominant trend in transmission design is conversion to 6- to 8-speed planetary-based automatics and to DCTs, with continuously variable transmissions remaining a niche application. Given the close linkage between the effects of fuel-consumption-reducing engine technologies and transmission technologies, the present study has for the most part considered the combined effects of engines and transmission combinations rather than potential separate effects.

Accessories are also being introduced to new vehicles to reduce the power load on the engine. Higher-efficiency air conditioning systems are available that more optimally match cooling with occupant comfort. Electric and electric/hydraulic power steering also reduces the load on an engine by demanding power only when the operator turns the wheel. An important motivating factor affecting the introduction of these accessories is whether or not their impact is measured during the EPA driving cycles used to estimate fuel consumption.

Modeling Reductions in Fuel Consumption Obtained from Vehicle Technologies

The two primary methods for modeling technologies' reduction of vehicle fuel consumption are full system simulation (FSS) and partial discrete approximation (PDA). FSS is the state-of-the-art method because it is based on integration of the equations of motion for the vehicle carried out over the speed-time representation of the appropriate driving or test cycle. Done well, FSS can provide an accurate assessment (within +/–5 percent or less) of the impacts on fuel consumption of implementing one or more technologies. The validity of FSS modeling depends on the accuracy of representations of system components. Expert judgment is also required at many points and is critical to obtaining accurate results. Another modeling approach, the PDA method, relies on other sources of data for estimates of the impacts of fuel economy technologies and relies on mathematical summation or multiplication methods to aggregate the effects of multiple technologies. Synergies among technologies can be represented using engineering judgment and lumped parameter models[2] or can be synthesized from FSS results. Unlike FSS, the PDA method cannot be used to generate estimates of the impacts of individual technologies on fuel consumption. Thus, the PDA method by itself, unlike FSS, is not suitable for estimating the fuel consumption impacts of technologies that have not already been tested in actual vehicles or whose fuel consumption benefits have not been estimated by means of FSS.

[2]Lumped parameter models are simplified analytical tools for estimating vehicle energy use based on a small set of energy balance equations and empirical relationships. With a few key vehicle parameters, these methods can explicitly account for the sources of energy loss and the tractive force required to move the vehicle.

Comparisons of FSS modeling and PDA estimation supported by lumped parameter modeling have shown that the two methods produce similar results when similar assumptions are used. In some instances, comparing the estimates made by the two methods has enhanced the overall validity of estimated fuel consumption impacts by uncovering inadvertent errors in one or the other method. In the committee's judgment both methods are valuable, especially when used together, with one providing a check on the other. However, more work needs to be done to establish the accuracy of both methods relative to actual motor vehicles.

The Department of Transportation's Volpe National Transportation Systems Center has developed a model for the NHTSA to estimate how manufacturers can comply with fuel economy regulations by applying additional fuel savings technologies to the vehicles they plan to produce. The model employs a PDA algorithm that includes estimates of the effects of interactions among technologies applied. The validity of the Volpe model could be improved by taking into account main and interaction effects produced by the FSS methodology described in Chapter 8 of this report. In particular, modeling work done for the committee by an outside consulting firm has demonstrated a practical method for using data generated by FSS models to accurately assess the fuel consumption potentials of combinations of dozens of technologies on thousands of vehicle configurations. A design-of-experiments statistical analysis of FSS model runs demonstrated that main effects and first-order interaction effects alone could predict FSS model outputs with an R^2 of 0.99. Using such an approach could appropriately combine the strengths of both the FSS and the PDA modeling methods. However, in the following section, the committee recommends an alternate approach that uses FSS to better assess the contributory effects of the technologies applied in the reduction of energy losses and to better couple the modeling of fuel economy technologies to the testing of such technologies on production vehicles.

Application of Multiple Vehicle Technologies to Vehicle Classes

Figures 9.1 to 9.5 in Chapter 9 of this report display the technology pathways developed by the committee for eight classes of vehicles and the aggregated fuel consumption benefits and costs for the SI engine, CI engine, and hybrid power train pathways. The results of the committee's analysis are that, for the intermediate car, large car, and unibody standard truck classes, the average reduction in fuel consumption for the SI engine path is about 29 percent at a cost of approximately $2,200; the average reduction for the CI engine path is about 37 percent at a cost of approximately $5,900; and the average reduction for the hybrid power train path is about 44 percent at a cost of $6,000. These values are approximate and are provided here as rough estimates that can be used for qualitative comparison of SI engine-related technologies and other candidates for the reduction of vehicle fuel consumption, such as light-duty diesel or hybrid vehicles.

Improvements to Modeling of Multiple Fuel Economy Technologies

Many vehicle and power train technologies that improve fuel consumption are currently in or entering production or are in advanced stages of development in European or Asian markets where high consumer fuel prices have made commercialization of the technologies cost-effective. Depending on the intended vehicle use or current state of energy-loss reduction, the application of incremental technologies will produce varying levels of improvement in fuel consumption. Data made available to the committee from automobile manufacturers, Tier 1 suppliers, and other published studies also suggest a very wide range in estimated incremental cost. As noted above in this Summary, estimates based on teardown cost analysis, currently being utilized by the EPA in its analysis of standards for regulating light-duty-vehicle greenhouse gas emissions, should be expanded for developing cost impact analyses. The committee notes, however, that cost estimates are always more uncertain than estimates of fuel consumption.

FSS modeling that is based on empirically derived power train and vehicle performance and on fuel consumption data maps offers what the committee believes is the best available method to fully account for system energy losses and to analyze potential improvements in fuel consumption achievable by technologies as they are introduced into the market. Analyses conducted for the committee show that the effects of interactions between differing types of technologies for reducing energy loss can and often do vary greatly from vehicle to vehicle.

Recommendation: The committee proposes a method whereby FSS analyses are used on class-characterizing vehicles, so that synergies and effectiveness in implementing multiple fuel economy technologies can be evaluated with what should be greater accuracy. This proposed method would determine a characteristic vehicle that would be defined as a reasonable average representative of a class of vehicles. This representative vehicle, whether real or theoretical, would undergo sufficient FSS, combined with experimentally determined and vehicle-class-specific system mapping, to allow a reasonable understanding of the contributory effects of the technologies applied to reduce vehicle energy losses. Data developed under the United States Council for Automotive Research (USCAR) Benchmarking Consortium should be considered as a source for such analysis and potentially expanded. Under the USCAR program, actual production vehicles are subjected to a battery of vehicle, engine, and transmission tests in sufficient detail to understand how each candidate technology is applied and how they contribute to the overall performance and fuel consumption of light-duty vehicles. Combining the results of such testing with FSS modeling, and thereby making all simulation variables and subsystem maps transparent to all interested parties, would allow the best opportunity to define a technical baseline against which potential improvements could be analyzed more accurately and openly than is the case with the current methods employed.

The steps in the recommended process would be as follows:

1. Develop a set of baseline vehicle classes from which a characteristic vehicle can be chosen to represent each class. The vehicle may be either real or theoretical and will possess the average attributes of that class as determined by sales-weighted averages.
2. Identify technologies with a potential to reduce fuel consumption.
3. Determine the applicability of each technology to the various vehicle classes.
4. Estimate each technology's preliminary impact on fuel consumption and cost.
5. Determine the optimum implementation sequence (technology pathway) based on cost-effectiveness and engineering considerations.
6. Document the cost-effectiveness and engineering judgment assumptions used in step 5 and make this information part of a widely accessible database.
7. Utilize modeling software (FSS) to progress through each technology pathway for each vehicle class to obtain the final incremental effects of adding each technology.

If such a process were adopted as part of a regulatory rule-making procedure, it could be completed on 3-year cycles to allow regulatory agencies sufficient lead time to integrate the results into future proposed and enacted rules.

CONCLUDING COMMENTS

A significant number of approaches are currently available to reduce the fuel consumption of light-duty vehicles, ranging from relatively minor changes to lubricants and tires to large changes in propulsion systems and vehicle platforms. Technologies such as all-electric propulsion systems have also demonstrated the potential to reduce fuel consumption, although further development is required to determine the degree of improvement, cost-effectiveness, and durability. The development and deployment of vehicles that consume less fuel will be influenced not only by technological factors but also by economic and policy factors whose examination is beyond the scope of this study. Future NRC committees will be responsible for periodic assessments of the cost and benefits of technologies that reduce vehicle fuel consumption, including how such technologies might be used to meet new fuel economy standards.

1

Introduction

The impacts of fuel consumption by light-duty vehicles are profound, influencing economic prosperity, national security, and Earth's environment. Increasing energy efficiency has been a continuing and central objective for automobile manufacturers and regulators pursuing objectives that range from reducing vehicle operating costs and improving performance to reducing dependence on petroleum and limiting greenhouse gas emissions. Given heightened concerns about the dangers of global climate change, the needs for energy security, and the volatility of world oil prices, attention has again been focused on reducing the fuel consumption of light-duty vehicles. A wide array of technologies and approaches exist for reducing fuel consumption. These improvements range from relatively minor changes with low costs and small fuel consumption benefits—such as use of new lubricants and tires—to large changes in propulsion systems and vehicle platforms that have high costs and large fuel consumption benefits.

CURRENT POLICY CONTEXT AND MOTIVATION

The rapid rise in gasoline and diesel fuel prices experienced during 2006-2008 and growing recognition of climate-change issues have helped make vehicle fuel economy an important policy issue once again. These conditions have motivated several recent legislative and regulatory initiatives. The first major initiative was the mandate for increased CAFE standards under the Energy Independence and Security Act of 2007. This legislation requires the National Highway Traffic Safety Administration (NHTSA) to raise vehicle fuel economy standards, starting with model year 2011, until they achieve a combined average fuel economy of at least 35 miles per gallon (mpg) for model year 2020. The policy landscape has also been significantly altered by separate Supreme Court decisions related to the regulation of carbon dioxide as an air pollutant and the California greenhouse gas vehicle standards. These decisions helped spur the Obama administration to direct the U.S. Environmental Protection Agency (EPA) and the NHTSA to develop a joint fuel economy/greenhouse gas emission standard for light-duty vehicles that mirrors the stringency of the California emissions standard. Finalized on April 1, 2010, the rule requires that fleet-averaged fuel economy reach an equivalent of 35.4 mpg by model year 2016.

The significant downturn in the United States and world economies that occurred during the course of this study has had substantial negative impacts on the global automobile industry. Most manufacturers have experienced reduced sales and suffered losses. The automobile industry is capital intensive and has a very steep curve on profits around the break-even point: a small increase in sales beyond the break-even point can results in large profits, while a small decrease can result in large losses. Consumer spending decreased markedly due to lack of confidence in the economy as well as difficulties in the credit markets that typically finance a large portion of vehicle purchases. The U.S. market for light-duty vehicles decreased from about 16 million vehicles annually for the last few years to about 10 million in 2009. The overall economic conditions resulted in Chrysler and GM deciding to file for Chapter 19 bankruptcy and in Ford excessively leveraging its assets. GM and Chrysler have recently exited bankruptcy, and the U.S. government is now the major shareholder of GM. Fiat Automobiles has become a 20 percent shareholder in Chrysler, with the potential to expand its ownership to 35 percent, and the newly formed Voluntary Employee Beneficiary Association has a 55 percent stake.

These economic conditions will impact automotive companies' and suppliers' ability to fund in a timely manner the R&D necessary for fuel economy improvements and the capital expenditures required. Although addressing the impact of such conditions on the adoption of vehicle fuel economy technologies is not within the purview of this committee, these conditions do provide an important context for this study. Manufacturers will choose fuel economy technologies based on what they think will be most effective and best received by consumers. Customers also will have a central role in what technologies are actually chosen and will make those choices based partly on initial and operating costs.

Subsidies and other incentives also can significantly impact the market acceptance rate of technologies that reduce fuel consumption. Finally, adoption of these technologies must play out in a sometimes unpredictable marketplace and policy setting, with changing standards for emissions and fuel economy, government incentives, consumer preferences, and other events impacting their adoption. Thus, the committee acknowledges that technologies downplayed here may play a bigger role than anticipated, or that technologies covered in this report may never emerge in the marketplace.

The timing for introducing new fuel consumption technologies may have a large influence on cost and risk. The individual vehicle models produced by automobile manufacturers pass through a product cycle that includes introduction, minor refreshments of design and features, and then full changes in body designs and power trains. To reduce costs and quality concerns, changes to reduce fuel consumption normally are timed for implementation in accordance with this process. Further, new technologies are often applied first in lower-volume, higher-end vehicles because such vehicles are better able to absorb the higher costs, and their lower volumes reduce exposure to risk. In general, 2 to 3 years is considered the quickest time frame for bringing a new vehicle model to market or for modifying an existing model. Significant carryover technology and engineering from other models or previous vehicle models are usually required to launch a new model this quickly, and the ability to significantly influence fuel consumption is thus smaller. More substantial changes to a model occur over longer periods of time. Newly styled, engineered, and redesigned vehicles can take from 4 to 8 years to produce, each with an increasing amount of new content. Further, the engine development process often follows a path separate from that for other parts of a vehicle. Engines have longer product lives, require greater capital investment, and are not as critical to the consumer in differentiating one vehicle from another as are other aspects of a car. The normal power train development process evolves over closer to a 15-year cycle, although refinements and new technologies will be implemented throughout this period. It should be noted that there are significant differences among manufacturers in their approaches to introducing new models and, due to regulatory and market pressures, product cycles have tended to become shorter over time.

Although it is not a focus of this study, the global setting for the adoption of these fuel economy technologies is critical. The two main types of internal combustion engines, gasoline spark-ignition (SI) and diesel compression-ignition (CI), are not necessarily fully interchangeable. Crude oil (which varies in composition) contains heavier fractions that go into diesel production and lighter fractions that go into gasoline. A large consumer of diesel, Europe diverts the remaining gasoline fraction to the United States or elsewhere. China is now using mostly gasoline, and so there is more diesel available globally. And automobile manufacturers and suppliers worldwide are improving their capabilities in hybrid-electric technologies. Further, policy incentives may help favor one technology over another in individual countries.

STATEMENT OF TASK

The NHTSA has a mandate to keep up-to-date on the potential for technological improvements as it moves into planned vehicular regulatory activities. It was as part of its technology assessment that the NHTSA asked the National Academies to update the 2002 National Research Council report *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards* (NRC, 2002) and add to its assessment other technologies that have emerged since that report was prepared. The statement of task (see Appendix B) directed the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy to estimate the efficacy, timing, cost, and applicability of technologies that might be used over the next 15 years. The list of technologies includes diesel and hybrid electric power trains, which were not considered in the 2002 NRC report. Weight and power reductions also were to be included, but not size or power-to-weight ratio reductions. Updating the fuel economy-cost relationships for various technologies and different vehicle size classes as represented in Chapter 3 of the 2002 report was central to the study request.

The current study focuses on technology and does not consider CAFE issues related to safety, economic effects on industry, or the structure of fuel economy standards; those issues were addressed in the 2002 report. The new study looks at lowering fuel consumption by reducing power requirements through such measures as reduced vehicle weight, lower tire rolling resistance, or improved vehicle aerodynamics and accessories; by reducing the amount of fuel needed to produce the required power through improved engine and transmission technologies; by recovering some of the exhaust thermal energy with turbochargers and other technologies; and by improving engine performance and recovering energy through regenerative braking in hybrid vehicles. Additionally, the committee was charged with assessing how ongoing changes to manufacturers' refresh and redesign cycles for vehicle models affect the incorporation of new fuel economy technologies. The current study builds on information presented in the committee's previously released interim report (NRC, 2008).

CONTENTS OF THIS REPORT

The committee organized its final report according to broad topics related to the categories of technologies important for reducing fuel consumption, the costs and issues associated with estimating the costs and price impacts of these technologies, and approaches to estimating the fuel consumption benefits possible with combinations of these technologies. Chapter 2 describes fundamentals of determining vehicle fuel consumption, tests for regulating fuel economy, and basic energy balance concepts, and it discusses why this report presents primarily fuel consumption data. Chapter 3 describes cost estimation for vehicle technologies, including methods for estimating the costs of a new technology and issues related to translating those costs into impacts on the retail price of a vehicle. Chapters 4 through 7 describe technologies for improving fuel consumption in spark-ignition gasoline engines (Chapter 4), compression-ignition diesel engines (Chapter 5), and hybrid-electric vehicles (Chapter 6). Chapter 7 covers non-engine technologies for reducing light-duty vehicle fuel consumption. Chapter 8 provides a basic overview of and discusses the attributes of two different approaches for estimating fuel consumption benefits—the discrete approximation and the full-system simulation modeling approaches. Chapter 9 provides an estimate of the costs and the fuel consumption benefits of multiple technologies for an array of vehicle classes. The appendixes provide information related to conducting the study (Appendixes A through C), a list of the acronyms used in the report (Appendix D), and additional information supplementing the individual chapters (Appendixes E through K).

REFERENCES

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Washington, D.C.: National Academy Press.

NRC. 2008. Interim Report of the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy. Washington, D.C.: The National Academies Press.

2

Fundamentals of Fuel Consumption

INTRODUCTION

This chapter provides an overview of the various elements that determine fuel consumption in a light-duty vehicle (LDV). The primary concern here is with power trains that convert hydrocarbon fuel into mechanical energy using an internal combustion engine and which propel a vehicle though a drive train that may be a combination of a mechanical transmission and electrical machines (hybrid propulsion). A brief overview is given here of spark-ignition (SI) and compression-ignition (CI) engines as well as hybrids that combine electric drive with an internal combustion engine; these topics are discussed in detail in Chapters 4 through 6. The amount of fuel consumed depends on the engine, the type of fuel used, and the efficiency with which the output of the engine is transmitted to the wheels. This fuel energy is used to overcome (1) rolling resistance primarily due to flexing of the tires, (2) aerodynamic drag as the vehicle motion is resisted by air, and (3) inertia and hill-climbing forces that resist vehicle acceleration, as well as engine and drive line losses. Although modeling is discussed in detail in later chapters (Chapters 8 and 9), a simple model to describe tractive energy requirements and vehicle energy losses is given here as well to understand fuel consumption fundamentals. Also included is a brief discussion of customer expectations, since performance, utility, and comfort as well as fuel consumption are primary objectives in designing a vehicle.

Fuel efficiency is a historical goal of automotive engineering. As early as 1918, General Motors Company automotive pioneer Charles Kettering was predicting the demise of the internal combustion engine within 5 years because of its wasteful use of fuel energy: "[T]he good Lord has tolerated this foolishness of throwing away 90 percent of the energy in the fuel long enough" (Kettering, 1918). And indeed, in the 1920s through the 1950s peak efficiencies went from 10 percent to as much as 40 percent, with improvements in fuels, combustion system design, friction reduction, and more precise manufacturing processes. Engines became more powerful, and vehicles became heavier, bigger, and faster. However, by the late 1950s, fuel economy had become important, leading to the first large wave of foreign imports. In the wake of the 1973 oil crisis, the issue of energy security arose, and Congress passed the Energy Policy and Conservation Act of 1975 as a means of reducing the country's dependence on imported oil. The act established the Corporate Average Fuel Economy (CAFE) program, which required automobile manufacturers to increase the average fuel economy of passenger cars sold in the United States in 1990 to a standard of 27.5 miles per gallon (mpg) and allowed the U.S. Department of Transportation (DOT) to set appropriate standards for light trucks. The standards are administered in DOT by the National Highway Traffic Safety Administration (NHTSA) on the basis of U.S. Environmental Protection Agency (EPA) city-highway dynamometer test procedures.

FUEL CONSUMPTION AND FUEL ECONOMY

Before proceeding, it is necessary to define the terms *fuel economy* and *fuel consumption*; these two terms are widely used, but very often interchangeably and incorrectly, which can generate confusion and incorrect interpretations:

- *Fuel economy* is a measure of how far a vehicle will travel with a gallon of fuel; it is expressed in miles per gallon. This is a popular measure used for a long time by consumers in the United States; it is used also by vehicle manufacturers and regulators, mostly to communicate with the public. As a metric, fuel economy actually measures distance traveled per unit of fuel.
- *Fuel consumption* is the inverse of fuel economy. It is the amount of fuel consumed in driving a given distance. It is measured in the United States in gallons per 100 miles, and in liters per 100 kilometers in Europe and elsewhere throughout the world. Fuel consumption is a fundamental engineering measure that is directly related to fuel consumed per 100 miles and is useful because it can be employed as a direct measure of volumetric fuel savings. It is actually fuel consumption

that is used in the CAFE standard to calculate the fleet average fuel economy (the sales weighted average) for the city and highway cycles. The details of this calculation are shown in Appendix E. Fuel consumption is also the appropriate metric for determining the yearly fuel savings if one goes from a vehicle with a given fuel consumption to one with a lower fuel consumption.

Because fuel economy and fuel consumption are reciprocal, each of the two metrics can be computed in a straightforward manner if the other is known. In mathematical terms, if fuel economy is X and fuel consumption is Y, their relationship is expressed by $XY = 1$. This relationship is not linear, as illustrated by Figure 2.1, in which fuel consumption is shown in units of gallons per 100 miles, and fuel economy is shown in units of miles per gallon. Also shown in the figure is the decreasing influence on fuel savings that accompanies increasing the fuel economy of high-mpg vehicles. Each bar represents an increase of fuel economy by 100 percent or the corresponding decrease in fuel consumption by 50 percent. The data on the graph show the resulting decrease in fuel consumption per 100 miles and the total fuel saved in driving 10,000 miles. The dramatic decrease in the impact of increasing miles per gallon by 100 percent for a high-mpg vehicle is most visible in the case of increasing the miles per gallon rating from 40 mpg to 80 mpg, where the total fuel saved in driving 10,000 miles is only 125 gallons, compared to 500 gallons for a change from 10 mpg to 20 mpg. Likewise, it is instructive to compare the same absolute value of fuel economy changes—for example, 10-20 mpg and 40-50 mpg. The 40-50 mpg fuel saved in driving 10,000 miles would be 50 gallons, as compared to the 500 gallons in going from 10-20 mpg. Appendix E discusses further implications of the relationship between fuel consumption and fuel economy for various fuel economy values, and particularly for those greater than 40 mpg.

Figure 2.2 illustrates the relationship between the percentage of fuel consumption decrease and that of fuel economy increase. Figures 2.1 and 2.2 illustrate that the amount of fuel saved by converting to a more economical vehicle depends on where one is on the curve.

Because of the nonlinear relationship in Figure 2.1, consumers can have difficulty using fuel economy as a measure of fuel efficiency in judging the benefits of replacing the most inefficient vehicles (Larrick and Soll, 2008). Larrick and Soll further conducted three experiments to test whether people reason in a linear but incorrect manner about fuel economy. These experimental studies demonstrated a systemic misunderstanding of fuel economy as a measure of fuel efficiency. Using linear reasoning about fuel economy leads people to undervalue small improvements (1-4 mpg) in lower-fuel-economy (15-30 mpg range) vehicles where there are large decreases in fuel consumption (Larrick and Soll, 2008) in this range, as shown in Figure 2.1. Fischer (2009) further discusses the potential benefits of utilizing a metric based on fuel consumption as a means to aid consumers in calculating fuel and cost savings resulting from improved vehicle fuel efficiency.

Throughout this report, fuel consumption is used as the metric owing to its fundamental characteristic and its suitability for judging fuel savings by consumers. In cases where the committee has used fuel economy data from the

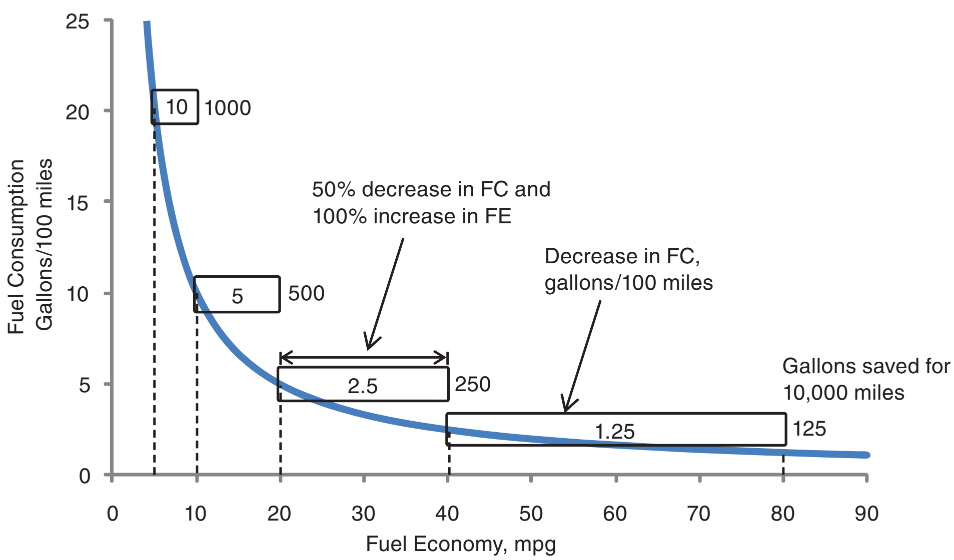

FIGURE 2.1 Relationship between fuel consumption (FC) and fuel economy (FE) illustrating the decreasing reward of improving fuel economy (miles per gallon [mpg]) for high-mile-per-gallon vehicles. The width of each rectangle represents a 50 percent decrease in FC or a 100 percent increase in FE. The number within the rectangle is the decrease in FC per 100 miles, and the number to the right of the rectangle is the total fuel saved over 10,000 miles by the corresponding 50 percent decrease in FC.

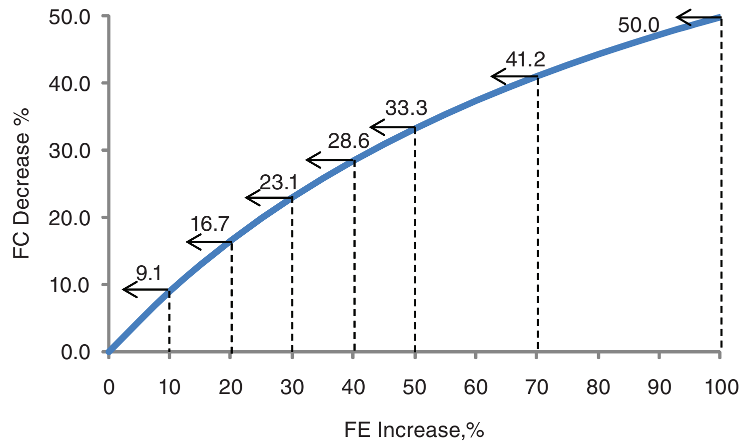

FIGURE 2.2 Percent decrease in fuel consumption (FC) as a function of percent increase in fuel economy (FE), illustrating the decreasing benefit of improving the fuel economy of vehicles with an already high fuel economy.

literature, the data were converted to fuel consumption, using the curve of either Figure 2.1 or 2.2 for changes in fuel economy. Because of this, the committee recommends that the fuel economy information sticker on new cars and trucks should include fuel consumption data in addition to the fuel economy data so that consumers can be familiar with this fundamental metric since fuel consumption difference between two vehicles relates directly to fuel savings. The fuel consumption metric is also more directly related to overall emissions of carbon dioxide than is the fuel economy metric.

ENGINES

Motor vehicles have been powered by gasoline, diesel, steam, gas turbine, and Stirling engines as well as by electric and hydraulic motors. This discussion of engines is limited to power plants involving the combustion of a fuel inside a chamber that results in the expansion of the air/fuel mixture to produce mechanical work. These internal combustion engines are of two types: gasoline spark-ignition and diesel compression-ignition. The discussion also addresses alternative power trains, including hybrid electrics.

Basic Engine Types

Gasoline engines, which operate on a relatively volatile fuel, also go by the name Otto cycle engines (after the person who is credited with building the first working four-stroke internal combustion engine). In these engines, a spark plug is used to ignite the air/fuel mixture. Over the years, variations of the conventional operating cycle of gasoline engines have been proposed. A recently popular variation is the Atkinson cycle, which relies on changes in valve timing to improve efficiency at the expense of lower peak power capability. Since in all cases the air/fuel mixture is ignited by a spark, this report refers to gasoline engines as spark-ignition engines.

Diesel engines—which operate on "diesel" fuels, named after inventor Rudolf Diesel—rely on compression heating of the air/fuel mixture to achieve ignition. This report uses the generic term compression-ignition engines to refer to diesel engines.

The distinction between these two types of engines is changing with the development of engines having some of the characteristics of both the Otto and the diesel cycles. Although technologies to implement homogeneous charge compression ignition (HCCI) will most likely not be available until beyond the time horizon of this report, the use of a homogeneous mixture in a diesel cycle confers the characteristic of the Otto cycle. Likewise the present widespread use of direct injection in gasoline engines confers some of the characteristics of the diesel cycle. Both types of engines are moving in a direction to utilize the best features of both cycles' high efficiency and low particulate emissions.

In a conventional vehicle propelled by an internal combustion engine, either SI or CI, most of the energy in the fuel goes to the exhaust and to the coolant (radiator), with about a quarter of the energy doing mechanical work to propel the vehicle. This is partially due to the fact that both engine types have thermodynamic limitations, but it is also because in a given drive schedule the engine has to provide power over a range of speeds and loads; it rarely operates at its most efficient point.

This is illustrated by Figure 2.3, which shows what is known as an engine efficiency map for an SI engine. It plots the engine efficiency as functions of torque and speed. The plot in Figure 2.3 represents the engine efficiency contours in units of brake-specific fuel consumption (grams per kilowatt-hour) and relates torque in units of brake mean effective pressure (kilopascals). For best efficiency, the engine should operate over the narrow range indicated by the roughly round contour in the middle; this is also referred to later in the chapter as the maximum engine brake thermal efficiency ($\eta_{b,max}$). In conventional vehicles, however, the engine needs to cover

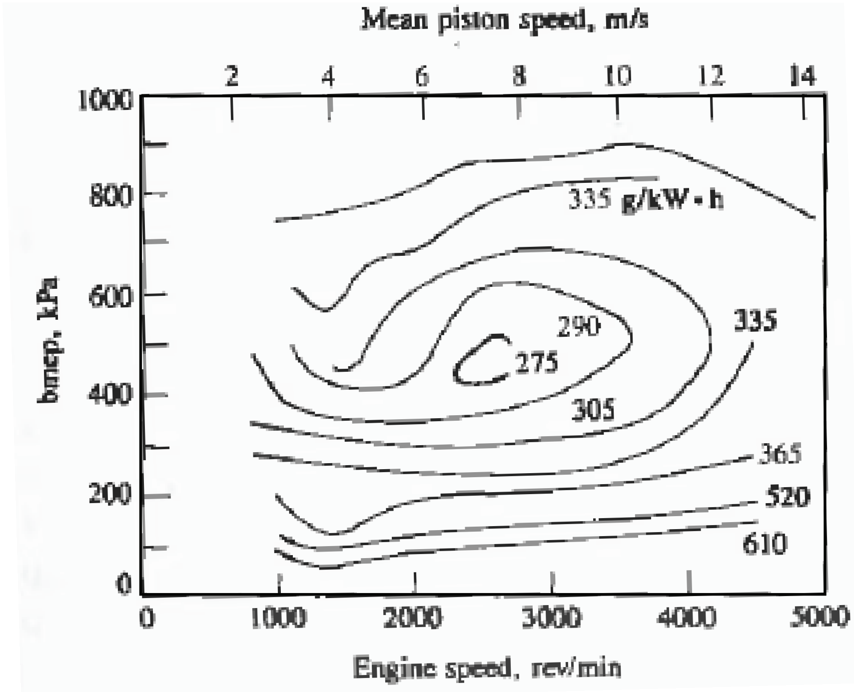

FIGURE 2.3 An example of an engine efficiency map for a spark-ignition engine. SOURCE: Reprinted with permission from Heywood (1988). Copyright 1988 by the McGraw-Hill Companies, Inc.

the entire range of torque and speeds, and so, on average, the efficiency is lower. One way to improve efficiency is to use a smaller engine and to use a turbocharger to increase its power output back to its original level. This reduces friction in both SI and CI engines as well as pumping losses.[1] Increasing the number of gear ratios in the transmission also enables the engine to operate closer to the maximum engine brake thermal efficiency. Other methods to expand the high-efficiency operating region of the engine, particularly in the lower torque region, are discussed in Chapters 4 and 5. As discussed in Chapter 6, part of the reason that hybrid electric vehicles show lower fuel consumption is that they permit the internal combustion engine to operate at more efficient speed-load points.

Computer control, first introduced to meet the air/fuel mixture ratio requirements for reduced emissions in both CI and SI engines, now allows the dynamic optimization of engine operations, including precise air/fuel mixture control, spark timing, fuel injection, and valve timing. The monitoring of engine and emission control parameters by the onboard diagnostic system identifies emission control system malfunctions.

A more recent development in propulsion systems is to add one or two electrical machines and a battery to create a hybrid vehicle. Such vehicles can permit the internal combustion engine to shut down when the vehicle is stopped and allow brake energy to be recovered and stored for later use. Hybrid systems also enable the engine to be downsized and to operate at more efficient operating points. Although there were hybrid vehicles in production in the 1920s, they could not compete with conventional internal combustion engines. What has changed is the greater need to reduce fuel consumption and the developments in controls, batteries, and electric drives. Hybrids are discussed in Chapter 6, but it is safe to say that the long-term future of motor vehicle propulsion may likely include advanced combustion engines, combustion engine-electric hybrids, electric plug-in hybrids, hydrogen fuel cell electric hybrids, battery electrics, and more. The challenge of the next generation of propulsion systems depends not only on the development of the propulsion technology but also on the associated fuel or energy infrastructure. The large capital investment in manufacturing capacity, the motor vehicle fleet, and the associated fuel infrastructure all constrain the rate of transition to new technologies.

Combustion-Related Traits of SI Versus CI Engines

The combustion process within internal combustion engines is critical for understanding the performance of SI versus CI engines. SI-engine combustion occurs mainly by turbulent flame propagation, and as turbulence intensity

[1] "Pumping loss" refers to the energy dissipated through fluid friction and pressure gradients developed from the air flow through the engine. A more detailed explanation is provided in Chapter 4 of this report.

tends to scale with engine speed, the combustion interval in the crank-angle domain remains relatively constant throughout the speed range (at constant intake-manifold pressure and engines having a conventional throttle). Thus, combustion characteristics have little effect on the ability of this type of engine to operate successfully at high speeds. Therefore, this type of engine tends to have high power density (e.g., horsepower per cubic inch or kilowatts per liter) compared to its CI counterpart. CI engine combustion is governed largely by means of the processes of spray atomization, vaporization, turbulent diffusion, and molecular diffusion. Therefore, CI combustion, in comparison with SI combustion, is less impacted by engine speed. As engine speed increases, the combustion interval in the crank-angle domain also increases and thus delays the end of combustion. This late end of combustion delays burnout of the particulates that are the last to form, subjecting these particulates to thermal quenching. The consequence of this quenching process is that particulate emissions become problematic at engine speeds well below those associated with peak power in SI engines. This ultimately limits the power density (i.e., power per unit of displacement) of CI diesel engines.

While power density gets much attention, torque density in many ways is more relevant. Thermal auto ignition in SI engines is the process that limits torque density and fuel efficiency potential. Typically at low to moderate engine speeds and high loads, this process yields combustion of any fuel/air mixture not yet consumed by the desired flame-propagation process. This type of combustion is typically referred to as engine knock, or simply knock. If this process occurs prior to spark ignition, it is referred to as pre-ignition. (This is typically observed at high power settings.) Knock and pre-ignition are to be avoided, as they both lead to very high rates of combustion pressure and ultimately to component failure. While approaches such as turbocharging and direct injection of SI engines alter this picture somewhat, the fundamentals remain. CI diesel engines, however, are not knock limited and have excellent torque characteristics at low engine speed. In the European market, the popularity of turbocharged CI diesel engines in light-duty vehicle segments is not only driven by the economics of fuel economy but also by the "fun-to-drive" element. That is, at equal engine displacement, the turbocharged diesel tends to deliver superior vehicle launch performance as compared with that of its naturally aspirated SI engine counterpart.

FUELS

The fuels and the SI and CI engines that use them have co-evolved in the past 100 years in response to improved technology and customer demands. Engine efficiencies have improved due to better fuels, and refineries are able to provide the fuels demanded by modern engines at a lower cost. Thus, the potential for fuel economy improvement may depend on fuel attributes as well as on engine technology. Implementing certain engine technologies may require changes in fuel properties, and vice versa. Although the committee charge is not to assess alternative liquid fuels (such as ethanol or coal-derived liquids) that might replace gasoline or diesel fuels, it is within the committee charge to consider fuels and the properties of fuels as they pertain to implementing the fuel economy technologies discussed within this report.

Early engines burned coal and vegetable oils, but their use was very limited until the discovery and exploitation of inexpensive petroleum. The lighter, more volatile fraction of petroleum, called gasoline, was relatively easy to burn and met the early needs of the SI engine. A heavier, less volatile fraction, called distillate, which was slower to burn, met the early needs of the CI engine. The power and efficiency of early SI engines were limited by the low compression ratios required for resistance to pre-ignition or knocking. This limitation had been addressed by adding a lead additive commonly known as tetraethyl lead. With the need to remove lead because of its detrimental effect on catalytic aftertreatment (and the negative environmental and human impacts of lead), knock resistance was provided by further changing the organic composition of the fuel and initially by reducing the compression ratio and hence the octane requirement of the engine. Subsequently, a better understanding of engine combustion and better engine design and control allowed increasing the compression ratios back to and eventually higher than the pre-lead-removal levels. The recent reduction of fuel sulfur levels to less than 15 parts per million (ppm) levels enabled more effective and durable exhaust aftertreatment devices on both SI and CI engines.

The main properties that affect fuel consumption in engines are shown in Table 2.1. The table shows that, on a volume basis, diesel has a higher energy content, called heat of combustion, and higher carbon content than gasoline; thus, on a per gallon basis diesel produces almost 15 percent more CO_2. However, on a weight basis the heat of combustion of diesel and gasoline is about the same, and so is the carbon content. One needs to keep in mind that this difference in energy content is one of the reasons why CI engines have lower fuel consumption when measured in terms of gallons rather than in terms of weight. Processing crude oil into fuels for vehicles is a complex process that uses hydrogen to break

TABLE 2.1 Properties of Fuels

	Lower Heat of Combustion (Btu/gal)	Lower Heat of Combustion (Btu/lb)	Density (lb/gal)	Carbon Content (g/gal)	Carbon Content (g/lb)
Gasoline	116,100	18,690	6.21	2,421	392
Diesel	128,500	18,400	6.98	2,778	392
Ethanol (E85)	76,300	11,580	6.59	1,560	237

SOURCE: After GREET Program, Argonne National Laboratory, http://www.transportation.anl.gov/modeling_simulation/GREET/.

down heavy hydrocarbons into lighter fractions. This is commonly called cracking. Diesel fuel requires less "molecular manipulation" for the conversion of crude oil into useful fuel. So if one wants to minimize the barrels of crude oil used per 100 miles, diesel would be a better choice than gasoline.

Ethanol as a fuel for SI engines is receiving much attention as a means of reducing dependence on imported petroleum and also of producing less greenhouse gas (GHG). Today ethanol is blended with gasoline at about 10 percent. Proponents of ethanol would like to see the greater availability of a fuel called E85, which is a blend of 85 percent ethanol and 15 percent gasoline. The use of 100 percent ethanol is widespread in Brazil, but it is unlikely to be used in the United States because engines have difficulty starting in cold weather with this fuel.

The effectiveness of ethanol in reducing GHG is a controversial subject that is not addressed here, since it generally does not affect the technologies discussed in this report. It is interesting to note that in a very early period of gasoline shortage, it was touted as a fuel of the future (Foljambe, 1916).

Ethanol has about 65 percent of the heat of combustion of gasoline, so the fuel consumption is roughly 50 percent higher as measured in gallons per 100 miles. Ethanol has a higher octane rating than that of gasoline, and this is often cited as an advantage. Normally high octane enables increases in the compression ratio and hence efficiency. To take advantage of this form of efficiency increase, the engine would need to be redesigned to accommodate an increased combustion ratio. For technical reasons the improvement with ethanol is very small. Also, during any transition period, vehicles that run on 85 to 100 percent ethanol must also run on gasoline, and since the compression ratio cannot be changed after the engine is built, the higher octane rating of ethanol fuel has not led to gains in efficiency. A way to enable this efficiency increase is to modify the SI engine so that selective ethanol injection is allowed. This technology is being developed and is further discussed in Chapter 4 of this report.

FUEL ECONOMY TESTING AND REGULATIONS

The regulation of vehicle fuel economy requires a reproducible test standard. The test currently uses a driving cycle or test schedule originally developed for emissions regulation, which simulated urban-commute driving in Los Angeles in the late 1960s and the early 1970s. This cycle is variously referred to as the LA-4, the urban dynamometer driving schedule (UDDS), and the city cycle. The U.S. Environmental Protection Agency (EPA) later added a second cycle to better capture somewhat higher-speed driving: this cycle is known as the highway fuel economy test (HWFET) driving schedule, or the highway cycle. The combination of these two test cycles (weighted using a 55 percent city cycle and 45 percent highway cycle split) is known as the Federal Test Procedure (FTP). This report focuses on fuel consumption data that reflect legal compliance with the CAFE requirements and thus do not include EPA's adjustments for its labeling program, as described below. Also discussed below are some technologies—such as those that reduce air-conditioning power demands or requirements—that improve on-road fuel economy but are not directly captured in the FTP.

Compliance with the NHTSA's CAFE regulation depends on the city and highway vehicle dynamometer tests developed and conducted by the EPA for its exhaust emission regulatory program. The results of the two tests are combined (harmonic mean) with a weighting of 55 percent city and 45 percent highway driving. Manufacturers self-certify their vehicles using preproduction prototypes representative of classes of vehicles and engines. The EPA then conducts tests in its laboratories of 10 to 15 percent of the vehicles to verify what the manufacturers report. For its labeling program, the EPA adjusts the compliance values of fuel economy in an attempt to better reflect what vehicle owners actually experience. The certification tests yield fuel consumption (gallons per 100 miles) that is about 25 percent better (less than) EPA-estimated real-world fuel economy. Analysis of the 2009 EPA fuel economy data set for more than 1,000 vehicle models yields a model-averaged difference of about 30 percent.

The certification test fails to capture the full array of driving conditions encountered during vehicle operations. Box 2.1 provides some of the reasons why the certification test does not reflect actual driving. Beginning with model year 2008, the EPA began collecting data on three additional test cycles to capture the effect of higher speed and acceleration, air-conditioner use, and cold weather. These data are part of air pollution emission compliance testing but not fuel economy or proposed greenhouse gas compliance. However, the results from these three test cycles will be used with the two FTP cycles to report the fuel economy on the vehicle label. Table 2.2 summarizes the characteristics of the five test schedules. This additional information guides the selection of a correction factor, but an understanding of fuel consumption based on actual in-use measurement is lacking.

The unfortunate consequence of the disparity between the official CAFE (and proposed greenhouse gas regulation) certification tests and how vehicles are driven in use is that manufacturers have a diminished incentive to design vehicles to deliver real-world improvements in fuel economy if such improvements are not captured by the official test. Some examples of vehicle design improvements that are not completely represented in the official CAFE test are more efficient air conditioning; cabin heat load reduction through heat-resistant glazing and heat-reflective paints; more efficient power steering; efficient engine and drive train operation at all speeds, accelerations, and road grades; and reduced drag to include the effect of wind. The certification tests give no incentive to provide information to the driver that would improve operational efficiency or to reward control strategies that compensate for driver characteristics that increase fuel consumption.

BOX 2.1
Shortcomings of Fuel Economy Certification Test

- *Dynamometer test schedules.* The UDDS and HWFET test schedule (driving cycles) were adopted in 1975 to match driving conditions and dynamometer limitations of that period. Maximum speed (56.7 mph) and acceleration (3.3 mph/sec, or 0-60 mph in 18.2 sec) are well below typical driving. The 55 percent city and 45 percent highway split may not match actual driving. Recent estimates indicate that a weighting of 57 percent highway and 43 percent city is a better reflection of current driving patterns in a number of geographic areas.
- *Test vehicles.* The preproduction prototypes do not match the full range of vehicles actually sold.
- *Driver behavior.* The unsteady driving characteristic of many drivers increases fuel consumption.
- *Fuel.* The test fuel does not match current pump fuel.
- *Air conditioning.* Air conditioning is turned off during the certification test. In addition to overestimating mileage, there is no regulatory incentive for manufacturers to increase air-conditioning efficiency. However, there is substantial market incentive for original equipment manufacturers both to increase air-conditioning efficiency and to reduce the sunlight-driven heating load for customer comfort benefits.
- *Hills.* There are no hills in the EPA certification testing.
- *Vehicle maintenance.* Failure to maintain vehicles degrades fuel economy.
- *Tires and tire pressure.* Test tires and pressures do not generally match in-use vehicle operation.
- *Wind.* There is no wind in the EPA certification testing.
- *Cold start.* There is no cold start in the EPA CAFE certification testing.
- *Turns.* There is no turning in the EPA certification testing.

The measurement of the fuel economy of hybrid, plug-in hybrid, and battery electric vehicles presents additional difficulties in that their performance on the city versus highway driving cycles differs from that of conventional vehicles. Regenerative braking provides a greater gain in city driving than in highway driving. Plug-in hybrids present an additional complexity in measuring fuel economy since this requires accounting of the energy derived from the grid. The Society of Automotive Engineers (SAE) is currently developing recommendations for measuring the emissions and fuel economy of hybrid-electric vehicles, including plug-in and battery electric vehicles. General Motors Company recently claimed that its Chevrolet Volt extended-range electric vehicle achieved city fuel economy of at least 230 miles per gallon, based on development testing using a draft EPA federal fuel economy methodology for the labeling of plug-in electric vehicles (General Motors Company press release, August 11, 2009).

CUSTOMER EXPECTATIONS

The objective of this study is to evaluate technologies that reduce fuel consumption without significantly reducing customer satisfaction. Although each vehicle manufacturer has a proprietary way of defining very precisely how its vehicle must perform, it is assumed here that the following parameters will remain essentially constant as the technologies that reduce fuel consumption are considered:

- Interior passenger volume;
- Trunk space, except for hybrids, where trunk space may be compromised;
- Acceleration, which is measured in a variety of tests, such as time to accelerate from 0 to 60 mph, 0 to 30, 55 to 65 (passing), 30 to 45, entrance ramp to highway, etc.;

TABLE 2.2 Test Schedules Used in the United States for Mileage Certification

	Test Schedule				
Driving Schedule Attributes	Urban (UDDS)	Highway (HWFET)	High Speed (US06)	Air Conditioning (SC03)	Cold Temperature UDDS
Trip type	Low speeds in stop-and-go urban traffic	Free-flow traffic at highway speeds	Higher speeds; harder acceleration and braking	Air conditioning use under hot ambient conditions	City test with colder outside temperature
Top speed	56.7 mph	59.9 mph	80.3 mph	54.8 mph	56.7 mph
Average speed	19.6 mph	48.2 mph	48 mph	21.4 mph	19.6 mph
Maximum acceleration	3.3 mph/sec	3.2 mph/sec	8.40 mph/sec	5.1 mph/sec	3.3 mph/sec
Simulated distance	7.45 mi.	10.3 mi.	8 mi.	3.58	7.45 mi.
Time	22.8 min	12.75 min	10 min	10 min	22.8 min
Stops	17	None	5	5	17
Idling time	18% of time	None	7% of time	19% of time	18% of time
Lab temperature	68-86°F			95°F	20°F
Vehicle air conditioning	Off	Off	Off	On	Off

SOURCE: After http://www.fueleconomy.gov/feg/fe_test_schedules.shtml.

TABLE 2.3 Average Characteristics of Light-Duty Vehicles for Four Model Years

	1975	1987	1998	2008
Adjusted fuel economy (mpg)	13.1	22	20.1	20.8
Weight	4,060	3,220	3,744	4,117
Horsepower	137	118	171	222
0 to 60 acceleration time (sec)	14.1	13.1	10.9	9.6
Power/weight (hp/ton)	67.5	73.3	91.3	107.9

SOURCE: EPA (2008).

- Safety and crashworthiness; and
- Noise and vibration.

These assumptions are very important. It is obvious that reducing vehicle size will reduce fuel consumption. Also, the reduction of vehicle acceleration capability allows the use of a smaller, lower-power engine that operates closer to its best efficiency. These are not options that will be considered.

As shown in Table 2.3, in the past 20 or so years, the net result of improvements in engines and fuels has been increased vehicle mass and greater acceleration capability while fuel economy has remained constant (EPA, 2008). Presumably this tradeoff between mass, acceleration, and fuel consumption was driven by customer demand. Mass increases are directly related to increased size, the shift from passenger cars to trucks, the addition of safety equipment such as airbags, and the increased accessory content. Note that although the CAFE standards for light-duty passenger cars have been for 27.5 mpg since 1990, the fleet average remains much lower through 2008 due to lower CAFE standards for light-duty pickup trucks, sport utility vehicles (SUVs), and passenger vans.

TRACTIVE FORCE AND TRACTIVE ENERGY

The mechanical work produced by the power plant is used to propel the vehicle and to power the accessories. As discussed by Sovran and Blaser (2006), the concepts of tractive force and tractive energy are useful for understanding the role of vehicle mass, rolling resistance, and aerodynamic drag. These concepts also help evaluate the effectiveness of regenerative braking in reducing the power plant energy that is required. The analysis focuses on test schedules and neglects the effects of wind and hill climbing. The instantaneous tractive force (F_{TR}) required to propel a vehicle is

$$F_{TR} = R + D + \left[M + 4\left(\frac{I_W}{r_W^2}\right)\right]\frac{dV}{dt} = r_0 Mg + C_D A \frac{V^2}{2}\rho + \left[M + 4\left(\frac{I_W}{r_W^2}\right)\right]\frac{dV}{dt} \tag{2.1}$$

where R is the rolling resistance, D is the aerodynamic drag with C_D representing the aerodynamic drag coefficient, M is the vehicle mass, V is the velocity, dV/dt is the rate of change of velocity (i.e., acceleration or deceleration), A is the frontal area, r_o is the tire rolling resistance coefficient, g is the gravitational constant, I_w is the polar moment of inertia of the four tire/wheel/axle rotating assemblies, r_w is its effective rolling radius, and ρ is the density of air. This form of the tractive force is calculated at the wheels of the vehicle and therefore does not consider the components within the vehicle system such as the power train (i.e., rotational inertia of engine components and internal friction).

The tractive energy required to travel an incremental distance dS is $F_{TR}\,Vdt$, and its integral over all portions of a driving schedule in which $F_{TR} > 0$ (i.e., constant-speed driving and accelerations) is the total tractive-energy requirement, E_{TR}. For each of the EPA driving schedules, Sovran and Blaser (2006) calculated tractive energy for a large number of vehicles covering a broad range of parameter sets (r_0, C_D, A, M) representing the spectrum of current vehicles. They then fitted the data with a linear equation of the following form:

$$\frac{E_{TR}}{MS} = \alpha r_0 + \beta\left(\frac{C_D A}{M}\right) + \gamma\left(1 + \frac{4I_w}{Mr_w^2}\right) \tag{2.2}$$

where S is the total distance traveled in a driving schedule, and α, β, and γ are specific but different constants for the UDDS and HWFET schedules. Sovran and Blaser (2006) also identified that a combination of five UDDS and three HWFET schedules very closely reproduces the EPA combined fuel consumption of 55 percent UDDS plus 45 percent HWFET, and provided its values of α, β, and γ.

The same approach was used for those portions of a driving schedule in which $F_{TR} < 0$ (i.e., decelerations), where the power plant is not required to provide energy for propulsion. In this case the rolling resistance and aerodynamic drag retard vehicle motion, but their effect is not sufficient to follow the driving cycle deceleration, and so some form of wheel braking is required. When a vehicle reaches the end of a schedule and becomes stationary, all the kinetic energy of its mass that was acquired when $F_{TR} > 0$ has to have been removed. Consequently the decrease in kinetic energy produced by wheel braking is

$$E_{BR}/MS = \gamma\left(1 + 4I_w/Mrw^2\right) - \alpha' r_0 - \beta'\left(C_D A/M\right). \tag{2.3}$$

The coefficients α' and β' are also specific to the test schedule and are given in the reference. Two observations are of interest: (1) γ is the same for both motoring and braking as it relates to the kinetic energy of the vehicle; (2) since the energy used in rolling resistance is $r_0\,M\,g\,S$, the sum of α and α' is equal to g.

Sovran and Blaser (2006) considered 2,500 vehicles from the EPA database for 2004 and found that their equations fitted the tractive energy for both the UDDS and HWFET schedules with an $r = 0.999$, and the braking energy with an

$r = 0.99$, where r represents the correlation coefficient based on least squares fit of the data.

To illustrate the dependence of tractive and braking energy on vehicle parameters, Sovran and Blaser (2006) used the following three sets of parameters. Fundamentally the energy needed by the vehicle is a function of the rolling resistance, the mass, and the aerodynamic drag times frontal area. By combining the last three into the results shown in Table 2.4, Sovran and Blaser (2006) covered the entire fleet in 2004. The "high" vehicle has a high rolling resistance, and high aerodynamic drag relative to its mass. This would be typical of a truck or an SUV. The "low" vehicle requires low tractive energy and would be typical for a future vehicle. These three vehicles cover the entire spectrum in vehicle design.

The data shown in Table 2.5 were calculated using these values. The low vehicle has a tractive energy requirement that is roughly two-thirds that of the high vehicle. It should also be noted that as the vehicle design becomes more efficient (i.e., the low vehicle), the fraction of energy required to overcome the inertia increases. As expected, for both driving schedules the *normalized* tractive energy, E_{TR}/MS, decreases with reduced rolling and aerodynamic resistances. What is more significant, however, is that at each level, the *actual tractive* energy is strongly dependent on vehicle mass, through its influence on the rolling and inertia components. This gives mass reduction high priority in efforts to reduce vehicle fuel consumption.

TABLE 2.4 Vehicle Characteristics

Vehicle	r_o	C_dA/M
High	0.012	0.00065
Mid	0.009	0.0005
Low	0.006	0.0003

SOURCE: Based on Sovran and Blaser (2006).

TABLE 2.5 Estimated Energy Requirements for the Three Sovran and Blaser (2006) Vehicles in Table 2.4 for the UDDS and HWFET Schedules

	E_{TR}/MS (Normalized)	Rolling Resistance (%)	Aerodynamic Drag (%)	Inertia (%)	Braking/ Tractive (%)
UDDS Vehicle					
High	0.32	28	22	50	36
Mid	0.28	24	19	57	45
Low	0.24	19	14	68	58
HWFET Vehicle					
High	0.34	32	56	13	6
Mid	0.27	30	54	16	10
Low	0.19	29	47	24	18

Effect of Driving Schedule

It is evident from Table 2.5 that inertia is the dominant component on the UDDS schedule, while aerodynamic drag is dominant on the HWFET. The larger any component, the greater the impact of its reduction on tractive energy.

On the UDDS schedule, the magnitude of required braking energy relative to tractive energy is large at all three vehicle levels, increasing as the magnitude of the rolling and aerodynamic resistances decreases. The high values are due to the many decelerations that the schedule contains. The braking energy magnitudes for HWFET are small because of its limited number of decelerations.

In vehicles with conventional power trains, the wheel-braking force is frictional in nature, and so all the vehicle kinetic energy removed is dissipated as heat. However, in hybrid vehicles with regenerative-braking capability, some of the braking energy can be captured and then recycled for propulsion in segments of a schedule where $F_{TR} > 0$. This reduces the *power plant* energy required to provide the E_{TR} necessary for propulsion, thereby reducing fuel consumption. The significant increase in normalized tractive energy (E_{TR}/MS) with decreasing rolling and aerodynamic resistances makes reduction of these resistances even *more* effective in reducing fuel consumption in hybrids with regenerative braking than in conventional vehicles. The relatively small values of braking-to-tractive energy on the HWFET indicate that the fuel consumption reduction capability of regenerative braking is minimal on that schedule. As a result, hybrid power trains only offer significant fuel consumption reductions on the UDDS cycle. However, as pointed out in Chapter 6, hybridization permits engine downsizing and engine operation in more efficient regions, and this applies to the HWFET schedule also.

Effect of Drive Train

Given the tractive energy requirements (plus idling and accessories), the next step is to represent the efficiency of the power train. The power delivered to the output shaft of the engine is termed the *brake output power,* and should not be confused with the *braking energy* mentioned in the previous section. The brake output power, P_b, of an engine is the difference between its indicated power, P_i, and power required for pumping, P_p; friction, P_f; and engine auxiliaries, P_a (e.g., fuel, oil, and water pumps).

$$P_b = P_i - P_p - \left(P_f + P_a\right) \tag{2.4}$$

Brake thermal efficiency is the ratio of brake power output to the energy rate into the system (the mass flow rate of fuel times its energy density).

$$\eta_b = \eta_i - \frac{P_p}{\dot{m}_f H_f} - \frac{\left(P_f + P_a\right)}{\dot{m}_f H_f} \tag{2.5}$$

The brake thermal efficiency is η_b, while η_i is the indicated thermal efficiency, and H_f is the lower heating value of the fuel. This equation provides the means for relating pumping losses, engine friction, and auxiliary load to the overall engine efficiency. Equations for fuel use during braking and idling are not shown here but can be found in Sovran and Blaser (2003), as can the equations for average schedule and maximum engine efficiency.

Ultimately the fuel consumption is given by Equation 2.6:

$$g^* = \left\{ \frac{\dfrac{E_{TR}}{\eta^*_{dr}} + E_{Accessories}}{H_f \eta_{b,\max} \left(\dfrac{\eta^*_b}{\eta_{b,\max}} \right)} \right\} + g^*_{braking} + g^*_{idling} \qquad (2.6)$$

where in addition to the terms defined earlier, g^* is the fuel consumption over the driving schedule, $g^*_{braking}$ and g^*_{idling} represent the fuel consumed during idling and braking, H_f is the fuel density of fuel, η^*_{dr} is the average drive train efficiency for the schedule, $\eta_{b,max}$ is the maximum engine brake thermal efficiency, η^*_b is the average engine brake thermal efficiency, and $E_{Accessories}$ is the energy to power the accessories. The term $\eta_{b,max}$ is repeated in the denominator to show that to minimize fuel consumption the fraction in the denominator should be as large as possible. Thus things should be arranged so that the average engine efficiency be as close to the maximum.

The principal term in Equation 2.6 is the bracketed term. Clearly fuel consumption can be reduced by reducing E_{TR} and $E_{Accessories}$. It can also be reduced by increasing $\eta^*_b/\eta_{b,max}$. As stated earlier, this can be done by downsizing the engine or by increasing the number of gears in the transmission so that average engine brake thermal efficiency, η^*_b, is increased. Equation 2.6 explains why reducing rolling resistance or aerodynamic drag without changes in engine or transmission may not maximize the benefit, since it may move $\eta^*_b/\eta_{b,max}$ farther from its optimum point. In other words, changing to lower-rolling-resistance tires without modifying the power train will not give the full benefit.

The tractive energy E_{TR} can be precisely determined given just three parameters, rolling resistance r_0, the product of aero coefficient and frontal area C_DA, and vehicle mass M. However, many of the other terms in Equation 2.6 are difficult to evaluate analytically. This is especially true of the engine efficiencies, which require detailed engine maps. Thus converting the tractive energy into fuel consumption is best done using a detailed step-by-step simulation. This simulation is usually carried out by breaking down the test schedule into 1-second intervals, computing the E_{TR} for each interval using detailed engine maps along with transmission characterizations, and adding up the interval values to get the totals for the drive cycle analyzed. Such a simulation is frequently called a full system simulation, FSS.

The discussion above on tractive energy highlights the fact that the effects of the three principal aspects of vehicle design—vehicle mass, rolling resistance, and aerodynamic drag—can be used to calculate precisely the amount of energy needed to propel the vehicle for any kind of drive schedule. Further, the equations developed highlight both the effect of the various parameters involved and at the same time demonstrate the complexity of the problem. Although the equations provide understanding, in the end estimating the fuel consumption of a future vehicle must be determined by FSS modeling and ultimately by constructing a demonstration vehicle.

DETAILED VEHICLE SIMULATION

The committee obtained results of a study by Ricardo, Inc. (2008) for a complete simulation for a 2007 Camry passenger car. This FSS is discussed further in Chapter 8; one set of results is used here for illustration. Table 2.6 gives the specifications of the vehicle in terms of the parameters used in the simulation.

First, the tractive energy and its components for this vehicle were calculated to illustrate how these vary with different test schedules. Although the US06 cycle described in Table 2.2 is not yet used for fuel economy certification, it is interesting to note how it affects the energy distribution. Table 2.7 shows the results. Energy to the wheels and rolling resistance increase from the UDDS to the US06, with the total tractive energy requirement being almost double that of the UDDS. The aero energy requirement increases from the UDDS to the HWFET, but it is not much increased in going to the US06, in spite of the higher peak speed. What is somewhat surprising is the amount of braking energy for the UDDS and the US06 compared to the HWFET. This is where hybrids excel.

For the highway, rolling resistance and aero dominate, and very little energy is dissipated in the brakes. As expected, the aero is dominant for the US06, where it is more than

TABLE 2.6 Specifications of Vehicle Simulated by Ricardo, Inc. (2008)

Mass	1,644 kg
C_D	0.30
A	2.3 m^2

TABLE 2.7 Energy Distribution for Various Schedules (in kilowatt-hours)

	Total Tractive Energy	Total Rolling Resistance	Total Aerodynamic Drag	Braking Energy	Braking/ Tractive (%)
Urban	1.250	0.440	0.310	0.500	40.00
Highway	1.760	0.610	1.000	0.150	8.52
US06	2.390	0.660	1.170	0.560	23.43

half the total tractive energy. Note, though, that the US06 has a significant amount of energy dissipated in the brakes.

As discussed earlier, some people will drive in a UDDS environment and some on the highway. A vehicle optimized for one type of driving will not perform as well for the other, and it is not possible to derive a schedule that fits all driving conditions. Table 2.7 shows the impractically of developing a test that duplicates the actual driving patterns.

Note that the data in Table 2.7 show the actual energy in kilowatt-hours used to drive each schedule. The unit of total energy is used to allow for an easier comparison between the schedules on the basis of energy distribution. Since as shown in Table 2.2, the distances are 7.45 miles for the UDDS, 10.3 miles for the HWFET, and 8 miles for the US06, the energies should be divided by distance to provide the energy required per mile.

An FSS provides a detailed breakdown of where the energy goes, something that is not practical to do with real vehicles during a test schedule. Figure 2.4 illustrates the total energy distribution in the midsize car, visually identifying where the energy goes.

Table 2.8 shows the fuel consumed for this vehicle for the UDDS, HWFET, and US06 schedules. Efficiency is the ratio of tractive energy divided by "fuel energy input." Clearly this gives a more succinct picture of the efficiency of an internal combustion engine power train in converting fuel to propel a vehicle and to power the accessories. Depending on the drive schedule, it varies from 15 to 25 percent (including the energy to power accessories). This range is significantly less than the peak efficiency $\eta_{b,max}$ discussed earlier.

In addition to the specific operating characteristics of the particular components, the computation of engine fuel consumption depends on the following inputs: (1) the transmission gear at each instant during the driving schedule and (2) the engine fuel consumption rate during braking and idling. None of these details is available, so the data in Table 2.8 should be considered as an illustrative example of the energy distribution in 2007 model-year vehicles with conventional SI power trains.

FINDINGS AND RECOMMENDATIONS

Finding 2.1: Fuel consumption has been shown to be the fundamental metric to judge fuel efficiency improvements from both an engineering and a regulatory viewpoint. Fuel economy data cause consumers to undervalue small increases (1-4 mpg) in fuel economy for vehicles in the 15- to 30-mpg range, where large decreases in fuel consumption can be realized with small increases in fuel economy. For example, consider the comparison of increasing the mpg rating from 40 mpg to 50 mpg, where the total fuel saved in driving 10,000 miles is only 50 gallons, compared to 500 gallons for a change from 10 mpg to 20 mpg.

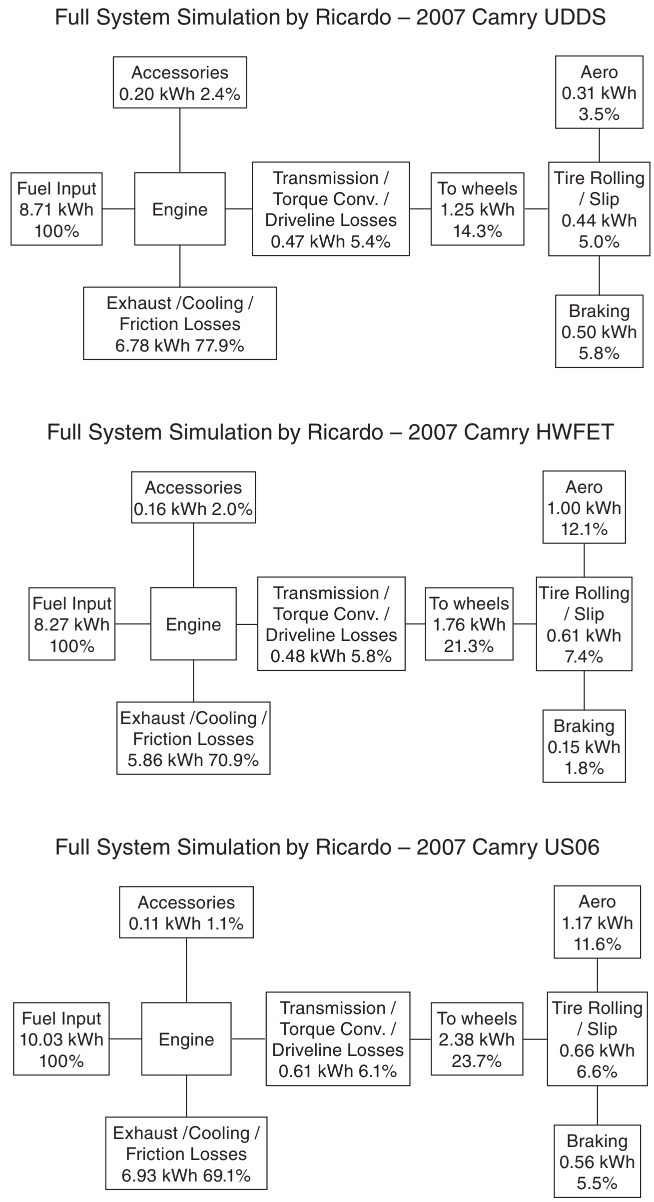

FIGURE 2.4 Energy distribution obtained through full-system simulation for UDDS (top), HWFET (middle), and US06 (bottom). SOURCE: Ricardo, Inc. (2008).

TABLE 2.8 Results of Full System Simulation (energy values in kilowatt-hours)

	Total Tractive Energy	Fuel Input Energy	Power Train Efficiency (%)
Urban	1.250	8.59	14.6
Highway	1.760	8.01	22.0
US06	2.390	9.66	24.7

Recommendation 2.1: Because differences in the fuel consumption of vehicles relate directly to fuel savings, the labeling on new cars and light-duty trucks should include information on the gallons of fuel consumed per 100 miles traveled in addition to the already-supplied data on fuel economy so that consumers can become familiar with fuel consumption as a fundamental metric for calculating fuel savings.

Finding 2.2: Fuel consumption in this report is evaluated by means of the two EPA schedules: UDDS and HWFET. In the opinion of the committee, the schedules used to compute CAFE should be modified so that vehicle test data better reflect actual fuel consumption. Excluding some driving conditions and accessory loads in determining CAFE discourages the introduction of certain technologies into the vehicle fleet. The three additional schedules recently adopted by the EPA for vehicle labeling purposes—ones that capture the effects of higher speed and acceleration, air-conditioner use, and cold weather—represent a positive step forward, but further study is needed to assess to what degree the new test procedures can fully characterize changes in in-use vehicle fuel consumption.

Recommendation 2.2: The NHTSA and the EPA should review and revise fuel economy test procedures so that they better reflect in-use vehicle operating conditions and also better provide the proper incentives to manufacturers to produce vehicles that reduce fuel consumption.

REFERENCES

EPA (U.S. Environmental Protection Agency). 2008. Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008. EPA420-R-08-015. September. Washington, D.C.

Fischer, C. 2009. Let's turn CAFE regulation on its head. Issue Brief No. 09-06. May. Resources for the Future, Washington, D.C.

Foljambe, E.S. 1916. The automobile fuel situation. SAE Transactions, Vol. 11, Pt. I.

General Motors Company. 2009. Chevy Volt gets 230 mpg city EPA rating. Press release. August 11.

Heywood, J.B., 1988. Internal Combustion Engine Fundamentals. McGraw-Hill, New York.

Kettering, C.F. 1918. Modern aeronautic engines. SAE Transactions, Vol. 13, Pt. II.

Larrick, R., and J. Soll. 2008. The mpg illusion. Science 320(5883):1593-1594.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for the U.S. Environmental Protection Agency. EPA420-R-08-004. Contract No. EP-C-06-003. Work Assignment No. 1-14. Ann Arbor, Michigan.

Sovran, G., and D. Blaser. 2003. A contribution to understanding automotive fuel economy and its limits. SAE Paper 2003-01-2070. SAE International, Warrendale, Pa.

Sovran, G., and D. Blaser. 2006. Quantifying the potential impacts of regenerative braking on a vehicle's tractive-fuel consumption for the US, European and Japanese driving schedules. SAE Paper 2006-01-0664. SAE International, Warrendale, Pa.

3

Cost Estimation

INTRODUCTION

As a general rule, reduced fuel consumption comes at a cost. The cost may be due to more expensive materials, increased manufacturing complexity, or a tradeoff with other vehicle attributes such as power or size. In addition to increased manufacturing costs, other costs of doing business are likely to be affected to a greater or lesser degree. These indirect costs include research and development (R&D), pensions and health care, warranties, advertising, maintaining a dealer network, and profits. The most appropriate measure of cost for the purpose of evaluating the costs and benefits of fuel economy regulations is the long-run increase in retail price paid by consumers under competitive market conditions.[1] The retail price equivalent (RPE) cost of decreasing fuel consumption includes not only changes in manufacturing costs but also any induced changes in indirect costs and profit.

Most methods for estimating manufacturing costs begin by identifying specific changes in vehicle components or designs, and they then develop individual cost estimates for each affected item. Most changes result in cost increases, but some, such as the downsizing of a V6 engine to an I4, will reduce costs. Component cost estimates can come from a variety of sources, including interviews of original equipment manufacturers (OEMs) and suppliers, prices of optional equipment, and comparisons of models with and without the technology in question. Total costs are obtained by adding up the costs of changes in the individual components.

An alternative method, which has only just begun to be used for estimating fuel economy costs, is to tear down a component into the fundamental materials, labor, and capital required to make it, and then to estimate the cost of every nut and bolt and every step in the manufacturing process (Kolwich, 2009). A potential advantage of this method is that total costs can be directly related to the costs of materials, labor, and capital so that as their prices change, cost estimates can be revised. However, this method is difficult to apply to new technologies that have not yet been implemented in a mass-production vehicle, whose designs are not yet finalized and whose impact on changing related parts is not yet known.

Differences in cost estimates from different sources arise in a number of ways:

- Assumptions about the costs of commodities, labor, and capital;
- Judgments about the changes in other vehicle components required to implement a given technology;
- Definitions of "manufacturing cost" and what items are included in it; and
- Assessments of the impacts of technologies on indirect costs.

This chapter discusses the premises, concepts, and methods used in estimating the costs of fuel economy improvement, highlights areas where differences arise, and presents the committee's judgments on the key issue of RPE markup factors.

Information on costs can be used with assumptions on payback periods, discount rates, price of fuel, and miles driven per year to provide an estimate of the cost-effectiveness of technologies. However, the statement of task given to the committee is to look at the costs and fuel consumption benefits of individual technologies. Performing cost-effectiveness analysis was not included within the committee's task and was not done by the committee. The accurate calculation of benefits of improved fuel efficiency is a complex task that is being undertaken by the National Highway Traffic Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA) as part of their current joint regulatory efforts.

[1] As explained below, this rests on the premise that the global automotive market can be reasonably characterized (in economic jargon) as either a perfectly competitive or a monopolistically competitive market. Under such market conditions, products are sold, in the long run, at their average cost of production, including a normal rate of return to capital but no excess profits. Increased costs of production will therefore be fully passed on to consumers. The total cost of resources plus the consumers' surplus loss due to the price increase is, to a close approximation, equal to the increase in long-run retail price times the volume of sales.

PREMISES

In the committee's judgment, the concept of incremental retail price equivalent cost is most appropriate for the NHTSA's purposes because it best represents the full, long-run economic costs of increasing fuel economy. The NHTSA has used the RPE method in its rulemakings on fuel economy, for example in the final rule for model year 2011 light-duty vehicles (DOT/NHTSA, 2009, pp. 346-352). Incremental RPE estimates are intended to represent the average additional price that consumers would pay for a fuel economy technology implemented in a typical vehicle under average economic conditions and typical manufacturing practices. These estimates are intended to represent long-run, high-volume, industry-average production costs, incorporating rates of profit and overhead expenses including warranties, transport, and retailing. Although learning and technological progress never stop, RPEs are intended to represent costs after an initial period of rapid cost reduction that results from learning by doing.[2] The committee uses the term *substantially learned* as opposed to *fully learned* to convey that cost reductions due to increasing volumes may continue to occur. RPEs are not intended to replicate the market price of a specific vehicle or a specific optional feature at a specific time. The market price of a particular vehicle at a particular time depends on many factors (e.g., market trends, marketing strategies, profit opportunities, business cycles, temporary shortages or surpluses) other than the cost of manufacturing and retailing a vehicle or any given component. It is not appropriate to base a long-term policy such as fuel economy standards on short-run conditions or special circumstances.

The RPE concept, unfortunately, is not easy to apply. It raises a number of difficult questions about appropriate premises and assumptions and reliable sources of data. It frequently relies on the application of markup factors, which could vary depending on the nature of the technology and the basis for the original cost estimate. When an RPE markup factor is used, the definition of the cost to which it applies is critical. Much of the disagreement over RPE multipliers can be traced to inconsistent definition of the cost to be marked up. The following are key premises of the committee's application of the RPE method.

- *Incremental RPE*. The relevant measure of cost is the change in RPE in comparison to an equivalent vehicle without the particular fuel economy technology. More often than not, a fuel economy technology replaces an existing technology. For example, a 6-speed automatic transmission replaces a 5-speed, a compression-ignition (CI) engine replaces a spark-ignition (SI) engine, or a set of low-rolling-resistance tires replaces a set with higher rolling resistance. What matters is the change in RPE rather than the total RPE of the new technology. This requires that an estimate of the RPE of the existing technology be subtracted from that of the new technology.
- *Equivalent vehicle size and performance*. Estimating the cost of decreasing fuel consumption requires one to carefully specify a basis for comparison. The committee considers that to the extent possible, fuel consumption cost comparisons should be made at equivalent acceleration performance and equivalent vehicle size. Other vehicle attributes matter as well, such as reliability, noise, and vibration. Ideally, cost and fuel economy comparisons should be made on the basis of no compromise for the consumer. Often there are differences of opinion about what design and engineering changes may be required to ensure no compromise for the consumer. This, in turn, leads to differing bills of materials to be costed out, which leads to significant differences in incremental RPE estimates.
- *Learning by doing, scale economies, and competition.* When new technologies are first introduced and only one or two suppliers exist, costs are typically higher than they will be in the long run due to lack of scale economies, as-yet-unrealized learning by doing, and limited competition. These transitional costs can be important to manufacturers' bottom lines and should be considered. However, nearly all cost estimates are developed assuming long-run, high-volume, average economic conditions. Typical assumptions include (1) high volume, (2) substantially learned component costs, and (3) competition provided by at least three global suppliers available to each manufacturer (Martec Group, Inc., 2008a, slide 3). Under these assumptions, it is not appropriate to employ traditional learning curves to predict future reductions in cost as production experience increases. However, if cost estimates are for novel technology and do not reflect learning by doing, then the application of learning curves as well as the estimation of scale economies may be appropriate. The use of such methods introduces substantial uncertainty, however, since there are no proven methods for predicting the amount of cost reduction that a new technology will achieve.
- *Normal product cycles.* As a general rule, premises include normal redesign and product turnover schedules. Accelerated rates of implementation can increase costs by decreasing amortization periods and by demanding more engineering and design resources than are available. Product cycles are discussed in Chapter 7.
- *Purchased components versus in-house manufacture.* Costs can be estimated at different stages in the manufacturing process. Manufacturing cost estimates gen-

[2]Learning by doing represents the increase in productivity and decrease in cost that occurs during a technology's lifetime as a result of manufacturers' gaining experience in producing the technology. The impacts of learning on costs can be represented as a volume-based learning where costs reductions occur with increasing production levels or as a time-based learning where cost reductions occur over time.

erally do not include warranty, profit, transportation, and retailing costs, and may not include overhead or research and development. Other estimates are based on the prices that original equipment manufacturers (OEMs) would pay a Tier 1 supplier for a fully manufactured component.[3] These estimates include the supplier's overhead, profit, and R&D costs, but not costs incurred by the OEM. RPEs attempt to estimate the fully marked-up cost to the ultimate vehicle purchaser. A key issue for cost estimates based on Tier 1 supplier costs is the appropriate markup to RPE. This will depend on the degree to which the part requires engineering and design changes to be integrated into the vehicle, and other factors.

- *Allocation of overhead costs.* Specific changes in vehicle technology and design may affect some of an OEM's costs of doing business and not others. A reduction in engine friction, for example, might not affect advertising budgets or transportation costs. To date there is a very limited understanding of how to determine which costs of doing business are affected by each individual technology and how to develop technology-specific markups (e.g., Rogozhin et al., 2009). In theory, this approach has the potential to yield the most accurate results. However, in practice, unambiguous attribution of costs to specific vehicle components is difficult. For example, despite extensive reliability testing, it is not possible to predict with certainty what impact a technology or design change will have on warranty costs. Furthermore, there are significant cost components that cannot logically be allocated to any individual component. Among these are the maintenance of a dealer network and advertising. Yet, these costs must be paid. The RPE method assumes that such costs should be allocated in proportion to the component's cost and that overall overhead costs will increase in proportion to total vehicle cost. This will not necessarily produce the most accurate estimate for each individual item but is consistent with the goal of estimating long-run average costs.

COMPONENTS OF COST

Although different studies describe and group the components of the retail price equivalent (long-run average cost) in different ways, there are four fundamental components: (1) the variable costs of manufacturing components, (2) fixed costs of manufacturing components, (3) variable costs of vehicle assembly, and (4) fixed costs of vehicle assembly and sale. The distinction between variable and fixed costs is not a sharp one, because many "fixed" costs scale to some extent with production volume. In fact, the degree to which fixed or overhead costs scale with variable costs is a key area of uncertainty.

Although many components are manufactured in-house by OEMs, it is useful to distinguish between component and vehicle assembly costs, because many manufacturers purchase 50 percent or more of a vehicle's components from suppliers. Transaction prices and price estimates from Tier 1 and Tier 2 suppliers are a major source of information on the costs of fuel economy technologies.

Variable manufacturing costs of components include materials, labor, and direct labor burden (Table 3.1). Variable manufacturing costs are sometimes referred to as *direct manufacturing costs,* although when this term is used it typically includes the depreciation and amortization of manufacturing equipment. Fixed costs of component manufacturing include tooling and facilities depreciation and amortization associated with capital investments, manufacturing overhead (e.g., R&D, engineering, warranty, etc.), and profit (or return to capital). Unfortunately, terminology frequently differs from one study to another. Total manufacturing costs (variable plus fixed) are equivalent to the price that a Tier 1 supplier would charge an OEM for a finished component, ready for installation.

OEM or assembly costs include the variable costs of materials, labor, and direct labor burden for vehicle assem-

TABLE 3.1 Components of Vehicle Retail Price Equivalent (Long-Run Average Cost)

Component Manufacturing (Subassembly)
Variable component manufacturing costs
Materials
Labor
Direct labor burden
Fixed component manufacturing costs
Tooling and facilities depreciation and amortization
R&D
Engineering
Warranty
Other overhead
Profit
Vehicle Assembly and Marketing
Variable costs
Assembly materials
Assembly labor
Direct labor burden
Fixed costs
Tooling and facilities depreciation and amortization
Warranty
R&D
Engineering
Warranty
Other overhead
Transportation
Marketing and advertising
Dealer costs and profit
Original equipment manufacturer profit

[3] Tier 1 suppliers contract directly with OEMs, whereas Tier 2 suppliers contract with Tier 1 suppliers.

bly. Fixed costs include facilities and tooling depreciation and amortization, warranty, R&D, engineering, advertising, dealer expenses and profit, transportation, and OEM return on investment (profit). The sum total of all costs, divided by the Tier 1 supplier price (or equivalent), is called the RPE markup.

The costs of inputs to the production process can vary over time. Some key components, such as electrical systems, emissions controls, and hybrid vehicle batteries, use relatively expensive metals whose prices can be volatile, significantly impacting manufacturing costs. The prices of many of these metals increased dramatically prior to the global recession beginning in 2008, but have since returned to previous levels. Most publicly available estimates of technology costs do not explicitly reflect uncertainties about future commodity prices.

FACTORS AFFECTING COSTS OVER TIME AND ACROSS MANUFACTURERS

Cost estimates for fuel economy technologies are typically presented as a single point estimate or as a range. In fact, costs will vary over time and even across manufacturers owing to technological progress, experience (learning by doing), prices of commodities, labor and capital, and the nature of the vehicles manufactured.

Economies of Scale

Scale economies describe the tendency for average manufacturing costs to decrease with increasing volume, as fixed costs are distributed over a greater number of units produced. The automobile industry is characterized by large economies of scale. Although sources differ, full scale economies are generally considered to be reached at between 100,000 and 500,000 units per year. Martec Group, Inc. (2008a), for example, asserts that production efficiencies are maximized at 250,000 to 300,000 units. Honda cited a maximum efficiency of 300,000 units in its comments to the DOT/NHTSA (2009, p. 185).

Technological Progress and Learning by Doing

Although cost estimates are generally premised on full scale economies and fully learned technologies, both the EPA and the NHTSA believe that not all Tier 1 supplier or piece cost estimates represent fully learned technology costs. In their view, learning curves should be applied for the more novel technologies not in widespread use today.[4] The EPA listed 16 advanced technologies that, in its judgment, would experience future cost reductions relative to current estimates through learning by doing. Technologies such as cylinder deactivation, camless valve trains, gasoline direct injection with lean burn, turbocharging with engine downsizing, and hybrid systems from stop-start to full hybrids and plug-in hybrids were all assumed to have progress ratios of 0.8 (i.e., a doubling of cumulative production would reduce costs by 20 percent). Diesel emissions control systems were assumed to have smaller progress ratios of 0.9 (EPA, 2008a, Table 4.2-3).

If supplier cost estimates truly represent fully learned costs (at full scale economies), then there is no justification for assuming future learning by doing. The cost estimates made by Martec for the Northeast States Center for a Clean Air Future (NESCCAF), for example, were intended to reflect cost reductions by learning that would occur over the period 2009-2011. In its study for the Alliance of Automobile Manufacturers, Martec intended that its cost estimates reflect full scale economies and full learning: "Martec specified an extremely high annual volume target [500,000 units per year] specifically to drive respondents to report mature, forward costs expected in the future with the impact of learning fully reflected" (Martec Group, Inc., 2008b, p. 7). But Martec identifies two sources of learning: (1) improvement in manufacturing productivity, largely as a result of production volume; and (2) changes in system design. Martec considered the latter to be technological innovations that would change the system architecture and thus the technology itself, requiring new cost estimates. Thus, the learning considered by Martec in its estimates is based on the belief that the Tier 1 and Tier 2 suppliers would implicitly include learning effects of the first type in their high-volume cost estimates, and would exclude learning of the second type.

In its 2011 corporate average fuel economy (CAFE) rulemaking, the NHTSA recognized two types of learning by doing: "volume-based" learning and "time-based" learning. Neither is based on cumulative production, as is much of the literature on learning by doing. DOT/NHTSA (2009, p. 185) judged that a first cycle of volume-based learning would occur at a volume of 300,000 units per year and that costs would be reduced by 20 percent over low-volume estimates. A second learning threshold was set at 600,000 units per year, at which point a second cost reduction of 20 percent was taken. No further volume-based learning was assumed. The NHTSA applied this procedure to only three technologies in its 2011 rule: integrated starter generator, two-mode hybrid, and plug-in hybrid.

DOT/NHTSA (2009, p. 188) also applies time-based or year-over-year learning by doing to widely available, high-volume, mature technologies. Either time-based or volume-based learning, but not both, is applied to a particular technology. Time-based learning is applied at the rate of 3 percent per year in the second and all subsequent years of a technology's application.

The use of learning curves poses a dilemma. On the one hand, there is no rigorous method for determining how much

[4] The EPA generally does not use typical continuous learning curves but instead stepwise learning as a function of time, rather than cumulative production. Usually, costs are assumed to decrease by 10 percent after the first year of production, and by another 10 percent after the second year, and then to remain constant.

and how rapidly a specific technology's costs can be reduced by learning by doing.[5] On the other hand, the phenomenon of learning by doing is widely and generally observed in the manufacturing of new technologies (e.g., Wene, 2000). This does not mean that no learning should be assumed. Rather, learning curves should be applied cautiously and should reflect average rates of learning based on empirical evidence from the motor vehicle industry. Expert judgment should be used to determine the potential for learning, depending on the nature of the technology in question.

Vehicle Type or Class

The costs of fuel economy technology also vary across vehicle classes. To a large extent this is a function of vehicle size and power. For example, an eight-cylinder engine has twice as many valves as a four-cylinder, and so the costs of valve train technologies will be higher. When technologies, such as turbocharging, increase the power output per unit of displacement and thereby enable engine downsizing at constant performance, the starting cylinder count can affect the options for downsizing. In general, an eight-cylinder engine can be replaced by a smaller six-cylinder engine of equivalent performance without additional costs for mitigating vibration. Downsizing a four-cylinder to a three-cylinder would require significant modifications to offset increased vibration, and this might even rule out reducing the cylinder count. Since most of the cost savings from downsizing accrue from reducing the number of cylinders, technologies that enable engine downsizing will be relatively more expensive for four-cylinder engines. Since different vehicle classes have different distributions of cylinder counts, the costs of certain technologies should be class-dependent. As another example, the cost of a 1 percent weight reduction by material substitution will depend on the initial mass of the vehicle.

National Research Council (2002) did not vary technology costs by vehicle class. The NHTSA's Volpe model's algorithm, however, operates at the level of make, model, engine, and transmission configuration. Some technology costs are scaled to the specific attributes of each vehicle. Other costs are class-dependent. In its final rule for 2011, DOT/NHTSA (2009, p. 165) specified eight passenger car classes and four light truck classes (Table 3.2). Passenger cars were divided into size classes on the basis of their footprint. Each class was divided into a standard and high-performance class on the basis of class-specific cut-points determined using expert judgment. This reflects the NHTSA's view that in addition to size, performance is the key factor determining differences in technology applicability and cost. The classification of light trucks was based on structural and design considerations (minivans) and footprint size (sport utility vehicles [SUVs], pickups, and vans).

[5] Not only the progress ratio, but also the assumed initial cumulative production (or threshold volume) strongly influences estimated future cost reductions. Numerous after-the-fact estimations of progress ratios are available. However, in general, there is no scientific method for deciding on these parameters ex ante.

TABLE 3.2 Vehicle Classification by the National Highway Traffic Safety Administration

Passenger Cars
Subcompact
Subcompact performance
Compact
Compact performance
Midsize
Midsize performance
Large
Large performance
Light Trucks
Minivans
Small SUV/pickup/van
Midsize SUV/pickup/van
Large SUV/pickup/van

Although classification can improve the accuracy of cost estimates, there is no perfect classification system, and there will always be some heterogeneity within a class.

METHODS OF ESTIMATING COSTS

As a generalization, there are two basic methods of cost estimation. The first and most common is to obtain estimates of the selling prices of manufactured components. The second is to tear down a technology into its most basic materials and manufacturing processes and to construct a bottom-up estimate by costing out materials, labor, and capital costs for every step. Both methods ultimately rely heavily on the expertise and the absence of bias on the cost estimator's part.

Estimation Using Supplier Prices for Components, or "Piece Costs"

The supplier price method relies on comparing an estimate of the price that a Tier 1 component manufacturer would charge an OEM for a reference component to an estimate of the price that it would charge for an alternative that delivered reduced fuel consumption. In the past, information on the prices that manufacturers pay to Tier 1 suppliers for components has come from a variety of sources, including the following:

- The NRC (2002) report on the CAFE standards;
- The NESCCAF (2004) study on reducing light-duty vehicle greenhouse gas emissions;
- The California Air Resources Board study in support of its greenhouse gas regulations;
- The study by Energy and Environmental Analysis, Inc. (EEA, 2006) for Transport Canada;

- Confidential data submitted by manufacturers to the NHTSA in advance of rulemakings; and
- Confidential data shared by manufacturers in meetings with the NHTSA and the EPA in 2007.

Component cost estimates can be obtained from discussions with suppliers or OEMs, from published reports, or by comparing the prices of vehicles with and without the component in question (Duleep, 2008), bearing in mind that costs and market prices may differ significantly. The NHTSA also receives cost estimates in the form of confidential data submitted by manufacturers. Depending on how fuel economy technologies are defined, estimates for more than one component may be involved. Given a supplier price estimate, a markup factor is applied to estimate the RPE. A single markup factor is often used for all components, but different markups may be used according to the nature of the component. The key issues are, therefore, the accuracy of the supplier price estimates and the accuracy of the markup factor(s).

First at the request of NESCCAF (2004) and later at the request of the Alliance of Automobile Manufacturers, Martec Group, Inc. (2008b) estimated the variable (or manufacturing) costs of fuel economy technologies based on the bill of materials (BOM) required. The term *materials* as used in the Martec studies refers to manufactured components supplied by Tier 1 and Tier 2 suppliers. The direct and indirect changes in vehicle components associated with a particular technology were determined in discussions with engineering consultants and OEM engineers. The Tier 1 and Tier 2 suppliers were the primary sources of information on the costs of manufactured components required to implement the fuel economy increases (Martec Group, Inc., 2008b, p. 7).

Teardown or Bottom-Up Estimation

A change in the design and content of a vehicle induces changes in the materials of which it is made, the quantity and types of labor required to construct it, and changes in the capital equipment needed to manufacture it. Such estimates not only are time-consuming but also require analysts with a thorough knowledge of and experience with automotive manufacturing processes.

Bottom-up cost estimation methods have been used by the NHTSA for assessing the impacts of safety regulations. For example, in a study of air bag costs, an NHTSA contractor used a teardown method to identify all components of 13 existing air bag systems. This study (Ludtke and Associates, 2004) is described in Appendix F. The contractor analyzed each part or assembly and identified each manufacturing process required for fabrication, from raw material to finished product. The analysis identified parts purchased from suppliers as well as parts made in-house. Process engineers and cost estimators then carried out a process and cost analysis for each part and assembly. Two costs were developed: (1) variable costs associated with the actual manufacturing and (2) fixed or burden costs. Estimating costs to the consumer (analogous to the retail price equivalent) requires additionally estimating the OEM's amortized costs, as well as other costs and profit. Dealers' costs are added to the manufacturer's cost plus profit to obtain the consumer's cost (Figure 3.1). As the NHTSA report is careful to point out, estimating costs "is not an exact science" but rather one strongly dependent on the expertise and judgment of the estimators at every step.

The teardown method was applied by Kolwich (2009) to estimate the incremental manufacturing cost of a downsized 1.6-liter, four-cylinder, stoichiometric direct injection, turbocharged engine versus a 2.4-liter, four-cylinder, naturally aspirated base engine. The study did not attempt to estimate the markup from manufacturing costs to RPE. Rather, the cost estimated is equivalent to the price that a Tier 1 supplier would charge an OEM for the fully manufactured engine. Unit costs are composed of direct manufacturing costs (material + labor + fixed manufacturing costs) + "markup costs" (scrap + overhead + profit) + packaging costs (Figure 3.2).

Manufacturing costs are estimated in a series of highly detailed steps based on what is learned in disassembling the technology. Both the new and the base technologies must be torn down and costed in order to estimate the difference in cost. First, the technology to be evaluated is identified and defined. Next, candidate vehicles for teardown are identified (this limits the analysis to technologies already in production). A pre-teardown, high-level bill of materials (consisting of subsystems and components) is then created, subject to amendment, as discoveries might be made during the teardown process. At that point, the actual teardown process begins. During the teardown, all of the processes necessary for assembly are identified and recorded, and every component and the material of which it is made are identified. The data generated in the disassembly are then reviewed by a team of experts. Following the review, the components are torn down and assembly processes are identified, as is each and every piece of each component. A worksheet is then constructed for all parts, containing all cost elements. Parts with high or unexpected cost results are double-checked, and then entered into a final spreadsheet in which they are totaled and formatted.

Once manufacturing costs have been estimated, a markup reflecting all other costs of doing business is typically applied to estimate the long-run cost that consumers will have to pay. Applying this markup was outside the scope of the FEV (2009) study but was included in the Ludtke and Associates (2004) study. Estimates of the consumer's cost of curtain air bag systems installed in five different vehicles from the Ludtke and Associates study are shown in Table 3.3. Although costs vary, it is clear that Ludtke and Associates used the same markup factors for Tier 1 manufacturers' markups over their direct costs (24 percent), OEM markups (36 percent), and dealer markups (11 percent). These markups result in multipliers for the consumer's cost over the Tier 1 supplier's cost of

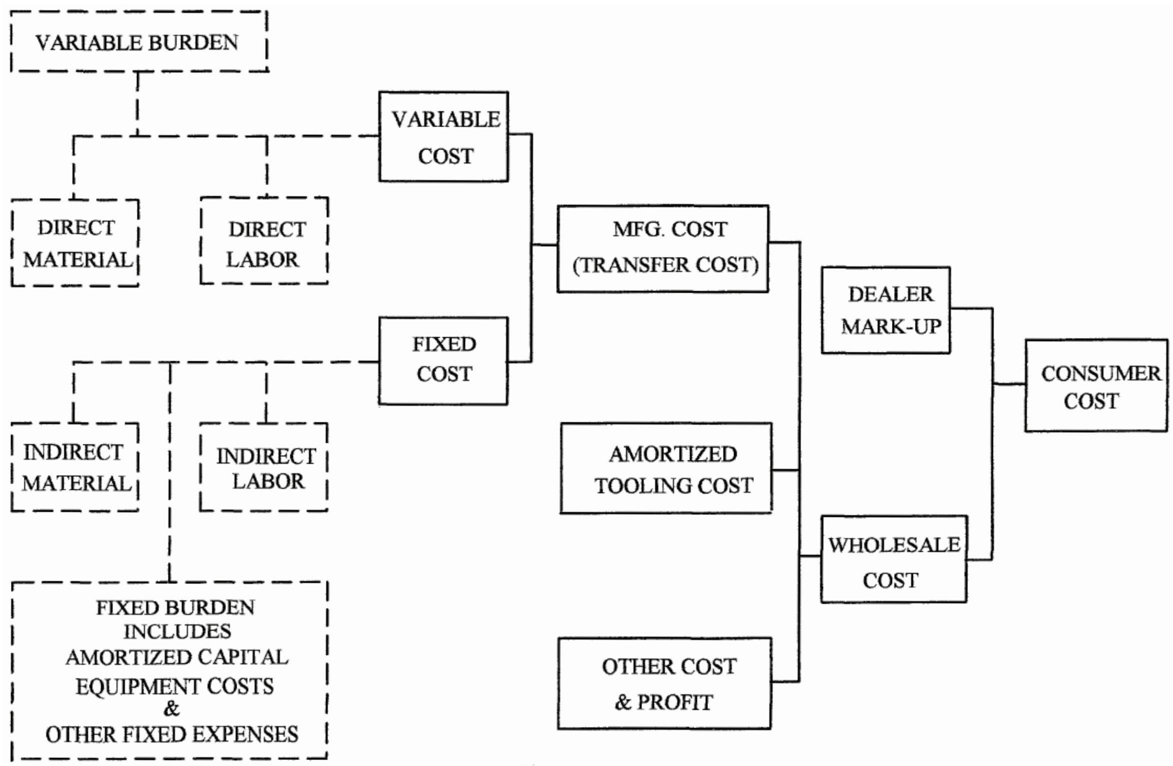

FIGURE 3.1 Determination of manufacturing and consumer cost. SOURCE: Ludtke and Associates (2004), p. B-10.

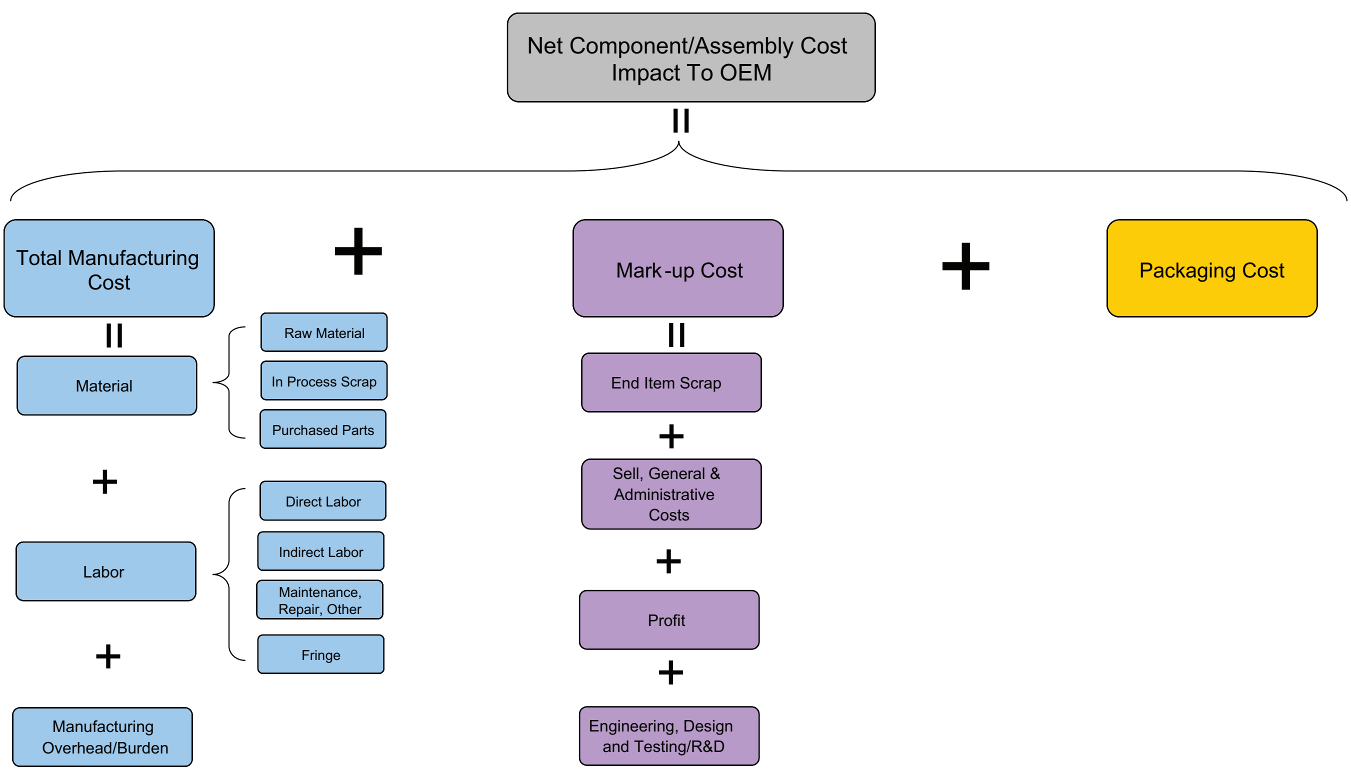

FIGURE 3.2 Unit cost model. SOURCE: FEV, Inc. (2009) (FEV.com), Figure 5.

TABLE 3.3 Estimated Consumer Cost (2003 dollars) for Installed Air Bag Systems and Markups

Item	VW Jetta	Toyota Camry	Cadillac CTS	Mercury Monterey[a]	Jeep Grand Cherokee
Material	$30.04	$27.45	$48.46	$69.88	$54.43
Direct labor	$11.11	$20.54	$16.54	$37.62	$17.68
Direct labor burden	$22.59	$34.40	$24.61	$55.91	$23.93
Tier 1 markup	$15.40	$19.89	$21.93	$39.66	$23.21
Manufacturer markup	$28.49	$36.82	$40.15	$73.11	$42.93
Dealer markup	$11.84	$15.30	$16.69	$30.38	$17.84
Consumer's cost	$119.47	$154.40	$168.38	$306.55	$180.02
Variable cost	$63.74	$82.39	$89.61	$163.41	$96.04
Variable manufacturing cost	$79.14	$102.28	$111.54	$203.07	$119.25
Markup Tier 1 cost	1.51	1.51	1.51	1.51	1.51
Markup variable manufacturing cost	1.87	1.87	1.88	1.88	1.87
Tier 1 markup	24.2%	24.1%	24.5%	24.3%	24.2%
OEM markup	36.0%	36.0%	36.0%	36.0%	36.0%
Dealer markup	11.0%	11.0%	11.0%	11.0%	11.0%

NOTE: Original equipment manufacturer (OEM) manufacturing costs (2003$) per vehicle—head protection air bag systems (curtain-type system without a torso airbag already installed in vehicle).

[a]Cost estimates for the Mercury Monterey are substantially higher than those for the other vehicles. Ludtke and Associates (2004) do not offer an explanation for the design differences that account for the higher cost.

SOURCE: Ludtke and Associates (2004).

1.51 ($1.36 \times 1.11 = 1.51$), and for the consumer's cost over the direct variable costs of manufacturing ("Total Manufacturing Costs" minus "Manufacturing Overhead Burden" in the FEV [2009] study; see Figure 3.2 above) the component of 1.87 ($1.24 \times 1.36 \times 1.11 = 1.87$). The costs shown in Table 3.3 are in 2003 dollars and assume a manufacturing scale of 250,000 units per year for the air bags.

While Ludtke and Associates (2004) use a markup factor of 1.24 for direct manufacturing costs, Kolwich (2009) uses markup factors ranging from 10.3 percent to 17.7 percent, depending on the complexity of the component (Table 3.4). Note that the Kolwich rates do not include manufacturing overhead whereas the Ludtke rates do, and thus the former should be higher.

The FEV teardown study (FEV, 2009; Kolwich, 2009) allows total manufacturing costs to be broken down by engine subsystem as well as cost component. Figure 3.3 shows the incremental manufacturing costs by cost component. The largest single component of the $537.70 total is material ($218.82), followed by manufacturing burden ($154.24), labor ($72.58), corporate overhead ($33.96), profit ($33.12), engineering and R&D ($12.36), and scrap ($11.72). The total markup on manufacturing costs is just over 20 percent. Figure 3.4 shows the same total cost broken down by engine subsystem. By far the largest components are the induction air charging system ($258.89) and the fuel induction system ($107.32). Cost savings occur in counterbalance ($35.95) and intake systems ($12.73).

TABLE 3.4 Total Manufacturing Cost Markup Rates for Tier 1 and Tier 2/3 Suppliers

Primary Manufacturing Equipment Group	End Item Scrap Markup (%)	SG&A Markup (%)	Profit Markup (%)	ED&T Markup (%)	Total Markup (%)
Tier 2/3—large size, high complexity	0.7	7.0	8.0	2.0	17.7
Tier 2/3—medium size, moderate complexity	0.5	6.5	6.0	1.0	14.0
Tier 2/3—small size, low complexity	0.3	6.0	4.0	0.0	10.3
Tier 1 complete system/subsystem supplier (system/subsystem integrator)	0.7	7.0	8.0	6.0	21.7
Tier 1 high-complexity-component supplier	0.7	7.0	8.0	4.0	19.7
Tier 1 moderate-complexity-component supplier	0.5	6.5	6.0	2.5	15.5
Tier 1 low-complexity-component supplier	0.3	6.0	4.0	1.0	11.3

SOURCE: Kolwich (2009), Table 2.

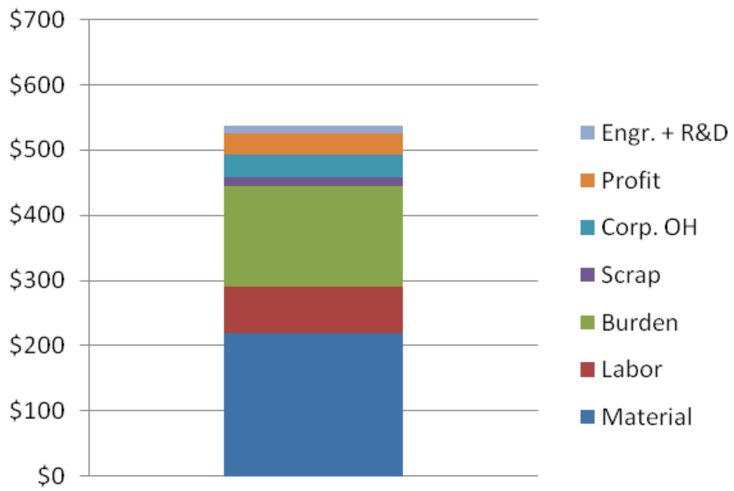

FIGURE 3.3 Incremental cost of turbocharged, downsized, gasoline direct-injection I4 engine broken down by cost category. SOURCE: Kolwich (2009), Figure 19.

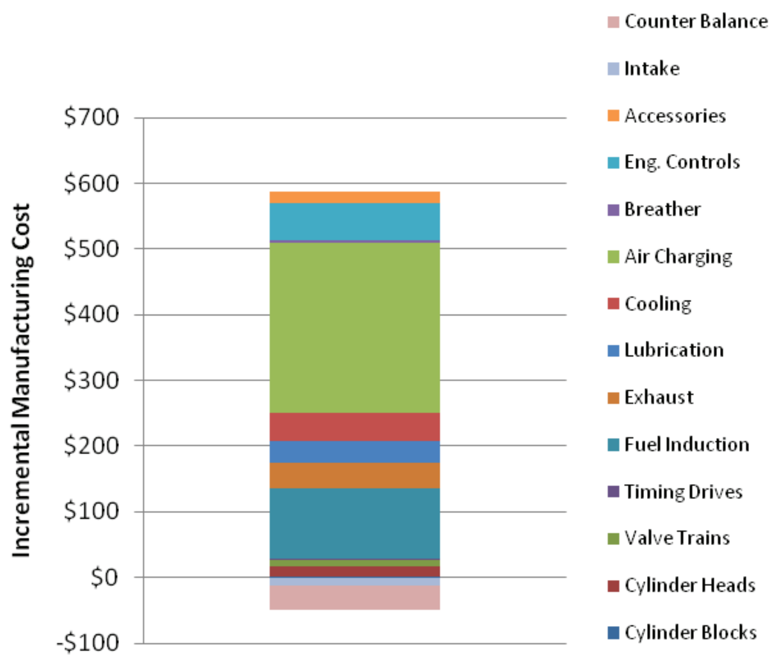

FIGURE 3.4 Incremental cost of turbocharged, downsized, gasoline direct-injection I4 engine broken down by engine subsystem. SOURCE: Kolwich (2009), Figure 19.

RETAIL PRICE EQUIVALENT MARKUP FACTORS

Markup factors relating component costs to RPE add significantly to the estimated costs of automotive technologies and are the subject of continuing controversy. The cost of making and selling light-duty vehicles is not limited to the manufacture of components and their assembly. Even for a single technological or design change, cost impacts are generally not limited to the component that is changed. Engineering expertise must be supplied to design these changes, which may or may not induce other changes in the cost of manufacturing. These integration costs can be substantial for major components, such as engines, or when, as is more often the case than not, many changes are made simultaneously. There are also indirect costs for research and development, administrative overhead, warranties, and marketing and advertising. Vehicles must be transported to dealers who have their own labor, material, and capital costs. All of these additional costs are represented by RPE markup factors.

Existing RPE Markup Factors

For the automobile industry, there is a reasonable consensus on the ratio of total costs of doing business to the cost of fully manufactured components (the price that a Tier 1 supplier would charge an OEM). This average RPE markup factor is approximately 1.5, according to the available evidence, reviewed in detail in Appendix F of this report. Part of the disagreement over the size of the RPE markup factor arises from the difference between the variable costs versus the variable plus fixed costs of a manufactured component. An appropriate RPE markup over the variable (or direct) costs of a component is approximately 2.0 (Bussmann and Whinihan, 2009). Part of the disagreement arises over the difficulty of attributing indirect and other fixed costs to a particular vehicle component.

Every fuel economy technology does not affect fixed or indirect costs in the same way. Some costs may be affected by engineering and design changes to decrease fuel consumption; others may not. This can have a very large impact on the appropriate RPE of a given fuel economy technology. Some studies use a single, average RPE markup factor (e.g., NRC, 2002; Albu, 2008; DOT/NHTSA, 2009), while others attempt to tailor the markup to the nature of the technology (Rogozhin et al., 2009; Duleep, 2008). The problem of how best to attribute indirect and fixed costs to a specific change in vehicle technology remains unresolved.

Existing estimates of the RPE markup factor are similar when interpreted consistently. Vyas et al. (2000) compared their own markup factors to estimates developed by EEA, Inc., and Chrysler. Unfortunately, differences in the definitions of categories of costs preclude precise comparisons. Vyas et al. concluded that an appropriate markup factor over the variable costs of manufacturing a motor vehicle was 2.0. The Vyas et al. (2000) report also summarized the cost methodology used by EEA, Inc., in a study for the Office of Technology Assessment (OTA, 1995). Vyas et al. (2000) concluded that the markup over variable manufacturing costs used in that study was 2.14, while the markup over outsourced parts (e.g., purchased from a Tier 1 supplier) was 1.56 (Table 3.5).

A markup factor of 1.5 was also used by the NHTSA (2009, p. 173) in its final fuel economy rule for 2011. A somewhat lower RPE markup factor of 1.4 was used by the NRC (2002) and Albu (2008), while the EPA has used a markup of 1.26 (EPA, 2008a).

The use of a markup of approximately 2 over the direct manufacturing costs of parts manufactured in-house by an OEM was also supported by Bussmann (2008), who cited a 2003 study of the global automotive industry by McKinsey Global Institute that produced a markup factor of 2.08, and his own analysis of Chrysler data for 2003-2004 that produced factors of 1.96 to 1.97. Information supplied by EEA, Inc., to the committee (Duleep, 2008) implies higher markup factors: 2.22 to 2.51 for the markup over variable costs and 1.65 to 1.73 for the markup over Tier 1 supplier costs.

Average RPE factors can be inferred by costing out all the components of a vehicle, summing those costs to obtain an estimate of OEM Tier 1 costs or fully burdened in-house manufacturing costs, and then dividing the sum into the selling price of a vehicle. The committee contracted with IBIS Associates (2008) to conduct such an analysis for two high-selling model-year 2009 vehicles: the Honda Accord sedan and the Ford F-150 pickup truck. For the Honda, the RPE multipliers were 1.39 to market transaction price and 1.49 to manufacturer's suggested retail price (MSRP). The multiplier to dealer invoice cost is 1.35, implying that dealer costs, including profit, amount to about 4 percent of manufacturing costs, not considering any dealer incentives provided by OEMs. For the Ford F-150, the RPE multipliers were 1.52 for market price and 1.54 for MSRP. The markup factor for dealer invoice is 1.43, implying that dealer costs and profit amount to about 9 percent of total manufacturing costs, not including any possible OEM incentives to dealers.

TABLE 3.5 Comparison of Markup Factors

Markup Factor for	ANL	Borroni-Bird	EEA
In-house components	2.00	2.05	2.14
Outsourced components	1.50	1.56	1.56

SOURCE: Vyas et al. (2000).

The EPA Study on RPE Factors and Indirect Cost Multipliers

Concerns with the Existing RPE Method

Objections have been raised with respect to the use of a single RPE markup factor for components manufactured by Tier 1 suppliers and sold to OEMs. The EPA has pointed out that not all technologies will affect indirect costs equally, and it has proposed to investigate technology-specific markups, by attempting to identify only those indirect costs actually affected by each technology (EPA, 2008b). In a similar vein, the importance of "integration costs" has been cited as a factor that would justify different markup factors for different technologies (Duleep, 2008).[6] Because a vehicle is a system, it is almost always the case that the design of one part affects others. Manufacturers cannot simply buy a list of parts and

[6] Duleep (2008) recommends using different markup factors for different kinds of components to account for differences in the cost of integrating components into the overall vehicle design. For parts purchased from Tier 1 suppliers, Duleep recommends a range of markup factors from 1.45 to 1.7, depending chiefly on integration costs. As an example, Duleep presented to the committee an estimated markup factor of 1.72 for injector, pump, and rail costs for a stoichiometric GDI engine. This is at the high end of his markup range, reflecting the greater integration costs for engine technologies. Duleep (2008) proposed using judgment to divide technologies into three groups. He recommended a markup factor of 1.7 for technologies requiring extensive integration engineering, 1.56 for those having average integration costs, and 1.4 for those with little or no integration costs.

bolt them together to produce a vehicle that meets customers' expectations and satisfies all regulatory requirements.[7] Integrating a new engine or transmission to decrease fuel consumption will have much greater ramifications for vehicle design and is likely to generate greater integration costs than simpler components.

In a presentation to the committee, the EPA raised concerns that markup factors on piece or supplier costs tended to overestimate the costs of most fuel economy technologies: "Our first preference is to make an explicit estimate of all indirect costs rather than rely on general markup factors" (EPA, 2008b, slide 4). Nonetheless, in its assessment of the costs of greenhouse gas mitigation technologies for light-duty vehicles, the EPA staff assumed a uniform markup of 50 percent over supplier costs (i.e., a markup factor of 1.5). Still, the EPA maintains that such a markup is too large: "We believe that this indirect cost markup overstates the incremental indirect costs because it is based on studies that include cost elements—such as funding of pensions—which we believe are unlikely to change as a result of the introduction of new technology" (EPA, 2008a, p. 47).

Following up on this assertion, the EPA commissioned a study of RPE factors and indirect cost (IC) multipliers (Rogozhin et al., 2009). The IC multiplier attempts to improve on the RPE by including only those specific elements of indirect costs that are likely to be affected by vehicle modifications associated with environmental regulation. In particular, fixed depreciation costs, health care costs for retired workers, and pensions may not be affected by many vehicle modifications caused by environmental regulations.

The EPA study (Rogozhin et al., 2009) also criticizes the RPE method on the grounds that an increase in the total cost of producing a vehicle will not be fully reflected in the increased price of the vehicle due to elasticities of supply and demand. For this reason, the report argues that manufacturer profits should not be included in the RPE multiplier. The committee disagrees with this assertion for two reasons. First, as noted earlier, the global automotive industry approximates what economists term a monopolistically competitive market, that is, a market in which there is product differentiation but a high degree of competition among many firms. In a monopolistically competitive market, in the long run the full costs of production will be passed on to consumers. In the long run, monopolistically competitive market supply is perfectly elastic at the long-run average cost of production (this includes a normal rate of return on capital). Since cost estimates by convention assume long-run conditions (full scale economies and learning), long-run supply assumptions should be used to ensure consistency. The increase in RPE is a reasonable estimate of the change in welfare associated with the increased vehicle cost especially, as noted above, in the long run.

[7] For some parts, the effort required for integration may be small. Tires are often cited as an example. Still, even tires have implications for a vehicle's suspension and braking systems.

The EPA study (Rogozhin et al., 2009) estimated RPEs for the largest manufacturers for the year 2007 using publicly available data in manufacturers' annual reports. Several assumptions were required to infer components not reported, or reported in different ways by different manufacturers. The method is similar to that used by Bussman (2008) and produced similar results. One notable difference is that the estimates shown in Table 3.6 attempt to exclude legacy health care costs, estimated at 45 percent of total health care costs, which in turn were estimated to be 3 percent of fully burdened manufacturing costs. This would lower the estimated RPEs by 1 to 2 percent relative to estimates in other reports, all else being equal. The estimated RPE multipliers were remarkably consistent across manufacturers (Table 3.6) and very comparable to the studies cited above. Estimated RPE multipliers ranged from 1.42 for Hyundai to 1.49 for Nissan, with an industry average of 1.46. Adding 1 to 2 percent for health care costs would bring the average multiplier even closer to 1.5.

Estimating Technology-Specific Markup Factors and IC Multipliers

The assertion that different technologies will induce different changes in indirect costs seems evident. The question is how to identify and measure the differences. At the present time a rigorous and robust method for estimating these differential impacts does not exist (Bussmann and Whinihan, 2009). Therefore, it is not clear that the accuracy of fuel consumption cost assessment would be increased by the use of technology-specific, as opposed to an industry-average, markup factor. The EPA (Rogozhin et al., 2009), however, has taken the first steps in attempting to analyze this problem in a way that could lead to a practical method of estimating technology-specific markup factors.

The EPA-sponsored study (Rogozhin et al., 2009) went on to estimate IC multipliers as a function of the complexity or scope of the innovation in an automaker's products caused by the adoption of the technology. A four-class typology of innovation was used:

- *Incremental innovation* describes technologies that require only minor changes to an existing product and permit the continued use of an established design. Low-rolling-resistance tires were given as an example of incremental innovation.
- *Modular innovation* is that which does not change the architecture of how components of a vehicle interact but does change the core concept of the component replaced. No example was given for modular innovation.
- *Architectural innovation* was defined as innovation that requires changes in the way that vehicle components are linked together but does not change the core design concepts. The dual-clutch transmission was offered as an example, in that it replaces the function of an

TABLE 3.6 Individual Manufacturer and Industry Average Retail Price Equivalent (RPE) Multipliers: 2007

	Relative to Cost of Sales								
RPE Multiplier Contributor	Industry Average	Daimler Chrysler	Ford	GM	Honda	Hyundai	Nissan	Toyota	VW
Vehicle Manufacturing									
Cost of sales	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Production Overhead									
Warranty	0.03	0.04	0.03	0.03	0.01	0.02	0.03	0.04	0.02
R&D product development	0.05	0.04	0.02	0.06	0.07	0.04	0.06	0.05	0.06
Depreciation and amortization	0.07	0.11	0.05	0.06	0.05	0.06	0.09	0.08	0.09
Maintenance, repair, operations cost	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total production overhead	0.18	0.22	0.13	0.17	0.16	0.15	0.21	0.19	0.20
Corporate Overhead									
General and administrative	0.07	0.05	0.12	0.07	0.11	0.08	0.03	0.06	0.03
Retirement	<0.01	0.01	0.00	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Health	0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total corporate overhead	0.08	0.06	0.13	0.08	0.14	0.09	0.04	0.07	0.04
Selling									
Transportation	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.10
Marketing	0.04	0.02	0.04	0.05	0.03	0.05	0.08	0.03	0.02
Dealers									
Dealer new vehicle net profit	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dealer new vehicle selling cost	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total selling and dealer contributors	0.14	0.12	0.14	0.14	0.13	0.15	0.18	0.12	0.17
Sum of Indirect Costs	0.40	0.40	0.39	0.40	0.44	0.39	0.43	0.38	0.41
Net income	0.06	0.07	0.05	0.05	0.04	0.03	0.06	0.09	0.02
Other costs (not included as contributors)	0.04	0.04	0.11	0.06	0.02	0.01	0.01	<0.01	0.05
RPE multiplier	1.46	1.47	1.45	1.45	1.47	1.42	1.49	1.48	1.43

SOURCE: Rogozhin et al. (2009), Table 3-3.

existing transmission but does require redesign and reintegration with other components.

- *Differential innovation* involves significant changes in the core concepts of vehicle components, as well as their integration. Hybrid vehicle technology was cited as an example because it changes the functions of such key components as the engine, brakes, and battery.

An industry average was computed for each component of the RPE, omitting profit, or net income. As stated above, the committee considers this omission to be in error. The resulting components are shown in Table 3.7. Next, based on the judgment of an expert panel, short- and long-term effects on the RPE components were estimated for the four categories of technology innovation (Rogozhin et al., 2009). A value of zero for the effect of a technology innovation on an RPE component implies that the application of that technology has no impact on the cost of that particular RPE component. There will be no increase in expenditure on that RPE component as a result of the adoption of the technology. A value of 1 implies that the cost of the component will increase directly with the increased cost of the component. Values greater than 1 imply a greater-than-proportional increase. Each RPE component is multiplied by its respective short- or long-term effect, and the results are summed and

TABLE 3.7 Weighted Industry Average RPE Components Omitting Return on Capital

Cost Contributor	Light Car Industry Average
Production Overhead	
Warranty	0.03
R&D (product development)	0.05
Depreciation and amortization	0.07
Maintenance, repair, operations cost	0.03
Total production overhead	0.18
Corporate Overhead	
General and administrative	0.07
Retirement	0.00
Health care	0.01
Total corporate overhead	0.08
Selling	
Transportation	0.04
Marketing	0.04
Dealers	
Dealer new vehicle selling cost	0.06
Total selling and dealer costs	0.14
Sum of Indirect Costs	0.40

SOURCE: Rogozhin et al. (2009), Table 4-1.

TABLE 3.8 Short- and Long-Term Indirect Cost Multipliers

	Low Complexity	Medium Complexity	High Complexity	Industry Average RPE
Short term	1.05	1.20	1.45	1.46
Long term	1.02	1.05	1.26	1.46

SOURCE: Rogozhin et al. (2009), Table 4-5.

added to 1.0 to produce the IC multipliers. The multipliers range from 1.05 to 1.45 in the short run and 1.02 to 1.26 in the long run (Table 3.8). This implies that none of the fuel economy technologies considered, no matter how complex, could cause an increase in indirect costs as large as the industry average indirect costs, especially in the long run. This result would imply that the more that regulatory requirements increase the cost of automobile manufacturing, the lower the overall industry RPE would be.

FINDINGS

Large differences in technology cost estimates can result from differing assumptions. Carefully specifying premises and assumptions can greatly reduce these differences. These include the following:

- Whether the total cost of a technology or its incremental cost over the technology that it will replace is estimated;
- Whether long-run costs at large-scale production are assumed or short-run, low-volume costs are estimated;
- Whether learning by doing is included or not;
- Whether the cost estimate represents only direct in-house manufacturing costs or the cost of the purchase of a component from a Tier 1 supplier;
- Whether the RPE multiplier is based on industry average markups or is specific to the nature of the technology; and
- What other changes in vehicle design, required to maintain vehicle quality (e.g., emissions, towing, gradability, launch acceleration, noise, vibration, harshness, manufacturability), have been included in the cost estimate.

Finding 3.1: For fully manufactured components purchased from a Tier 1 supplier, a reasonable *average* RPE markup factor is 1.5. For in-house direct (variable) manufacturing costs, including only labor, materials, energy, and equipment amortization, a reasonable *average* RPE markup factor is 2.0. In applying such markup factors, it is essential that the cost basis be appropriately defined and that the *incremental* cost of fuel economy technology is the basis for the markup. The factors given above are averages; markups for specific technologies in specific circumstances will vary.

Finding 3.2: RPE factors certainly do vary depending on the complexity of the task of integrating a component into a vehicle system, the extent of the required changes to other components, the novelty of the technology, and other factors. However, until empirical data derived by means of rigorous estimation methods are available, the committee prefers to use average markup factors.

Finding 3.3: Available cost estimates are based on a variety of sources: component cost estimates obtained from suppliers, discussions with experts at OEMs and suppliers, comparisons of actual transaction prices when publicly available, and comparisons of the prices of similar vehicles with and without a particular technology. There is a need for cost estimates based on a teardown of all the elements of a technology and a detailed costing of material costs, accounting for labor time and capital costs for all fabrication and assembly processes. Such studies are more costly than the current approaches listed above and are not feasible for advanced technologies whose designs are not yet finalized and/or whose system integration impacts are not yet fully understood. Nonetheless, estimates based on the more rigorous method of teardown analysis are needed to increase confidence in the accuracy of the costs of reducing fuel consumption.

Technology cost estimates are provided in the following chapters for each fuel economy technology discussed. Except as indicated, the cost estimates represent the price that an OEM would pay a supplier for a finished component. Thus, on average, the RPE multiplier of 1.5 would apply.

REFERENCES

Albu, S. 2008. ARB perspective on vehicle technology costs for reducing greenhouse gas emissions. Presentation by Assistant Chief, Mobile Source Division, California Air Resources Board, to the Committee on Technologies for Improving Light-Duty Vehicle Fuel Economy, January 24, Detroit, Mich.

Bussmann, W.V. 2008. Study of industry-average markup factors used to estimate retail price equivalents (RPE). Presentation to the Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, January 24, Detroit, Mich.

Bussmann, W.V., and M.J. Whinihan. 2009. The estimation of impacts on retail prices of regulations: A critique of "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers." Prepared for Alliance of Automobile Manufacturers, May 6, Southfield, Mich.

DOT/NHTSA (Department of Transportation/National Highway Traffic Safety Administration). 2009. Average fuel economy standards, passenger cars and light trucks, model year 2001: Final rule. 49 CFR Parts 523, 531, 533, 534, 536, and 537, Docket No. NHTSA-2009-0062, RIN 2127-AK29. March 23. Washington D.C.

Duleep, K.G. 2008. Analysis of technology cost and retail price. Presentation to Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, January 25, Detroit, Mich.

EEA (Energy and Environmental Analysis, Inc.). 2006. Technologies to Reduce Greenhouse Gas Emissions from Light-Duty Vehicles. Report to Transport Canada, Ottawa, Ontario, March. Arlington, Va.

EPA (U.S. Environmental Protection Agency). 2008a. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. Washington, D.C.

EPA. 2008b. The use of markup factors to estimate indirect costs. Presentation from National Vehicle and Fuel Emissions Laboratory, Office of Transportation and Air Quality, to the Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, National Research Council, March 31, Washington, D.C.

FEV, Inc. 2009. Light-duty technology cost analysis overview. Presentation to the Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, March 16, Washington, D.C.

IBIS Associates, Inc. 2008. Data Collection and Analysis: Vehicle Systems Costs. Report to the Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, National Research Council, December, 2008, Waltham, Mass.

Kolwich, G. 2009. Light-Duty Technology Cost Analysis Pilot Study. Report FEV 07-069-103F. Prepared for the U.S. Environmental Protection Agency, Ann Arbor, Michigan, September 3. FEV, Inc., Auburn Hills, Mich.

Ludtke and Associates. 2004. Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201. DOT HS 809 842. December. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C.

Martec Group, Inc. 2008a. Variable costs of fuel economy technologies. Presentation to the Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, National Research Council, January 24, Detroit, Mich.

Martec Group, Inc. 2008b. Variable Costs of Fuel Economy Technologies. Report prepared for the Alliance of Automobile Manufacturers. June 1. Washington, D.C.

NESCCAF (Northeast States Center for a Clean Air Future). 2004. Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles. Available at http://www.nesccaf.org/documents/rpt040923ghglightduty.pdf. Accessed July 6, 2009.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

OTA (Office of Technology Assessment). 1995. Advanced Automotive Technology: Visions of a Super-Efficient Family Car. OTA-ETI-638. Washington, D.C.

Rogozhin, A., M. Gallaher, and W. McManus. 2009. Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Report by RTI International to Office of Transportation and Air Quality. U.S. Environmental Protection Agency. RTI Project Number 0211577.002.004. February. Research Triangle Park, North Carolina.

Vyas, A., D. Santini, and R. Cuenca. 2000. Comparison of Indirect Cost Multipliers for Vehicle Manufacturing. Center for Transportation Research, Argonne National Laboratory. April. Argonne, Ill.

Wene, C. 2000. Experience Curves for Energy Technology Policy. International Energy Agency, Paris.

4

Spark-Ignition Gasoline Engines

INTRODUCTION

A large majority of light-duty vehicles in the United States are powered with spark-ignition (SI) engines fueled with gasoline. Several technologies have been developed to improve the efficiency of SI engines. This chapter updates the status of various SI engine technologies described in the National Research Council report that focused on reduction of fuel consumption (NRC, 2002). As stated in Chapter 2 of the present report, the objective is to evaluate technologies that reduce fuel consumption without significantly reducing customer satisfaction—therefore, power and acceleration performance are not to be degraded. The primary focus is on technologies that can be feasibly implemented over the period to 2025.

The present study examines these SI engine technologies in the context of their incremental improvements in reducing fuel consumption, as well as the associated costs of their implementation. It also discusses the mechanisms by which fuel consumption benefits are realized along with the interactions that these technologies have with the base-engine architecture. As with the other vehicle technologies examined in this report, the committee's estimates of incremental reduction of fuel consumption and the costs of doing so for the SI technologies presented in this chapter are based on published data from technical journals and analyses conducted by Northeast States Center for a Clean Air Future (NESCCAF), Energy and Environmental Analysis, Inc. (EEA), U.S. National Highway Traffic Safety Administration (NHTSA), U.S. Environmental Protection Agency (EPA), and other organizations. In addition, the expert judgment of committee members whose careers have focused on vehicle and power train design, development, and analysis, as well as the results of consultation with individual original equipment manufacturers (OEMs) and suppliers, were also incorporated in the estimates.

SI ENGINE EFFICIENCY FUNDAMENTALS

It is common practice to group engine-efficiency-related factors with their respective process fundamentals (i.e., thermodynamic factors, friction losses, etc.). For example, consider the basic stages of the SI engine cycle that contribute to positive work: heat released during fuel combustion, volumetric expansion, and associated heat transfer. The factors related to this process can be grouped together as the thermodynamic component. In addition, there are several processes within the engine that mitigate the positive work produced; these can be grouped as either gas exchange losses (pumping losses) or frictional losses within the engine. Furthermore, the engine architecture and the use of accessory/operational components (i.e., power steering, coolant, oil and fuel pumps) can be the source of additional parasitic losses. The fundamental aspects of each category of engine efficiency factors are discussed further in the following sections.

Thermodynamic Components

Thermodynamic factors include combustion interval, effective expansion ratio, and working fluid properties. In consideration of these factors there are some fundamental methods that can be used to improve efficiency, including:

- *Short combustion intervals*—allow for more of the heat of combustion to undergo more expansion and thus yield an increase in positive work.
- *High compression ratios and late exhaust-valve-opening event—c*an be used to influence the expansion ratio in order to improve efficiency. However, these factors are constrained by other considerations.
- *High specific heat ratio of working fluid* (i.e., c_p/c_v.)—working-fluid property of significance related to the specific heat ratio. Atmospheric air is preferred over exhaust gas as a combustion diluent thermodynamically, but exhaust emis-

sions after-treatment challenges limit this as an option for reducing fuel consumption.

• *Optimize timing of spark event*—an important factor since this affects the countervailing variables of in-cylinder heat loss and thermodynamic losses. This is discussed in more detail below.

Maximum efficiency occurs when the two countervailing variables, heat loss and thermodynamic losses, sum to a minimum. The optimum spark timing is often referred to as minimum advance for best torque or maximum brake torque (MBT). At low to moderate speeds and medium to high loads, SI engines tend to be knock-prone, and spark-timing retardation is used to suppress the knock tendency. Spark-timing adjustments are also made to enable rapid-response idle load control to compensate for such things as AC compressor engagement. For this to be effective, idle spark timing must be substantially retarded from MBT. Retardation from MBT for either of the aforementioned reasons compromises fuel consumption.

Gas Exchange or Pumping Losses

Gas exchange or pumping losses, in the simplest terms, refer to the pressure-gradient-induced forces across the piston crown that oppose normal piston travel during the exhaust and intake strokes. The pumping loss that principally affects fuel consumption is that which occurs during the intake stroke when the cylinder pressure and the intake manifold are approximately equal. The pumping loss component that occurs during the exhaust stroke mainly affects peak power. Both of these oppose the desired work production of the engine cycle and thus are seen as internal parasitic losses, which compromise fuel efficiency.

Frictional Losses

The main source of friction losses within an SI engine are the piston and crankshaft-bearing assemblies. The majority of the piston-assembly friction comes from the ring-cylinder interface. The oil-control ring applies force against the cylinder liner during all four strokes while the compression rings only apply minor spring force but are gas-pressure loaded. Piston-assembly friction is rather complex as it constantly undergoes transitions from hydrodynamic to boundary-layer friction. Hydrodynamic piston-assembly friction predominates in the mid-stroke region while boundary-layer friction is common near the top center. Avoidance of cylinder out-of-roundness can contribute to the minimization of piston-ring-related friction. Crankshaft-bearing friction, while significant, is predominately hydrodynamic and is relatively predictable.

Engine Architecture

Engine architecture refers to the overall design of the engine, generally in terms of number of cylinders and cylinder displacement. The engine architecture can affect efficiency mainly through bore-stroke ratio effects and balance-shaft requirements.

Trends in power train packaging and power-to-weight ratios have led in-line engines to have under-square bore-stroke ratios (i.e., less than unity) while most V-configuration engines have over-square ratios. Under-square ratios tend to be favored for their high thermodynamic efficiency. This is due to the surface-area-to-volume ratio of the combustion chamber; under-square designs tend to exhibit less heat transfer and have shorter burn intervals. Over-square designs enable larger valve flow areas normalized to displacement and therefore favor power density. These interactive factors play a role in determining overall vehicle fuel efficiency.

Balance-shafts are used to satisfy vibration concerns. These balance shafts add parasitic losses, weight, and rotational inertia, and therefore have an effect on vehicle fuel efficiency. I4 engines having displacement of roughly 1.8 L or more require balance shafts to cancel the second-order shake forces. These are two counter-rotating balance shafts running at twice crankshaft speed. The 90° V6 engines typically require a single, first-order balance shaft to cancel a rotating couple. The 60° V6 and 90° V8 engines need no balance shafts. Small-displacement I3 engines have received development attention from many vehicle manufacturers. These require a single first-order balance shaft to negate a rotating couple. While low-speed high-load operation of small displacement I3 engines tends to be objectionable from a noise, vibration, and harshness (NVH) perspective, they could be seen as candidate engines for vehicles such as hybrid-electric vehicles (HEVs) where some of the objectionable operating modes could be avoided.

Parasitic Losses

Parasitic losses in and around the engine typically involve oil and coolant pumps, power steering, alternator, and balance shafts. These impose power demands and therefore affect fuel consumption. Many vehicle manufacturers have given much attention to replacing the mechanical drives for the first three of these with electric drives. Most agree that electrification of the power steering provides a measurable fuel consumption benefit under typical driving conditions. Fuel consumption benefit associated with the electrification of oil or coolant pumps is much less clear. Electrification of these functions provides control flexibility but at a lower efficiency. Claims have been made that the coolant pump can be inactive during the cold-start and warm-up period; however, consideration must be given to such things as gasket failure, bore or valve seat distortion, etc. These factors result from local hot spots in the cooling system since much of the waste heat enters the cooling system via the exhaust ports.

Further discussion on the parasitic losses associated with these types of engine components is provided in Chapter 7 of this report.

THERMODYNAMIC FACTORS

Fast-Burn Combustion Systems

Fast-burn combustion systems are used to increase the thermodynamic efficiency of an SI engine by reducing the burn interval. This is generally achieved either by inducing increased turbulent flow in the combustion chamber or by adding multiple spark plugs to achieve rapid combustion.

Fluid-mechanical manipulation is used to increase turbulence through the creation of large-scale in-cylinder flows (swirl or tumble) during the intake stroke. The in-cylinder flows are then forced to undergo fluid-motion length-scale reduction near the end of the compression stroke due to the reduced clearance between the piston and the cylinder head. This reduction cascades the large-scale fluid motion into smaller scale motions, which increases turbulence. Increased turbulence increases the turbulent flame speed, which thereby increases the thermodynamic efficiency by allowing for reduced burn intervals and by enabling an increase in knock-limited compression ratio by 0.5 to 1.0. This decrease in burn interval increases dilution tolerance of the combustion system. Dilution tolerance is a measure of the ability of the combustion system to absorb gaseous diluents like exhaust gas. Exhaust gas is introduced by means of an exhaust-gas-recirculation (EGR) system or by a variable-valve-timing scheme that modulates exhaust-gas retention without incurring unacceptable increases in combustion variability on a cycle-by-cycle basis. Combustion variability must be controlled to yield acceptable drivability and exhaust emissions performance.

Multiple spark plugs are sometimes used to achieve rapid combustion where fluid-mechanical means are impractical. Here, multiple flame fronts shorten the flame propagation distance and thus reduce the burn interval. High dilution-tolerant combustion systems can accept large dosages of EGR, thereby reducing pumping losses while maintaining thermodynamic efficiency at acceptable levels.

Fuel Consumption Benefit and Cost of Fast-Burn Combustion Systems

Combining fast-burn and strategic EGR usage typically decreases fuel consumption by 2 to 3 percent, based on manufacturer's input. The implementation of this technology is essentially cost neutral. Variable mixture-motion devices, which may throttle one inlet port in a four-valve engine to increase inlet swirl and in-cylinder mixture momentum, may add another 1 to 2 percent benefit at a cost of $50, $80, and $100 for I4, V6, and V8 engines, respectively, based on manufacturer's input. As of 2007 the implementation of this technology has become common; therefore, fast burn and strategic EGR is considered to be included in the baseline of this analysis.

Variable Compression Ratio

If an engine's compression ratio could be adjusted to near the knock-limited value over the operating range, significant fuel economy gains could be realized. Many mechanisms to realize variable compression ratios have been proposed in the literature and many have been tested. However, to date all these attempts add too much weight, friction, and parasitic load as well as significant cost and have therefore not been implemented into production designs (Wirbeleit et al., 1990; Pischinger et al., 2001; Tanaka et al., 2007). It should be recalled that alterations to the effective compression ratio via intake-valve closing (IVC) timing adjustments with higher-than-normal geometric compression ratios achieves some of this benefit.

VALVE-EVENT MODULATION OF GAS-EXCHANGE PROCESSES

Alteration of valve timing can have a major impact on volumetric efficiency over an engine's speed range, and thus peak torque and power are affected by this. IVC timing is the main determinant of this effect (Tuttle, 1980). Early IVC (compression stroke) favors torque, and later IVC favors power. Implementations of valve-event modulation (VEM) typically are referred to as specific technologies such as variable valve timing, variable valve timing and lift, two-step cam phasing, three-step cam phasing, and intake-valve throttling. VEM aids fuel consumption reduction by means of reducing pumping loss. Pumping loss is reduced by either allowing a portion of the fresh charge to be pushed back into the intake system (late IVC during the compression stroke) or by allowing only a small amount of the mixture to enter the cylinder (early IVC during the intake stroke).

It should be noted that any of the VEM schemes that reduce or eliminate the pumping loss also reduce or eliminate intake-manifold vacuum. Alternative means to operate power brakes, fuel vapor canister purge, and positive crankcase ventilation (PCV) systems, normally driven by intake-manifold vacuum, must then be considered. To overcome this issue, an electrically operated pump may need to be added. It should also be noted that while the implementation of VEM techniques can boost torque output of a given engine, this report assumes that constant torque will be maintained, leading to engine downsizing. The fuel consumption benefits listed in the following section consider a constant-torque engine.

VEM History

The first modern successful production implementation of a varying valve-event setup was Honda's VTEC in the late 1980s. Honda's system allowed a stepped increase in the duration and lift of the intake valves. Prior to the development of a multi-step cam profile system, a cam profile was chosen based on performance compromises. Engineers were confronted with a tradeoff, as it is difficult to satisfy the needs of both good low-speed torque and high-speed torque with a single cam profile. The cam profiles and timings necessary to maximize these needs are completely different in their characteristics.

Honda's technology was one of the first discrete variable valve lift (DVVL)-type systems. Over the years, many other companies have developed various implementations of DVVL-type setups, as well as other innovative VEM technologies. Some newer developments in VEM technology include systems that offer continuously variable lift and duration. Nissan's VEL, BMW's Valvetronic, and Fiat's Multi-Air are all examples of continuously variable lift systems that also incorporate adjustable valve timing (Takemura et al., 2001; Flierl and Kluting, 2000; Bernard et al., 2002). These systems attempt to operate throttle-less and rely on varying lift and timing to throttle the incoming air. Throttle-less operation allows a reduction in pumping losses at part load, and thus reduces fuel consumption. However, these throttle-less approaches also generally result in slight variations in the very small valve lifts necessary for idle operation even with well-controlled manufacturing tolerances. These small variations result in a slightly different charge mass from cylinder to cylinder, causing somewhat rougher idle engine operation, which is detrimental to customer satisfaction.

The cam phaser, used to vary the valve timing, is another technology that has been in constant development by the OEMs. Early cam phasers featured only two-step phasing, allowing two possible cam positions relative to the crankshaft. Today, cam phasing is fully variable, offering a wide range of positions. Due to the system's relative simplicity and long evolution, many production vehicles now utilize cam phasing technology. Until recently, cam phasing had only been applied to overhead cam style setups due to ease of integration. This recently has changed with GM's development and production of an in-block cam phaser applied to its overhead valve (OHV) 6.2-L engine.

Intake-Valve Closing Timing

Intake-valve closing timing, also known as intake cam phasing (ICP), is a form of VEM. At moderate speeds and light loads, late intake valve closing (i.e., during the compression stroke) can reduce the pumping loss; however, it also slows combustion. Typically this configuration yields effective compression ratios that are lower than the effective expansion ratio. To achieve a lower effective compression ratio, the intake valve closing is delayed until later on the compression stroke at light loads. By closing the valve later on the compression stroke, a larger portion of the air that was drawn in on the intake stroke is pushed back out through the valve. This phenomenon allows a decrease in pumping losses by relying on the timing of the intake valve to regulate engine load. From the reduction in pumping losses, a reduction in fuel consumption will occur. Some refer to late IVC as the Atkinson cycle (Boggs et al., 1995), and most engines have some of this character. For boosted engines, late IVC is termed by some as the Miller cycle (Hitomi et al., 1995).

A diagram of a typical oil-actuated variable cam phaser system installed on the intake cam (exhaust cam timing for this engine is fixed), Figure 4.1 shows the complexity of integrating a variable cam phaser into the standard engine architecture with fixed timing. As indicated in the figure, two separate oil passages are fed to the phaser. A solenoid controls the direction of the fluid to the two different passages. These passages are used to control whether the cam will be advanced or retarded relative to the crankshaft. In order for the engine control unit (ECU) to sense the relative position of the camshaft, a position sensor is installed that provides feedback information to the ECU. It is important to note that, like many of the vehicle technologies discussed in this chapter, implementing a variable cam phaser involves a complete system integration as illustrated in Figure 4.1 and is not as simple as bolting on a component.

Fuel Consumption Benefit and Cost of IVC Timing

OEM input suggests intake cam phasing results in roughly a 1 to 2 percent fuel consumption reduction. Both the EPA and NESCCAF also estimate approximately 1 to 2 percent fuel consumption reduction (EPA, 2008; NESCCAF, 2004). EEA claims a fuel consumption improvement of 1.1 to 1.7 percent can occur with the addition of an ICP (EEA, 2007). In agreement with most sources, the committee has also estimated a 1 to 2 percent reduction in fuel consumption using ICP. However, as with the other VEM technologies that are listed in the chapter, a generalized statement can be made that smaller-cylinder-count engines (i.e., four cylinders) will be closer to the low end of this improvement range, and higher-cylinder-count engines will be closer to the high end of the fuel consumption reduction ranges that are listed.

OEM input suggests that fixed-duration intake systems add a cost of about $35/phaser. OEM input does not reflect a retail price equivalent (RPE) factor. The EPA estimates an RPE cost increase of $59/phaser (EPA, 2008). NESCCAF quoted a literature RPE of $18 to $70 (NESCCAF, 2004) and EEA estimates an RPE of $52/phaser (EEA, 2007). A 1.5 RPE factor was used to develop the committee estimate of $52.50 for an in-line engine and $105 for a V-configuration that requires two phasers.

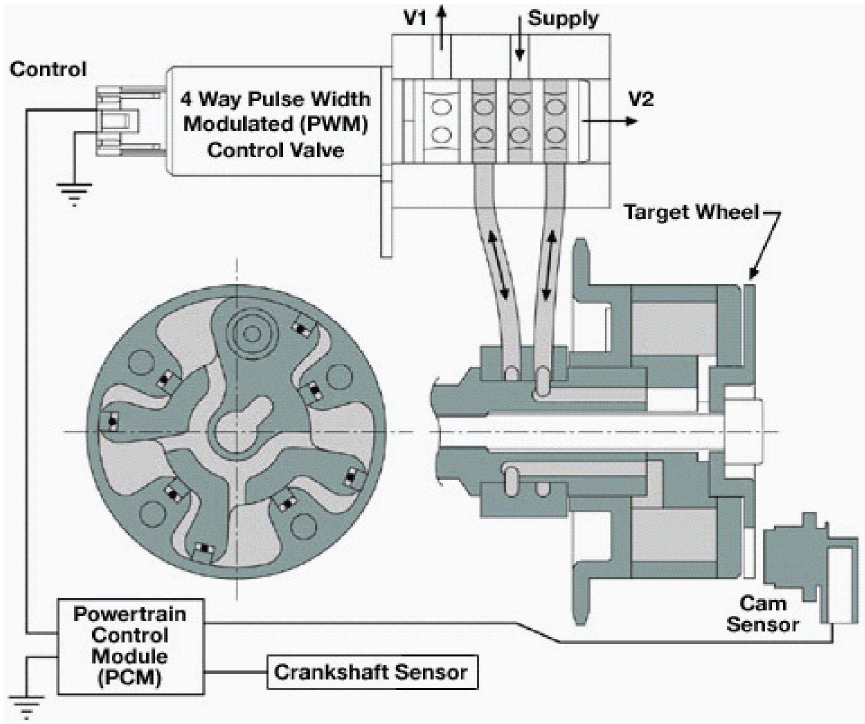

FIGURE 4.1 System-level mechanization of the variable cam phaser, oil control valve, control module, crank sensor, and cam sensor to the engine. SOURCE: Delphi (2009). Reprinted by permission from Delphi Corporation.

Valve Overlap Control

Valve overlap control, also known as dual cam phasing (DCP), is another form of VEM. Valve overlap (i.e., the interval between intake-valve opening [IVO] and exhaust-valve closing [EVC]) can affect residual-gas retention at low loads and can reduce pumping loss in a manner similar to that with EGR (exhaust gas recirculation). Valve overlap control can also be utilized to tune performance at high engine speeds, resulting in increased torque, which, in principle, can allow for minor engine downsizing. Valve overlap can be modulated by changing the phasing of either the intake or exhaust cam. Typically it is done with the exhaust cam because exhaust-cam phasing for increased overlap also delays exhaust-valve opening (EVO) timing. Thus both EVO and EVC move in ways favorable to low-speed and light-load fuel consumption reduction. Modulating valve overlap with an intake cam yields countervailing effects, i.e., increased valve overlap in this manner tends to reduce pumping loss while the corresponding IVC event will occur earlier, thus offsetting some of the increased-overlap benefit. At idle, too much valve overlap will destabilize combustion. When variable phasing, fixed-duration intake and exhaust cams are implemented, valve-overlap control may eliminate the need for an external EGR system.

Fuel Consumption Benefit and Cost of Valve Overlap Control

The fuel consumption reduction from valve overlap control/DCP is expected to be slightly greater than just controlling the IVC timing at about 2 percent over intake phasing alone, based on manufacturer input. The EPA and NESCCAF both estimate a reduction in consumption of 2 to 4 percent (EPA, 2008; NESCCAF, 2004). EEA estimates a 1.8 to 2.6 percent improvement in fuel economy (EEA, 2007). The committee concluded that adding variable exhaust cam phasing to ICP will yield an incremental 1.5 to 3 percent reduction in fuel consumption. This would mean the total estimated effect of adding DCP would be about 2.5 to 5 percent over an engine without any variable valve timing technology. The high end of 5 percent has been verified by OEMs and Ricardo, Inc.'s full-vehicle system simulation (FSS) (Ricardo, Inc., 2008).

Dual overhead cam (DOHC) V-engines with variable intake and exhaust would require four cam phasers, adding roughly $140 of manufacturer cost based on manufacturer input, but a portion of this is offset by the elimination of the external EGR system. EEA estimates an RPE of $76 to $84 for an I4, and $178 to $190 for V6 and V8 engines (EEA, 2007). The EPA estimates an incremental cost increase of $89 for an I4 and $209 for V6 and V8 engines (EPA, 2008).

NESCCAF quotes a literature RPE of $35 to $140 for dual cam phasers (NESCCAF, 2004). Discussion with OEMs also verified that by simply doubling the cost of ICP, a reasonably accurate DCP cost can be attained. The committee has estimated an RPE cost of $52.50 for an in-line engine and $105 for a V-configuration, incremental to the cost of ICP technology.

Intake-Valve Throttling

Using very short duration and low-lift intake-valve-opening events during the intake stroke can reduce (or eliminate) the pumping loss. This VEM, also known as intake-valve throttling, also tends to slow combustion, mainly at low engine speeds. (Small-scale turbulence generated by this approach dissipates rapidly, well before the start of combustion, and thus this does not generally contribute to rapid combustion). Note that low valve lift is simply a consequence of short-duration cam design. Manufacturing tolerance control is of extreme importance with intake valve throttling if cylinder-to-cylinder variability at idle is to be acceptable. BMW and Nissan currently offer this technology on some of their engine models, which use varying lift and timing to throttle the engine. Other manufacturers have announced plans to introduce engines with throttle-less operation within the next few years.

The above options (DCP and ICP) are focused mainly on pumping-loss reduction by means of late IVC timing and exhaust-gas recycling via variable valve overlap. Very early IVC (i.e., during the intake stroke) is another effective means of reducing pumping losses, but it involves much more complex and costly means of implementation. Two types of intake-valve-opening techniques are considered: discrete variable valve lift and continuously variable valve lift.

Discrete Variable Valve Lift

A discrete variable valve lift (DVVL) system is one which typically uses two or three different cam profiles over the range of engine speeds and loads. This system attempts to reduce pumping losses by varying the lift profile of the camshaft. By varying the lift of the valves, it is possible to limit the use of the throttle and significantly reduce the pumping losses.

As described earlier, Honda has been using a DVVL-type setup on its vehicles known as VTEC. To engage the different cam profile on Honda's system, there is a third cam lobe and follower, located in between the two main lobes, which is hydraulically activated by an internal solenoid controlled oil passage. During low-speed and low-load operation, the engine runs using the base cam profile(s). Once a certain load point is reached, the ECU activates a control valve to direct oil pressure from the main gallery to an oil passage that engages the third follower. Once the third follower engages, it is then locked into place by a locking pin. Honda's VTEC system is more cost-effective on its single overhead cam (SOHC) engines, due simply to the fact that a DOHC engine would require more hardware. This is an example of one manufacturer's method of DVVL implementation. It should be noted that other manufacturers have developed different designs to accomplish the same goal, and as a result the different systems have differing amounts of pumping loss reduction and friction increase. This situation reinforces the point that advanced VEM technologies are not simply "bolt-on" parts that provide a uniform fuel consumption reduction to all OEMs.

Delphi performed testing on a GM 4.2-L I6 equipped with a two-step variable valve actuation system and a camshaft phaser on the intake (Sellnau et al., 2006). The engine was already outfitted with an exhaust cam phaser. Delphi's two-step valve actuation system consisted of oil-actuated switchable rocker arms. Testing on the engine revealed a 4.3 percent fuel consumption reduction during the EPA city drive cycle, compared to the base engine with no variable lift and timing. These results were obtained with no other modifications besides the VVL, a phaser, and control system reconfiguration. Delphi claimed that "mixture motion is nearly absent for low lift profiles, so an enhanced combustion system, with higher tumble for low-lift profiles, would likely yield significant improvements in fuel economy." In the second portion of the test Delphi modified the cylinder head and added flow restriction that generates turbulence in an attempt to speed up combustion, thereby furthering the fuel economy gain. Chamber masks were used to increase the tumble motion. The lift profile on the exhaust cam and the port were also modified. For the second phase of testing with the altered cylinder head and calibration, the fuel consumption reduction was estimated to be 6.5 percent in comparison to the original engine. These values were estimated from data taken at multiple load points rather than over a driving cycle (Sellnau et al., 2006).

Fuel Consumption Reduction and Cost of DVVL

Two (or three)-step cams that yield short intake durations using DVVL can yield fuel consumption reductions in the 4 to 5 percent range based on vehicle OEM input. A reduction of 3 to 4 percent in fuel consumption (FC) is estimated from the EPA (EPA, 2008). FEV has developed a two-stage switch of the intake valve lift that is claimed to offer up to a 6 to 8 percent reduction in consumption when combined with variable valve timing, during the New European Drive Cycle (Ademes et al., 2005). NESCCAF and EEA estimate that a 3 to 4 percent reduction is possible (NESCCAF, 2004; EEA, 2007) on the U.S. driving cycles. EEA also estimates a fuel economy improvement of 7.4 to 8.8 percent when DVVL is combined with DCP and the engine is downsized to maintain constant torque. Simulation work by Sierra Research indicated a 6.3 to 6.8 percent benefit when combined with variable valve timing, which accounts for up to 5 percent of that amount (Sierra Research, 2008). The committee concluded that a 1.5 to 4.0 percent drive-cycle-based FC reduction is possible, incremental to an OHC engine with DCP or an OHV engine with CCP.

Vehicle OEM input suggests a \$35 to \$40/cylinder cost for implementing DVVL. The Martec Group estimates an OEM cost of \$320 to implement a two-step VVL on a V6 DOHC engine (Martec Group, Inc., 2008). The EPA estimates an incremental cost increase of \$169 for an I4, \$246 for a V6, and \$322 for a V8 (EPA, 2008). EEA estimates RPEs for an OHC-4V; \$142 to \$158 (equivalent to \$95 to \$105 assuming an RPE multiplier of 1.5) for an I4, \$188 to \$212 (equivalent to \$125 to \$141 assuming an RPE multiplier of 1.5) for a V6, and \$255 to \$285 (equivalent to \$170 to \$190 assuming an RPE multiplier of 1.5) for a V8 (EEA, 2007). The committee estimates the manufacturing cost of implementing DVVL to be about \$30 to \$40/cylinder.

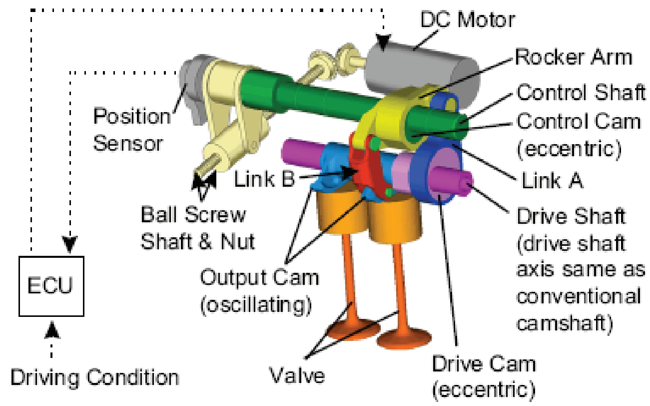

FIGURE 4.3 Nissan valve event and lift design. SOURCE: Takemura et al. (2001). Reprinted with permission from SAE Paper 2001-01-0243, Copyright 2001 SAE International.

Continuously Variable Valve Lift

The continuously variable valve lift (CVVL) system allows a wide control range of the camshaft profile (see Figures 4.2 and 4.3 for schematics). A continuous system allows for calibration of the optimal valve lift for various load conditions, versus the discrete system, which will only offer two or three different profiles. The combination of a continuous VVL system and an intake cam phaser has the potential to allow the engine to operate throttle-less. In the following, greater detail of this particular VEM technology is given due to its relative novelty to the mass production environment and the large fuel consumption benefits it offers. Two approaches to CVVL have been considered, electromechanical and electrohydraulic.

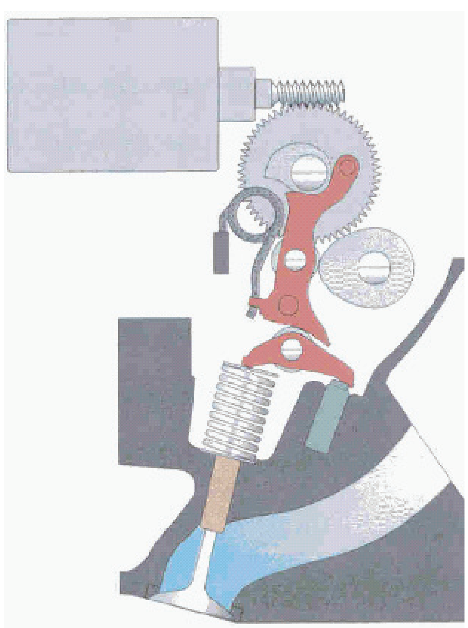

FIGURE 4.2 BMW Valvetronic. SOURCE: Flierl et al. (2006). Reprinted with permission from SAE Paper 2006-01-0223, Copyright 2006 SAE International.

Electromechanical CVVL Systems

BMW was the first to offer a mass production fully variable valve train incorporating CVVL in 2001, which it calls Valvetronic, Figure 4.2. This system is an electromechanical system that when combined with variable intake and exhaust cam phasers provides a fully throttle-less induction system. To vary the lift of the valve, an intermediate lever was added along with an eccentric shaft. The eccentric shaft is operated by an electric motor that adjusts the positioning of the lever over the camshaft. The lever contains a profile with one side being relatively flat and the other side being relatively steep. Adjusting the relative positioning of the lever controls the valve lift. BMW claims that up to a 10 percent reduction in fuel consumption is possible with this system (Sycomoreen). Figure 4.2 shows the many added components needed for the Valvetronic system.

Nissan Motor Company has also developed a continuous variable valve event and lift (VEL) system (Figure 4.3). The electromechanical system allows continuous variation of valve timing and lift events similar to the BMW system, but achieves this using a different architecture. Nissan estimates a 10 percent reduction in fuel consumption over the Japanese 10-15 drive cycle (Takemura et al., 2001) for its VEL system. The 10-15 drive cycle is intended to simulate a typical urban drive cycle, and an EPA combined FTP cycle rating would be somewhat lower. Nissan attributes the reduction in consumption to "lower friction loss due to the use of extremely small valve lift-timing events and reduction of pumping loss resulting from effective use of internal gas recirculation." Nissan evaluated the consumption benefits distribution at a fixed speed and load of 1,600 rpm and 78 N-m. The distribution of effects was the following: (1) pumping loss decrease yielded a consumption reduction of 5.2 percent, (2) friction reduction yielded a consumption benefit of 1.1 percent, and (3) an improvement in combustion caused a reduction in consumption of 3 percent.

Figure 4.3 shows the layout of Nissan's VEL system. The electromechanical system uses an oscillating cam to open and close the valve. An oscillating cam (output cam) looks like half of a camshaft, but it is hinged on one end to allow full opening and closing of the valve on the same cam face. To change the valve lift and duration of the cam, the control shaft is adjusted by a motor to change the distance between the control cam and the oscillating cam. An increase in distance is caused by the lobe on the control shaft turning and pushing the rocker arm assembly out. This changes which portion of the output cam contacts the valve to control the amount of lift.

Toyota Motor Company has recently developed its own type of a CVVL timing system. The new system will first be applied to their newly developed 2.0-L engine. Toyota's system features separate cam phasers on the intake and exhaust camshafts to vary the camshaft timing, along with a continuously variable valve lift system. Toyota claims that the system "improves fuel efficiency by 5 to 10 percent (depending on driving conditions), boosts output by at least 10 percent and enhances acceleration." Toyota did not state what features the base engine already had in order to generate fuel efficiency improvement percentages (Toyota Motor Co., 2007).

The Technical University of Kaiserslautern performed testing on a 2.0-L four-cylinder gasoline engine that was outfitted with a fully variable lift and timing system (VVTL) called Univalve, Figure 4.4. The Univalve system allows for either the use of standard throttle or unthrottled operation. At a load point of 2000 rpm and a BMEP of 2 bar, a 13 percent reduction in fuel consumption occurred compared to the base engine with a nonvariable valve train. This reduction is due to the reduction in the pumping work and an improvement in the formation of the mixture. The Univalve system varies the lift and duration of the valve by adjusting the eccentric contour (see Figure 4.4). Adjusting the eccentric shaft changes the rocker arm pivot point (Flierl et al., 2006).

The Univalve system in Figure 4.4 operates similar to BMW's version of a CVVL system. In Figure 4.4 the image to the left demonstrates a fixed pivot ratio on the rocker with constant valve lift. The image to the right features variable valve lift. To vary the lift the rocker arm is no longer fixed to a single pivot point. An eccentric shaft creates a varying pivot point by adjustment of the shaft's contour contact point on the rocker.

Honda has also patented its new Advanced-VTEC system, which turns its current DVVL VTEC system into a throttleless CVVL setup. While initial claims are up to a 10.5 percent reduction in fuel consumption, this system is not currently in

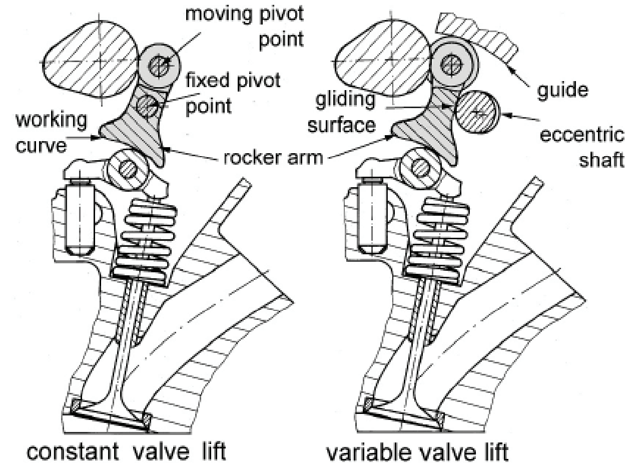

FIGURE 4.4 Univalve. SOURCE: Flierl et al. (2006). Reprinted with permission from SAE Paper 2006-01-0223, Copyright 2006 SAE International.

production and the testing cycle used to produce this estimate is unclear. Therefore, Advanced-VTEC is only mentioned to demonstrate an example of emerging CVVL technology.

Electrohydraulic CVVL Systems

The electrohydraulic approach to CVVL has been under development for over a decade. One of the organizations which has been active in this development is Fiat Central Research (CRF). The major focus of the work by CRF is a system that it calls Uniair (Bernard et al., 2002). Fiat recently announced a system it calls Multiair that is derived from Uniair. Multiair is a joint development between Fiat and valve train component supplier INA that promises a 10 percent reduction in fuel consumption. Other organizations have also been active in the development of systems using similar principles (Misovec et al., 1999). The Uniair/Multiair system has been described as a lost-motion system wherein the camshaft lobe drives the piston of a small pumping chamber, one for each cylinder intake and one for each exhaust. Multiair utilizes the system only for the intake valves.

The output from the pump is controlled by a solenoid-actuated flow control valve that directs the hydraulic output of the pump directly to the hydraulic actuator on the valve(s) or to the accumulator. If the control valve directs the hydraulic pressure to the valve actuator(s), the valve(s) open normally following the camshaft profile. In principle a lost-motion system allows opening the valve(s) at any fraction of the normal valve lift profile by directing part of the hydraulic pressure to the accumulator rather than to the valve actuator. By appropriately controlling the application of the hydraulic pressure to the valve actuators or to the accumulator, a wide range of valve lift profiles can be achieved, including multiple small lifts during one valve event. This latter capability is not achievable with mechanical CVVL systems. However, electrohydraulic CVVL systems tend to be less efficient considering the energy lost by the hydraulic pump and the increased friction losses from the additional number of components. The committee believes that the large increase in parasitic losses that will offset the perceived fuel consumption reduction benefit, combined with the high component cost, will limit the market penetration of this technology. In addition, achieving consistent and uniform valve lifts under idle conditions to maintain a smooth idle may be more challenging than with mechanical CVVL systems.

Fuel Consumption Benefit and Cost of CVVL

The above discussion reviewed the technology of VEM approaches and various FC benefits ascribed to each system. As noted in Chapter 2, the fuel consumption reduction benefits for the technology approaches considered are based on the combined city and highway driving cycles, while some of the benefits described earlier are not necessarily based on these driving cycles. CVVL is expected to be in the 5 to 7 percent range based on manufacturer input. The EPA and NESCCAF both estimate a 4 to 6 percent reduction in fuel consumption (EPA, 2008; NESCCAF, 2004), while EEA estimates a 6.5 to 8.3 percent reduction in fuel consumption at constant engine size and 8.1 to 10.1 percent with an engine downsize to maintain constant performance (EEA, 2007). Sierra Research's simulation work resulted in a 10.2 to 11.0 percent benefit when combined with variable valve timing (Sierra Research, 2008). The committee has estimated that CVVL will have an additional 3.5 to 6.5 percent reduction in fuel consumption over an engine already equipped with DCP. Going from a base DOHC engine to one with continuously variable lift and timing could provide a 6 to 11 percent fuel consumption reduction assuming engine size adjustments for constant acceleration performance.

Vehicle OEM input suggests that the cost of a continuously variable intake-valve is two to three times that of the two-step system plus the cost of the actuation system ($40 to $80) plus the cost of the intake and exhaust cam-phasing system. Vehicle integration could add another cost in the range of $140. The EPA estimates an RPE incremental cost of $254 (or $169 cost assuming an RPE multiplier of 1.5) for I4, $466 (or $311 cost) for V6, and $508 (or $339 cost) for V8 engines (EPA, 2008). The Martec Group estimates a manufacturing cost of $285 for an I4, $450 for a V6, and $550 for a V8 (Martec Group, Inc., 2008). For a CVVL system, EEA (2007) estimates RPEs of $314 to $346 (or $209 to $231 cost) for an I4, $440 to $480 (or $293 to $320 cost) for a V6, and $575 to $625 (or $383 to $417 cost) for a V8 (EEA, 2007), all assuming an RPE multiplier of 1.5. The committee estimates the manufacturing cost of CVVL to be $159 to $205 for I4 engines, $290 to $310 for V6 engines, and $350 to $390 for V8 engines, not including an RPE factor.

VEM Implementation Techniques

Many of the above-mentioned VEM systems are often implemented as a package combining varying valve lift and timing events. The combination of these technologies will provide further reduction in the use of the throttle.

General Motors Research and Development (Kuwahara et al., 2000; Cleary and Silvas, 2007) performed testing on a single-cylinder model of their 3.4-L DOHC engine. The model made use of varying intake valve cam timing, duration, and intake valve lift. A combination of the varying parameters allowed for the engine to operate without a throttle. From the study by General Motors, an approximate reduction in fuel consumption of up to 7 percent occurred at part load conditions. By unthrottling the engine, a large reduction in throttling losses occurs and the engine was able to operate at higher intake manifold pressures. It is important to note that the cost and fuel consumption reductions of the various VEM approaches are highly variable and dependent upon the basic engine architecture to which they are applied.

Cylinder Deactivation

Cylinder deactivation is utilized during part load situations to reduce thermal and throttling losses. During constant speed operation, the power demand is relatively low. By shutting off multiple cylinders, a higher load is placed on the remaining operating cylinders. The higher load requires the throttle to be open further and therefore reduces the throttling losses. The decrease in losses reduces the overall fuel consumption. Cylinder deactivation via valve deactivation has been applied to four-, six-, and eight-cylinder engines, in some cases rather successfully. Most commonly, cylinder deactivation is applied to engines that have at least six cylinders; four-cylinder engines typically are not equipped with deactivation due to additional noise, vibration, and harshness concerns that are deemed unsatisfactory for consumers. Even current production V6 offerings have NVH levels that are very noticeable to customers. Increased NVH can be perceived as a low-quality characteristic that deters potential customers from purchasing vehicles with this technology.

History of Cylinder Deactivation

Cylinder deactivation was first implemented on a production vehicle in 1981 on the Cadillac V8-6-4. The engine could operate in four-, six-, and eight-cylinder mode depending on power demand. To deactivate the cylinders, a solenoid mounted on top of the rocker arm assembly would disconnect the pivot point for the rocker and the rocker would then pivot against a soft spring. The valves would remain closed and the cylinder would not fire, but rather act as a compressed air spring. This system helped to reduce fuel consumption at cruising type conditions. However, drivability and the need for quick re-engagement of the cylinders caused customer dissatisfaction, and the technology was soon taken out of production. Since then, engine control systems and programming ability have diminished the drivability concerns with modern day deactivation systems. New solutions have been developed to address the NVH concerns that arise when cylinders become deactivated. The NVH is a concern during deactivation due to the "lower frequency, higher amplitude torque pulsations at the crankshaft" (Leone and Pozar, 2001). With the addition of active engine mounts, any vibrations which would normally transfer to the passenger compartment of the vehicle, causing customer dissatisfaction, are nearly eliminated. However, active engine mounts add cost. Today's trend toward overhead cam (OHC) valve trains has an added a level of cost and complexity to integrate cylinder deactivation.

Implementation of Cylinder Deactivation

The integration of a cylinder deactivation system varies depending on the engine layout. For overhead valve V8 and V6 engines, this can be accomplished fairly simply by modifications to the passages that supply oil to the valve lifters along with different valve lifters (Falkowski et al., 2006). Implementation of a deactivation system on an OHC engine is slightly different than on an OHV engine. One of the methods utilized for cylinder deactivation in an OHC roller finger follower system involves the use of a switchable roller finger follower. In the follower's normal mode, the valve will operate as usual and maximum lift will still be achieved. To deactivate the cylinder, a locking mechanism must be released on the follower by oil pressure (Rebbert et al., 2008), collapsing the follower and rendering the valve inactive.

Fuel Consumption Benefit and Cost of Cylinder Deactivation

Vehicle OEMs estimate cylinder deactivation typically yields fuel consumption reductions in the 6 to 10 percent range on V8 configurations. Testing done by FEV on a V8 engine found that a decrease in fuel consumption of 7 percent occurred on the New European Drive Cycle (NEDC). According to FEV, these reductions would be "even higher for the US driving cycle, because of the US cycle's higher proportion of part load operating conditions" (Rebbert et al., 2008). NESCCAF estimates a 4 to 6 percent reduction in fuel consumption (NESCCAF, 2004). The EPA estimates a 6 percent reduction in fuel consumption (EPA, 2008). Sierra Research's simulation estimated a reduction in consumption of 7.5 to 8.8 percent (Sierra Research, 2008). EEA estimates a 5.3 to 7.1 percent reduction in fuel consumption (EEA, 2007). For OHV engines, the committee estimates a 4 to 6 percent drive-cycle fuel consumption reduction on a V6, and a 5 to 10 percent reduction on a V8. For OHC engines, the committee assumes manufacturers would have already implemented DCP and VVL based on the cost/benefit ratio. This means that there is less pumping loss left to reduce, resulting in an incremental 1 to 2.5 percent reduction for a V6 and a 1.5 to 4 percent reduction for V8 configurations. The lower cost-benefit ratio for cylinder deactivation makes the technology far less attractive on DOHC engines. Despite the existence of prototype four-cylinder engines with cylinder deactivation, the committee believes the cost and customer dissatisfaction issues related to NVH outweigh the benefits of implementing this technology on four-cylinder engines.

Vehicle OEMs estimate the cost for deactivation is approximately $115. Vehicle integration items that mitigate NVH issues may incur additional costs in the $140 range. The cost of applying cylinder deactivation to OHC engines is much higher, i.e., $340 to $400 because more complex and costly valve train elements must be changed. The EPA estimates the incremental RPE cost to be $203 (or $135 cost) for six cylinders and $229 (or $153 cost) for eight cylinders (EPA, 2008) (both assuming an RPE multiplier of 1.5). NESCCAF quotes a literature RPE of $112 to $746 (NESCCAF, 2004) (or $75 to $497 cost). Martec estimates a manufacturing cost increase of $220 for a V6 DOHC engine (Martec Group, Inc., 2008). Sierra Research estimates an incremental cost of $360 to $440 (Sierra Research, 2008). EEA (2007) estimates for six-cylinder engines an RPE of $162 to $178 (or cost of $108 to $119) with an additional cost of $140 for NVH. For eight-cylinder engines, EEA estimates an RPE of $205 to $225 (EEA, 2007) (or cost of $137 to $150 assuming an RPE of 1.5). The committee estimates that the manufacturing cost of implementing cylinder deactivation for OHV would be $220 to $255 and $340 to $420 for engines with SOHC (not including RPE).

Camless Valve Trains

A fully camless valve train eliminates the need for camshafts, as well as various other supporting hardware, and operates the valves individually by means of actuators. This would allow for VEM fuel consumption saving technologies, such as cylinder deactivation and continuously variable valve lift and timing, to be applied all in one package. However, the complexity of the controls required makes for a difficult integration. Camless valve trains are electromagnetic, hydraulic, pneumatic, or combinations of these that all face fundamental obstacles. By replacing the valve train, BMW claims the frictional saving from just the roller-bearing valve train achieves a further 2 percent reduction in fuel consumption. BMW also claims an overall reduction of up to 10 percent from camless operation (Hofmann et al., 2000). However, none of these has been shown to offer advantages not observed with the aforementioned cam-based systems. The very high valve-timing precision associated with most cam-driven systems is subject to compromise with camless approaches. The ballistic character of the valve assembly with any camless system presents many control challenges. In addition, the power demand for camless systems is generally higher than that of their cam-driven counterparts.

Camless systems are perceived to have significant durability risk, and as a result, no production implementations of camless systems have been announced. It is the judgment of the committee that camless systems need further development and are not expected on the market before 2015.

GASOLINE DIRECT INJECTION

The most recent development of direct injection spark ignition (DISI) (also known as GDI) systems (Wurms et al., 2002) have focused on early-injection, homogeneous-charge implementations using stoichiometric mixture ratios under most operating conditions. These conditions allow for the use of highly effective and well-proven closed-loop fuel control and three-way catalyst exhaust aftertreatment systems. Fuel consumption benefits of these homogeneous versions are derived mainly from a knock-limited compression ratio increase (typically +1.0) enabled by forcing all of the fuel to vaporize in the cylinder. This yields a charge-cooling effect that suppresses the knocking tendency. Another added benefit of charge-cooling is an increase in the volumetric efficiency from the increase in density of the incoming charge. In contrast, with port fuel injection (PFI) systems some of the fuel vaporizes in the intake port, and this conveys heat from outside of the cylinder, i.e., from the intake port, to the in-cylinder charge. While heating of the intake charge is a negative (relative to the knock-limited compression ratio and performance) it does provide a measure of "thermal throttling" at typical road loads, which reduces negative pumping work. Thermal throttling, like common pressure throttling, lowers the mass of inducted fuel-air mixture thus reducing power, which is the objective of throttling. It does this, however, with less pumping loss than the conventional throttling used with homogeneous DISI.

In terms of additional losses, DISI relies on fuel pressures that are higher than those typically used with PFI systems (e.g., 150-200 bar versus 3-5 bar for PFI), and the increase in required fuel pump work increases parasitic loss. Finally, these homogeneous, stoichiometric DISI systems cannot exploit the thermodynamic expansion efficiency gains possible with lean overall mixtures.

History of Direct Injection

Early (1960s and 1970s) versions focused on late-injection, lean overall stratified-charge implementations as exemplified by the Texaco TCCS (Alperstein et al., 1974) and Ford PROCO (Simko et al., 1972) systems, neither of which entered volume production. These systems were attempts to utilize gasoline and other fuels in spark-ignited engines designed to take advantage of two of the three thermodynamic advantages of diesels, namely lack of throttling to eliminate pumping losses, and lean overall mixture ratios to achieve more thermodynamically efficient expansion processes. However, the TCCS and PROCO systems suffered from injector fouling, high exhaust emissions and low power density. Nonetheless, the goals of these engine systems remained valid and interest returned to DISI following progress in fuel-injection systems and engine controls during the 1980s and early 1990s. Mitsubishi introduced the first production implementation of DISI (which they called GDI) in Europe in 1996 (Iwamoto et al., 1997) in a 1.8-L four-cylinder engine, followed shortly after by a 3.5-L V6 in 1997. These GDI systems utilized lean-overall stratified-charge combustion but with some inlet throttling. It was soon found that typical in-use fuel consumption was significantly higher than European emissions-test-schedule results suggested.

Following an initial burst of interest, Mitsubishi GDI sales were lower than expected. Hence, this system was withdrawn from the market, and there was a return to conventional PFI systems. It was believed that this withdrawal stemmed not only from disappointing sales but also because meeting upcoming NO_x emissions standards in Europe and especially the United States using only combustion system control was more difficult than anticipated, and lean NO_x aftertreatment systems were seen as very costly and of questionable reliability for volume production.

Implementation of Direct Injection

A concern today (as in the past) with DISI systems is the matter of fuel-based carbonaceous deposits forming from residual fuel in the injector nozzle upon hot engine shutdown. Carbonaceous deposits can restrict fuel flow and also modify fuel-spray geometry in some unfavorable manner (Lindgren et al., 2003). Locating the injector in a relatively cool part of the cylinder head is one approach to alleviating this problem. Fuel variability in the United States is of some concern relative to this issue based largely upon the olefin content of the fuel, which typically is higher than that found in European gasoline. While some concerns with deposits remain, they are being alleviated mainly by injector design improvements.

DISI researchers often make reference to wall-guided, flow-guided, or spray-guided injection (Kuwahara et al., 2000), and in general these terms refer to different geometric arrangements of the fuel injection and mixture preparation processes. For example, wall-guided usually refers to placement of the fuel injector to the side of the cylinder near the corner of the cylinder head with the cylinder wall. The spray is then aimed across the cylinder toward the top of the piston when the piston is near the top of the cylinder. In this case the piston crown shape is the "wall" which guides the spray (Kuwahara et al., 2000). In spray-guided engines, the injector is located in the cylinder head near the center of the cylinder with the spray aimed down the cylinder axis (Schwarz et al., 2006). Injection in this case would be timed later during the induction process. The fuel-spray trajectory is then guided mainly by the direction of the spray and its interaction with the cylinder gas motion rather than by directly impinging on a surface such as the piston.

BMW performed a fuel consumption comparison study using a four-valve port fuel injection engine with fixed timing and lift as the base engine for comparison. For the study a direct injection system operating at stoichiometric was applied to an engine, and a fuel consumption benefit of 5 percent resulted. BMW claimed that if a spray-guided system were adapted, the engine could operate with lean mixtures, which would allow for up to a 20 percent fuel consumption reduction (EEA, 2007).

Fuel Consumption Benefit and Cost of Direct Injection

The increase in knock-limited compression ratio possible for DISI configurations would be expected to yield a fuel consumption reduction in the 2 percent range based on vehicle OEM input, but the countervailing effect of pumping and parasitic loss increases may reduce this benefit somewhat to about 1.8 percent. Based on modeling by EPA, consumption reduction estimates for converting from a PFI to a DISI system are in the range of 1 to 2 percent for four-, six-, and eight-cylinder engines (EPA, 2008). Sierra Research estimates a reduction in consumption of 5.9 to 6.2 percent (Sierra Research, 2008). EEA estimates a 2.9 to 3.8 percent reduction in fuel consumption (EEA, 2007). Ricardo Inc.'s simulation work (Ricardo, Inc., 2008) attributes a 2 to 3 percent benefit to DISI. The committee believes that a 1.5 to 3 percent fuel consumption reduction can be realized from stoichiometric direct injection.

Vehicle OEMs estimate that the variable cost of DISI for parts is in the range of $60 per cylinder plus about $136 for vehicle noise abatement features, excluding the cylinder-head design and retooling costs. This input does not reflect an RPE factor. The EPA estimates the incremental cost for converting from a PFI to a DISI system on a four-cylinder engine to be from $122 to $420, on a six-cylinder from $204 to $525, and on an eight-cylinder from $228 to $525 (EPA, 2008). Martec Group estimates incremental costs of $293 for a four-cylinder, $372 for a six-cylinder, and $497 for an eight-cylinder engine (Martec Group, Inc., 2008). The estimates from Martec were based on converting to a homogeneous, side-mount direct injection from a port injection system. The committee estimates that the manufacturing cost of implementing a stoichiometric direction injection system would be $117 to $351 depending on the cylinder count (not including RPE). The cost range for noise abatement-related items causes the most uncertainty in the estimates, as the various manufacturers have different standards for acceptable noise levels. Luxury vehicles, for example, require more money to be spent to reduce noise to levels that customers expect. See Table 4.A.1 in the annex at the end of this chapter for a complete breakdown of cost and fuel consumption benefits for each engine size, including ranges for costs.

DOWNSIZED ENGINES WITH TURBOCHARGING

Turbocharging and downsizing engines (Petitjean et al., 2004) reduces engine mass and pumping losses, but the fuel consumption benefit is based somewhat on the measures taken to avoid knock and pre-ignition. Some engines in this category are developed and calibrated in such a way that premium fuel is required in order to avoid knock without decreasing the compression ratio. If this is the case, any fuel consumption benefit cannot be solely attributed to turbocharging and downsizing. Based on vehicle OEM input, a compression-ratio reduction of 1 to 2 from non-turbocharged versions is typically required if this system is to be regular-fuel compatible. Furthermore, reduction in the number of cylinders, e.g., V6 to I4, may require countermeasures necessary to satisfy NVH expectations.

Implementation of Downsizing and Turbocharging

Several conditions must be addressed in implementing downsizing and turbocharging. Piston oil squirters aimed at the underside of the piston and oil coolers are employed to mitigate knock and pre-ignition conditions. An increase in intake air temperature is a natural by-product of compressing the air. To counter this effect, charge-air coolers are frequently employed to reduce charge temperature prior to its entry into the cylinder. In order to maximize the power output of the engine, the charge cooler acts as a heat exchanger and typically uses ambient air for cooling. The addition of a charge cooler creates packaging concerns since a location must be chosen where the cooler will experience a large amount of cross flow in order to avoid becoming heat soaked during prolonged high load conditions.

Additional parasitic loads are often imposed by the use of increased oil and coolant pump capacities relative to their non-turbocharged counterparts. The increase in capacities results from the increase in power and heat rejection with the same physical displacement.

As mentioned above, a port fuel-injected engine typically requires a decrease in compression ratio, which decreases the thermal efficiency and the part load response of a turbocharged engine. Direct injection alleviates some of the knock tendencies associated with turbocharging through the charge cooling effect created by the high atomization of the fuel that results from high injection pressure. This cooling effect allows for a less significant reduction in compression ratio compared to a port fuel-injected engine. A concern with direct injection is the injector nozzle fouling upon hot engine shutdown, as noted previously. However, a positive synergism is possible by combining DISI, turbocharging, and dual cam phasers, because under some operating conditions the intake manifold pressure is higher than that of the exhaust manifold. This positive pressure difference enables improved exhaust scavenging and thus improved volumetric efficiency. This condition is sometimes referred to as blow-through because it occurs during valve overlap. This synergism of turbocharging, DISI, and blow-through can enable further engine downsizing, and an additional fuel consumption benefit may thus result. Unfortunately, this engine performance opportunity occurs in the knock-sensitive operating range. As a result, establishing acceptable vehicle launch performance with turbocharged and downsized engines is challenging.

The distinction between research octane number (RON) and motor octane number (MON) is particularly noteworthy when fuels other than traditional gasoline are considered. The test methodology on which RON is based reflects resistance to thermal auto-ignition resulting from both chemical and heat-of-vaporization (evaporative cooling) properties, whereas MON is relatively insensitive to the latter of these. The difference between these two metrics is termed *sensitivity* (RON – MON = sensitivity). When fuels like ethanol are considered, the aforementioned distinction should be emphasized as this fuel has a very high RON, but its MON is moderate. Hence, the sensitivity of ethanol is 18, whereas that of a typical gasoline is considerably lower, e.g., 10. The consequence of high-sensitivity fuels when aggressive boosting and high compression ratios are pursued is an increased vulnerability to pre-ignition problems. This typically results from engine operation in the peak-power range where all surface temperatures to which the fuel is exposed are very high. This tends to reduce the heat-of-vaporization benefit associated with ethanol. It has been widely recognized for most of the history of the SI engine that water induction along with the fuel and air can reduce the thermal auto-ignition tendency and thus can increase the torque and power output. While this has been widely used in racing communities, there are some practical limitations to the general applicability of this, e.g., water can find its way into the crankcase and form an emulsion with the oil and therefore compromise the lubrication system.

The evaporative characteristic of any liquid largely depends upon intermolecular affinity, and in the cases cited above the so-called hydrogen bonding is a major component. This involves the polarized bonds between hydrogen and oxygen atoms where there is a slight positive charge on the hydrogen atom that is bound to an adjacent oxygen atom, which carries a slight negative charge. Hence, the positive charge on the hydrogen atom of the –OH group applies an attractive force acting on the negative charge on the oxygen atom of a nearby molecule. This grouping of –OH-containing molecules, be they ethanol or water, is responsible for their relatively high evaporative-cooling characteristic. This evaporative cooling characteristic can be utilized to prevent knock at certain engine operating conditions by implementing a system that can selectively inject the charge cooling liquid. This system is discussed below in this chapter in the section "Ethanol Direct Injection."

Exhaust-gas recirculation (EGR) is well known as a means to reduce pumping losses and thereby increase fuel efficiency. With downsized turbocharged engines (including those with direct fuel injection) it has been found that cooled EGR can be seen as an alternative means for controlling knock at moderate engine speeds and medium to high loads. Under certain operating and base-engine conditions, passing the EGR through a heat exchanger to reduce its temperature can be a more fuel-efficient means of controlling knock compared to spark-timing retardation and fuel-air ratio enrichment. The fuel consumption benefits of this feature are highly dependent upon the base engine to which it is applied and the engine's operating map in a particular vehicle. As the heat exchanger must be equipped with a diverter valve to accommodate heat-exchanger bypass for lighter-load operation, the sequences of carbonaceous deposit formation in the heat exchanger, in the diverter and control valves, and in the turbine are among the real-world factors that can compromise the overall performance of this feature. This feature is in production for CI engines for which the exhaust particulate level is much higher than for downsized and boosted SI engines; however, packaging the system into certain vehicles can make implementation difficult.

Variable geometry turbochargers (VGTs), commonly used on CI diesel engines, have not reached mainstream use on SI engines. The concern with using VGTs on gasoline-engine exhaust has been the ability of the adjustable blades and their adjustment mechanism to withstand the higher temperatures of the gasoline exhaust gases. A diesel engine typically has lower exhaust gas temperatures, and material selection for the adjustable blades has been successful in production. Recently, Porsche and Borg Warner have developed a variable geometry turbo to be used on the Porsche 911. This turbocharger required the development of new material specifications that could withstand the higher temperatures of the exhaust gases. Due to the high cost of material to withstand the heat and ensure long-term functionality of the vane guides, VGTs are currently seen only for use in high-end vehicles. Alternatively, a downsized, fixed-geometry turbocharger may be used, but this approach will compromise power output because the fixed exhaust turbine geometry will restrict airflow through the engine in order to provide acceptable low-speed turbocharger transient response. Extra-slippery torque converters (e.g., those with higher stall speed) can help to alleviate turbo lag issues, but they will also impose a fuel consumption penalty from increased slippage.

General Motors performed simulation testing on its 2.4-L port fuel-injected four-cylinder engine in the Chevrolet Equinox. The port fuel-injected 2.4-L engine was compared to an engine of the same displacement equipped with direct injection, turbocharger, and dual VVT. GM claims that this approach "can improve fuel consumption on the FTP cycle by up to 10 percent relative to an engine with VVT" but without DI and turbocharging (EEA, 2007).

Ford Motor Company has been developing downsized and turbocharged engines equipped with direct injection. The company plans to offer these engines in nearly all its upcoming models in the future. One of the engines is 3.5 L in displacement and features twin turbochargers with direct injection. From testing, Ford has claimed that this engine will reduce fuel consumption by 13 percent when compared to a V8 with similar performance (EEA, 2007).

Fuel Consumption Benefit and Cost of Downsizing and Turbocharging

The EPA estimates that a fuel consumption reduction of 5 to 7 percent can occur with downsizing and turbocharging (EPA, 2008). This estimate assumes that the vehicle is currently equipped with a DISI fuel system. NESCCAF estimates a 6 to 8 percent reduction in fuel consumption (NESCCAF, 2004). A study performed by Honeywell Turbo Technologies estimates that a 20 percent reduction in fuel consumption is possible from downsizing by 40 percent (Shahed and Bauer, 2009). FEV claims by downsizing and turbocharging a consumption reduction of 15 percent can occur in the New European Drive Cycle. An additional 5 to 6 percent is possible with the addition of a DI fuel system (Ademes et al., 2005). The expected consumption reductions are highly load dependent. The highest benefits will occur at low load conditions. Reduction in consumption is due to higher engine loads and lower friction loss. Sierra Research estimates midsize sedans will increase fuel consumption by 0.3 percent and pickup trucks will decrease consumption by 0.3 percent (Sierra Research, 2008). Sierra's values are lower than others since Sierra did not increase the octane requirement for the engine or combine it with direct injection. Sierra was therefore forced to lower the compression ratio in order to reduce the knocking tendencies while avoiding an octane requirement increase. Sierra claims that "turbocharging and downsizing without the use of gasoline direct injection does not yield benefits on a constant performance basis, based on a statistical analysis of available CAFE data done in 2004" (Sierra Research, 2008). The committee concluded that for the purposes of this report, turbocharging and downsizing will always be applied following DI in order to minimize the need to reduce compression ratio. This order of implementation is in agreement with recent industry trends. The committee estimates that a 2 to 6 percent reduction in fuel consumption is possible when downsizing and turbocharging is added to an engine with DI.

There is a large variation in the cost estimates from the various sources, which arises from a couple of key items. One item is whether or not there is a credit included in the cost from decreasing the engine cylinder count (e.g., going from V6 to I4) and the amount of the credit. Another source of difference is from the use of a split scroll turbine housing or a standard housing on the turbocharger. The split scroll adds cost compared to the standard-type housing.

Vehicle OEM input indicates that basic, fixed-geometry turbochargers add roughly $500 system cost, and dual-scroll turbocharger systems can add about $1,000 (not considering an RPE factor). Currently no pricing information is available for gasoline VGTs. System detail choices depend largely on vehicle performance targets. Martec estimates that the manufacturing cost of downsizing a six-cylinder to a turbocharged four-cylinder engine is $570, and a downsize from an eight-cylinder to a six-cylinder turbo adds a manufacturer cost of $859 (Martec Group, Inc., 2008). For the six-cylinder to a four-cylinder case, Martec is including a $310 downsizing credit and a $270 credit for eight cylinders to six cylinders. Martec's system price includes a water-cooled charge air cooler, split scroll turbo, and upgraded engine internals (not including "modifications to cylinder heads, con-rods, and piston geometry or coatings") (Martec Group, Inc., 2008). It should be noted that most manufacturers tend to use air-cooled charge air coolers. Sierra research estimates an incremental RPE adjusted cost increase of $380 to $996 (Note: values have been adjusted from Sierra's 1.61 RPE factor to 1.5) (Sierra Research, 2008). Sierra's price estimate is based on a "relatively simple turbocharger system that would not be able to match the launch performance of the larger, naturally aspirated engine." The value provided by Sierra is "not including the catalyst plus $650 in additional variable cost for a turbo system marked up to RPE using a factor of 1.61" (Sierra Research, 2008). The EPA provided incremental costs for large cars, minivans, and small trucks at $120. This cost included a downsizing credit. For the small car classification, the EPA has estimated an incremental cost of $690. The higher cost for the small car is due to the lack of significant engine downsizing possibilities (EPA, 2008). EEA estimates a V6 approximately 3 liters in displacement to have an RPE adjusted cost of $540 (or $360 cost assuming an RPE factor of 1.5) (EEA, 2007). Pricing for the EEA study was based on a standard turbo, air-to-air intercooler, engine upgrades, additional sensors and controls, and intake and exhaust modifications.

The committee estimated that the manufacturing costs for integrating downsizing and turbocharging would be in the range of a $144 cost savings to a $790 additional cost, depending on the engine size and configuration. See Table 4.A.1 in the annex at the end of the chapter for a complete breakdown of cost benefits for each engine size. The teardown studies currently being performed for the EPA by FEV (Kolwich, 2009, 2010) have been deemed the most accurate source of cost information by the committee, and therefore these studies were the primary source used for these cost estimates. As with other sources, the committee encourages the reader to view the original document to gain a better understanding of how the costs were derived. The cost increase for an I4 is somewhat obvious, due to the cost of additional components and a lack of significant downsizing credit. The downsizing credit is small because the cylinder count remains the same and generally the same number of valve train, fuel system, and other supporting components are still required. The very low cost of converting from a DOHC V6 to a turbocharged DOHC I4 is due to the very large downsizing credit from removing two cylinders and the supporting hardware for a whole bank of the engine, such as moving from four camshafts to two. In this report, the conversion from a Vee-type engine to an in-line is used only when moving from a V6 to an I4, as an I6 (from a V8) is far less common in the market. When converting from a V8 to a V6, the downsizing credit is much smaller, as you lose two cylinders but still have a Vee engine with two banks requiring two cam drive systems, four camshafts, etc. Also, turbocharging a V6 usually requires a more expensive twin-turbo system, versus the single turbo on the I4. To summarize, the downsizing credit is much smaller and the turbocharging cost is much higher for going from a V8 to a V6 than for going from a V6 to an I4.

ENGINE FRICTION REDUCTION EFFORTS

Engine friction can account for up to 10 percent of the fuel consumption in an IC-powered vehicle (Fenske et al., 2009). Therefore, reducing friction is a constant aim of engine development for improved fuel economy. A large majority of the friction in an IC engine is experienced by three components: piston-assembly, bearings (i.e., crankshaft journal bearings), and the valve train. Within these components friction comes in two general forms: hydrodynamic viscous shear of the lubricant (mainly in journal bearings) and surface contact interactions, depending on the operating conditions and the component.

There are several approaches to reduce frictional losses in an SI engine, mainly through the design of the engine and lubricant. A common trend has been to utilize low-viscosity lubricants (LVL) to reduce energy loss through lowered viscous shear (Nakada, 1994); significant fuel economy improvements have been demonstrated through this adaptation (Taylor and Coy, 1999; Fontaras et al., 2009). However, lowering viscosity also effectively reduces the lubricant thickness between interacting component surfaces, which can increase the occurrence of surface contact. Increased surface contact can have the detrimental effect of increased wear and heat generation, which can in turn affect engine durability. In addition to lowered lubricant viscosity, other SI technology trends (in particular turbo charging and downsizing) lead to increased power density, which can cause increased surface interaction (Priest and Taylor, 2000). In order to maintain engine durability, improving mixed lubrication performance in vulnerable components should be considered. Improvements in lubricant additives (low friction modifiers) and surface engineering (surface coatings and surface topography design) are methods that have been used to improve performance in these surface contact conditions (Erdemir, 2005; Etsion, 2005; Sorab et al., 1996; Priest and Taylor, 2000).

The following sections discuss in more detail specific engine design considerations for reducing friction, and also provide further discussion of low-viscosity lubricants.

Piston-Assembly Friction

Piston-assembly friction is a major component of overall engine friction, and of this the oil-control ring is the biggest contributor. Efforts have been underway for several decades to minimize the radial dimension of the rails to render them more conformable, with minimum spring force, to bores that may not be perfectly circular. Unlike oil-control rings, which are forced against the cylinder liner surface only by their expander spring, the forces pushing the compression rings against the cylinder are gas-pressure forces in the ring groove behind the rings. This gas pressure comes from the cylinder gases that pass down into the ring groove by way of the ring end gap, and little can be done to reduce the frictional contribution of compression rings. It should be noted that it is only during the high-pressure portions of the cycle that their frictional contribution is significant. It is noteworthy that bore distortion either due to thermal distortion of the cylinder block when the engine heats up to operating temperature or to mechanical distortion caused by the forces resulting from torquing the cylinder-head attachment bolts must be minimized if ring friction is to be minimized (Abe and Suzuki, 1995; Rosenberg, 1982).

Crankshaft Offset

Crankshaft offset from the cylinder centerlines will alter connecting-rod angularity. If this is done in a manner that reduces the piston side loading during the high-pressure portion of the engine cycle (i.e., the expansion stroke), a piston-skirt friction reduction is theoretically possible. Some early 20th-century engines employed this concept, and some relatively recent claims have been made on this design strategy. Recent efforts to document any friction reduction have failed to show any benefit (Shin et al., 2004). It is likely that the tribological state at the piston-skirt-to-cylinder-wall interface will affect this, i.e., presence or absence of a hydrodynamic oil film in the critical area under typical operating conditions.

Valve Train Friction

Valve train friction underwent a major reduction in the mid-1980s with near-universal adoption of roller cam followers. Valve-spring tension reduction may also reduce valve train friction, but reduction down to the valve-motion dynamic-stability limit have been found to yield susceptibility to compression loss under circumstances where carbonaceous deposits become detached from chamber surfaces and become trapped between the valve seat and valve face and thus cause major valve leakage.

Crankshaft Journal Bearing Friction

Energy loss due to crankshaft journal bearing friction tends to scale as the cube of the diameter times the length, or (diameter)^3 × (length). Efforts are always made to minimize this source of friction, but adequate crankshaft stiffness at the pin-to-main joints and overall length constrain this option. In V6 engines adequate pin-to-pin joint strength integrity must also be maintained.

Low-Viscosity Lubricants

As discussed previously, lowering lubricant viscosity reduces viscous shear. Therefore moving to advanced low-viscosity lubricants has the potential to improve fuel economy; however, there is debate about the range of effectiveness. Several studies have examined the effectiveness of LVL in lowering friction and reducing fuel consumption (Sorab et al., 1996; Taylor and Coy, 1999; Fontaras et al., 2009). Variations in test methodologies, i.e., vehicle fuel consumption measurement versus engine-dynamometer motoring tests, have led to some confusion in this area. Sorab tested the effectiveness of low-viscosity lubricants on one component of an IC engine, the connecting rod journal bearing. Experimental testing showed significant friction reduction; however, it is difficult to extend these results to an overall fuel consumption benefit. Taylor and Coy (1999) reviewed several modeling techniques that analyzed the fuel consumption benefit of designed lubricants. It was shown that lubricants with designed low-viscosity properties can reduce FC by up to 1 percent. Fontaras et al. (2009) tested the fuel consumption benefit of LVL in different drive cycles. The benefit ranged from 3.6 percent down to negligible depending on the driving cycle. For a cycle that includes a cold start, the LVL effectiveness is higher since the low-temperature viscous behavior prevails in this cycle. In a fully warmed-up engine the FC benefits are not as noticeable and can even be negligible.

Fuel Consumption Benefit and Cost of Reducing Engine Friction

The effectiveness of low-viscosity lubricants has limited drive cycle testing. Fontaras et al. (2009) performed several tests of LVL over different drive cycles, with the conclusion that a benefit of 1 to 1.5 percent can be achieved without affecting the overall engine performance. It was noted that the actual consumption reduction will vary by the amount of time spent in transient operation and if the drive cycle is one in which the engine must be started cold (Fontaras et al., 2009). The EPA estimated that a reduction in consumption of 0.5 percent can occur with the use of LVL at a cost of $3 per vehicle (EPA, 2008). Considering the more relevant U.S. drive cycle and the current widespread use of 5W30, the committee estimates that an additional 0.5 percent FC benefit can be realized with more advanced synthetic LVL at a cost of $3 to $5 per vehicle.

Improved engine friction reduction is a constant aim, yet there is still opportunity for additional FC benefit. Additional friction reduction can be achieved through engine component design and through improvements of surface engineering (surface coatings, material substitutions, selective surface hardening and surface topography control). The EPA estimated potential FC benefit at a range of 1 to 3 percent with a cost of $7 per cylinder (EPA, 2008). Given recent advancements in engine friction reduction, the committee estimates that the potential FC benefit is 0.5 to 2.0 percent at a manufacturing cost of $8 to $13 per cylinder.

ENGINE HEAT MANAGEMENT

As there is never a shortage of waste heat in and around IC engines, efforts to utilize this in productive ways have been ongoing for decades. Following are some methods of improving heat management; however, these techniques are not assigned a fuel consumption benefit or cost for this analysis.

Piston-Crown Design

Piston-crown design can affect its temperature. In some cases moving the piston-ring pack upward motivated by hydrocarbon-emissions reduction efforts to reduce crevice volume also tended to reduce piston-crown temperatures and thus reduced the knock tendency in some cases. To the extent that this enabled a small increase in compression ratio, a small fuel consumption benefit may result along with a significant reduction in hydrocarbon emissions. In some cases this piston modification shortened the heat-conduction pathway by which heat in the piston crown is transferred through the second piston land and then into the top ring and to the cylinder and into the coolant.

Cylinder-Temperature Profile

Cylinder-temperature profile has been found to have subtle effects on efficiency. If the upper portion of the cylinder can be made to run cooler and the lower portion hotter, then both friction and hydrocarbon emissions may benefit. This result can readily be achieved by shortening the coolant jacket such that only about 75 percent of the piston stroke equivalent is cooled by the coolant. At a fixed coolant pump capacity, higher coolant flow velocities are available at the top of the cylinder. This can enable an overall friction reduction by reducing the extent of boundary-layer piston ring friction at the top and a lubricant viscosity reduction at the bottom of the stroke. In addition, the higher temperature of the lower portion of the cylinder promotes post-flame oxidation of the fuel-air mixture that leaves the piston top-land crevice late in the expansion stroke.

Exhaust Port Surface Area

Exhaust port surface area can affect the heat input to the cooling system, and this has subtle efficiency and exhaust emissions consequences. A significant portion (~50 percent) of the heat that enters the cooling system does so by way of the exhaust port. Typically, the high temperature of the exhaust that leaves the cylinder at the beginning of the exhaust-valve open period is also characterized by its highly turbulent state. The associated high rates of heat transfer can affect both the heat load on the cooling system as well as the time required for the catalyst system to achieve operating temperatures following cold start. It is noteworthy that at peak power the highest exhaust flows occur during the blowdown process when the valve flow area is a limiting factor, and when the valve is fully open near mid-exhaust stroke, the so-called displacement flow is somewhat lower.

Typically if the exhaust-port cross-sectional area is reduced until there is evidence of incremental exhaust pumping work under peak power operating conditions, no power loss is to be expected. Efforts to reduce exhaust-port surface area may reduce the heat load on the cooling and also cause the exhaust temperatures to be somewhat higher. This can yield a fuel consumption benefit if ignition-timing retardation, which is often used to facilitate rapid catalyst light-off, can be minimized. A downsized coolant pump, cooling fan, and radiator core may also be beneficial.

Electrically Driven Coolant Pumps

Electrically driven coolant pumps are also frequently mentioned as fuel consumption enablers. While these tend to decrease parasitic loads during warm-up, local hot spots may cause bore and valve-seat distortion or gasket failures. Fuel consumption reduction derived from the above items depends on the details of the initial engine design. A more detailed discussion of the electrification of water pumps can be found in Chapter 5 of this report.

HOMOGENEOUS-CHARGE COMPRESSION IGNITION

While homogeneous-charge compression ignition (HCCI) has received much attention in the recent past, some fundamental control-related challenges remain. The absence of a discrete triggering event in close temporal proximity to the desired time of combustion is the basis for these challenges. In this type of combustion system, temperature is all important; many real-world factors can come into play that will yield unexpected outcomes, e.g., previous-cycle effects and piston and valve temperature swings. As HCCI combustion is essentially instantaneous, it produces very high rates of pressure rise and high peak pressures. Engine structural attributes must take this into account.

Unthrottled HCCI combustion at light loads may produce very high hydrocarbon emissions when the exhaust-gas temperature is relatively low, and this may challenge exhaust aftertreatment processes. Nonetheless, advanced prototype vehicles using HCCI over a portion of the operating range were shown to the public (Alt et al., 2008) suggesting that controls-related progress has been made. As system definition, fuel consumption benefits, and costs are uncertain at this time, HCCI is believed to be beyond the 15-year time horizon of this study.

COMBUSTION RESTART

Combustion restart can be seen as an enabler for idle-off operation, which has the potential to reduce fuel consumption under drive conditions that have significant idle time. The principle challenge relates to the crankshaft position when the engine comes to rest. One cylinder must be in the early phase of the expansion stroke such that fuel can be injected via DISI and spark(s) delivered to initiate combustion and expansion with sufficient potency to initiate sustained engine rotation. Overcoming the aforementioned challenge is highly dependent upon many real-world conditions over which there are limited opportunities without the addition of some form of electro-machine to properly position the crankshaft prior to restart. Given this challenge, it is believed that this approach will not attain significant market penetration during the time horizon of this study.

ETHANOL DIRECT INJECTION

An approach to cooling the charge to control knock and detonation ties in with both the octane ratings of fuels and their heats of vaporization. This approach is to inject into the intake charge or into the cylinder a fluid with a larger heat of vaporization than the fuel itself. This fluid would then vaporize drawing the heat of vaporization from the intake or cylinder gases thus lowering their temperature. Direct-injected (DI) E85 (i.e., a mixture of ~85 percent ethanol and ~15 percent gasoline) has recently been proposed for use both as an anti-knock additive and as a way to reduce petroleum consumption (Cohn et al., 2005) for boosted SI engines. A recent in-depth study of this concept was carried out at Ford (Stein et al., 2009) where engine dynamometer studies were carried out with a turbocharged 3.5-L V6 engine using gasoline PFI combined with DI E85. The promise of this approach is to enable three benefits, namely, allowing increasing the compression ratio of the boosted engine; allowing increasing the level of boost usable without knock and pre-ignition limitations; and enabling operation closer to MBT, timing. These three benefits provide greater thermal efficiency as well as increased power, which allows further downsizing and downspeeding, thus adding potential fuel consumption reductions. The Stein et al. study (2009) used a prototype V6 DI turbocharged engine (termed *Ecoboost* by Ford) with a PFI gasoline injection system added to the original direct-injection fuel system. The DI fuel system was separated from the PFI system and supplied only with E85 from a separate tank and pump. The engine was operated at both the base 9.8:1 compression ratio and a high value of 12:1. E85 injection quantities and spark advance were optimized, and measured results were then extrapolated to application with a 5.0-L engine in a pickup truck by means of full system simulation. The anticipated benefits were observed. Namely, MBT spark timing was achievable up to higher loads than were possible without the E85 injection, leading to a reduction in both gasoline and overall (combined gasoline and E85) fuel consumption. One of the conclusions reached by Stein et al. (2009) was the following:

> By enabling increased CR [compression ratio], engine downsizing, and downspeeding, E85 DI + gasoline PFI makes the engine more efficient in its use of gasoline, thereby leveraging the constrained supply of ethanol in an optimal manner to reduce petroleum consumption and CO_2 emissions. For a hypothetical 5.0 L E85 DI + gasoline PFI engine in a Ford F-series pickup, the leveraging due to 12:1 CR is approximately 5:1 on the EPA M/H drive cycle. That is, 5 gallons of gasoline are replaced by 1 gallon of E85. This leveraging effect will be significantly reduced for more aggressive drive cycles.

Since the focus of the present report is reducing petroleum consumption, the implications of the Stein et al. work on optimizing ethanol utilization will not be considered. However, the combination of increased compression ratio as well as downsizing and increased boosting possible with the ethanol injection enables reducing fuel consumption compared with operation on gasoline alone.

Any approach to inject an anti-knock fluid such as E85 would require an additional tank on the vehicle to provide the anti-knock fluid for injection and would require a willingness on the part of the vehicle driver to fill the anti-knock fluid tank. In the study by Stein et al. (2009), the authors estimated based on vehicle simulations for a full-size pickup truck that E85 usage on the FTP urban/highway schedule would be only about 1 percent of the total fuel used, thus providing an E85 refill driving range of ~20,000 miles with a 26-gallon gasoline fuel tank and a 10-gallon E85 tank. For the higher-load US06 driving cycle, E85 would constitute 16 percent of the fuel used for an E85 refill range of ~900 miles. For towing a trailer up the Davis Dam slope (~6 percent grade for over 10 miles), E85 usage would be 48 percent of the fuel used with an E85 tank refill range of ~100 miles. Once all the anti-knock fluid has been consumed, spark timing would have to be retarded and turbocharger boost reduced to prevent knock if a high compression ratio were chosen for the engine (e.g., 12 versus 9.8) based on reliance on injection of an anti-knock fluid to control knock. Operating with retarded spark timing and reduced boost would not harm the engine but may impact available power.

Based on the costs for the urea dosing systems used for CI engine selective catalytic reduction aftertreatment that has similar componentry (see Chapter 5), the cost of converting a boosted DI engine to PFI gasoline with DI E85 injection is estimated to be $300 to $350.

FINDINGS

SI engines are widely accepted as the primary source of propulsion for light-duty vehicles in the United States. There have been significant improvements in the fuel consumption reduction of SI engines in response to past trends of rising fuel prices. These improvements are in large part due to past advancements in fast-burn combustion systems with strategic exhaust-gas recirculation (EGR), multi-point fuel injection, and reduced engine friction. Newly available SI technologies are assessed with respect to fuel consumption benefit and cost measured against the aforementioned technologies as the baseline. These current technologies address improvements in the areas of continuing friction reduction, reduced pumping losses through advanced VEM, thermal efficiency improvements, and improved overall engine architecture, including downsizing using turbocharging and GDI. The significant finds are as follows:

Finding 4.1: SI technologies offer a means of reducing fuel consumption in relatively small, incremental steps. OEMs can thus create packages of technologies that can be tailored to meet specific cost and effectiveness targets. It is the combination of numerous, affordable SI technologies in a package that makes them appealing when compared to diesel or full hybrid alternatives—which offer a single large benefit at a large cost. Because of this capability, and considering the wide acceptance of SI engine applications, the committee believes that the implementation of SI engine technologies will continue to play a large role in achieving reduced levels of fuel consumption. Table 4.A.1 at the end of this chapter summarizes the fuel consumption reductions and costs for these technologies.

Finding 4.2: Cylinder deactivation is most cost-effective when applied to OHV V6 and V8 engines; it typically affords 4 to 10 percent fuel consumption reduction. The higher cost of applying cylinder deactivation to DOHC V6 and V8 engines, combined with the reduced fuel consumption benefit when cylinder deactivation is added to an engine with VVT, has caused most OEMs to avoid its application to DOHC engines. For this reason, the committee believes that cylinder deactivation will be applied only to OHV engines in most cases.

Finding 4.3: Stoichiometric gasoline direct injection (SGDI) applied to naturally aspirated engines typically affords a knock-limited compression ratio increase of 1.0 to 1.5 and a reduction in fuel consumption of 1.5 to 3.0 percent at a cost of $117 to $351, depending on cylinder count and including noise-abatement items. Versions of direct injection that provide some measure of charge stratification can further reduce fuel consumption, but emissions and implementation issues have inhibited high-volume applications.

Finding 4.4: Turbocharging and downsizing, while maintaining vehicle performance, can yield fuel consumption reductions ranging from 2 to 6 percent, depending on many implementation details such as changes in cylinder count. Industry trends and input from OEMs show that this technology is usually added in combination with direct injection when the goal is improved efficiency. SGDI will help negate the need to reduce compression ratio when turbocharging, giving the combination a positive synergistic effect. If the cylinder count is reduced, NVH-related issues will reduce the benefit level. Cost estimates were based primarily on the 2009 EPA teardown study and range from around zero additional cost when converting from a V6 to an I4, to about $658 when converting from a V8 to a V6.

Finding 4.5: The VEM over the speed-load range of an SI engine can further reduce the pumping loss over that of the previously described configurations and can also cause a slight increase in engine performance, which will offer a potential downsizing opportunity. There are many different implementations of this, and the cost-benefit relationship for these implementations depends on the engine architecture to which they are applied. Fuel consumption reduction can range from 1.0 percent with only intake cam phasing, to about 11 percent with a continuously variable valve lift and timing setup. The total cost range is $35 to $530, depending on the implementation technique and engine architecture.

Finding 4.6: It is important to note that, according to industry trends and input from OEMs, the major OEMs are either pursuing advanced VEM technologies, such as CVVL (Nissan, Toyota, and Honda), or turbocharging and downsizing with SGDI (Ford, GM, and VW), but usually not both (aside from BMW, which has both on its new N55 engine). However, there would still be a benefit, diminished somewhat by synergistic effects, to be gained by adding VVL to a turbo/SGDI engine with VVT. The committee concluded that thus far the industry has deemed the cost-benefit ratio too small to implement both technologies on one engine for mainstream vehicles. Adding continuously variable valve lift and timing to a baseline DOHC engine with intake cam phasing can result in a 5 to 9 percent reduction in fuel consumption. Implementing dual cam phasing, SGDI, and turbocharging and downsizing to a baseline DOHC engine with intake cam phasing can provide a 6 to 11 percent fuel consumption reduction.

Finding 4.7: Variable compression ratio, camless valve trains, homogeneous-charge compression ignition, and cooled EGR were all given careful consideration during the course of this study. Because of either questionable benefits or major implementation issues, it is highly uncertain whether any of these technologies will have any significant market penetration even in the 10- to 15-year time horizon.

BIBLIOGRAPHY

Abe, S., and M. Suzuki. 1995. Analysis of cylinder bore-distortion during engine operation. SAE Paper 950541. SAE International, Warrendale, Pa.

Ademes, N., O. Lang, S. Lauer, W. Salber, and H. Jene. 2005. Valve train variability for advanced gasoline engines. MTZ 66(12; December).

Alperstein, M., G. Shafer, and F. Villforth. 1974. Texaco's stratified-charge-engine—Multifuel, efficient, clean, and practical. SAE Paper 740563. SAE International, Warrendale, Pa.

Alt, M., U.D. Grebe, J.R. Dulzo, V.A. Ramappan, P. Kafarnik, and P.M. Najt. 2008. HCCI—From lab to the road. 29th Vienna Motor Symposium.

Automobile Magazine. 2002. Fiat multiair technology increases power, lowers emissions. Available at http://rumors.automobilemag.com/6476771/green/fiat-multiair-technology-increases-power-lowers-emissions/index.html.

Bernard, L., A. Ferrari, R. Rinolfi, and C. Vafidis. 2002. Fuel economy improvement potential of UNIAIR throttleless technology. SAE Paper 2002-33-0012. SAE International, Warrendale, Pa.

Boggs, D.L., H.S. Hilbert, and M.M. Schecter. 1995. The Otto-Atkinson-Cycle engine: Fuel economy and emissions results and hardware design. SAE Paper 950089. SAE International, Warrendale, Pa.

Cleary, D., and G. Silvas. 2007. Unthrottled engine operation with variable intake valve lift, duration, and timing. SAE Paper 2007-01-1282. SAE International, Warrendale, Pa.

Cohn, D.R., L. Bromberg, and J.B. Heywood. 2005. Direct Injection Ethanol Boosted Gasoline Engines: Biofuel Leveraging for Cost-Effective Reduction of Oil Dependence and CO_2 Emissions. MIT Laboratory for the Environment Report LFEE 2005-01 RP. Massachusetts Institute of Technology, Cambridge, Mass.

Delphi. 2009. Gasoline engine management systems. Available at http://delphi.com/manufacturers/auto/powertrain/gas/valvetrain/vcp/.

EEA (Energy and Environmental Analysis, Inc.). 2007. Update for Advanced Technologies to Improve Fuel Economy of Light Duty Vehicles. Prepared for U.S. Department of Energy. August. Arlington, Va.

EPA (U.S. Environmental Protection Agency). 2008. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. March. Washington, D.C.

Erdemir, A. 2005. Review of engineered tribological interfaces for improved boundary lubrication. Tribology International 38:249.

Etsion, I. 2005. State of the art in laser surface texturing. Journal of Tribology 127(January):248.

Falkowski, A., M. McElwee, and M. Bonne. 2006. Design and development of the DaimlerChrysler 5.7 L Hemi® engine multi-displacement cylinder-deactivation-system. SAE Paper 2004-01-2106. SAE International, Warrendale, Pa.

Fenske, G., R. Erck, O. Ajayi, A. Masoner, and A. Comfort. 2009. Impact of friction reduction technologies on fuel economy for ground vehicles. Proceedings of the 2009 Ground Vehicle Systems Engineering and Technology Symposium (GVSETS).

Flierl, R., and M. Kluting. 2000. The third generation of valvetrains—New fully variable valvetrains for throttle-free load control. SAE Paper 2000-01-1227. SAE International, Warrendale, Pa.

Flierl, R., D. Gollasch, A. Knecht, and W. Hannibal. 2006. Improvements to a four cylinder gasoline engine through the fully variable valve lift and timing system univalve. SAE 2006-01-0223. SAE International, Warrendale, Pa.

Fontaras, G., E. Vouitsis, and Z. Samaras. 2009. Experimental evaluation of the fuel consumption and emissions reduction potential of low viscosity lubricants. SAE Paper 2009-01-1803. SAE International, Warrendale, Pa.

Hitomi, M., J. Sasaki, K. Hatamura, and Y. Yano. 1995. Mechanism of improving fuel efficiency by Miller-cycle and its future prospect. SAE Paper 950974. SAE International, Warrendale, Pa.

Hofmann, R., J. Liebl, M. Kluting, and R. Flierl. 2000. The new BMW 4-cylinder gasoline engine—Reduction in fuel consumption without compromise. SAE Paper 2001-08-0043. SAE International, Warrendale, Pa.

Iwamoto, Y., K. Noma, O. Nakayama, and T. Yamauchi. 1997. Development of gasoline direct injection engine. JSAE Technical Paper No. 9732009.

Kojima, S. 2008. Development of high-performance and low-emission gasoline engine. SAE Paper 2008-01-0608. SAE International, Warrendale, Pa.

Kolwich, G. 2009. Light-Duty Technology Cost Analysis Pilot Study. Report FEV 07-069-103F. Prepared for U.S. Environmental Protection Agency, Ann Arbor, Mich. September 3. FEV, Inc., Auburn Hills, Mich.

Kolwich, G. 2010. Light-Duty Technology Cost Analysis—Report on Additional Case Studies. Prepared for U.S. Environmental Protection Agency. FEV, Inc., Auburn Hills, Mich.

Kuwahara, K., T. Watanabe, H. Tanda, K. Ueda, and H. Ando. 2000. Intake-port design for Mitsubishi GDI-Engine to realize distinctive in-cylinder flow and high charge coefficient. SAE Paper 2000-01-2801. SAE International, Warrendale, Pa.

Leone, T.G., and M. Pozar. 2001. Fuel economy benefit of cylinder deactivation sensitivity to vehicle application and operating constraints. SAE Paper 2001-01-3591. SAE International, Warrendale, Pa.

Lindgren, R., M. Skogsberg, H. Sandquist, and I. Denbratt. 2003. The influence of injector deposits on mixture formation in a DISC SI engine. JSAE Technical Paper No. 20030110.

Martec Group, Inc. 2008. Variable Costs of Fuel Economy Technologies. Prepared for Alliance of Automobile Manufacturers. June 1; amended September 26 and December 10.

Misovec, K., B. Johnson, G. Mansouri, O. Sturman, and S. Massey. 1999. Digital valve technology applied to the control of an hydraulic valve actuator. SAE Paper 1999-01-0825. SAE International, Warrendale, Pa.

Nakada, M. 1994. Trends in engine technology and tribology. Triblogy International 27(1), February.

NESCCAF (Northeast States Center for a Clean Air Future). 2004. Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles. March.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

Petitjean, D., L. Bernardini, C. Middlemass, and S.M. Shahad. 2004. Advanced gasoline engine turbocharging technology for fuel economy improvements. SAE Paper 2004-01-0988. SAE International, Warrendale, Pa.

Pischinger, S., K. Yapici, M. Schwanderlapp, and K. Habermann. 2001. Variable compression in SI engines. SAE Paper 2001-24-0050. SAE International, Warrendale, Pa.

Priest, M., and C.M. Taylor. 2000. Automobile engine tribology—Approaching the surface. Wear 241:193-203. SAE International, Warrendale, Pa.

Rebbert, M., G. Kreusen, and S. Lauer. 2008. A new cylinder deactivation by FEV and Mahle. SAE Paper 2008-01-1354. SAE International, Warrendale, Pa.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for U.S. Environmental Protection Agency. EPA420-R-08-004. Contract No. EP-C-06-003. Work Assignment No. 1-14. Ann Arbor, Mich.

Rosenberg, R.C. 1982. General friction considerations for engine design. SAE Paper 821576. SAE International, Warrendale, Pa.

Schwarz, C., E. Schünemann, B. Durst, J. Fischer, and A. Witt. 2006. Potentials of the spray-guided BMW DI combustion system. SAE Paper 2006-01-1265. SAE International, Warrendale, Pa.

Sellnau, M., T. Kunz, J. Sinnamon, and J. Burkhard. 2006. 2-step variable valve actuation: System optimization and integration on an SI engine. SAE Paper 2006-01-0040. SAE International, Warrendale, Pa.

Shahed, S.M., and Karl-Heinz Bauer. 2009. Parametric studies of the impact of turbocharging on gasoline engine downsizing. SAE Paper 2009-01-1472. SAE International, Warrendale, Pa.

Shin, S., A. Cusenza, and F. Shi. 2004. Offset crankshaft effects on SI engine combustion and friction performance. SAE Paper 2004-01-0606. SAE International, Warrendale, Pa.

Sierra Research. 2008. Basic Analysis of the Cost and Long-Term Impact of the Energy Independence and Security Act Fuel Economy Standards. Sacramento, Calif., April 24.

Simko, A., M. Choma, and L. Repko. 1972. Exhaust emission control by the Ford-programmed combustion process—P ROCO. SAE Paper 720052. SAE International, Warrendale, Pa.

Sorab, J., S. Korcek, C. Brower, and W. Hammer. 1996. Friction reducing potential of low-viscosity-engine oils in bearings. SAE Paper 962033. SAE International, Warrendale, Pa.

Stein, R.A., C.J. House, and T.G. Leone. 2009. Optimal use of E85 in a turbocharged direct-injection engine. SAE Paper 2009-01-1490. SAE International, Warrendale, Pa.

Sycomoreen. BMW Valvetronic. See http://sycomoreen.free.fr/imgs/IMAGES/autoconcept/ BMW_valvetronic.jpg.

Takemura, S., S. Aoyama, T. Sugiyama, T. Nohara, K. Moteki, M. Nakamura, and S. Hara. 2001. A study of a continuous variable valve event and lift (VEL) system. SAE Paper 2001-01-0243. SAE International, Warrendale, Pa.

Tanaka, H., T. Nagashima, T. Sato, and S. Kawauchi. 1999. The effect of 0W-20 low viscosity engine oil on fuel economy. SAE Paper 1999-01-3468. SAE International, Warrendale, Pa.

Tanaka, Y., R. Hiyoshi, S. Takemura,Y. Ikeda, and M. Sugawara. 2007. A study of a compression-ratio-control mechanism for a multiple-link variable-compression-ratio engine. SAE Paper 2007-01-3547. SAE International, Warrendale, Pa.

Taylor, C.M. 1998. Automobile engine tribology—Design considerations for efficiency and durability. Wear 221:1-8.

Taylor, R.I., and C.R. Coy. 1999. Improved fuel efficiency by lubricant design: A review. Proceedings Institution of Mechanical Engineers 214, Part J.

Toyota Motor Company. 2007. Toyota develops next generation engine valve mechanism. June 12, available at http://www2.toyota.co.jp/en/news/07/0612.html.

Tuttle, J.H. 1980. Controlling engine load by means of late intake-valve closing. SAE Paper 800794. SAE International, Warrendale, Pa.

Verhelst, S., J. De Landtsheere, F. De Smet, C. Billiouw, A. Trenson, and R. Sierens. 2008. Effects of supercharging, EGR and variable valve timing on power and emissions of hydrogen internal combustion engines. SAE Paper 2008-01-1033. SAE International, Warrendale, Pa.

Wirbeleit, F., K. Binder, and D. Gwinner. 1990. Development of pistons with variable-compression-height for increasing efficiency and specific power output of combustion engines. SAE Paper 900229. SAE International, Warrendale, Pa.

Wurms, R., M. Grigo, and W. Hatz. 2002. Audi FSI technology—Improved performance and reduced fuel consumption. SAE Paper 2002-33-0002. SAE International, Warrendale, Pa.

ANNEX

TABLE 4.A.1 Summary Table for Fuel Consumption Reduction Techniques for SI Engines: Incremental Percentage Reduction of Fuel Consumption with Associated Incremental Total Cost (with 1.5 RPE). See Figures 9.1 through 9.5 in Chapter 9 to understand the intended order for the incremental values.

Technologies		Consumption Benefit			Incremental Cost $						Comments
		I4	V6	V8	I4		V6		V8		
SI Techniques		(%) Range	(%) Range	(%) Range	Low	High	Low	High	Low	High	
Low-viscosity lubricants	LUB	0.5	0.5	0.5	4.5	7.5	4.5	7.5	4.5	7.5	• Small consumption benefit • Dependent on drive cycle
Engine friction reduction	EFR	0.5-2.0	0.5-2.0	1.0-2.0	48	78	72	117	96	156	• Roller follower valve trains and piston kit friction reduction measures were nearly universally implemented in the mid-1980s
VVT—coupled cam phasing (CCP), SOHC	CCP	1.5-3.0	1.5-3.5	2.0-4.0	52.5		105		105		• On SOHC setup cam phaser adjusts both exhaust and intake valve timing events • Manufacturer cost estimate of $35/phaser
Discrete variable valve lift (DVVL), SOHC/DOHC	DVVL	1.5-3.0	1.5-3.0	2.0-3.0	195	240	270	315	420	480	• Short durations may reduce pumping loss, and the reduced lift is a consequence of this • As intake manifold vacuum vanishes, alternate means must be found to implement power brakes and PCV • DVVL features two to three separate fixed profiles • Manufacturer cost estimate of $40/cylinder + $35/phaser

Technologies		Consumption Benefit			Incremental Cost						Comments
		I4	V6	V8	I4		V6		V8		
SI Techniques		(%) Range	(%) Range	(%) Range	Low	High	Low	High	Low	High	
Cylinder deactivation, SOHC	DEAC	NA	4.0-6.0	5.0-10.0	NA		510	600	536	630	• Effectiveness depends on power to weight ratio, previously added technologies, NVH, and drivability issues • Reduction in pumping losses from higher cylinder loading • Higher cost when applied to OHC engines • Manufacturer cost estimate for OHC engines of $340 to $400 • Additional manufacturer cost of $140 for NVH issues
Cylinder deactivation, OHV	DEAC	NA	4.0-6.0	5.0-10.0	NA		330	375	383		• Effectiveness depends on power to weight ratio, previously added technologies, NVH, and drivability issues • Reduction in pumping losses from higher cylinder loading • OHV has a lower cost when compared to OHC setups
VVT—intake cam phasing (ICP)	ICP	1.0-2.0	1.0-2.0	1.5-2.0	52.5		105		105		• Implementations include intake cam phaser (ICP) • Timing is important, and lift is merely a consequence of duration change • Some of this can be achieved with variable geometry intake manifolds • Manufacturer cost estimate of $35/phaser

continued

TABLE 4.A.1 Continued

Technologies		Consumption Benefit			Incremental Cost						Comments
		I4	V6	V8	I4		V6		V8		
SI Techniques		(%) Range	(%) Range	(%) Range	Low	High	Low	High	Low	High	
VVT—dual cam phasing (DCP)	DCP	1.5-2.5	1.5-3.0	1.5-3.0	52.5		105		105		• Implementations include exhaust only and dual-cam phaser (DCP) • Manufacturer cost estimate of $35/phaser
Continuously variable valve lift (CVVL)	CVVL	3.5-6.0	3.5-6.5	4.0-6.5	239	308	435	465	525	585	• Short durations may reduce pumping loss, and the reduced lift is a consequence of this • As intake manifold vacuum vanishes, alternate means must be found to implement power brakes and PCV • CVVL features wide range of cam profiles • Manufacturer cost estimate of $300 for an I4, and $600 for a V-8
VVT—coupled cam phasing (CCP), OHV	CCP	1.5-3.0	1.5-3.5	2.0-4.0	52.5		52.5		52.5		• Requires in block cam phaser • Manufacturer cost estimate of $35/phaser
Stoichiometric gasoline direct injection (GDI)	SGDI	1.5-3.0	1.5-3.0	1.5-3.0	176	293	254	384	443	527	• Enables about +1.0 knock limited compression ratio • High pressure fuel pump increases parasitic loss • Increased volumetric efficiency increases pumping loss • Injector deposits formed upon hot shut down has been a traditional concern • Manufacturer cost estimates $80/cylinder and $136 for injector noise abatement items

Technologies		Consumption Benefit			Incremental Cost						Comments
		I4	V6	V8	I4		V6		V8		
SI Techniques		(%) Range	(%) Range	(%) Range	Low	High	Low	High	Low	High	
Turbocharging and downsizing	TRBDS	2.0-5.0	4.0-6.0	4.0-6.0	555	735	-50	308	788	1185	• Vehicle launch performance will likely be compromised • Piston underside oil squirters, an oil cooler, and an intercooler may contribute to system merits • Dual scroll and VNT units will improve vehicle launch performance • Manufacturer estimates $550-$920 for a fixed geometry system

5

Compression-Ignition Diesel Engines

INTRODUCTION

Light-duty compression-ignition (CI) engines operating on diesel fuels have the highest thermodynamic cycle efficiency of all light-duty engine types. The CI diesel thermodynamic cycle efficiency advantage over the more common SI gasoline engine stems from three major factors: the CI's use of lean mixtures, its lack of throttling of the intake charge, and its higher compression ratios. In a CI diesel engine-equipped vehicle, there is an additional benefit of reduced volumetric fuel consumption (e.g., gal/100 miles) because diesel fuel provides more energy per gallon than gasoline, as is discussed later in this chapter.

Lean mixtures, whose expansions are thermodynamically more efficient because of their higher ratio of specific heats, are enabled by the CI diesel combustion process. In this process, diesel fuel, which has chemical and physical properties such that it self-ignites readily, is injected into the cylinder late in the compression stroke. Ignition occurs following atomization of the fuel jet into small droplets that vaporize and mix, creating pockets of heterogeneous combustible mixtures. These heterogeneous mixtures burn with localized diffusion flames even though the overall fuel-to-air ratio may be too lean to support turbulent flame propagation such as occurs in an SI gasoline engine. This ability to successfully burn overall lean mixtures allows CI diesel engine power output to be controlled through limiting the amount of fuel injected without resorting to throttling the amount of air inducted. This attribute leads to the second major factor enabling the higher efficiency of CI diesel engines, namely the absence of throttling during the intake process, which otherwise leads to negative pumping work. SI gasoline engines must be throttled to control their power output while still keeping the fuel-air ratio at the stoichiometric ratio necessary for proper functioning of their three-way exhaust catalyst. Finally, the diesel combustion process needs higher compression ratios to ensure ignition of the heterogeneous mixture without a spark. The higher CI diesel compression ratios (e.g., 16-18 versus 9-11 for SI gasoline) improve thermodynamic expansion efficiency, although some of the theoretical gain is lost due to increased ring-to-bore wall friction from the associated higher cylinder pressures.

Fuel economy technologies considered in the NRC's (2002) earlier report on fuel economy did not include diesel-powered CI engines because the costs and emission control systems to meet upcoming nitrogen oxides (NO_x) and particulate emission standards were not developed at that time. The motivation for including light-duty CI engine technology in this report stems from two factors. Light-duty CI engine vehicles are now in widespread use in Europe because a high fuel tax on diesel and gasoline fuel allowed diesel retail prices to be substantially lower than gasoline prices. This differential is disappearing in some countries but still persists in others. European buyers have accepted initial higher CI vehicle purchase prices in return for their lower fuel consumption as well as excellent performance and driving dynamics resulting from their high torque. CI diesel vehicles constitute around 50 percent of the new light-duty vehicle market in Europe (DieselNet, 2008). However, in the 2007 U.S. light-duty market, CI diesel vehicles accounted for only about 1.7 percent of the new light-duty vehicles sales (EIA, 2009a). Recent demonstrations of diesel combustion and exhaust aftertreatment systems have shown the capability to meet U.S. 2010 Tier 2, Bin 5 and LEV II emissions regulations for light-duty vehicles. As a result of the emissions control capability achieved by original equipment manufacturers (OEMs) with their internal development projects, at the 2008 Detroit auto show 12 vehicle manufacturers announced the introduction of 13 new CI diesel powered vehicles for the 50-state 2009 U.S. market (Diesel Forum, 2008). However, due to the large fuel price increases of early 2008 and the resulting reduction in vehicle sales of larger vehicles, many OEMs canceled CI vehicle introductions announced for 2009. Nonetheless, four OEMs have offered 12 2009 CI vehicle models.

TECHNOLOGIES AFFECTING FUEL CONSUMPTION

The fuel consumption of engine systems is driven by two major elements, the base engine (i.e., combustion subsystem, friction, accessories, etc.) and the exhaust aftertreatment subsystem. As a result, the fuel consumption of an engine system depends on both the base engine and the aftertreatment. Technologies affecting engine system fuel consumption through changes to the base engine and to the aftertreatment system are discussed below.

Base Engine Fuel Efficiency Technologies

The strategies being pursued to improve base engine efficiency are the following:

- Downsizing the engine while maintaining equal power,
- Improving thermodynamic cycle efficiency (e.g., improved combustion),
- Reducing engine friction (e.g., reduced piston skirt friction), and
- Reducing accessory loads (e.g., electric water pump, reduced fuel pump loads by avoiding fuel recirculation, modulated oil pump).

Note that all these strategies apply as well to SI engines, although the gains may have different magnitudes due to process differences between CI and SI engines.

Downsizing the Engine

The most significant of these strategies is engine downsizing, which consists of using a smaller displacement engine for a given vehicle mass while still maintaining the same power to give equal vehicle performance.[1] This approach requires higher cylinder pressures (i.e., higher engine brake mean effective pressure [BMEP], which is equivalent to torque) at any given point on the vehicle drive cycle, which reduces engine brake specific fuel consumption (BSFC). To downsize an engine while still maintaining the same vehicle performance, the torque and hence BMEP of the downsized engine must be raised at all speeds including the maximum-power speed. One of the key enablers to raising the BMEP is increasing the intake boost provided by the turbocharger system. The emerging approach to increase intake boost is two-stage turbocharging (Figure 5.1). Increased boosting is also used for downsizing SI engines.

Most current light-duty CI diesel engines use a single-stage, variable-geometry turbocharger (VGT). Two-stage turbocharger (turbo) systems are being actively developed for two reasons. First, they are a key enabler for engine downsizing. Second, they enable increased exhaust gas recirculation (EGR) rates. Cooled EGR is the principal method to reduce engine-out NO_x emissions, as discussed later. With a two-stage turbo system, two separate turbos are combined with additional flow-control valves. The first-stage turbo is usually sized smaller than the normal single-stage VGT used currently, and the second-stage turbo is usually sized larger than the current single-stage VGT. Electronic flow control valves triggered by the engine controller are used to direct exhaust flows to the small turbo and/or to the large one. At lower engine speeds only the smaller turbo is used and a relatively high inlet pressure is generated, even for the low inlet air flow characteristic of operation at high EGR rates.

At higher engine speeds, when the air flow rates have increased and the smaller turbo does not have sufficient flow capacity, air flow rates are sufficient to generate high intake pressures when the exhaust flow is directed through the larger turbo. Therefore, with the use of a two-stage turbo system, the problem of insufficient inlet boost pressure at low speeds with high EGR flow rates is solved without losing engine power at high speeds. The ability of two-stage turbo systems to generate higher boost pressures at low engine speeds is the key characteristic of two-stage systems that makes them enablers for engine downsizing. By providing higher intake boost, two-stage systems provide more air in the cylinder, thus allowing increased BMEP and torque to compensate for the smaller engine displacement. Naturally, two-stage turbo systems are more expensive than single-stage systems.

To utilize the increased charge mass in the cylinder resulting from the higher boost, more fuel must be injected per unit of engine displacement. The resulting increased power output per unit of engine displacement then compensates for the downsized engine displacement. Increasing the fuel flow is generally accomplished by increasing the maximum injection pressure, which enables higher injection-pressures at all loads. To support the increased cylinder pressures, the engine structure, sealing (e.g., head gasket), and lubrication (e.g., connecting rod bearings must support higher cylinder pressures with the same bearing areas) must be improved. Cylinder pressures also increase piston/ring friction, and an additional challenge is to keep the increase to a minimum. These changes require careful engineering but increase engine cost only slightly.

Improving Thermodynamic-Cycle Efficiency by Optimizing Combustion and Emissions for Maximum Efficiency

The combustion process and its phasing relative to piston motion are important determinants of thermodynamic-cycle

[1] Truly equal performance involves nearly equal values for a large number of measures such as acceleration (e.g., 0-60 mph, 30-45 mph, 40-70 mph, etc.), launch (e.g., 0-30 mph), gradability (steepness of slopes that can be climbed without transmission downshifting), maximum towing capability, and others. In the usage herein, equal performance means 0-60 mph times within 5 percent. This measure was chosen because it is generally available for all vehicles. The equal-performance constraint is important because vehicle FC can always be reduced by lowering vehicle performance. Thus objective comparisons of the cost-effectiveness of different technologies for reducing FC can be made only when vehicle performance remains equivalent.

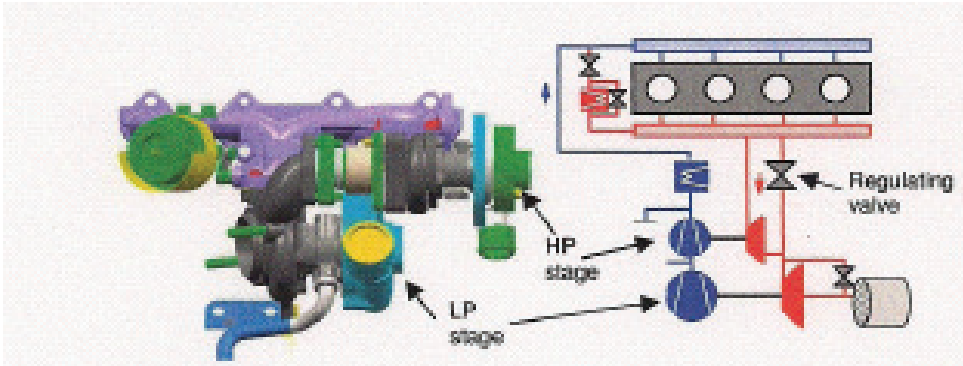

FIGURE 5.1 Schematic of two-stage turbocharger system. HP, high pressure; LP, low pressure. SOURCE: Joergl et al. (2008). Reprinted with permission from SAE Paper 2008-01-0071, Copyright 2008 SAE International.

efficiency. However, the combustion process also plays the key role in the engine-out emissions. As a result, optimizing combustion to minimize FC and emissions simultaneously requires careful analysis of the interactions between fuel spray dynamics, in-cylinder fluid motions resulting from the interactions of the intake flow with the piston bowl shape (i.e., combustion chamber), gas temperature history, and chemical reactions of the fuel. As fuel composition evolves from entirely petroleum based to a mixture of petroleum and bio-sourced components in the next decade to reduce petroleum dependence and increase sustainability, it is critical that understanding of combustion be increased. It is believed that advanced combustion research with tools such as three-dimensional computational fluid dynamic computer codes, including spray and combustion as well as coordinated experiments in highly instrumented engines with optical access for advanced laser-based tools, will improve understanding of combustion in the longer term. This improved understanding is critical to reducing exhaust emissions without compromising engine efficiency and along with new technologies discussed later should enable reductions in FC.

Reducing Engine Friction

Friction sources in engines are journal bearing friction, valve-train friction, and piston assembly friction. In the past 10 to 15 years, all significant sliding interfaces in valve trains have been replaced by rolling interfaces, which minimize friction. Connecting rod, camshaft, and main bearing friction is hydrodynamic, thus coming primarily from lubricating oil shear processes. This friction has been reduced by the use of lower viscosity lubricants. Therefore, the largest remaining friction sources in both CI and SI engines is that due to the piston assembly. Friction from this assembly comes from both piston skirt-to-wall interactions as well as piston ring-to-wall interactions. Both skirt and ring friction can be decreased by improved cylinder-bore roundness, which depends on both cylinder block design and associated thermal distortions as well as bore distortion due to mechanical loading by the preloaded cylinder head attachment bolts. Rounder bores under hot and loaded conditions allow lower ring tension, which in turn decrease ring-to-wall friction. Coatings to reduce ring friction are also being developed, although it is not yet clear whether such coatings can be both friction reducing and sufficiently durable. Piston skirt friction can be reduced by improved skirt surface coatings. Most current pistons have proprietary skirt coatings, but new materials are continuously being studied to further reduce skirt-to-wall friction.

Reducing Accessory Loads

Engine loads to drive accessories include those for coolant pump, oil pump, alternator, air-conditioning compressor, power-steering pump, etc. Electric-motor-driven coolant pumps are being considered because they can be turned off or run slowly during engine warm-up and at other conditions when coolant flow can be reduced without engine damage, thus reducing fuel use to drive the electrical alternator. Two-mode mechanical water pumps are also being developed that require less power to drive at part-load engine conditions but still provide more coolant flow at high-load conditions. Oil pumps, like coolant pumps, are sized for maximum engine power conditions and are hence oversized for part-load, low-speed conditions. Two-mode oil pumps are being developed and becoming available.

Exhaust Emissions Control of CI Diesel Engines

The most critical aspect of increasing the use of CI diesel engines in the United States to take advantage of their excellent efficiency is the development and production of technologies that can enable these engines to meet the 2010 and post-2010 exhaust emissions standards. As noted above, CI diesel engines without emission controls have very low

FC characteristics. So the challenge for CI engines is to reduce emissions into compliance without losing the excellent fundamental CI low FC. This challenge is in contrast to the case of the SI gasoline engines, for which reducing FC is the major issue. As noted earlier, in the 2009 model year 13 new CI diesel vehicles were announced for introduction to the U.S. market (Diesel Forum, 2008). These vehicles have been developed to meet the 2010 emissions standards, and so whatever efficiency deterioration has occurred as a result of applying the combustion and exhaust aftertreatment technologies necessary to meet the standards is reflected by the fuel economy of these vehicles. Data from the 2009 VW Jetta indicated that the fuel consumption reduction between the diesel and gasoline versions of the Jetta expected from earlier (e.g., 2006) models has been retained, in spite of the significantly reduced emissions, although this result may not hold true for all the new diesel models. As a result, the overall choice between investing in SI gasoline engine technologies to reduce the SI gasoline fleet FC on the one hand and replacing some SI gasoline engines with CI diesel engines on the other hand will rest on the total cost for emissions-compliant CI diesel engines and their remaining FC advantage after emissions control measures are implemented. In addition to the specific FC tradeoffs between SI and CI FC, business decisions on whether to tool up CI engines also depend heavily on the availability of investment capital in an industry undergoing drastic financial problems as well as expectations of the willingness of buyers to invest in CI engines, with which they are largely unfamiliar or have out-of-date perceptions.

Combustion System Technologies

The direction for CI diesel combustion system technology development has been toward more premixed combustion and away from traditional CI diesel engine diffusion-type combustion. Diffusion-type combustion tends to generate both high NO_x and high particulate matter (PM) engine-out emissions because diffusion flames tend to stabilize at a nearly stoichiometric local mixture ratio that is characterized by high temperatures and resultant high NO_x formation. Surrounding this local stoichiometric diffusion flame are rich local fuel mixtures whose thermal and mixture environment also cause high PM formation. Higher levels of dilution by means of large amounts of EGR as well as earlier injection and longer ignition delays reduce both average and local temperatures as well as allowing more mixing time, thus making the local fuel-air ratios much leaner. This combination of lower temperatures and locally leaner mixtures minimizes the extent of diffusion flame occurrence and thereby reduces both NO_x and PM emissions. The combustion strategies that utilize this approach have been given many different names in the literature, including PCI (premixed compression ignition) (Iwabuchi et al., 1999), PCCI (premixed-charge compression ignition) (Kanda et al., 2005), LTC (low-temperature combustion) (Pickett and Siebers, 2004), and others. All these partially homogeneous charge strategies drive the combustion process in the direction of HCCI (homogeneous-charge compression ignition) (Ryan and Callahan, 1996). The term HCCI in its purest form refers to virtually homogeneous rather than partially homogeneous charge.

To utilize these premixed forms of combustion, a number of measures are used to reduce temperatures and improve mixing of the charge. The simplest and most effective measure is increased EGR, as noted above. In addition to increased EGR, lowering compression ratio also reduces mixture temperatures and, as a bonus, allows increasing engine power without exceeding cylinder-pressure design limits. Lower compression ratios make developing acceptable cold-start performance more challenging in spite of improved glow plugs and glow plug controls.

Technologies being developed to support this move in combustion technology toward premixed low-temperature combustion are cylinder-pressure-based closed-loop control; piezo-actuated higher-pressure fuel injectors; two-stage turbocharger systems; and combinations of high- and low-pressure EGR systems.

Cylinder-Pressure-Based Closed-Loop Combustion Control Technologies

Cylinder-pressure-based closed-loop combustion control technologies enable operating the engine closer to the low-temperature limit without encountering misfire or excessive hydrocarbon and carbon monoxide (HC/CO) emissions. This technology is especially important in the North American market, where the variation of North American diesel fuel ignition quality (i.e., cetane number) is greater than in Europe. This large cetane number variability makes combustion control more difficult especially for more dilute, lower-temperature combustion strategies. The FC impact of cylinder-pressure-based closed-loop combustion control is 0 to 5 percent. However, since certification fuels are well controlled, the efficiency impact would not be observed on the drive cycle for vehicle emissions certification, but only in customer use when poor ignition quality fuels are encountered in the marketplace.

Piezo-Triggered Common-Rail Fuel Injectors

Piezo-actuated common-rail fuel injectors are being developed aggressively by the global diesel fuel-injection system suppliers (e.g., Bosch, Continental, Delphi, and Denso). These injectors open faster and more repeatably than do solenoid-actuated injectors, thereby enabling more injections per combustion event. The latest generations of these injectors designed on direct-acting principles entered low-volume production for the 2009 model year in European passenger cars. Multiple injections per combustion cycle allow lower combustion noise (i.e., diesel knock) and more precise control of mixing and local temperatures than is possible with a single injection per cycle. This additional level of control is useful to maximize the benefits of premixed low-temperature combustion. In addition to combustion control, multiple-injection capability is used to enable post-combustion injections, which have been used as part of the engine control strategy used to trigger and sustain regeneration of particulate filters.

EGR Issues

Using increased EGR levels to reduce mixture temperatures to suppress formation of NO_x and PM creates two major difficulties in addition to the points mentioned above. First, the levels of EGR at idle and part-load conditions typical of urban and extra-urban driving can reach 60 to 70 percent. This means that with normal high-pressure EGR, only 30 to 40 percent of the engine air flow is going through the turbocharger with the remainder recirculated back through the engine. As a result, the turbine generates less torque and the ability of the turbocharger to boost intake pressure is severely hampered. Low inlet pressures lead to lower cylinder charge masses, causing richer mixtures and thus increasing PM formation as well as making it more difficult for post-combustion oxidation of both PM and HC/CO due to lower oxygen availability.

The second difficulty associated with very high EGR levels is that EGR cooling requirements increase. EGR cooling is extremely important because EGR enters the EGR cooler at exhaust temperatures. Mixing this hot EGR with intake air, which is already heated through compression in the turbocharger compressor, leads to hot inlet mixtures. Hot inlet mixtures negate some of the potential of lowering NO_x and PM formation through lower mixture temperatures. Therefore, high EGR levels require larger and more effective EGR coolers. Not only do these larger coolers present packaging difficulties in already crowded engine compartments, but they also are subject to fouling through condensation of heavy hydrocarbons and water vapor present in the EGR stream, which form deposits inside the EGR cooler decreasing their cooling efficiency (Styles et al., 2008).

High- and Low-Pressure EGR Systems

In most CI diesel engines, EGR is supplied to the intake manifold directly from the exhaust manifold before the turbo. This approach provides high-pressure, high-temperature exhaust gas to the intake manifold. Thus this type of system is called an HP (for high-pressure) system. The HP approach is simple in principle because the exhaust manifold pressure is normally slightly higher than the intake manifold pressure. Thus EGR can be passed directly from the exhaust manifold into the intake manifold at a rate controlled by both the EGR flow control valve and the pressure difference between the exhaust and intake manifolds. This approach was inexpensive and effective in the early days of CI engine emissions control. However, as emission standards tightened, more EGR was needed, resulting in the hot intake mixture problem noted above. Partly to avoid the hot-EGR and EGR cooler fouling problems, low-pressure (LP) EGR systems have been developed (Keller et al., 2008).

In low-pressure systems, exhaust gas is taken from the exhaust system downstream of the particulate filter. As a result, particulates and heavy hydrocarbons have been removed. In addition, these exhaust gases are much cooler since energy has been removed by expanding the gases down to atmospheric pressure through the turbocharger turbine and by heat transfer in the exhaust piping leading to the particulate filter. As a result, these cooler, cleaner low-pressure exhaust gases now have to be pumped back up the intake boost pressure by passing them through the turbocharger compressor and subsequently through the charge cooler. EGR systems combining both high-pressure and low-pressure circuits have been developed and put into production on light-duty vehicles (e.g., the 2009 VW Jetta) (Hadler et al., 2008).

Variable Valve Timing

Some suggestions have been put forth that variable valve timing (VVT) mechanisms may provide opportunities for improved usage of EGR as well as other emissions control functionality (Bression et al., 2008) for CI engines. However, the current consensus from advanced development groups at OEMs and consulting firms is that VVT for CI diesels provides little or no benefit and therefore is not cost effective.

Exhaust Aftertreatment Technologies

HC/CO Control

The control of HC/CO has traditionally been relatively easy for CI engines due to the relatively low levels of these constituents emitted from conventional CI diesel combustion, in spite of relatively low exhaust temperatures. However, that situation has changed as the CI diesel combustion process has been modified to reduce combustion-gas temperatures, which reduces exhaust temperatures even further. As the combustion temperatures have been reduced, HC/CO emissions have risen. The diesel oxidation catalyst (DOC) was introduced around 1996 to reduce hydrocarbon emissions and in turn to reduce the soluble organic fraction of the dilute particulate matter. As a result of the reduced exhaust temperatures noted above, the DOC is being moved closer and closer to the turbocharger outlet to increase the temperature of the catalyst to increase its conversion efficiency. This packaging trend need not significantly increase costs but such minimal cost increases are only possible when other vehicle changes provide the opportunity to modify the engine compartment packaging to allow space for close-coupling the DOC. In addition, oxidation catalyst coatings are being added to diesel particulate filters (DPFs) and NO_x storage catalysts for additional HC/CO control.

Particulate Control

Particulate filter control of emissions from CI diesel engines is presently in use by vehicle manufacturers in Europe and the United States. These particulate filters are quite effective, filtering out 90 to 99 percent of the particulates from the exhaust stream, making CI diesel engines more attractive from an environmental impact point of view. Obviously, particulates accumulate in the filters and impose additional back pressure on the engine's exhaust system, thus increasing pumping work done by the engine. This increase in pumping work increases fuel consumption. In addition, there is a second fuel economy decrement caused by the additional fuel required to regenerate the filter by oxidizing retained particulates. The low exhaust temperatures encountered in light-duty automotive applications of these filters are insufficient to passively oxidize the accumulated particulates. As a result, temperatures must be increased by injecting fuel (most frequently in the engine cylinder after combustion is over) to be oxidized, raising the temperature of the cylinder gases. These hot gases then pass from the cylinder out into the exhaust system and then downstream to the particulate filter to oxidize the particulates retained in the filter. To achieve sufficiently rapid regeneration for practical use in light-duty vehicles (e.g., in around 10 to 15 minutes), exhaust gases must be raised to 625 to 675°C.

Engine control algorithms for filter regeneration not only must sense when the filters need to be regenerated and bring about the regeneration without overheating the filter, but also these algorithms must contend with other events like the driver turning off the vehicle while regeneration is underway, thus leaving an incompletely regenerated filter. When the vehicle is then restarted, the control algorithms must appropriately manage either completion of the regeneration or start of a new filling and regeneration cycle. These algorithms have become quite sophisticated, with the result that particulate filter systems are quite reliable and durable.

NO_x Control

There are two approaches to aftertreatment of NO_x emissions: NO_x storage and reduction catalysts (NSC), which are also called lean NO_x traps (LNT) (Myoshi et al., 1995), and selective catalytic reduction devices.

NO_x Storage Catalysts

NO_x storage catalysts utilize a typical monolith substrate that has both barium and/or potassium as well as precious metal (e.g., platinum) coatings. These coatings adsorb NO_x from the exhaust gas stream to form nitrates, thus storing the NO_x in the catalyst. As NO_x is adsorbed from the exhaust, adsorption sites on the surface of the coating fill up. Once all the coating sites have adsorbed NO_x, the NSC is no longer effective at adsorbing additional NO_x, which then passes right through the NSC. Therefore, at some point before the catalyst is filled, the NSC must be regenerated to purge the adsorbed NO_x and free the sites to adsorb the next wave of NO_x. By supplying the NSC with a rich exhaust stream containing CO and hydrogen, the CO and H_2 molecules desorb the NO_x from the catalyst surface and reduce the NO_x to N_2, H_2O, and CO_2. Therefore, like the particulate filter, the NSC operates in a cyclic fashion, first filling with NO_x from the lean diesel exhaust (i.e., an oxidizing atmosphere) and then being purged of NO_x in a rich exhaust (i.e., a reducing atmosphere) that, with the help of precious metals also part of the catalyst surface coating, reduces the NO_x back to N_2.

Accordingly, application of an NSC to any engine that has a lean exhaust stream like diesel engines requires that periodically (every 30 to 60 seconds depending on the size of the catalyst and the operating condition of the engine) the engine system must create a rich exhaust stream for 10 to 15 seconds to clear the catalyst surface of NO_x, thus preparing it to adsorb the next wave of NO_x. One approach to creating the required rich exhaust stream in the engine cylinder is by throttling the engine to reduce airflow, thus enriching the mixture in the cylinder. Although gasoline engines operate quite happily with rich mixtures, operating a CI diesel engine with a rich mixture without forming excessive particulate and hydrocarbon emissions is quite challenging. If the combustion process is carried out at sufficiently low temperatures, particulate formation is minimized, but both hydrocarbon emissions and FC increase significantly during this brief rich operation.

An additional difficulty with NSCs is that the catalyst coatings preferentially adsorb sulfur compounds from the exhaust. These sulfur compounds originate mostly from the sulfur in the fuel. This sulfur takes up the adsorbing surface sites on the catalyst, leaving no sites to adsorb NO_x. This sulfur adsorption, termed sulfur poisoning, is problematic even with today's low-sulfur (<15 ppm) diesel fuel. Some of the sulfur in the exhaust gases may also come from the engine lubricating oil. Thus the NSC must also be periodically regenerated to clear out the adsorbed sulfur. Sulfur forms a much stronger bond with the catalyst surface than does NO_x and as a result, sulfur regeneration requires not only a rich exhaust stream but also higher temperatures like ~650°C rather than the typical 200 to 300°C temperatures adequate for NO_x regeneration. While the sulfur regeneration does not need to be done nearly as frequently as NO_x regeneration, sulfur regeneration also causes a FC penalty.

The current NO_x aged conversion capability of NSCs is around 70 percent. Early attempts to develop NSCs had difficulty achieving even 50 percent aged conversion efficiency in spite of ~80 percent for a fresh NSC. Extensive development on catalyst test benches indicated that excessive temperatures, particularly during sulfur regeneration, caused the observed deterioration in conversion efficiency. Recently, two factors have enabled improvements. First, newer catalyst formulations have been developed to allow sulfur regeneration at somewhat lower temperatures. Second, empirical models of catalyst behavior have been developed and incorporated into the engine controller. The combined effect of these two developments has enabled increasing aged conversion efficiency to ~70 percent. In the summer of 2008, VW released the 2009 Jetta TDI for the U.S. market which utilizes an NSC and meets Tier 2, Bin 5, as well as LEV II emissions standards, enabling VW to sell the vehicle in all 50 states and Canada. A schematic of the aftertreatment system used on this vehicle is shown in Figure 5.2.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) was originally developed for stationary power plants but is now being applied to heavy-duty truck CI engines in Europe (Müller et al., 2003) and in the United States in 2010. SCR was also introduced in the United States in 2009 on some Mercedes, BMW, and VW vehicles. This system, called BlueTec, was jointly developed by all three manufacturers. SCR works by having ammonia in the exhaust stream in front of a copper-zeolite or iron-zeolite SCR catalyst. The ammonia gets stored on the catalyst surface where it is available to react with the NO_x over the catalyst converting the NO_x into N_2 and water. To provide ammonia to the exhaust stream, a liquid urea-water mixture is injected into the exhaust sufficiently upstream of the SCR catalyst unit and before a mixer, to allow time for vaporization and mixing of the urea and creation of ammonia from the urea, which is an industrial chemical used primarily as a fertilizer. In the fertilizer application, urea is relatively inexpensive, but for use with an SCR system, it must be considerably more pure and as a result is more expensive. SCR systems tend to have NO_x conversion efficiencies of 85 to 93 percent or more without the increased engine-out hydrocarbon emissions and FC resulting from NSC regenerations. As a result, vehicles using SCR have better FC characteristics at equivalent emission levels than those using NSC systems.

When urea is used to provide the ammonia, the urea-water mixture that is injected into the exhaust stream must be carried on board the vehicle. The amount of urea that needs to be supplied to the SCR catalyst depends on the level of NO_x in the exhaust and therefore depends on driving conditions, but for light-duty vehicles it is a small fraction of the fuel flow. Initial discussions regarding the possibility of using an SCR-urea approach to NO_x aftertreatment for the U.S. market were met with concern on the part of the EPA that there was considerable risk that drivers would not keep their urea tanks filled thus rendering the system ineffective. However, together with EPA oversight, vehicle manufacturers have developed systems to monitor the supply of urea in the urea tank, which will not allow the engine to restart more than a small number of times (e.g., 20) when the urea supply starts running out, following appropriate warnings to the driver. As a result of such safeguards, the EPA has approved the certification of the 2009 vehicles using the SCR-urea approach to NO_x aftertreatment. One example of an SCR-urea-based exhaust aftertreatment system is illustrated in Figure 5.3.

Combined NSC and SCR Systems

Another strategy that has been proposed is to use a system in which the NSC is followed by SCR without external urea addition. It is well known that under some operating conditions with the appropriate washcoat formulation, NSCs can convert NO_x to ammonia, which is undesirable for an NSC-only system and hence must be cleaned up before exiting the exhaust system. However, by following the NSC with SCR without urea injection, which is generally called passive SCR, SCR will capture and store the ammonia generated by the NSC and use it to reduce NO_x. Since the amount of am-

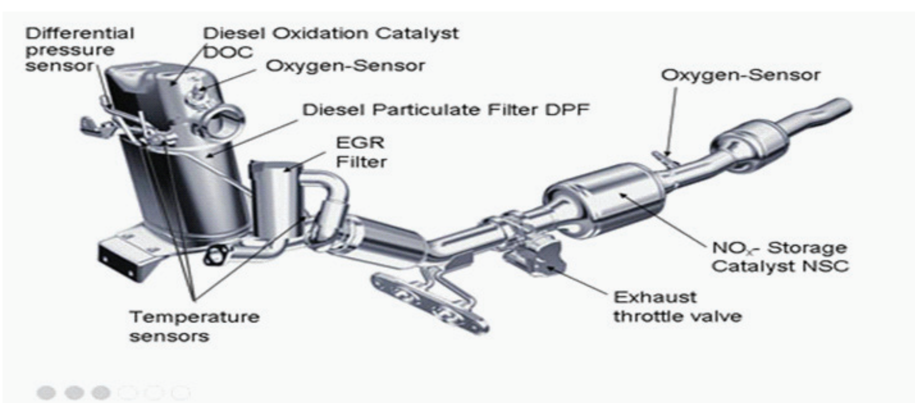

FIGURE 5.2 Exhaust aftertreatment system on the 2009 VW Jetta using NO_x storage and reduction catalyst technology for control of NO_x.
SOURCE: Courtesy of Volkswagen AG.

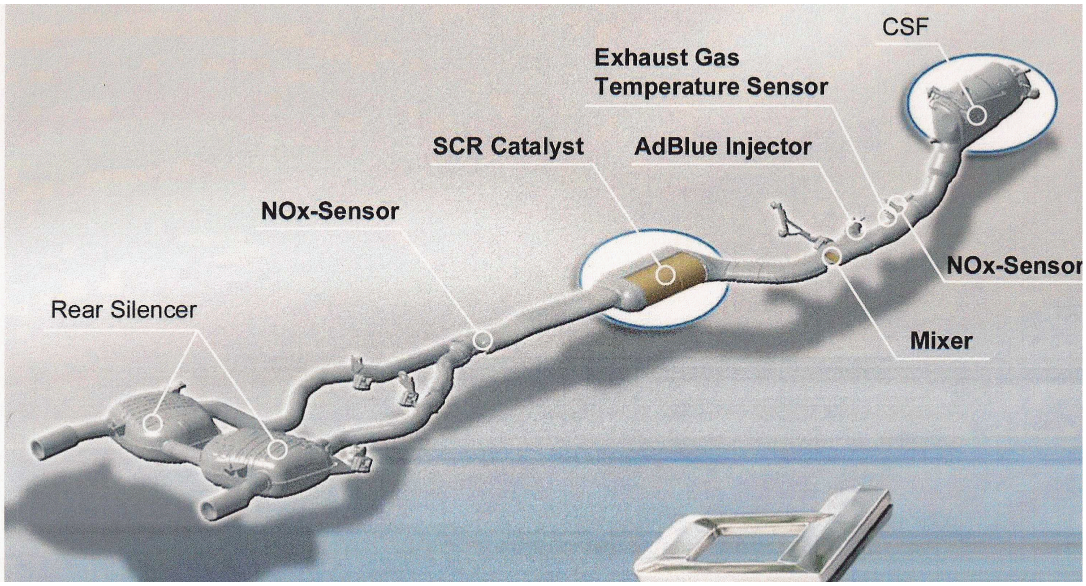

FIGURE 5.3 Schematic of a BMW exhaust aftertreatment system with selective catalytic reduction (SCR) for NO_x control using urea (called AdBlue) addition. The catalyzed soot filter (CSF) is close-coupled to the engine. SOURCE: Mattes et al. (2008). Reprinted with permission.

monia generated by the NSC is not large, the passive SCR unit will have low conversion efficiencies but can be a useful supplement to the NSC system. This approach has been used by Mercedes in its Blue-Tec I system used in Europe.

Choosing Between NSC and SCR Systems

There are both cost and functionality differences between NSC and SCR systems which would influence which choice an OEM might make for NO_x aftertreatment with CI engines. NSC systems use much more PGM (platinum group metals) than do SCR systems. (The SCR unit itself uses no PGM.) As a result, NSC system costs increase faster with increasing engine displacement than do SCR systems. Thus, from a cost point of view, NSC systems would be chosen for smaller displacement engines for which the current 70 percent NO_x conversion efficiency of the NSC is sufficient to reduce engine-out NO_x levels to below the Bin 5 emissions standards. As engine displacement is increased and engine-out NO_x emissions increase, there is an engine displacement above which the 70 percent conversion efficiency of NSCs is insufficient and the higher (approximately 85 to 93 percent) conversion efficiency of SCR is required. If PGM commodity prices are sufficiently low, NSC systems costs for larger displacement I4 engines (e.g., 2.5 to 2.8 L) might be lower than those for SCR systems for those same engines, but NO_x conversion efficiencies might not be high enough to meet the standards. Thus, the engine displacement above which an OEM would choose SCR rather than the NSC is not simply a cost-based decision.

FUEL CONSUMPTION REDUCTION POTENTIAL

CI Fuel Consumption Reduction Advantage

In a study for the EPA (EPA, 2008), Ricardo, Inc., carried out full system simulation (FSS) to assess the FC and CO_2 impact of many of the technologies expected to enable reduced FC by 2020. FSS calculations were made for the 2007 model-year light-duty vehicle fleet for a set of vehicles representing five vehicle classes. Combinations of technologies deemed to be complementary were applied to baseline vehicles considered to be representative of each class. For the selected combinations of power train and vehicle technologies, final drive ratios were varied to find the ratios that enabled performance equivalent to the baseline vehicles based on a comprehensive set of performance measures while minimizing FC. CI diesel power trains were evaluated among the combinations of technologies considered. Results for the CI diesel power train CO_2 emissions and FC versus the baseline vehicles for three of the five vehicle classes are summarized in Table 5.1. CI power trains were not applied to the other two vehicle classes, but the results for the three classes for which CI engines were evaluated are considered representative of all classes.

As indicated in Table 5.1, for the three vehicle classes considered, the average reduction in CO_2 emissions was about 23 percent and the corresponding average reduction in FC was 33 percent when the baseline 2007 model year SI power trains were replaced with CI power trains utilizing DCT6, EACC, HEA, and EPS. The 2009 VW Jetta was introduced with a 6-speed DSG (VW's name for DCT6) transmission.

TABLE 5.1 Estimated CO_2 and Fuel Consumption Reductions for Three EPA Vehicle Classes, as Determined from Full System Simulation (FSS)

Vehicle	Technology Package	Major Features	SI to CI Downsize Ratio	Combined CO_2 Emissions g/mi.	Combined Fuel Consumption gal/100 mi.	Combined CO_2 Reduction	Combined Fuel Consumption Reduction
Full-size car	Baseline	3.5-L V6 gasoline SI, AT5		356	4.051	Baseline	Baseline
	5	2.8-L I4 diesel, DCT6, EACC, HEA, EPS	80%	273	2.707	23.3%	33.2%
Small MPV	Baseline	2.4-L I4 gasoline SI, DCP, EPS, AT4		316	3.596	Baseline	Baseline
	5	1.9-L I4 diesel, DCT6, EACC, HEA, EPS	79%	247	2.449	21.8%	31.9%
Truck	Baseline	5.4-L V8, gasoline SI, CCP, AT4		517	5.883	Baseline	Baseline
	5	4.8-L V8 diesel, DCT6, EACC, HEA, EPS	89%	391	3.877	24.4%	34.1%
		Average CI diesel versus gasoline				23.2%	33.0%

NOTE: See Chapters 2 and 8 for more information on FSS. To determine the FC reductions, the CO_2 emissions results taken from EPA (2008) were converted to volumetric FC using conversion factors from EPA (2005). AT5, lockup 5-speed automatic transmission; AT4, lockup 4-speed automatic transmission; CCP, coordinated cam phasing; DCP, dual (independent) cam phasing; DCT6, dual-clutch 6-speed automated manual transmission; EACC, electric accessories (water pump, oil pump, fans); EPS, electric power steering; HEA, high-efficiency alternator.
SOURCE: Based on EPA (2008).

Note also that CI engines were downsized in displacement by an average of about 83 percent from the SI engines they replaced. Tables 7.13, 7.15, and 7.18 from EPA (2008) for small MPVs, full-size cars, and trucks, respectively, indicate that these CI engine-powered vehicles with DCT6 transmissions provided equivalent performance to the vehicles with larger-displacement original SI engines and transmissions.

The 2007 model-year baseline vehicles were equipped with 4- and 5-speed automatic transmissions. As noted above, the 33 percent FC reduction indicated in Table 5.1 reflected DCT6 transmissions and more efficient engine accessories as well as the engine change. To estimate the separate effect of replacing SI engines and transmissions by CI engines with equivalent transmission technology and without advanced accessories, a European database of 2009 vehicles was analyzed. Using vehicles that are offered with 5- and 6-speed transmissions for both SI and CI engines, an estimate was derived of the reduction in FC from replacing SI engines with CI engines at equivalent vehicle performance without the effect of simultaneously converting from 4- and 5-speed automatics to DCT6 transmissions. The data used for this estimate are plotted in Figure 5.4 and shown in tabular form in Table 5.A.1 in the annex at the end of this chapter.

Figure 5.4 indicates that the average FC reduction for this vehicle subset was about 25 percent. Therefore, the FC reductions achievable from engine replacement alone without a simultaneous transmission change to DCT6 (and EACC with HEA) would be about 25 percent.

Fuel Volumetric Energy Effect

It should be noted that part of the volumetric FC benefit of CI diesel engines stems from the differences in volumetric energy content between gasoline and diesel fuels. The energy content of a gallon of diesel fuel is about 11 percent higher than that of gasoline. While this factor can be an advantage for drivers if diesel fuel is selling at gasoline prices or lower, the carbon dioxide emissions advantage for the diesel would be less than would be indicated by the volumetric FC advantage of the CI diesel engine. As indicated in Table 5.1, the CO_2 reduction advantage for CI engines is about 10 percent less than their FC reduction advantage.

Fuels for CI Engines

The performance and emissions of diesel engines are also influenced by the fuel characteristics and fuel quality. Although fuel is not a focus of this report, several relevant characteristics for performance and emissions are important in connection with their influence on engine performance,

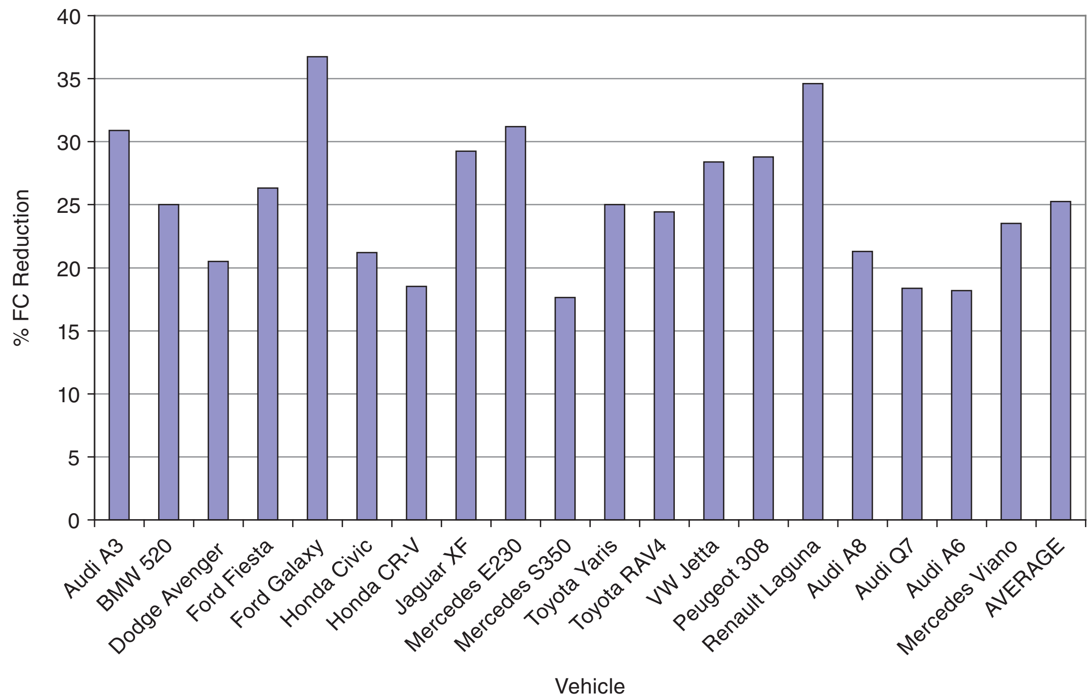

FIGURE 5.4 Percent reduction of fuel consumption (FC) on the NEDC driving cycle for a subset of 2009 European vehicle platforms offered with both SI and CI engines. The subset was selected from a larger set of 2009 vehicle platforms offered with both SI and CI engines by including only those platforms for which 0-62 mph (0-100 km/mile) times were within 5 percent, which was considered to be equivalent performance. The data used to construct this figure are shown in Table 5.A.1 in the annex at the end of this chapter.

efficiency, and emissions. These characteristics are *cetane number* (a measure of fuel self-ignition in the CI cycle—important in cycle efficiency, but also in low-temperature operation), *density/heating value* (a measure of volumetric energy content), *lubricity* (important for fuel system wear and durability), and *sulfur level* (important for proper operation of the engine exhaust aftertreatment system).

In the U.S. market, there is only one diesel fuel suited for on-road transportation; its characteristics are specified by the ASTM Standard D975. Most state regulations require the enforcement of these specifications. In the EU, where light-duty CI diesel passenger cars are widespread and about half the new cars are powered by diesel engines, the diesel fuel is specified by the EN590 standard. There are significant differences between the EU and the ASTM standards. The EU fuel has much higher cetane (e.g., 52 versus 40-48), the fuel density is limited to a minimum to assure adequate energy density (no limit exists in the ASTM standard), and the lubricity is better. In terms of fuel sulfur, European fuel has similar levels to U.S. fuels, for which sulfur level is regulated by the 2006 EPA standards to 15 ppm or less.

In the near future, most diesel passenger cars in the United States will be imports from Europe. Their engines have been adapted for use of U.S. diesel fuel, and the manufacturers do not expect to encounter performance and emission issues connected with the fuel, as long as fuel specifications are enforced and quality is adequate. Cylinder-pressure-based closed-loop control, as discussed earlier and utilized in one of the new 2009 CI diesel vehicles, can adjust for market variability in the cetane number of the fuel and provide compensation over the entire operating engine map. The lower lubricity of the U.S. diesel fuel requires protective coatings for the high-pressure pump in the fuel injection system. As noted earlier, the ultralow level of sulfur in the fuel regulated to less than 15 ppm is a necessary enabler for the efficient and durable operation of the exhaust aftertreatment system. Nonetheless, all OEMs marketing CI diesel vehicles in the North American (NA) market have concerns over the seasonal and regional variability of diesel fuel as well as the enforcement of fuel quality.

At present, the ASTM D975 fuel standard allows up to 5 percent biodiesel blend stock in the fuel provided the blend stock meets the characteristics of the ASTM standard. The European OEMs exporting diesel vehicles to the United States have stated that their engines are robust to this fuel blend and that performance and emissions are not affected as long as the blend is at or under 5 percent. For the European market, the manufacturers may allow up to 7 percent FAME (fatty acid methyl ester), plus up to an additional 3 percent hydrogenated biofuel. The difference in the proportion allowed by the European OEMs for the U.S. market versus for the European market is due to their concern over the quality and stability of American blend stock and the variety of feedstocks, including soy, recycled used oils, fats, etc.

Efficiency Improvements from Transmissions

The transmission technology utilized in the FSS results shown in Table 5.1 was a dual-clutch 6-speed (automated manual) transmission (DCT), which is a very efficient design concept. Transmissions used for CI diesels must be designed to handle their larger torque, which may reduce their efficiencies slightly due to larger gears, bearings, and seals. DCTs are already in production for smaller displacement CI engines (e.g., 2009 VW Jetta). The most challenging aspect of designing DCTs with the higher torque capacities needed for larger displacement CI engines is providing adequate cooling for their wet clutches (i.e., oil-cooled clutches). Dual-mass flywheels, which reduce drive train vibration, thus reducing heat-generating clutch slippage, will be used. Nonetheless, it is not presently known when such DCT units will be available with 500-650 N-m torque capacities for larger CI engines.

Expected transmission-based CI vehicle efficiency improvements beyond those already comprehended by the use of the DCT6 transmissions are estimated at 1 to 2 percent for downspeeding the engine by increasing the number of discrete speed ratios beyond six. The increased number of ratios allows keeping the average engine speed lower while still maintaining equal performance, which is why this approach is called "downspeeding." Another 2 to 3 percent is expected from reduced transmission internal losses.

Overall Fuel Consumption Reduction Potential

The FC reduction potential via replacement of SI gasoline power trains by base-level CI power trains is illustrated by Table 5.1 (i.e., ~33 percent) for CI engines with advanced transmissions (plus EACC, HEA, and EPS) and by Figure 5.4 for engine replacement alone (i.e., ~25 percent). Additional technical improvements, as noted earlier, from downsizing, thermodynamic improvements, friction reduction, and engine accessory improvements, are being developed and will be implemented. CI engines with these technologies implemented are termed advanced-level CI engines. Transmission improvements are also possible.

Based on interactions with OEMs, consulting companies, review of the technical literature, and the judgment of the committee, estimates of the overall FC reduction potential from these advanced-level technology areas are presented in Table 5.2. For the ranges shown, the 10 percent for engine technologies alone and 13 percent for vehicles applies to larger vehicles with automatic transmissions. For smaller vehicles with manual transmissions and engine displacements less than 1.5 L, cost constraints are likely to reduce the extent of downsizing and the potential would be about 6 percent for engine alone and 7 percent for vehicle due to elimination of not only the gain from automatic transmission efficiency

TABLE 5.2 Estimated Fuel Consumption Reduction Potential for Advanced-Level CI Power Trains Compared to Base-Level CI Power Trains

Item	Average Reduction (%)	Min	Max
Large Vehicles			
Downsizing	4	3	5
Downspeeding	1.5	1	2
Friction reduction	1.5	1	2
Combustion improvement	3	2	4
Total engine improvement	10		
Accessory improvement	1	0.5	1.5
Transmission loss reduction	2	1.5	2.5
Combined engine and transmission potential	13		
Item	(%) Reduction	Min	Max
Small Vehicles (<1.5 L)			
Downsizing	1	0	2
Downspeeding	0.5	0	1
Friction reduction	1.5	1	2
Combustion improvement	3	2	4
Total engine improvement	6		
Accessory improvement	1	0.5	1.5
Thermal management	0	0	0
Transmission loss reduction	0	0	0
Combined potential	7		

NOTE: The values shown for the combined potential do not show a range. It is tempting to use the sum of the minimum values for the lower limit of the range and the sum of the maximum values for the upper end of the range. However, this would be inappropriate because no original equipment manufacturer is likely to simultaneously achieve either the minimum or the maximum for all items. Therefore, a realistic range for the combined potentials is about ±1 percent.

improvement (–2 percent) but also some of the gains from downsizing (–3 percent) and downspeeding (–1 percent).

TECHNOLOGY READINESS/SEQUENCING

In 2003, J.D. Power estimated the CI light-duty market share would reach 16 percent by 2015 (Peckham, 2003). However, the fuel price run-up of 2007-2008 caused a significant negative price differential between diesel and gasoline fuel (i.e., diesel fuel more expensive than gasoline) due to a global shortage of distillate/diesel fuel. This negative price differential has probably interfered with the growth of CI diesel vehicle sales. Even with the large fuel price reduction resulting from the economic slowdown of 2008 to 2009, the negative price differential has gone away slowly. Table 5.3 provides a brief summary of the average U.S. gasoline-to-diesel price differential evolution between May 2008 and June 2009. From Table 5.3 it can be seen that the negative price differential decreased substantially (from 54 cents/gal, or 15 percent, to 11 cents/gal, or 5.2 percent) between May 2008 and May 2009. Between May 2009 and June 2009, gasoline prices increased more than diesel (~45 cents/gal versus 17 cents/gal) causing a shift to a positive price differential. Whether this positive price differential remains when global economic activity returns to normal levels can only be guessed. The current positive price differential in combination with the new national fuel economy standards announced May 19, 2009, may strengthen interest in CI diesel vehicles, but it remains to be seen if the predicted U.S. CI diesel market share of 16 percent will be reached by 2015.

Application of CI technology into the NA market to reduce fuel consumption involves two steps. The first step is the introduction of vehicles with optional base-level CI power trains. The second step is the improvement of these CI power trains to advanced-level ones by implementation of the advanced technologies whose potential gains are indicated in Table 5.2.

The first step is underway now, as noted earlier in this chapter, as demonstrated by the introduction of a large number of vehicles for the 2009 model year. However, these vehicles primarily use versions of CI already in production for the European market. The decisions that put these introductions into product plans occurred several years earlier when it became clear first that there was encouraging development of technology enabling compliance with the 2010 Tier 2, Bin 5 and LEV II emissions standards for modified versions of these existing engines, and second that market conditions were supportive of such introductions due to increasing concern with the rise in both the price of fuel and in greenhouse gas (GHG) emissions. Had these conditions continued, it seems likely that additional vehicles beyond those announced for 2009 would have been introduced in model years 2010 and 2011. However, as noted earlier, as the petroleum price rose and fell during 2008, the unfavorable differential between gasoline and diesel fuel grew and then decreased, leaving potential CI vehicle buyers uncertain about future fuel prices. As a result, the pace of introduction of vehicle platforms with CI power trains for the NA market based on engines already in production is likely to decrease due to reduced market demand because of the fuel-price differential history as well as lower fuel prices in general. In addition, the global economic slowdown and the associated reduced tooling capital availability caused by the global auto industry's economic problems will also have a major impact on decisions about tooling new CI power trains for those OEMs that do not already have appropriately sized CI engines in production. Appropriately sized engines would be those with displacements suitable for the classes of vehicles whose fuel consumption reduction would have the largest impact on OEMs' specific fleet CAFE values.

Therefore, the second step, introduction into the market of CI technologies that could reduce light-duty fuel consumption beyond that shown in Table 5.1, will likely follow two paths. The first path is the introduction of the advanced-level technologies listed in Table 5.2 into post-2009 vehicles that were newly introduced in the 2009 model year. It is expected that this will occur in vehicles for model-years 2011-2014. This estimate is based on several factors. First, it is known that these technology areas are currently under development based on meetings with several OEMs. Second, European OEMs that are introducing CI-powered vehicles in the North American market in 2009 will also be preparing for Euro 6 emissions regulations that will take effect in 2014. Since Euro 6 NO_x requirements are less stringent than Tier 2, Bin 5 and LEV II emissions technologies to be used for Euro 6 will have already been developed to meet the U.S. requirements. As a result, it is expected that European OEM engineering resources in the 2009-2011 time frame will be partly applied

TABLE 5.3 Comparison of U.S. Average Gasoline and Diesel Fuel Prices Between May 2008 and June 2009

Date	Gasoline Cost ($/gal)	Diesel Cost ($/gal)	Gasoline to Diesel Cost Difference (cents)	Diesel to Gasoline Cost Difference (percent)
May 9, 2008	3.613	4.149	−54	−14.8
May 9, 2009	2.078	2.185	−11	−5.15
June 1, 2009	2.524	2.352	+17	+7.3

SOURCE: EIA (2009b).

to realizing some of the efficiency gains summarized in Table 5.2. For the OEMs active in the European market, this timeline is compatible with tax incentives expected in 2011 for early introduction of vehicles meeting Euro 6 as well as with the next European fleet CO_2 reduction target in 2012.

The second path for introduction of the advanced-level technologies summarized in Table 5.2 is their introduction simultaneously with new CI power trains in the period 2014-2020. These advanced-level versions will be required for market competitiveness for these new vehicles since the OEMs introducing CI vehicles between 2009 and 2011 will probably have already implemented advanced-level technology features. For example, BMW has already introduced an engine with two-stage turbocharging, one of the key features of the advanced-technology level. However, the pace of introduction of these vehicles with newly tooled CI engines will follow the new market conditions based on the economic recovery of global economies and the related automobile markets.

In addition, California Air Resources Board (CARB) LEV III standards are expected for 2013. The LEV III emissions levels currently under discussion would be very challenging. So OEMs will be developing technologies to enable their diesel products to meet LEV III and associated regulations. Studies at European OEMs with development vehicles using emissions control technologies developed to meet Tier 2, Bin 5 standards indicate that these technologies need additional development to achieve proposed LEV III requirements. As a result, it is expected that there will be some fuel consumption increase in order to meet the new standards.

In summary, the following technology sequencing is envisioned:

- For OEMs with existing CI engines, vehicles introduced in 2009 will be joined by additional models from 2011 to 2014, with base-level or advanced-level technology features depending on each OEM's particular marketing strategy.
- During the period 2015-2020, it is expected that development efforts for these OEMs will be focused on further reduction of power train cost and fuel consumption to achieve the upper limits of the ranges shown in Table 5.2.

For OEMs without existing CI engines with displacements in the range that would have the biggest impact on improving their CAFE values (e.g., V6 engines with displacements around 3.5 L for SUV and pickup trucks), new engines may be developed and put into production if three conditions are met. First, overall light-duty markets in the 2010-2012 period must improve sufficiently from those of 2009 to generate improved corporate financial health and required tooling capital. Second, a favorable customer perception of CI power trains must evolve based on the 2009-2012 CI vehicles already in the market. These new engines would probably be introduced in both base-level and advanced-level technology versions in order to both be technologically competitive with advanced-level technology products already in the market and to achieve market volumes necessary to justify the tooling investment. Third, fuel prices must increase from late 2009 levels but without significant negative price differential between gasoline and diesel in order to provide potential customers with sufficient incentive to offset the additional prices that must be charged for CI engines.

TECHNOLOGY COST ESTIMATES

There are a number of complexities in making cost estimations for CI engines to replace SI engines. The first of these involves selecting the appropriate displacement for the CI engine. This is important because CI engine costs depend significantly on their displacement for two primary reasons. First, the configuration and cost of their exhaust aftertreatment systems depend on engine displacement since component substrate (e.g., oxidation catalyst, particulate filter) volume is proportional to engine displacement and precious metal washcoat weights applied to the substrates are proportional to substrate volume. In addition to washcoat factors, NSC (NO_x storage catalyst) and urea-SCR-based NO_x reduction systems have different relationship multipliers to engine displacement. This is because urea-SCR-based systems use much less PGM compared to NSC-based systems, thus decreasing the rate at which costs increase with displacement.

Second, the degree of downsizing employed for the CI engine determines the cost and complexity of the air system for the engine. Maximum downsizing corresponding to advanced-level CI engines requires two-stage turbo systems, which cost about twice those of base-level single-stage turbo systems.

The cost of the engine structure and mechanical parts of CI engines depends less on displacement since smaller engines have all the same parts as larger displacement ones. These parts all require the same casting, fabrication, and machining processes and differ primarily in the amount of raw materials used, which has a relatively small influence on total cost. In the present work, no displacement-based adjustment was made to the cost estimates for the basic engine structure and parts.

Engine Sizing Methodology

The engine sizing methodology developed for this work is based on current and future product development directions. Two CI engine configurations have been considered, namely, base-level engines and advanced-level engines, as discussed above in the subsection titled "Overall Fuel Consumption Reduction Potential." Performance of a given vehicle depends primarily on the combined effect of the torque curve of the engine, the transmission characteristics (e.g., speed ratio range and internal efficiency), and final drive ratio. For base-level CI engines, a maximum specific torque density of 160 N-m/L is assumed. This level is achievable with single-stage turbo systems and, for example, is the level achieved by the Tier 2, Bin 5-compliant 2009 VW Jetta. The CI engines considered in the Ricardo, Inc., FSS analysis (EPA, 2008) from which the fuel consumption reduction values in Table 5.1 were determined had base-level technology features with single-stage turbo systems.

For advanced-level CI engines, a specific maximum torque density of 200 N-m/L is assumed. This level allows downsizing from base-level CI engines, thereby enabling additional fuel consumption reductions. The Tier 2 Bin 5 compliant 2009 BMW 335d with two-stage turbocharging achieves over 192 N-m/L and the Mercedes OM651 recently introduced in Europe achieves 233 N-m/L, and so the 200 N-m/L assumed for the advanced-level technology CI engine is considered realistic.

Based on the results from the full system simulation vehicle simulations carried out by Ricardo, Inc., for the EPA (EPA, 2008) (see Table 5.1) for 2007 model-year midsize MPV, full-size car, and truck-class vehicles, base-level CI engines displacing about 83 percent of the SI engines they replaced achieved equivalent vehicle performance when combined with advanced DCT6s (6-speed dual-clutch transmissions). It is therefore assumed that base-level CI engine displacement is about 83 percent of that of the 2007 model-year SI engine being replaced. Similarly, advanced-level CI engines having displacements about 80 percent of those of base-level CI engines can maintain equivalent vehicle performance. This is because the maximum torque of a base-level CI engine of displacement δ would be about $160 \times \delta$ N-m. Since the base-level maximum specific torque of 160 N-m/L is 80 percent of the 200 N-m/L for the advanced-level CI engine, the appropriately sized advanced-level CI engine would have 80 percent of the displacement of the base-level engine (i.e., 80 percent $\times\ \delta$). Then peak specific torque of the advanced-level CI sized at 80 percent would be equal to that of the base-level (i.e., $200 \times (80 \text{ percent} \times \delta) \approx 160 \times \delta$). With equal maximum torque, the advanced-level CI engine would enable equivalent vehicle performance.

Cost Estimation Methodology

The cost estimations from the sources considered in the present work (Martec Group, Inc., 2008; EPA, 2008, 2009; Duleep, 2008/2009) are then compared with those used by the NHTSA in its final rulemaking for 2011 (DOT/NHTSA, 2009). The Martec study used a BOM (bill of materials) approach based on technology packages consisting of combinations of components that fit together technically and made sense from a marketing point of view. BOM is also discussed in Chapter 3. This assessment was made by OEMs and suppliers with which Martec met. Martec then developed component-by-component costs and described the resultant BOM and cost sets in extensive detail. The resultant BOMs included not just the CI engine hardware added or SI hardware subtracted but also additional components that, in the judgments of the OEMs and suppliers, were necessary to make fully functional vehicles meeting both emissions standards and customer expectations. Martec reviewed the resultant cost tables with both the OEMs and the suppliers to reach consensus. It is often said by OEMs that cost numbers provided by suppliers are lower than what OEMs actually have to pay, while suppliers counter that the costs that OEMs say they have to pay include more content than that quoted by the supplier. It is hoped, therefore, that the approach used by Martec to reach consensus avoided this potential confusion and provided more correct estimates. Finally, the Martec study was carried out in 2007-2008—more recently than the years (2002-2006) on which the EPA (2009) estimates were based or the period covered (2005-2008) in Duleep (2008/2009) estimates.

To avoid the rather subjective issue of cost reductions over the production life of components, Martec developed cost estimates assuming very large production volumes so that all volume-related learning could be considered already reflected by its cost estimates. For some existing components, like common rail injection systems, global production volumes are already high enough to exceed the Martec volume threshold, and cost estimates for these items would automatically include cost reductions from high-volume learning. On the other hand, it is not expected that the CI diesel engines used for the NA market alone will exceed that volume threshold before 2020. However, since many of these engines will also be produced for the European Union (EU) market, whether by EU OEMs or by U.S. domestic OEMs that produce such engines for their EU products, the combined EU, U.S., and Canadian volumes may reach the 500,000-unit threshold. Thus the volume thresholds required to realize high-volume earnings will consist of combined EU and NA volumes for a number of the engines in the CI diesel fleet. It is expected that volumes will reach the 500,000-unit threshold primarily for the engines sold in the highest volumes in the EU (e.g., ~1.6 L). Thus for some of the smaller engine displacements likely to have low volumes in the U.S. market (e.g., <1.5 L) as well as for larger engines (e.g., 4.0-4.5 L) used in vehicles not marketed at high volume in the EU (e.g., large SUVs and pickups), the 500,000-unit volume target may not be reached by 2020 and costs will remain somewhat higher. To that extent, some of the Martec CI cost increment estimates could be too low.

The cost estimates developed in the present work were derived primarily from the Martec study (Martec Group, Inc., 2008). This choice was made for the reasons stated above. In addition, the Martec report included detailed specification of the exhaust aftertreatment system configuration, sizing, and PGM washcoat loadings. This type of information was not included in EPA (2008, 2009) studies or in Duleep (2008/2009). In addition, the Martec report described the commodity cost basis used, thus allowing modification of those costs in the present work to reflect recent decreases in commodity pricing for PGMs.

Base-Level Engine Technology Cost Estimates

Incremental CI diesel engine cost estimates developed in the present study for replacing 2007 model-year SI gasoline engines with equivalent performance CI diesels are summarized in Tables 5.4, 5.5, and 5.6. Appendix G contains the same information for full-size body-on-frame pickup trucks.

Emissions Systems Cost Estimates

Since the exhaust emissions systems are a significant fraction of the cost for CI diesel power trains, the brief entries in Tables 5.4 and 5.5 are described in more detail in Table 5.6. Note that the entries in Tables 5.4 and 5.5 reflect choices made for NO_x aftertreatment technologies. For the midsize sedan, it was assumed that the 70 percent aged conversion efficiency currently achievable with NSC-based systems would be sufficient for emissions compliance through the year 2020. Using the spreadsheet from which the cost estimates shown in Table 5.6 were obtained, it was also determined that for a 2.0-L CI engine for a midsize sedan, the NSC system is a lower cost approach ($688) than is a urea-SCR-based system ($837). As a result, Table 5.6 contains no cost estimates for the SCR-urea system for the midsize sedan. This choice could be changed depending on success in meeting LEV III requirements with NSC-based systems and changes in PGM commodity prices. However, for the heavier SUV, SCR-urea with its capability for 85 to 93 percent conversion efficiency will be required for emissions compliance. As a result, there are no entries in Table 5.6 for NCS NO_x aftertreatment for the SUV since it is assumed that SCR technology will be used.

Commodity prices were quite volatile between 2004 and 2008 (Martec Group, Inc., 2008), making product planning for CI diesel vehicles quite challenging. To illustrate the impact of PGM (platinum group metals consisting of platinum, palladium, and rhodium) commodity price volatility, Table 5.6 includes estimates for the precious metal wash coats used in the catalysts in separate rows labeled PGM loading. In addition, two columns are shown for each of the two reference vehicles. Columns two and four correspond to the PGM prices in November 2007 used in the Martec study (Martec Group, Inc., 2008). The estimates in columns three and five illustrate emissions systems costs based on PGM prices from April 2009 computed in the present study. These latter costs were used for the aftertreatment system cost estimates in Tables 5.4 and 5.5 because they are considered more representative of the post 2009 period. Obviously, this price situation must be monitored, since it is unlikely to remain at April 2009 levels until 2020. For the sedan with an advanced-level downsized 1.6-L engine, emissions system cost between November 2007 and April 2009 dropped 30 percent. Note that the catalyst volumes for the cost computation for the downsized 1.6-L engine were not reduced from the 2.0-L sizes since the 1.6-L engine must produce the same power

TABLE 5.4 Committee's Estimates of Incremental Cost of CI Diesel Engine over a Baseline SI Gasoline Engine for Replacing SI 2.4-L MPFI DOHC Four-Valve Engines in Midsize Sedans (e.g., Malibu, Accord) with Base-Level 2.0-L I4 CI Engines

50-State-Saleable ULEV II 2.0-L DOHC CI Diesel Engine Baseline: SI Gasoline 2.4- L MPFI DOHC 4V I4	Estimated Cost vs. Baseline ($)
Common rail 1,800 bar piezo-actuated fuel system with four injectors (@$75), high-pressure pump ($250), fuel rail, regulator, and fuel storage upgrades plus high-energy driver upgrades to the engine control module. Credit for SI content deleted ($32)	675
Variable-geometry turbocharger (VGT) ($250) with electronic controls, aluminum air-air charge air cooler, and plumbing ($125)	375
Upgrades to electrical system: starter motor, alternator, battery, and the 1-kW supplemental electrical cabin heater standard in Europe ($59)	125
Cam, crank, connecting rod, bearing, and piston upgrades, oil lines ($50) plus NVH countermeasures to engine ($40) and vehicle ($71)	161
HP/LP EGR system to suppress NO_x at light and heavy loads; includes hot side and cold side electronic rotary diesel EGR valves plus EGR cooler and all plumbing	215
Emissions control system including the following functionality: diesel oxidation catalyst (DOC), catalyzed diesel particulate filter (CDPF), NO_x storage catalyst (NSC), EGR catalyst, passive SCR. Stoichiometric MPFI emissions and evaporative systems credit ($245). See Table 5.6 for a detailed breakdown of the emissions control system components leading to the total shown here.	688
On-board diagnostics (OBD) and sensing including an electronic throttle control ($25), four temperature sensors (@$13), wide-range air-fuel ratio sensor ($30), two pressure-sensing glow plugs (@17), two conventional glow plugs (@$3), and Delta-P sensor for DPF ($25). Credit for two switching O_2 sensors (@$9).	154
Total variable cost with credits for SI parts removed. Excludes any necessary transmission, chassis, or driveline upgrades.	2,393

NOTE: The credit for downsizing from V6 to I4 included in the Martec Group, Inc. (2008) study was not used in the committee's estimates since baseline 2007 midsize sedan SI gasoline engines were not V6 but 2.4-L I4 engines. Cost estimates for aftertreatment systems reflect April 2009 prices for platinum group metals.

TABLE 5.5 Committee's Estimates of Incremental Cost of CI Diesel Engine over a Baseline SI Gasoline Engine for Cost Estimations to Replace SI MPFI DOHC Four-Valve 4.0- to 4.2-L Six-Cylinder Engine in a Midsize Body-on-Frame SUV (e.g., Explorer, Durango) with a 3.5-L V6 DOHC CI Engine

50-State-Saleable ULEV II 3.5-L V6 DOHC CI Diesel Engine Baseline: SI Gasoline DOHC 4V 4.0-4.2-L Six Cylinder	Estimated Cost vs. Baseline ($)
Common rail 1,800 bar piezo-actuated fuel system with six injectors (@$75), high-pressure pump ($270), fuel rail, regulator and fuel storage upgrades plus high-energy driver upgrades to the engine control module. Credit for MPFI content deleted ($48).	911
Variable-geometry turbocharger (VGT) ($350) with electronic controls, water-air charge air cooler, circulation pump, thermostat/valve and plumbing ($135)	485
Upgrades to electrical system: starter motor, alternator, battery, and the 1.5-kW supplemental electrical cabin heater standard in Europe ($99)	167
Cam, crank, connecting rod, bearing, and piston upgrades, oil lines ($62) plus NVH countermeasures to engine ($47) and vehicle ($85)	194
HP/LP EGR system to suppress NO_x at light and heavy loads; includes hot side and cold side electronic rotary diesel EGR valves plus EGR cooler and all plumbing	226
Emissions control system including the following functionality: DOC, CDPF, selective catalytic reduction (SCR), urea dosing system ($363). Stoichiometric MPFI emissions and evaporative systems credit ($343). See Table 5.6 for a detailed breakdown of the emissions control system components leading to the total shown here.	964
On-board diagnostics (OBD) and sensing including four temperature sensors (@$13), wide-range air-fuel ratio sensor ($30), NO_x sensor ($85), two pressure-sensing glow plugs (@17), four glow plugs (@$3), and Delta-P sensor for DPF ($25). Credit for four switching O_2 sensors (@$9)	227
Total variable cost with credits for SI parts removed. Excludes any necessary transmission, chassis, or driveline upgrades.	3,174

NOTE: The credit for downsizing from V8 to V6 included in Martec Group, Inc. (2008) was not used here because the baseline 2007 SI engine was a V6, not the V8 assumed in Martec Group, Inc. (2008). Aftertreatment system cost estimates reflect April 2009 prices for platinum group metals.

TABLE 5.6 Cost Estimates for Exhaust Emissions Aftertreatment Technologies Capable of Enabling Tier 2, Bin 5 Compliance

Item	Midsize Car (e.g., Malibu) Catalytic Device Sizing Based on 2 L (Nov. 2007 PGM prices)	Midsize Car (e.g., Malibu) Catalytic Device Sizing Based on 2 L (Apr. 2009 PGM prices)	Midsize SUV (e.g., Explorer), Catalytic Device Sizing Based on 3.5 L (Nov. 2007 PGM prices)	Midsize SUV (e.g., Explorer), Catalytic Device Sizing Based on 3.5 L (Apr. 2009 PGM prices)
DOC 1				
Monolith and can	$52	$52	$52	$52
PGM loading	$174	$139	$210	$200
DOC 2				
Monolith and can	Not used	$0	$52	$52
PGM loading	Not used	$0	$73	$70
EGR catalyst				
Monolith and can	$7	$7	Not used	Not used
PGM loading	$22	$13	Not used	Not used
Coated DPF				
Advanced cordierite brick and can	$124	$124	$270	$270
PGM loading	$160	$131	$29	$26
NSC system				
Catalyst brick and can	$114	$114	Not used	Not used
PGM loading	$533	$314	Not used	Not used
SCR-urea system				
SCR brick and can	$39	$39	$274	$274
Urea dosing system	Passive SCR	Passive SCR	$363	$363
Stoichiometric gasoline emissions and evaporative system credit	−$245	−$245	−$343	−$343
Emissions System Total	$980	$688	$980	$964

NOTE: The significant impact of platinum group metals (PGM) commodity prices is illustrated by the difference between the costs in columns 2 and 4 (based on November 2007 prices) and the costs in columns 3 and 5 (based on April 2009 prices).

output as the 2.0-L engine, requiring that exhaust gas flow rates remain virtually unchanged. For the SUV, a smaller 10 percent emissions system cost drop was observed due to the lower PGM usage with SCR-urea aftertreatment for out-of-engine NO_x control for the SUV. With SCR-urea systems, only the SCR device contains no PGM. As can be observed from examination of the entries in Table 5.6, DOC1, DOC2, and the coated DPF (called CDPF) all utilize PGM wash-coats. As noted earlier, the spreadsheet used to generate the aftertreatment cost estimates shown in Table 5.6 is available for recomputing the aftertreatment system cost estimates should PGM commodity prices change significantly.

Finally, there is a technology choice involved in DPF systems. The four substrate options currently available for particulate filters are silicon carbide (Si-C), conventional cordierite, advanced cordierite, and acicular mullite. Conventional cordierite is used for most nonparticulate filter substrates (e.g., DOC and NSC catalysts), whereas Si-C has been the predominant choice for light-duty DPF usage in Europe. Conventional cordierite is less expensive and lower in mass than Si-C. On the other hand, Si-C has much higher thermal conductivity and strength, which are very favorable properties for withstanding regeneration without local hot spots causing thermal stress cracking and ultimate failure of the filter. As a result of these property differences, Si-C filters are typically filled (i.e., loaded) with about twice the amount of particulate (e.g., 8-9 g/L) during vehicle operation before regeneration is carried out, whereas conventional cordierite filters must be regenerated after about half that loading (e.g., 4-5 g/L) of particulate.

There are two results from this difference. First, conventional cordierite-based filter systems tend to require more frequent regenerations with associated FC increases. Second, since during regeneration fuel is injected into the engine cylinder during the expansion stroke with the piston part way down the cylinder to raise the temperature of the gases by partial oxidation of this regeneration fuel in the cylinder and completion of oxidation of that fuel in the oxidation catalyst, some fuel from the high-pressure spray reaches the cylinder wall and some of that fuel escapes past the piston rings down into the crankcase, where it dilutes the lubricating oil with fuel. This dilution requires more frequent oil changes to protect engine durability. Since frequency of oil changes is a marketing attribute, the choice of substrate has multiple implications, namely cost, durability, mass, and oil-change interval.

Advanced cordierite is emerging as a compromise between the properties of Si-C and conventional cordierite (Tilgner et al., 2008). Therefore, for the purpose of this report, it has been assumed that new DPF applications will utilize advanced cordierite (as was assumed for the estimates in the Martec [2008] report) and that existing Si-C applications will be converted to advanced cordierite for the next design and development cycle. Thus the cost estimates shown in Table 5.7 are based on the use of advanced cordierite for DPF monoliths.

Finally, acicular mullite has recently been introduced to the market. This new material has a number of properties that are potentially advantageous for exhaust filtration. First, this material appears to have lower pressure drop than the other materials due to higher porosity. According to material property specifications (Dow, 2009), this higher porosity and lower pressure drop remain when catalytic coatings are applied. As a result, it may be possible to integrate additional exhaust aftertreatment system components (e.g., combining SCR and DPF units into one component), thus reducing system cost, packaging volume, and complexity. The first production application of this material is expected in 2011, after which its technical potential and cost tradeoff relative to other materials will become clearer.

TABLE 5.7 Comparison of CI Engine Cost Estimates from Different Sources and the Committee's Estimates

Source	I4 CI Engine ($)	V6 CI Engine	Engine Sizing Methodology Specified	Aftertreatment System Configurations and PGM Loadings	PGM Cost Basis	Dollar Basis
Martec Group Inc. (2008)	2,361	3,465	Partially	Yes	Nov. 2007	2007
EPA (2009)	2,052	2,746	Yes	Configuration, yes; sizing-loading, no	Not specified	2007[a]
Duleep (2008/2009)	1,975	2,590	No	Configuration, yes; sizing-loading, no	Not specified	2008
DOT/NHTSA (2009)[b]	2,667	3,733	Partially	Assumed to be based on those of Martec Group, Inc. (2008)	Nov. 2007	2007
NRC (2010)[c]	2,393	3,174	Yes	Yes[d]	Apr. 2009	2007

[a]EPA 2009 estimates provided were for dollar-year-basis 2002 for engine and 2006 for aftertreatment. The numbers shown have been corrected by applying the ratios of the yearly producer's price index (1.0169 for 2002 to 2007 and 1.0084 for 2006 to 2007). However, significant technology development has taken place since 2002, and so it is likely that technology-based component specifications and associated costs have changed.

[b]Costs from Tables IV-21, IV-22, and IV-23 of DOT/NHTSA (2009) were divided by 1.5 to convert from RPE (retail price equivalent) to cost.

[c]NRC (2010) refers to the present report. The CI engine costs are for base-level specifications. Detailed breakdowns of the committee's cost estimates are given in Tables 5.4 and 5.5.

[d]The spreadsheet used to compute aftertreatment system costs for the present work utilizes the configuration, sizing, and washcoat loadings included in the December 2008 version of the Martec Group, Inc. (2008) study.

Comparison of Cost Estimates with Those of Other Sources

The cost estimates from Martec Group, Inc. (2008), EPA (2009), and Duleep (2008/2009) are summarized in Table 5.7. From the left, the columns show:

- The cost estimate source;
- The cost estimates for replacing the baseline I4 SI engines in 2007 model-year midsize sedans (e.g., Malibu, Camry) with CI engines;
- The cost estimates for replacing the baseline six-cylinder SI engines in 2007 model-year midsize SUVs (e.g., Explorer, Trailblazer) with V6 CI engines;
- Whether the sources include details on how the displacements for the replacement CI engines were chosen;
- Whether the sources include details on exhaust aftertreatment system configurations, component sizing, and catalyst washcoat loading;
- What is the timing basis for PGM commodity costs;
- What is the dollar basis year.

Present Cost Estimates Compared to Martec Estimates

Although the cost estimates developed in the present study were based on the estimates from Martec Group, Inc. (2008), a number of revisions were made to the Martec estimates. First, the Martec estimates assumed that the 2-L four-cylinder CI engine replaced a V6 SI engine in the midsize sedan vehicle. As a result, Martec included a downsizing credit resulting from the savings from the elimination of two cylinders and their associated parts. Whether or not it is appropriate to include such a credit depends on what baseline vehicle is assumed. Because of the timing of the EISA that motivated the present study, the baseline vehicles for the present study are 2007 model-year vehicles. The vehicle class that would utilize the 2.0-L CI engine, namely the 2007 midsize sedan (e.g., Malibu, Camry), typically used a four-cylinder 2.4-L SI engine with 4/5-speed automatic transmission. Therefore, for the present study, the downsizing credit for reducing the number of cylinders was excluded from the cost estimate since a four-cylinder CI engine would replace a four-cylinder SI engine. This increased the estimate from the Martec value of $2,361 by $310 to $2,671. Second, the Martec cost estimates were based on November 2007 commodity prices for the precious metals used in the exhaust aftertreatment system washcoats. Based on the detailed exhaust aftertreatment system specifications provided in the Martec (2008) report, the committee constructed a spreadsheet to compute the exhaust aftertreatment system costs, and April 2009 rather than November 2007 PGM prices were used. This change was made to reflect the significant commodity price deflation since November 2007. The difference amounted to $292, which lowered the cost estimate from $2,671 to $2,379. Finally, an additional pressure-sensing glow plug was added to provide OBD backup for the single pressure-sensing glow plug assumed in the Martec BOM (replace 1 ceramic glow plug @$3 with pressure-sensing glow plug @$17 for net increase of $14). That brought the present estimate to the $2,393 shown in Tables 5.4 and 5.7.

For the SUV case, the Martec analysis assumed that a 3.0-L V6 CI engine would replace a V8 SI engine. As is discussed above for the I4 case, for the case of a baseline 2007 midsize SUV (e.g., Explorer, Trailblazer), the baseline SI engine was a 4.0- to 4.2-L six-cylinder engine rather than the V8 assumed in the Martec analysis. Therefore, the downsizing credit from V8 to V6 used in the Martec analysis ($270) was not included for the present analysis, increasing the cost estimate from $3,465 to $3,735. The Martec analysis assumed a two-stage turbo system for the 3.0-L V6 engine system. For the comparisons in Table 5.7, only the 3.5-L base-level technology engine was included to be compatible with the packages assumed in EPA (2009) and Duleep (2008/2009). Therefore, the air system cost from the Martec analysis was reduced for the present analysis by replacing the two-stage turbo system cost estimate ($1,030) with that for a single-stage system ($485). That reduced the estimate from $3,735 to $3,190. Finally, the increase in displacement from the Martec 3.0-L displacement to the 3.5 L of the present analysis along with the use of the April 2009 PGM prices rather than the November 2007 PGM prices used by Martec reduced the aftertreatment system cost from $980 to $964, which in turn reduced the total V6 SUV replacement cost from $3,190 to the $3,174 shown in Tables 5.5 and 5.7.

Present Cost Estimates Compared to EPA Estimates

The EPA cost estimate shown in Table 5.7 for the I4 CI replacement for the 2.4-L SI engine is $2,052, which is $341 less than the committee's estimate of $2,393. Using detailed breakdowns of the EPA estimates (EPA, 2009), one major difference is the cost credits used in the EPA breakdown for parts removed from the SI engine. The EPA estimate for the gasoline fuel system removed was $240 ($165 for injectors and rail and $75 for fuel pump and vapor recovery (Evap) system, whereas that used for the present work from Martec Group, Inc. (2008) was $32 for the injection system and $37 for the Evap canister and purge valve (included within the $245 emissions system credit). The fuel pump for the gasoline system is actually replaced by the low-pressure supply pump for the CI fuel system, which is very similar to the gasoline pump, and so there should be no credit for that item. The injectors and rail are extremely high-volume commodity items sold by suppliers at close to cost because of the strong global competition for such parts. Therefore, the $32 credit used for those items is considered representative. The difference between the EPA estimate and the committee's estimate for the fuel system and vapor recovery is thus $240 versus $69. The EPA assumed a $75 credit for ignition system parts removed from the SI engine. The pencil coils used in 2007 ignition systems are again extremely high-volume commodity items. The ignition control drivers used in such systems are up-integrated into the ECM, and so there is effectively no savings from their removal. For the CI engine, a glow plug and wire is required for each cylinder, so the SI to CI ignition cost difference was considered $0. There were other differences in the individual item estimates between the EPA estimate and that from the present estimate as well. The EPA estimate for the turbocharger system was less than that of the present study ($181 versus $375). The EPA estimate for emissions controls appeared to reflect a somewhat different approach to emission control, with more emphasis on aftertreatment and less emphasis on in-cylinder combustion-based control of emissions. This approach is illustrated by the EPA choice of a urea-SCR strategy for NO_x aftertreatment while that for the present approach was an NSC-based approach. The present approach also included an HP/LP EGR system, whereas the EPA system did not. The HP/LP EGR system will lower engine-out emissions, whereas the NSC NO_x conversion efficiency is lower than that of the urea-SCR approach, as noted earlier in the discussion of NO_x aftertreatment system technologies. As a result, the EPA emissions system cost estimate was significantly higher than that from the present work ($1,220 versus $903 ($688 for aftertreatment plus $215 for HP/LP EGR)). The urea-SCR subsystem cost in the EPA estimate versus that for the NSC in the present study was $670 versus $428, and the EPA CDPF cost was estimated at $480 versus $255 for the present study. No information was available concerning CDPF substrate volume or PGM loading to understand the source of these differences in more detail. The present study assumed that the aftertreatment system would also require an EGR catalyst ($20) to control EGR cooler fouling, and a passive SCR catalyst ($39), which would provide a small amount of NO_x reduction on the US06 test using the small amount of ammonia produced by the NSC at the higher load conditions of the US06 test rather than urea from a separate system like that in the urea-SCR system. OEMs will make the choice of emissions control strategy based on many factors, including cost, durability, customer convenience, and packaging. In addition to cost differences, the urea-SCR approach requires finding space to package a urea supply tank, which is more problematic in a smaller vehicle like the midsize sedan than for a larger vehicle like an SUV. As noted earlier, the 2009 VW Jetta utilizes a system very much like the system assumed in the present study. The other area in which different components were assumed by the EPA was for OBD and sensing. The present study assumed four temperature sensors ($52) and two pressure-sensing glow plugs ($34), which were not included in the EPA system. As noted earlier in discussions about combustion technologies, the closed-loop cylinder-pressure sensing system is beneficial for minimizing engine fuel consumption and emissions when different fuels of widely different cetane ratings are encountered in the market place, although the benefits of this technology will not show up on the EPA certification tests because those are conducted using standardized certification fuels for which the engines are calibrated during development.

As shown in Table 5.7 for the V6 midsize SUV case, the EPA estimate for replacing the SI engine with a CI engine was $2,746, which was $694 greater than that for the I4 CI engine substitution. The corresponding increment as determined in the present study was $781. The differences between the detailed items in the two cost estimates remain similar to those already discussed for the I4 case, and since the total cost differences were similar, the details are not discussed here. However, for the V6, both estimates assumed the urea-SCR approach for NO_x aftertreatment.

Present Cost Estimates Compared to EEA (Duleep) Estimates

The EEA (Duleep, 2008/2009) variable cost estimate for replacing the 2.4-L SI engine with a 2.0-L CI engine (Table 5.7) was $1,975. This total consisted of $1,145 for the engine and $830 for emissions control. The present study's engine cost estimate was $1,336. One of the larger differences between these two estimates was for the turbo system—EEA estimated a total of $280 and the Martec-based present study's estimate was $250 for the VGT turbo with electronic controls and $125 for the intercooler and plumbing, for a total turbo system cost of $375, or $95 above the EEA estimate. Also, the EEA estimate did not include a cabin heater, which is standard with CI diesel vehicles and which Martec estimated at $59. For exhaust emissions control, the differences between the EEA estimates and the Martec-based estimates used in the present study were also significant. EEA assumed an integrated DPF and NSC unit (called DPNR), which is proprietary to Toyota. All other OEMs are using separate DPF and NSC units. The EEA estimate assumed $730 for the DPNR unit, but no cost basis was specified for the PGM prices or loadings. The present study assumed $688 (see Table 5.6) based on April 2009 PGM prices for the separate DPF and NSC units. EEA assumed $60 for the EGR system and cooler, whereas the present study estimated $215 for an HP/LP EGR system (for details see Table 5.4). As noted in earlier discussion of emissions control technology, a combined HP/LP EGR system has many advantages for reducing engine-out NO_x, thus reducing the NO_x conversion requirements for the aftertreatment system. The LP EGR system requires several control valves and cooler in addition to those for the HP EGR system. The 2009 VW Jetta has such an HP/LP EGR system. For oxidative cleanup of the exhaust (e.g., unburned HC, CO, and soluble particulates), a DOC (diesel oxidation catalyst) is used. EEA assumed $50 for the DOC. Again, no information was provided about volume, PGM loading, or PGM cost basis for the EEA estimate. The present study assumed $52 for the monolith and housing and $139 for the PGM washcoat cost based on April 2009 PGM prices. The emissions control system cost estimate differences then totaled $227.

For the V6 SUV case, the EEA estimate was $2,590, whereas that of the present study was $3,174. The EEA estimate for the engine was $1,715 versus $1,983 for the present study. Of the $268 difference, the majority is explained by the lack of a cabin heater in the EEA estimate and inclusion of the cabin heater for the present study at $99 (more costly than that of the midsize sedan I4 vehicle because of the larger cabin volume for the midsize SUV with the V6) and the air system (turbocharger and intercooler) for which EEA estimated $365 versus $485 for the present study. The remainder of the difference was due to emissions control. Again, one of the main differences was the use of an HP/LP EGR system for the present study as included in the Martec BOM but not in the EEA estimate ($86 difference). In addition, the present study included the use of a second DOC ($122) included in the Martec BOM that was worked out in collaboration with OEMs and suppliers.

Present Cost Estimates Compared to NHTSA Estimates

According to the NHTSA final ruling for 2011 (DOT/NHTSA, 2009), costs for CI engines and DCT6 transmissions were also derived from the Martec estimates. For the 2.0-L I4, the NHTSA number from Table 5.7 is $2,667, whereas the corresponding number from the present study is $2,393. Most of the difference between these estimates is due to the $292 reduction in aftertreatment system costs used in the present study and derived from using April 2009 PGM prices rather than the November 2007 prices reflected in the Martec numbers presumably used by the NHTSA. It is not known whether the NHTSA estimate includes the downsizing credit or not.

The NHTSA cost estimate of $5,600 retail price equivalent ($3,733 cost) from Tables IV-21, IV-22, and IV-23 (DOT/NHTSA, 2009) for the larger vehicle classes (e.g., large car versus subcompact, compact, and midsize car) is assumed to derive from the Martec cost estimate of $3,465 for V6 diesel (Martec Group, Inc., 2008, p. 37). The corresponding value for the V6 CI engine from the present study was $3,174. A significant portion of the $559 difference between the NHTSA estimates and those of the present work is due to the inclusion in the Martec, and presumably also in the NHTSA, estimates of two-stage turbocharger systems that for the present study correspond to advanced-level engine technology, as described in the section "Engine Sizing Methodology." As noted above, the costs from the present work that were used in Table 5.7 were those for the base-level technology configuration. The base level was assumed to use single-stage VGT turbo systems and the advanced level to use two-stage turbo systems. The cost estimate from the present work, which is included in Table 5.7, is for the base-level CI engine. Including the two-stage turbo system in the cost estimate from the present study would increase the estimate from $3,174 to $3,719, leaving a difference between the NHTSA estimate and the present estimate of about $14.

There are also other differences between the assumptions made in the present study and those of the Martec study. For the engine sizing methodology used herein, the baseline six-cylinder engine for the midsize vehicle class of about 4.2 L downsized by the assumed 83 percent is 3.5 L, whereas the Martec study assumes 3.0 L. According to the costing methodology used in the present study, the increase of displacement from 3.0 L to 3.5 L increases cost (entirely as a result of aftertreatment systems cost) from $921 to $964. Subtracting this difference from the engine cost estimate of $3,174 increases the cost differential between the NHTSA estimate and the present study from $14 to $57. As for the remaining difference, there is insufficient information in the NHTSA report to understand the sources of this difference, although it is less than 10 percent, which is well within the uncertainty of these cost estimates in general.

Advanced-Level CI Engine Cost Estimates

Cost estimates for the technologies necessary to raise base-level CI engines to advanced-level engines inherent in the gains described in Table 5.2 are listed in Table 5.8.

Advanced-Level Transmission Cost Estimates

There seems to be an emerging consensus that dual-clutch automatically shifted manual transmissions (DCTs) offer a very attractive combination of efficiency and driver satisfaction with acceptable cost. In the Ricardo, Inc., FSS studies for the EPA (EPA, 2008), CI engines were combined with DCT6 units for the simulations, as noted in earlier discussions of Table 5.1. For that reason, it was assumed for the present analysis that the CI replacements for SI engines would use DCTs. Transmission technologies are discussed in Chapter 7, which considers non-engine vehicle technologies. Cost estimates for advanced transmissions used for this committee's work are also shown there and are summarized in Table 7.10.

Summary of Total SI to CI Power Train Replacement Cost Estimates

The total estimated costs to replace 2007 model-year SI power trains with base-level and advanced-level CI power trains for the example midsize sedan and midsize SUV vehicles indicated in Tables 5.4 and 5.5 are summarized in Table 5.9.

FINDINGS

Based on a combination of analysis and engineering judgment applied to information collected from many sources, the committee's key findings are as follows regarding tech-

TABLE 5.8 Committee's Estimates of Incremental Costs to Implement Advanced-Level Diesel Developments (downsizing, thermodynamic improvements, friction reduction, and engine accessory improvements) Whose Estimated Potential for Reducing Fuel Consumption Is Summarized in Table 5.2

Item	Midsize Car (e.g., Malibu) 1.6-Liter I4	Midsize SUV (e.g., Explorer) 2.8-Liter V6	Comment
Downsize engines from 2-L I4 to 1.6-L I4 and from 3.5-L V6 to 2.8-L V6	$50	$75	Higher load capacity rod bearings and head gasket for higher cylinder pressures (~$12.50/cylinder)
Two-stage turbocharger system	$375	$545	Additional air flow control valves, piping, cost of additional turbo, water-to-air intercooler with separate pump, control valve
Dual-pressure oil pump	$5	$6	Switchable pressure relief valve for high or low oil pressure
Non-recirculating low-pressure (LP) fuel pump	$10	$12	Variable output LP pump controlled by high-pressure (HP) pump output
Cylinder pressure sensors	—	—	Two pressure-sensing glow plugs, one to sense fuel property differences, second to provide on-board diagnostics durability backup for first, already included for both I4 and V6 in Tables 5.3 and 5.4
Low-pressure exhaust gas recirculation (EGR)	—	$95	Additional piping (~$20) and valves (e.g., integrated back pressure and LP EGR rate ~$75), much more difficult to package for V6 engine with underfloor diesel particulate filter, cost for I4 already included in Table 5.4
Direct-acting HP (maximum injection pressures >2,000 bar) piezo injectors	$80	$120	$20/injector, benefits derived from combination of higher rail pressure and more injector controllability
Total	$520	$853	

TABLE 5.9 Estimated Total Costs to Replace 2007 Model-Year SI Power Trains with Base- and Advanced-Level CI Power Trains for Example Midsize Sedan and Midsize SUV-Type Vehicles

	Base-Level CI Engine	Advanced-Level CI Engine
Midsize Sedan		
I4 engine	$2,393 (Table 5.4) or $2,400 (when rounded to nearest $50)	$2,913 (Tables 5.4 and 5.8) or $2,900 (when rounded to nearest $50)
DCT6/7[a] transmission	$140-$400 (Table 7.10)	$140-$400 (Table 7.10)
Total	$2,550-$2,800 (when rounded to nearest $50)	$3,050-$3,300 (when rounded to nearest $50)
Midsize SUV		
V6 engine	$3,174 (Table 5.5) or $3,150 (when rounded to nearest $50)	$4,027 (Tables 5.5 and 5.8) or $4,050 (when rounded to nearest $50)
DCT6/7 transmission	$140-$400 (Table 7.10)	$140-$400 (Table 7.10)
Total	$3,300-$3,550 (when rounded to nearest $50)	$4,150-$4,450 (when rounded to nearest $50)

[a]Note that the higher of the two estimates shown in Table 7.10 is for a 6/7-speed dual-clutch transmission (DCT). In accordance with the potential fuel consumption reduction gains discussed in Table 5.2 due to transmission improvements, it was assumed that 7-speed versions would be used. Due to the wide range of cost estimates for DCTs as discussed in Chapter 7, no adjustment was made for the higher torque requirements of the V6 CI.

nology combinations for reducing the fuel consumption of 2007 model-year SI gasoline engine vehicles by equipping them with advanced CI diesel power trains.

Finding 5.1: By a joint effort between OEMs and suppliers, new emissions control technology has been developed to enable a wide range of light-duty CI engine vehicles to meet the 2010 Tier 2, Bin 5, LEV II emissions standards.

Finding 5.2: Replacing 2007 model year MPFI SI gasoline power trains with base-level CI diesel engines with advanced dual-clutch (automated manual) transmissions (DCTs) (6-speed) and more efficient accessories packages can reduce fuel consumption by an average of about 33 percent (or reduce CO_2 emissions by about 23 percent) on an equivalent vehicle performance basis. Advanced-level CI diesel engines with advanced DCTs could reduce fuel consumption by about an additional 13 percent for larger vehicles and by about 7 percent for small vehicles with engine displacements less than 1.5 L.

Finding 5.3: The characteristics of CI diesel engines that enable their low fuel consumption apply over the entire vehicle operating range from city driving to highway driving, hill climbing, and towing. This attribute of CI diesel engines is an advantage when compared with other technology options that are advantageous for only part of the vehicle operating range (e.g., hybrid power trains reduce fuel consumption primarily in city cycle/city driving).

Finding 5.4: The identified advanced-level technology improvements to CI diesel engines are expected to reach market in the 2011-2014 time frame, when advanced technology additions to SI gasoline engines will also enter the market. Thus, there will continue to be a fuel consumption and cost competition between these two power train systems. For the period 2014-2020, further potential fuel consumption reductions for CI diesel engines may be offset by fuel consumption increases due to engine and emissions system changes required to meet stricter emissions standards (e.g., LEV III).

Finding 5.5: CI diesel engine market penetration will be strongly influenced both by the incremental cost of CI diesel power trains above the cost of SI gasoline power trains and by the price differential of diesel fuel relative to gasoline. The estimated incremental cost differential for base-level and advanced-level I4 CI diesel engines to replace 2007 model-year midsize sedan SI gasoline engines ranges from $2,400 (base level) to $2,900 (advanced level). For base-level I4 engines combined with DCTs, power train replacement cost is estimated at $2,550 to $2,800 and for advanced-level I4 power trains is estimated at $3,050 to $3,300 (both rounded to the nearest $50). For midsize 2007 model-year SUVs, the estimated cost for replacement of SI gasoline engines with base-level and advanced-level V6 CI diesel engines ranges from $3,150 (base level) to $4,050 (advanced level) (both rounded to the nearest $50). For V6 CI engines combined with DCTs, the estimated V6 CI power train replacement cost increment over 2007 model-year SI power trains is $3,300 to $3,550 (base level), and the advanced-level power train incremental cost is $4,200 to $4,500 (both rounded to nearest $50). These costs do not include the retail price equivalent factor.

REFERENCES

Bression, G., D. Soleri, S. Savy, S. Dehoux, D. Azoulay, H.B-H. Hamouda, L. Doradoux, N. Guerrassi, and N. Lawrence. 2008. A study of methods to lower HC and CO emissions in diesel HCCI. SAE Paper 2008-01-0034. SAE International, Warrendale, Pa.

Diesel Forum. 2008. Available at http://www.dieselforum.org/DTF/news-center/pdfs/Diesel%20Fuel%20Update%20-%20Oct%202008.pdf.

DieselNet. 2008. February 22. Available at http://www.dieselnet.com/news/2008/02acea.php.

DOT/NHTSA (Department of Transportation/National Highway Traffic Safety Administration). 2009. Average Fuel Economy Standards Passenger Cars and Light Trucks—Model Year 2011. Docket No. NHTSA-2009-0062, RIN 2127-AK29, March 23. Washington, D.C.

Dow. 2009. Available at http://www.dow.com/PublishedLiterature/dh_02df/0901b803802df0d2.pdf? filepath=automotive/pdfs/noreg/299-51508.pdf&fromPage=GetDoc.

Duleep, K.G. 2008/2009. Diesel and hybrid cost analysis: EEA versus Martec, presentation made to NRC Committee, February 25, 2008, updated June 3, 2009.

EIA (Energy Information Administration). 2009a. Light-Duty Diesel Vehicles: Efficiency and Emissions Attributes and Market Issues. February. Available at http://www.eia.doe.gov/oiaf/servicerpt/lightduty/execsummary.html.

EIA. 2009b. Diesel Fuel Prices. Available at http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp. Accessed May 9, 2009, and June 5, 2009.

EPA (U.S. Environmental Protection Agency). 2005. Document 420-F-05-001. Available at http://www.epa.gov/otaq/climate/420f05001.htm.

EPA. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Report 420r80040a. Revised June.

EPA. 2009. Updated cost estimates from those in U.S. EPA, 2008. Committee e-mail communications with EPA, May 27 and May 28.

Hadler, J., F. Rudolph, R. Dorenkamp, H. Stehr, T. Düsterdiek, J. Hilzendeger, D. Mannigel, S. Kranzusch, B. Veldten, M. Kösters, and A. Specht. 2008. Volkswagen's new 2.0 L TDI engine fulfills the most stringent emission standards, 29th Vienna Motor Symposium.

Iwabuchi, Y., K. Kawai, T. Shoji, and Y. Takeda. 1999. Trial of new concept diesel combustion system—Premixed compression-ignition combustion. SAE Paper 1999-01-0185. SAE International, Warrendale, Pa.

Joergl, Volker, P. Keller, O. Weber, K. Mueller-Haas, and R. Konieczny. 2008. Influence of pre-turbo catalyst design on diesel engine performance, emissions, and fuel economy. SAE Paper 2008-01-0071. SAE International, Warrendale, Pa.

Kanda, T., T. Hakozaki, T. Uchimoto, J. Hatano, N. Kitayama, and H. Sono. 2005. PCCI operation with early injection of conventional diesel fuel. SAE Paper 2005-01-0378. SAE International, Warrendale, Pa.

Keller, P.S., V. Joergl, O. Weber, and R. Czarnowski. 2008. Enabling components for future clean diesel engines. SAE Paper 2008-01-1530. SAE International, Warrendale, Pa.

Martec Group, Inc. 2008. Variable Costs of Fuel Economy Technologies. Prepared for Alliance of Automobile Manufacturers, June 1; amended September 26 and December 10.

Mattes, Wolfgang, Peter Raschl, and Nikolai Schubert. 2008. Tailored $DeNO_x$ concepts for high-performance diesel engines. Second $MinNO_x$ Conference, June 19-20, Berlin.

Müller, W., et al. 2003. Selective catalytic reduction—Europe's NO_x reduction technology. SAE 2003-01-2304. SAE International, Warrendale, Pa.

Myoshi, N., et al. 1995. Development of new concept three-way catalyst for automotive lean-burn engines. SAE Paper 95809. SAE International, Warrendale, Pa.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

Peckham, John. 2003. How JD Power/LMC calculate 16% light-duty diesel sales share for North America. Diesel Fuel News, October 13.

Pickett, L.M., and D.L. Siebers. 2004. Non-sooting, low flame temperature mixing-controlled DI diesel combustion. SAE Paper 2004-01-1399. SAE International, Warrendale, Pa.

Ryan, T.W., and T.J. Callahan. 1996. Homogeneous charge compression ignition of diesel fuel. SAE Paper 961160. SAE International, Warrendale, Pa.

Styles, D., J. Giuliano, J. Hoard, S. Sluder, J. Storey, S. Lewis, and M. Lance. 2008. Identification and control of factors that affect EGR cooler fouling. 14th Diesel Engine-Efficiency and Emissions Research Conference, Dearborn, Mich.

Tilgner, Ingo-C., T. Boger, C. Jaskula, Z.G. Pamio, H. Lörch, and S. Gomm. 2008. A new diesel particulate filter material for passenger cars: Cordierite diesel particulate filters for the new Audi A4 V6 TDI, 17. Aachener Kolloquium Fahrzeug- und Motorentechnik, p. 325.

ANNEX

Table 5.A.1 shows the data used in Figure 5.4 for the percentage reduction of fuel consumption in 2009 European vehicle platforms offered with both SI gasoline engines and CI diesel engines in configurations that provide virtually equal performance (i.e., 0 to 100 km/h acceleration times within 5 percent between SI and CI).

TABLE 5.A.1 Data Used in Figure 5.4

Vehicle	% FC Reduction
Audi A3	30.88
BMW 520	25.00
Dodge Avenger	20.51
Ford Fiesta	26.32
Ford Galaxy	36.73
Honda Civic	21.21
Honda CR-V	18.52
Jaguar XF	29.25
Mercedes E230	31.18
Mercedes S350	17.65
Toyota Yaris	25.00
Toyota RAV4	24.42
VW Jetta	28.38
Peugeot 308	28.79
Renault Laguna	34.62
Audi A8	21.30
Audi Q7	18.38
Audi A6	18.18
Mercedes Viano	23.53
AVERAGE	25.25

6

Hybrid Power Trains

INTRODUCTION

Hybrid vehicles achieve reduced fuel consumption by incorporating in the drive train, in addition to an internal combustion (IC) engine, both an energy storage device and a means of converting the stored energy into mechanical motion. Some hybrids are also able to convert mechanical motion into stored energy. In its most general sense, the storage device can be a battery, flywheel, compressible fluid, elastomer, or ultra capacitor. The means of converting energy between storage and mechanical motion is through the use of one or more motors/generators (e.g., electric, pneumatic, hydraulic). In motor mode, these devices convert stored energy into mechanical motion to propel the vehicle, and in generator mode, these devices convert vehicle motion into stored energy by providing part of the vehicle braking function (regeneration). Similarly, a fuel cell vehicle is also a hybrid in which the internal combustion engine is replaced by the fuel cell, but this system will likely need supplemental energy storage to meet peak power demands and to allow the fuel cell to be sized for the average power requirement.

In this chapter, hybrid vehicle designs employing an internal combustion engine and battery-energy storage are considered. Battery electric and fuel cell vehicles (BEVs and FCVs) are also briefly discussed as other alternative power trains.

Hybrid electric vehicles incorporate a battery, an electric motor, and an internal combustion engine in the drive train. In its most effective implementation this configuration permits the IC engine to shut down when the vehicle is decelerating and is stopped, permits braking energy to be recovered, and permits the IC engine to be downsized and operated at more efficient operating points. It should be emphasized that the benefits of hybrids are highly dependent on the drive cycle used to measure fuel consumption. For example, a design featuring only idle-stop operation, which shuts off the internal combustion engine when the vehicle is stopped, will demonstrate a large improvement on the city cycle portion of the Federal Test Procedure (FTP), where stop-start behaviors are simulated, but virtually no improvement on the highway cycle.

In addition to the introduction of an electric motor, hybrid designs may include the functions of idle-stop and regenerative braking, and the IC engine is frequently downsized from that in its equivalent conventional vehicle. As shown in Table 6.A.1 in the annex at the end of this chapter, for a hybrid vehicle, these operational and physical changes alone or in combination can result in an increase in fuel economy (mpg) of between 11 and 100 percent or a decrease in fuel consumption (gallons per 100 miles driven) of between 10 and 50 percent, depending on the vehicle class, as is discussed below in this chapter. Hybrid vehicles are the fastest-growing segment of the light-duty vehicle market, although they still make up less than 3 percent of the new car market in the United States.

HYBRID POWER TRAIN SYSTEMS

As stated above, hybrid vehicles are defined as having an internal combustion engine and one or more electric machines that in some combination can provide tractive force to propel the vehicle. An exception to this definition is the simple idle-stop design, which provides no electrically derived tractive force. Depending on the architectural configuration of the motors, generators, and engine, hybrid designs fall into three classes—parallel, series, and mixed series/parallel. The third design is commonly known as power split architecture. Schematics of these architectures are shown in Figures 6.1, 6.2, and 6.3. Within each class there are variations of implementation. Broadly defined, the series hybrid uses the internal combustion engine for the sole purpose of driving a generator to charge the battery and/or powering an electric drive motor. The electric motor provides all the tractive force. Energy flows from the IC engine through the generator and battery to the motor. In the parallel and mixed series/parallel designs, the IC engine not only charges the battery but also is mechanically connected to the wheels and, along with the electric motor, provides tractive power.

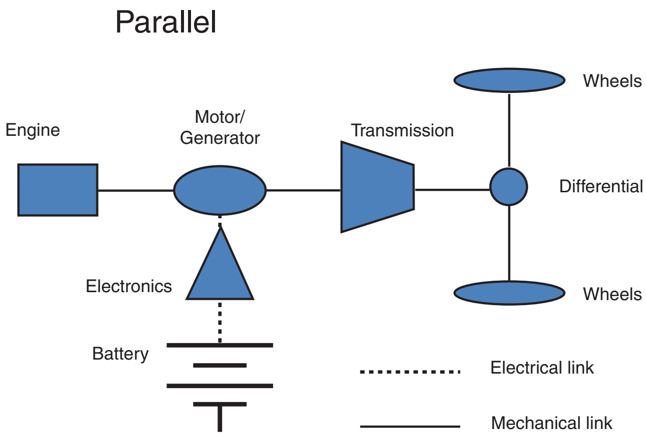

FIGURE 6.1 Schematic of parallel hybrid power train configuration.

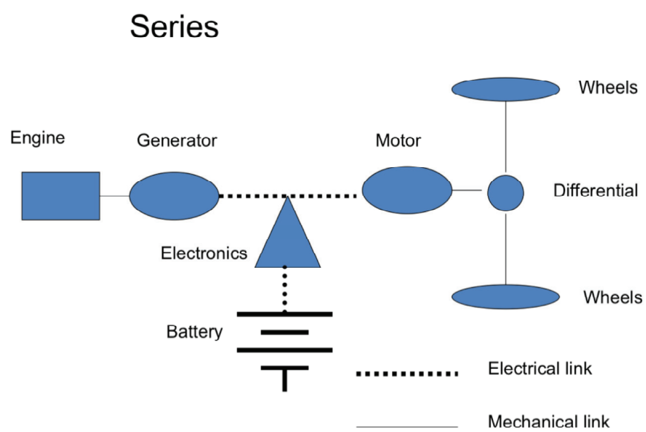

FIGURE 6.2 Schematic of series hybrid power train configuration.

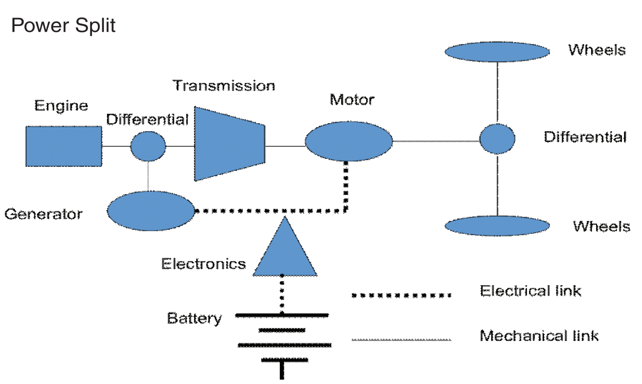

FIGURE 6.3 Schematic of power-split hybrid power train configuration.

Hybrid vehicles are further differentiated by the relative sizes of the IC engine, battery, and motor. Some of the more common variants of these broad classes are described in the following paragraphs. In all cases an economically and functionally significant component of the system is the power electronic subsystem necessary to control the electrical part of the drive train.

The hybridization of diesel (compression ignition; CI) vehicles is expected to have somewhat lower efficiency benefits than hybridization of gasoline vehicles, in part because conventional CI vehicles already exhibit lower fuel consumption than comparable gasoline vehicles. Further, CI vehicles also have very low fuel consumption at idle, making the benefits of idle-stop less attractive. Conventional CI power trains are more expensive than their gasoline counterparts (see Tables 5.4, 5.5, and 5.6), which, when added to the cost of hybridization, makes a CI hybrid power train very expensive for the additional fuel consumption reductions provided over and above just moving to a hybrid or CI power train alone. As a result, it is unlikely that original equipment manufacturers (OEMs) will offer a wide array of CI hybrids. The most likely levels of CI hybridization will be idle-stop and, perhaps, some mild hybrids. Idle-stop will not provide much fuel consumption reduction on the city driving portion of the FTP test cycle, upon which the judgments in this report are based. However, OEMs may still offer such technologies since they provide in-use fuel consumption reductions. In Europe, a number of new diesel hybrid vehicles have been announced for production in 2010 or 2011, especially for larger and heavier vehicles (e.g., Land Rover).

There are numerous hybrid vehicles now in production, and the committee believes it is more representative to quote actual data rather than analyze the effectiveness of each design to estimate fuel consumption benefits. This is preferable to having the committee and its consultants estimate fuel consumption benefits through simulations. It is assumed that the production vehicles are designed to meet customer expectations, including acceleration, passenger space, and adequate trunk space. The average fuel consumption of production hybrid HEVs was determined from fuel economy data supplied by Oak Ridge National Laboratory and included as Table 6.A.1 in the annex at the end of this chapter.

Belt-Driven Alternator/Starter

In the belt-driven alternator/starter (BAS) design, sometimes known as a micro or mild hybrid, the starter and generator of a conventional vehicle are replaced by a single belt- or chain-driven larger machine, capable of both starting the engine and generating electric power. In some BAS designs, in addition to the new belt-driven starter generator, the original geared-to-flywheel starter is retained for cold starts. Fuel consumption is reduced by turning off and decoupling the engine at idle and during deceleration. In some designs, particularly those that have replaced the belt with a chain for increased torque transmission, both electric vehicle launch and some degree of braking energy regeneration are possible.

This mode of operation is known as idle-stop, and while not technically qualifying as a hybrid since the motor/generator provides no or little tractive power, it is included in this chapter for completeness. Idle-stop designs reduce fuel consumption by up to 6 percent in urban driving with SI engines (Ricardo, Inc., 2008). For SI engines having variable valve timing to reduce inlet throttling loss the benefit may be less than 6 percent. For CI engines, the benefit of idle-stop drops to about 1 percent because CI engines are more efficient at idle due to their lack of inlet throttling.

The BAS design is not quite as simple as it first appears. Maintaining hydraulic pressure in the automatic transmission is necessary for smooth and rapid restart, and safety issues related to unexpected restart must be considered. The company ZF has designed a transmission that provides a means of maintaining hydraulic pressure using a "hydraulic impulse storage device" that appears to address the transmission problem (Transmission Technology International, 2008), which is also addressed in existing designs by an electrically driven hydraulic pump.

Full Hybrid

The full hybrid (HEV) has sufficient electrical energy storage and a powerful enough electric motor to provide significant electrical assist to the IC engine during acceleration and regeneration during braking. There are several architectural approaches to achieving a full hybrid, the three in current production being the integrated starter/generator (ISG) or integrated motor assist (IMA), the power split, and the two-mode. These are all parallel or power split designs. The HEV may also provide a limited electric-only range if the battery capacity and motor size are sufficient.

The ratio of electric to mechanical power provided for propulsion of an HEV varies with driving conditions and the state of charge of the battery. This operational feature is accomplished with sophisticated computer controls. Commercially available HEVs such as the Toyota Prius, Honda Civic, Nissan Altima, or Ford Escape can support a limited all-electric range at limited speeds. In these vehicles the battery is operated in a charge-sustaining (CS) mode; that is, the state of charge (SOC) of the battery is allowed to vary over a very narrow range, typically 15 to 20 percent, to ensure long battery life. The IC engine operates over a narrow speed/load range to improve efficiency, and regeneration is employed to recover braking energy. According to Toyota, as shown in Figure 6.4, the contributions of stop-start, regenerative braking, and engine modifications to fuel consumption improvements are approximately 5, 10, and 30 percent, respectively.

ISG/IMA Hybrid

In the ISG/IMA design, the starter and generator are replaced by a larger electrical machine connecting the engine and transmission. These vehicles generally use a larger

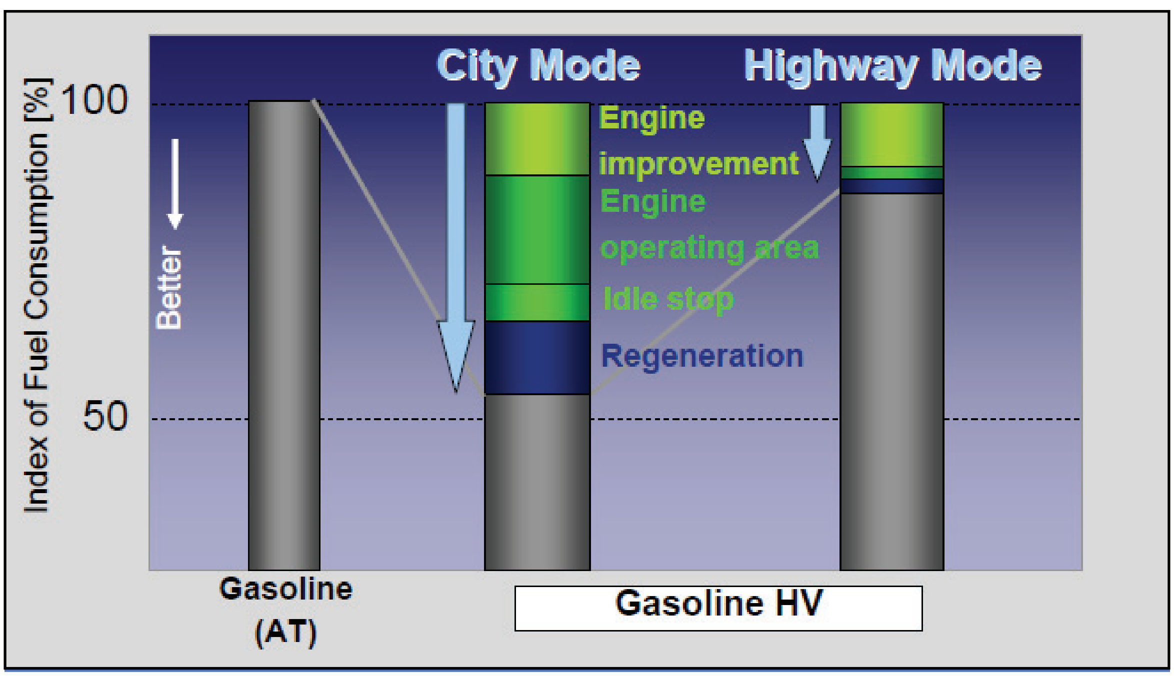

FIGURE 6.4 Individual technology contributions to fuel consumption in hybrid electric vehicles. SOURCE: Fushiki and Wimmer (2007). Reprinted with permission.

battery and a higher voltage (e.g., 140 V) than the BAS. Additionally, the motor/generator and battery are powerful enough to provide electrical launch from a stop and the ability to support some degree of electric-only travel. In its simplest form the ISG is mechanically fixed to the IC engine crankshaft, but in some designs a second clutch isolates the engine and the electrical machine to enable larger regeneration of braking energy (Dan Hancock, General Motors, personal communication, November 30, 2007). When incorporating an effective regenerative braking system, the ISG hybrid achieves a fuel consumption reduction of 34 percent in the combined driving cycle, as demonstrated by the Honda Civic. A part of the improved fuel consumption comes from vehicle modifications, including the use of a smaller, more efficient SI engine.

Power-Split Hybrid

The power-split hybrid design, typified by the Toyota Prius, the Ford Escape, and the Nissan Altima, incorporates a differential gear set that connects together the IC engine, an electrical generator, and the drive shaft. The drive shaft is also connected to an electric motor. This mechanical configuration incorporating the addition of a generator provides the flexibility of several operational modes. In particular the wheels can be driven by both the IC engine and the electric motor, with the motor's power coming from the generator, not the battery. The car is thus driven in both series and parallel modes simultaneously, which is not a possible mode for the ISG design. This operational mode allows the IC engine operation to be optimized for maximum reduction in fuel consumption. The vehicles that use this power split design show a range of fuel consumption reduction from 10 to 50 percent. The low end of this range is the Toyota Lexus, the design of which is optimized for performance, not low fuel consumption. In Chapter 9, where the committee estimates fuel consumption benefits for vehicle classes, the Lexus is not used in the range of benefits for the power split design. This gives the fuel consumption benefits from the power split design a range of 24 to 50 percent.

General Motors (GM) is working with BMW and Chrysler on a different split hybrid architecture that uses the so-called two-mode system (Grewe et al., 2007). This also splits the power flow from the engine but uses more clutches and gears to match the load to the drive and minimize electrical losses. The claim is that by using multiple gears the drive is more efficient in real-world driving situations and reduces fuel consumption when towing a trailer or driving at high speed. Toyota is using a similar approach with one or two gears in its latest hybrid systems. The fuel consumption reduction for the two-mode power split design, characterized by the Chevrolet Tahoe and Saturn Vue, ranges from 25 to 29 percent. However, the committee thinks that other implementations of the two-mode system could provide a maximum fuel consumption benefit of about 45 percent.

Series Hybrid

The series HEV is configured with the engine driving a generator providing electric power to charge the battery. The wheels are driven by an electric motor powered from the battery. The only function of the IC engine is to charge the battery while driving. Because there is no mechanical connection between the IC engine and the wheels, the motor and the battery must be sized for the vehicle's full torque and power requirements. The advantages of this configuration are that a smaller engine can be used since it is not required to provide the power needed for acceleration, and the engine can be optimized with respect to fuel consumption. At present the only OEM planning a series hybrid is GM, which is proposing it as a plug-in hybrid electric vehicle (PHEV).

Plug-In Hybrid

The principal difference between the previously described HEV variants and the PHEV is that the latter is fitted with a larger battery that can be charged from the electric utility grid ("plugged in") and that operates in a charge-depleting mode; that is, the state of charge of the battery is allowed to vary over a much larger range, 50 percent being typically proposed. The significant fuel consumption benefit is obtained during urban driving when the vehicle can be driven on electric power only. Once the all-electric range has been achieved and the battery discharged to its lowest allowable state of charge, the vehicle is operated in the charge-sustaining mode and differs little from the HEV. A small industry has developed around the conversion of the Prius power-split HEVs to PHEVs by supplementing the battery and modifying the control electronics.

PHEVs require a much larger battery than other hybrids (4 to 24 kWh)[1] depending on the desired electric-only range. There has been much activity related to PHEVs since the committee inaugurated its work in 2007. The General Motors Volt mentioned above is planned for introduction in 2010 provided that a suitable battery is developed (Tate et al., 2009). The Volt currently is expected to be launched late in 2010 as a 2011 model. Toyota has also announced plans for a plug-in hybrid for 2011, although it will be built on a Prius platform using its power split architecture (Fushiki and Wimmer, 2007). In addition to the Volt and the Prius, the Volkswagen Golf PHEV is expected in 2010 and Ford's Escape SUV PHEV is due out to the general public in 2012. A PHEV in China went on sale to the public in China early in 2010.

While the micro and ISG hybrids offer some improvement in fuel consumption for a relatively modest cost, it is

[1]The Energy Independence and Security Act of 2007 defines a plug-in hybrid as a light-, medium-, or heavy-duty vehicle that draws motive power from a battery with a capacity of at least 4 kilowatt-hours and can be recharged from an external source of electricity.

the power-split HEV and PHEV architectures that promise a significant improvement. The PHEV also offers the long-term potential for displacing fossil fuels with other primary energy sources such as nuclear or renewable sources of electricity, depending on the fuel source of the electric grid from which the PHEV draws electricity.

Battery Electric Vehicles

The prospect for widespread introduction of full-performance all-electric vehicles depends on significant advancements of the battery technologies discussed above, and the commercial viability of these vehicles depends on a battery cost breakthrough. Advances in electric motors, power electronics, and batteries for automotive applications, which have resulted from the development and production of hybrid vehicles, have renewed interest in the development of battery electric vehicles. However, the cost, low energy density, and required charging time of batteries will continue to constrain the introduction of BEVs. The high low-speed torque performance of electric motors gives the BEV a potential acceleration advantage over conventional internal combustion engine-powered vehicles, and this can be an attractive feature for some customers

A review of zero-emission vehicle technology commissioned by the California Air Resources Board (CARB) concluded that commercialization (tens of thousands of vehicles) of full-performance battery electric vehicles would not occur before 2015 and that mass production (hundreds of thousands of vehicles) would not occur before 2030 (Kalhammer et al., 2007). These projections were based on the continued development of lithium-ion (Li-ion) battery technology leading to reduced cost, higher energy densities, and reduced charging times, all of which allow greater range. They pointed to a possible role for a limited range, city electric vehicle (CEV), which could meet the requirements of a majority of household trips. However, recent BEV introductions suggest that progress in the technology and acceptance of Li-ion batteries may be more rapid than the CARB study concluded.

Early commercial application of Li-ion battery technology to vehicles includes the Tesla Roadster, a high-performance sports car. This vehicle, of which about 1,000 have been sold, has a fuel consumption of 0.74 gal/100 miles (energy equivalent basis, EPA combined city/highway).[2] The manufacturer claims a range of 244 miles (also EPA combined city/highway) and a useful battery life of more than 100,000 miles.[3] The base price of $128,000 indicates the continuing problem of battery cost when used in near full-performance vehicles. Tesla has announced that it will produce and sell, at about half the price of the Roadster, a five-passenger BEV, the Tesla S, with a range of 160, 230, or 300 miles, depending on optional battery size.[4] Nissan has also announced production of its Leaf EV, a five-passenger car with a range of 100 miles.[5] This vehicle has a Li-ion battery with a total storage capacity of 24 kWh.

Within the horizon of this study, the most likely future for large numbers of battery electric vehicles in the United States is in the limited-range, small-vehicle market. Range extended electric vehicles (hybrids and PHEVs) are more likely to satisfy the electricity-fueled full-performance—market, from both cost and technological considerations, over the next 15 years.

BATTERY TECHNOLOGY

In spite of the significant progress that battery technology has experienced in the last 20 years, the battery is still the most challenging technology in the design of hybrid vehicles. Figure 6.5 illustrates the dramatic difference between the energy densities of today's commercial batteries and gasoline, diesel fuel, ethanol, compressed natural gas, and hydrogen. At the time of this report, all production hybrid vehicles used batteries employing nickel-metal-hydride (NiMH) chemistry. It is anticipated that the NiMH battery will be replaced by Li-ion batteries in the near future. The acceptability of today's hybrid vehicles has been shown to be strongly dependent on the price of gasoline, as evidenced by the rapid growth of hybrid sales in 2008, when gasoline prices were high, and the fact that hybrid sales dropped dramatically in early 2009 when prices returned to lower values. The key to improving the competitive position of hybrid vehicles of the HEV and PHEV types is the commercial development of batteries with parameters that are substantially better than those of today's batteries, leading to reduced cost and size. The required parametric improvements are as follows:

- Higher cycle life at increased SOC variation,
- Higher energy density,
- Higher power density, and
- Lower cost.

Figure 6.6 shows the desirable characteristics of batteries suitable for the HEV, the PHEV, and the all-electric (EV or BEV) vehicles. The HEV uses electric propulsion primarily as an assist to the IC engine, thus requiring a battery with a high power capability but relatively little energy capacity, i.e., a high power to energy (P/E) ratio. To preserve battery life and maintain the capacity to recover charge through regenerative braking, the battery is cycled over a relatively small state of charge. This mode of operation is known as charge sustaining (CS). The PHEV is expected to provide

[2] California Air Resources Board (2009), available at http://www.driveclean.ca.gov.

[3] Tesla Motors (2009), available at http://www.teslamotors.com/display_data/teslaroadster_specsheet.pdf; IEEE Vehicular Technology, March 2010.

[4] See http://news.cnet.com/tesla-motors-ceo-model-s-is-cheaper-than-it-looks/.

[5] See http://www.nissanusa.com/leaf-electric-car/tour.jsp#/details.

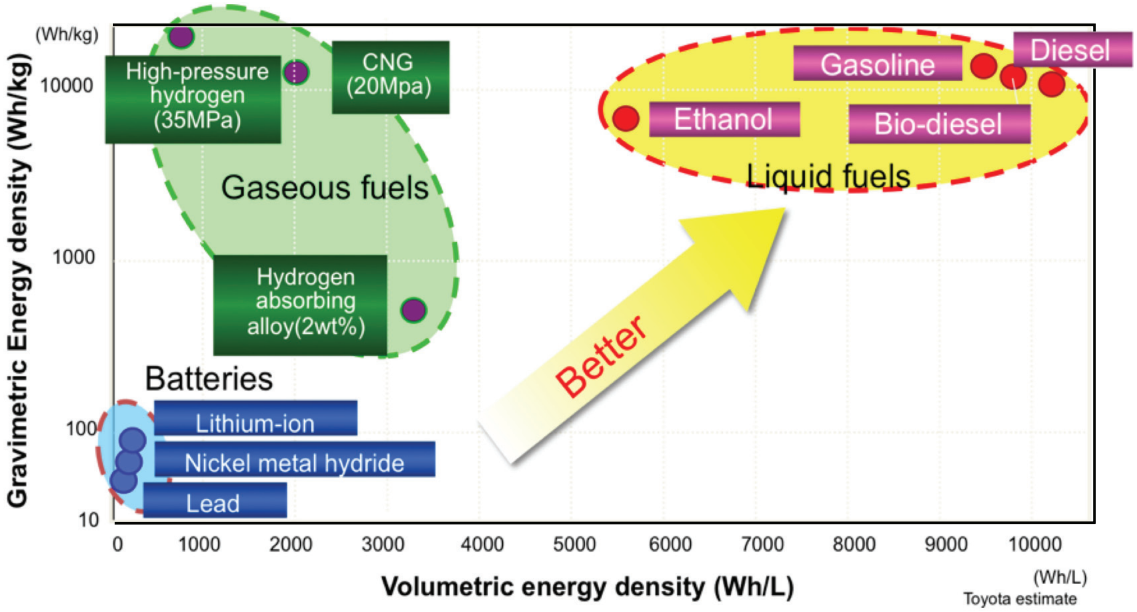

FIGURE 6.5 Volumetric and gravimetric energy densities of different energy storage mechanisms. SOURCE: Fushiki and Wimmer (2007). Reprinted with permission.

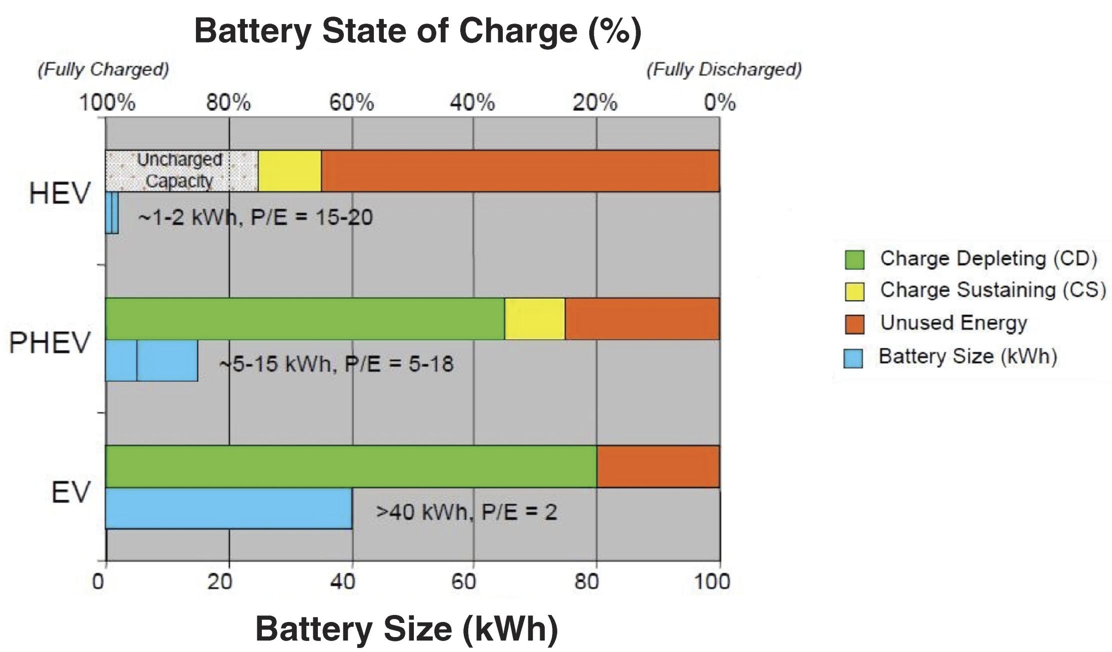

FIGURE 6.6 Energy capacity, state-of-charge variation, and relative power density to energy density ratios for batteries applicable to full-hybrid (HEV), plug-in hybrid (PHEV), and all-electric (EV) vehicles. The units of P/E are kW/kWh. SOURCE: Amine (2007).

some degree of electric-only range. Its battery must therefore contain sufficient energy to provide this range. The battery may be allowed to expend all of its stored energy to achieve this range goal, in which case the battery is said to be operated in the charge-depleting (CD) mode. The power requirement of this battery is not much different from that of the HEV battery, but because of the higher energy requirement, the P/E ratio is smaller. The BEV requires an even higher energy capacity battery than the PHEV, the value depending on the desired driving range. Since the BEV has no IC engine, its battery cannot be charged during driving, and therefore it cannot operate in a CS mode. In all cases the SOC variation is limited to a specified range by the vehicle manufacturer to preserve battery cycle life. Figure 6.6 shows typical ranges for the HEV, PHEV, and BEV. Thus the usable energy is less than the battery rated (or "nameplate") capacity.

Despite substantial improvements in the packaging and performance of lead-acid batteries, their energy and power densities are still considerably inferior to those of NiMH. And while other chemistries, like Li-air, have theoretically better performance than Li-ion, their development is not at a stage where one could envision them in practical automotive applications within the timeline of this study. Therefore the committee considers only NiMH and Li-ion as chemistries of interest here.

NiMH Batteries

The highest-performance battery currently available in commercially significant quantities for HEVs and PHEVs uses NiMH chemistry. Despite significant improvements in lifetime and packaging, these batteries are still expensive, heavy, and in application are restricted to a SOC range of about 20 percent to preserve battery cycle life. Because of their relatively poor charge/discharge efficiency, special consideration must be given to their thermal management. The NiMH chemistry also exhibits a high rate of self-discharge.

The most technically advanced NiMH battery used in the Toyota Prius has a weight of 45 kg and an energy capacity of 1.31 kWh. This results in a usable energy of approximately 0.262 kWh when applied with a SOC variation of 20 percent.

Li-Ion Batteries

The most promising battery technologies are those employing various Li-ion chemistries. Characteristics of the more common lithium-based cell compositions are shown in Table 6.1. The column heads denote the common abbreviation for the different chemistries: NCA (nickel-cobalt-aluminum), LFP (lithium-iron-phosphate), MS (manganese-spinel), MNS (manganese-nickel-spinel), and MN (manganese-nickel). The first entry gives the detailed composition of the anode and cathode materials, with the positive (cathode) material shown first. The second entry gives the gravimetric energy density of the chemistry in milliampere-hours/gram (mAh/g), the third entry shows the open-circuit terminal voltage when the cell is 50 percent depleted (50 percent state of charge), and the fourth entry gives the area specific impedance (ASI) as measured during a 10-second pulse at the 5C rate, which is indicative of the battery's ability to provide power necessary for acceleration. The relative safety of the different chemistries is given in the fifth entry. The safety of using Li-ion batteries has received considerable attention since the 2006 recall of Li-ion batteries used in laptops. In some of the chemistries, particularly those using a cobalt (Co)-based cathode, failure can occur due to overheating or separator failure. This problem is well known, and safety is a characterizing parameter common to all the Li systems. Some manufacturers believe they can solve the safety problem through careful monitoring and charge control. Relative cost among the different Li chemistries is shown in the seventh entry, although at this time the absolute cost of all is considerably higher than the cost for NiMH. The last entry in Table 6.1 indicates the state of the technology. Pilot scale indicates that cells are currently being manufactured in sufficient quantities for testing in vehicle fleets of limited size. Development means that the chemistry is well controlled, but the production of practical cells is anticipated and under development. Research indicates just that—the chemistry is still a subject of research, and the production of cells using the chemistry has not been demonstrated to an extent sufficient to anticipate their use.

TABLE 6.1 Comparative Characteristics and Maturity of Lithium-Ion Battery Chemistries

	Battery System				
	NCA-Graphite	LFP-Graphite	MS-TiO	MNS-TiO	MN-Graphite
Electrodes					
Positive	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	$LiFePO_4$	$LiMn_2O_4$	$LiMn_{1.5}Ni_{0.5}O_4$	$Li_{1.2}Mn_{0.6}Ni_{0.2}O_2$
Negative	Graphite	Graphite	$Li_4Ti_5O_{12}$	$Li_4Ti_5O_{12}$	Graphite
Capacity, mAh/g					
Positive	155	162	100	130	275
Negative	290	290	170	170	290
Voltage, 50% state of charge	3.6	3.35	2.52	3.14	3.9
ASI for 10-s,	25	25	9.2	100	25
Safety	Fair	Good	Excellent	Excellent	Excellent
Life potential	Good	Good	Excellent	Unknown	Unknown
Cost	Moderate	Moderate	Low	Moderate	Moderate
Status	Pilot scale	Pilot scale	Develop.	Research	Research

NOTE: NCA, Ni-Co-Al; LFP, Li-Fe-PO_4; MS-TiO, Mn(Spinel)-Ti-O; MNS-TiO, Mn-Ni(Spinel)-Ti-O; MN-Graphite, Mn-Ni-Graphite.

The relative gravimetric energy densities of Li-ion, NiMH, and Pb-acid are approximately 4, 2, and 1, respectively. An additional advantage of the Li systems is their high cell potential, approximately 3 times that of NiMH. This means that 66 percent fewer Li-ion cells are required to achieve a given battery voltage. The ecologically benign materials in the Li-ion systems are also an advantage. A disadvantage of Li-ion cells is that the requirement for cleanliness in the manufacturing environment is considerably more severe than for NiMH cells (Zempachi Ogumi, Kyoto University, personal communication, December 8, 2008). This increases manufacturing costs. Another critical issue is how the performance of Li-ion batteries is impacted by low and high temperatures (Amine, 2007; Reilly, 2007; Andermann, 2007).

The first three columns in Table 6.1—NCA-Graphite, LFP-Graphite, and MS-TiO—represent the most promising Li-ion systems currently under development. The NCA-graphite chemistry is used by JCS/SAFT in its VL41M module that has undergone dynamometer testing in a Toyota Prius at Argonne National Laboratories (ANL) (Rousseau et al., 2007). The lithium-iron phosphate (LFP) system is currently receiving a great deal of attention because of its stability, potentially lower material costs, and its application in power tools. Its development is being aggressively pursued by A123 and Enerdel. The manganese-spinel-lithium-titanate system (MS-TiO) is the safest of any being studied because of the mechanical stability of the spinel structure, but its cell voltage is considerably lower than those of the NCA and LFP systems. However, it has the highest charge/discharge efficiency, and it is predicted to be the lowest-cost system.

To put in perspective the merits of the Li-ion battery relative to NiMH, consider the requirements for a 20-mile all-electric range PHEV. According to an ANL study (Nelson et al., 2007), which assumed a 100 to 10 percent SOC range, the required battery capacity for its assumed vehicle is 6.7 kWh. For an MS-TiO battery the calculated weight is 100 kg. If an NiMH battery were used, with a SOC range of 20 to 80 percent and a gravimetric energy density one-half that of the MS-TiO system, the committee estimates that it would require a capacity of 10.35 kWh and weigh 300 kg.

The needs of HEVs and PHEVs are quite distinct, as shown in Figure 6.6. HEVs need high power density and long cycle life over a very small excursion of the SOC. For example the Prius battery has a nominal rating of 1.3 kWh but it uses only 260 Wh in +/−10 percent excursions around 50 percent SOC. On the other hand, the larger energy requirement of the PHEV argues for a battery with a higher energy rating and the capability of deeper cycling. The Volt, the PHEV being developed by GM, uses a 16-kWh battery to meet its advertised all-electric range of 40 miles. This is a substantial challenge to achieve at acceptable weight, volume, and cost. The Li-ion chemistry comes closest to meeting it, given the present state of battery development. It should be noted that the Volt is designed to use only 8 kWh by operating from 80 percent to 30 percent SOC.

POWER ELECTRONICS

The term *power electronics* refers to the semiconductor switches and their associated circuitry that are used to control the power supplied to the electrical machines or to charge the battery in an HEV or PHEV. For purposes of driving electric motors these circuits function as an inverter, changing the battery direct voltage into an alternating voltage of controlled amplitude and frequency. For charging the propulsion battery they function as a controlled rectifier, changing the ac voltage of the machine to the dc value required by the battery. The direction of power flow is either into or out of the battery, depending on vehicle mode of operation. Plug-in hybrids also require power electronic circuits to convert the ac main voltage to a precise dc voltage to charge the propulsion battery.

Power electronic circuits known as dc/dc converters change the propulsion battery dc voltage to the dc voltage appropriate to charging the accessory battery (i.e., the standard 12 V battery retained to power vehicle accessories). A dc/dc converter may also be used to increase system efficiency by stepping up the propulsion battery voltage before it is supplied to the inverter. The latest Toyota Prius uses such a design.

Both inverter and dc/dc converter technologies are well developed for industrial and other applications. The special problems for hybrid vehicles are cost, cooling, and packaging. Although the ambient environment for automotive electronics is much harsher than that in industrial or commercial applications, the cost in the automotive application is required to be lower. Figure 6.7 illustrates the improvement over a 10-year period in the volumetric power density of the motor drive inverter for Toyota's hybrid product line. The significant improvement after 2005 is due in large measure to the increased switching frequency made possible by the higher-speed motor and higher voltage introduced in 2005. These changes reduce the physical size of magnetic components and improve the utilization of silicon devices. Both these consequences result in improved packaging density.

ROTATING ELECTRICAL MACHINES AND CONTROLLERS

With the possible exception of microhybrids, all vehicles use permanent magnet alternating current motors. Since the battery capacity is the key limitation for hybrid vehicles, electrical machine efficiency is of paramount importance. Most systems employ "buried magnet" rotating machine configurations with expensive rare-earth high-strength magnets. GM and Honda are using flat wire for the armature winding to increase efficiency. Although rectangular conductors are common for large machines, their use in relatively small machines shows the extent to which manufacturers are going to get better efficiency. Rotating machine technologies and designs are well developed, and the automotive applica-

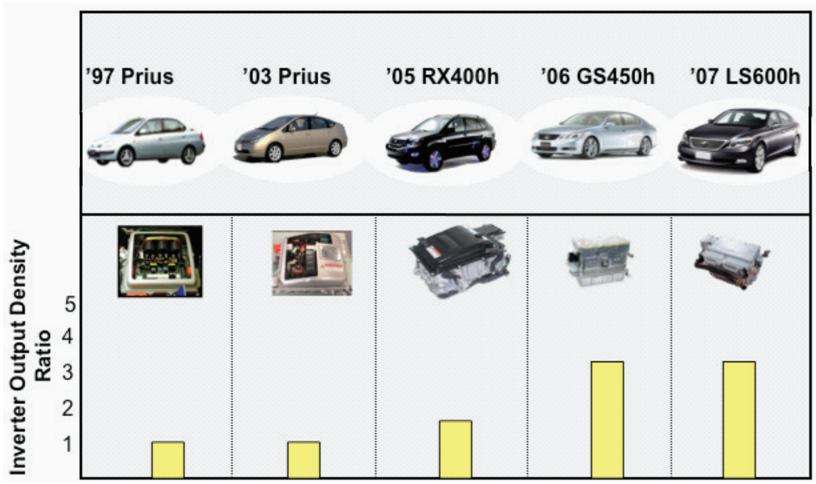

FIGURE 6.7 Evolution of hybrid drive inverter volumetric power density. SOURCE: Fushiki and Wimmer (2007). Figure used with permission of Toyota.

tion challenge is to lower their manufacturing cost. Because rotating machines are such a mature component, the cost of their manufacture in high volumes is driven principally by the cost of materials. Thus their cost is relatively unresponsive to technology developments. Major improvements in volumetric power density can be achieved by increasing the speed of the motor. This volumetric improvement results in materials reduction but generally also in increased losses. High-speed motors also require a gear set to match the mechanical speed required of the drive train. While the design of the motor/inverter system is an optimization problem, no technology breakthroughs that would radically improve the state of the art are foreseen. Figure 6.8 illustrates the improvement in volumetric power density that Toyota has achieved by increasing the speed of the electric motor in its hybrid vehicles.

Computers have been used to control emissions and optimize efficiency of conventional power trains. In addition to engine control, controllers in hybrid vehicles monitor the state of charge of the battery and determine power flows to and from the battery and engine. The control task is more complex for the PHEV where there is a greater opportunity to optimize the tradeoff between electric and IC engine use with respect to fuel consumption. One suggested approach is to have the controller predetermine the propulsion profile from expected route data provided by the driver or an off-board wirelessly connected server. Vehicle computers are powerful enough to handle these tasks, and no technical problems are expected.

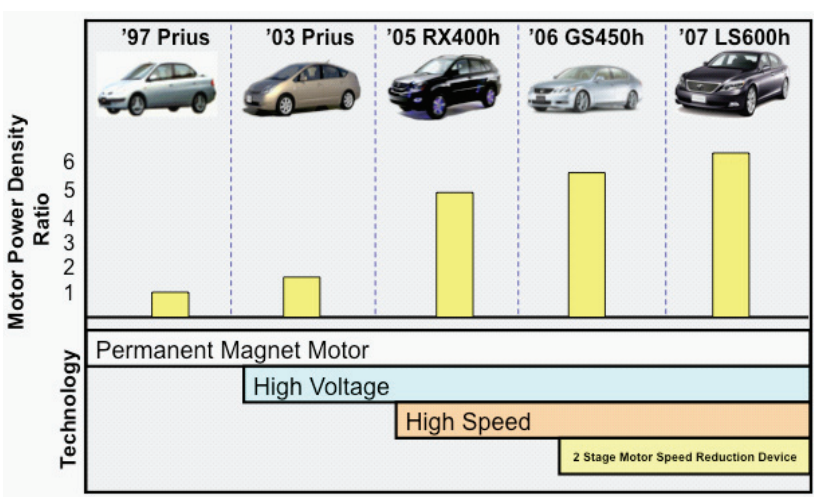

FIGURE 6.8 Evolution of the volumetric power density of electric motors used in Toyota's hybrid vehicles. SOURCE: Fushiki and Wimmer (2007). Figure used with permission of Toyota.

COST ESTIMATES

The objective in determining costs of new technologies is understanding their factory cost. The factory cost is the direct cost to the OEM of replacing existing production technology A by technology B. It is determined as follows:

1. Take the price (*B*) that a supplier charges the OEM for technology B;
2. Add the engineering cost (*C*) to the OEM of integrating technology B into a vehicle;
3. Add the cost (*D*) of any parts that the OEM makes in-house to implement the technology (labor cost plus factory overhead, plus amortization of required new investment); and
4. Subtract the cost (*A*) of technology A similarly calculated.

The *factory cost* is then $B + C + D - A$.

The cost estimates have been validated by soliciting feedback from a number of U.S. and Japanese OEMs and suppliers. The costs presented here are a consensus that the numbers are "about right." The costs of hybrid technologies vary depending on the degree of hybridization, from a low cost in the case of the BAS design, to a very high cost for a series PHEV. It should be noted that the factory cost definition used here includes engineering costs and other part costs, including labor and overhead, for integrating the technology. Using the studies described in Chapter 3, the committee developed a different markup factor for hybrids that relates the definition of factory cost to RPE. Although different studies use different definitions and allocations for items such as profit, vehicle warranty, corporate overhead, transportation, marketing, and dealer costs, the committee concluded that the factory markup for hybrids should be on the order of 1.33 rather than 1.5 for factory cost to RPE. The committee's justification for using an RPE of 1.33 for hybrids is that the factory cost estimates it developed already include engineering costs and other part costs, including labor and overhead, for integrating the technology. Using a cost multiplier of 1.5 would double count these costs.

As an example of the process, Table 6.2 shows an estimated breakdown of the factory cost of a "mature" Prius—a Prius-type drive that has benefited from the learning curve and has an annual production volume in excess of 100,000 units. The additional components and their estimated OEM costs from the supplier are listed. The committee also lists the cost decrement of items, such as the automatic transmission, that will be removed from the baseline vehicle, a Toyota Corolla in this case. The net cost increase for the mature Prius is then calculated as $3,385.

Next the committee projects costs for 5-year increments to 2025, as shown in Table 6.3. Percentage cost reductions

TABLE 6.2 Factory Cost Estimation Process Applied to a Mature Prius-type Hybrid Vehicle in U.S. Dollars

20 kW	Factory Cost ($B + C + D - A$)
Motor/generator/gears	1,100
Control electronics + dc/dc (1.2 kW)	1,100
Battery (NiMH 21 kW)	1,000
Electrical accessories	100
Electric PS and water pump	200
Automatic transmission	–850
Regenerative brakes	250
Electric A/C	300
Engine downsize	–120
Starter and alternator	–95
High-voltage cables (Martec 500 V)	200
Body/chassis/special components	200
Total	3,385

TABLE 6.3 Projections of the Future Factory Cost of a Mature Prius-type Hybrid in U.S. Dollars

20 kW	Cost Reductions (%)	Factory Cost ($B + C + D - A$) 2008	2015	2020	2025
Motor/generator/gears	5	1,100	1,050	990	940
Control electronics + dc/dc (1.2 kW)	15	1,100	940	800	680
Battery (NiMH 21 kW, Li-ion Martec)	15	1,000	850	720	720
Electrical accessories	5	100	90	90	85
Electric PS and water pump	5	200	190	180	170
Automatic transmission	0	–850	–850	–850	–850
Regenerative brakes	5	250	240	230	210
Electric A/C	10	300	270	240	220
Engine downsize	0	–120	–120	–120	–120
Starter and alternator	0	–95	–95	–95	–95
High-voltage cables (Martec 500 V)	10	200	180	160	150
Body/chassis/special components	10	200	180	160	150
Total		3,385	2,925	2,505	2,260

appropriate for each component are used. For example, expected reductions are on the order of 15 percent for each 5-year period for the battery and control electronics, 5 percent for the electrical machines, and no change in cost for the mature components such as engine downsizing, and the alternator.

A similar analysis has been done for the other hybrid classes, and the summary results are shown in Table 6.4. It should be noted that future costs for PHEVs and EVs are highly uncertain due to the uncertainties in future battery chemistries and tradeoffs between power and energy. Li-ion batteries for consumer electronics are a commercial technology, and costs have gone down along the learning curve. However, many OEMs and battery suppliers are expecting large cost reductions for Li-ion batteries with increasing applications in vehicles. Among its provisions related to fuel economy, the Energy Independence and Security Act of 2007 requires periodic assessments by the National Research Council of automobile vehicle fuel economy technologies. Thus, follow-on committees will be responsible for responding to this legislative mandate, including the periodic evaluation of PHEVs, EVs, and other technologies and how these technologies can help meet new fuel economy standards.

TABLE 6.4 Retail Price Estimates for Various Types of Hybrids Projected to 2025 (using an RPE of 1.33)

Vehicle	2009 ($)	2015 ($)	2020 ($)	2025 ($)
Prius-type power split	4,500	3,900	3,300	3,000
BAS/12 V	670	570	490	440
BAS/42 V	1,500	1,200	1,100	1,000
ISG 12 kW/144 V	2,900	2,500	2,100	2,000
Prius-type PHEV 10 (Li-ion battery)	8,800	7,600	6,500	5,900
Series PHEV 40 (Li-ion battery)	13,000	11,000	9,800	8,900
HEV crossover (V6)	6,900	6,000	5,200	4,700
Large SUV/pickup (V8)	8,700	7,500	6,400	5,700

FUEL CONSUMPTION BENEFITS OF HYBRID ARCHITECTURES

As noted earlier, the average fuel consumption of production hybrid HEVs was determined from fuel economy data supplied by Oak Ridge National Laboratory and included as Table 6.A.1 in the annex at the end of this chapter. For several specific models, these data were compared to data from conventional (nonhybrid) vehicles of approximately similar performance and physical specifications, and the results are shown in Table 6.5. As mentioned earlier, a significant contribution to the fuel consumption benefit of hybrid vehicles is due to modifications to the engine, body, and tires. For example, the fuel economy of the Prius is significantly influenced by engine improvements and optimized operating area. The 2007 model-year version of the Saturn Vue hybrid, which used a BAS design, exhibits a 25 percent improvement in fuel economy on the FTP cycle, but approximately half of that improvement is due to vehicle modifications, including a more aggressive torque converter lockup and fuel cutoff during vehicle deceleration (D. Hancock, General Motors, personal communications, November 30, 2007).

The Oak Ridge data did not include information on the Honda Accord, which was discontinued in 2007. The Accord has a motor/generator of 15 kW in motoring mode and a slightly higher 15.5 kW in regenerative mode (J. German, Honda, personal communication, February 28, 2008). The motor generator has high-energy-density magnets in an interior configuration. It also has flat wire windings that provide better packing density compared to round wire. The NiMH battery has 132 cells with a nominal voltage and energy of 144 V and 0.87 kWh, respectively (Iijima, 2006). Honda calls the system an integrated motor assist.

Plug-In Hybrids

The rules for assigning fuel economy ratings to plug-in hybrids are currently being developed by SAE (revision of J 1711). Thus the committee cannot predict at this time what

TABLE 6.5 Comparison of Fuel Economy, Fuel Consumption, Performance, and Physical Specifications of Hybrid and Comparable SI Engine-Powered Vehicles

Architecture	Volume Trunk	EPA Test (mpg, combined)	Fuel Consumption (gal/100 mi)	EPA Test Car Weight	Acceleration (Consumer Reports, mph/sec) 0 to 30	0 to 60	45 to 65	Edmund's MSRP Price
Prius								
Prius/Corolla	1.33	1.64	0.61	1.13	1.06	1.07	1.05	1.36
Prius/Camry	1.07	2.00	0.50	0.87	1.03	1.10	1.03	1.09
Honda Civic								
Civic hybrid/Civic SI	0.83	1.51	0.66	1.00	1.22	1.16	1.22	1.45
Chevy Tahoe 4WD								
Tahoe 4WD Hybrid/Tahoe 4WD SI	N/A	1.53	0.65	1.00	1.15	1.07	0.96	1.30

the official fuel economy rating of a specific PHEV design will be. At the time of this writing only two PHEVs have been announced for production—the GM Volt, which is expected to have a 40-mile range on battery alone, and the Toyota plug-in Prius, which will have a 12-mile all-electric range and the ability to cruise at highway speeds under all electric power.[6] GM has announced that LG Chem of Korea will be supplying the Volt's Li-ion battery.

FUEL CELL VEHICLES

Fuel cell vehicles have the potential to significantly reduce greenhouse gas emissions (depending on how hydrogen is produced) as well as U.S. dependence on imported oil over the long term. However, fuel cell vehicle technologies have technical challenges that are severe enough to convince the committee that it is unlikely such vehicles will be deployed in significant numbers within the time horizon of this study.

A recent report (NRC, 2008) states that under the following set of very optimistic assumptions, 2 million fuel cell vehicles could be part of the U.S. fleet in 2020:

- The technical goals are met and consumers readily accept such vehicles.
- Policy instruments are in place to drive their introduction.
- The necessary hydrogen production, supply, distribution, and fueling infrastructure is present.
- Oil prices are at least $100/barrel by 2020.
- Fuel cell vehicles are competitive on the basis of life-cycle cost.

Although the committee agrees with that study's conclusions under these optimistic assumptions, it believes that achieving them is unlikely. Almost every major OEM has a fuel cell vehicle program, and several have deployed limited fleets of experimental vehicles. These fleets invariably represent limited mission, localized experiments, city buses, or postal vehicles, for example. Through interviews and presentations, the committee can find little evidence that a commercially viable fuel cell light-duty vehicle will be available in significant numbers by 2020. The Japanese auto industry will not decide to pursue a commercial development program until 2015, thus making a 2020 introduction date very difficult. The committee confirmed this target decision date with Japan's NEDO, Japanese academics, and the OEMs themselves. All current fuel cell vehicle research assumes stored hydrogen as the fuel. The monumental difficulty of providing the necessary hydrogen distribution infrastructure is another factor mitigating against the presence of fuel cell vehicles in significant numbers by 2020.

For fuel cells, in spite of hundreds of millions of dollars having been devoted to their development by vehicle builders, equipment suppliers, and government organizations, there remain significant problems requiring technical and economic resolution, including the following:

- Higher cost of fuel cells compared to other energy converters,
- Lack of a hydrogen distribution infrastructure,
- Need for a low carbon source of hydrogen (biomass or water electrolysis using electricity produced with low emissions),
- Need to demonstrate acceptable durability and reliability, and
- Weight and volume of an on-board hydrogen storage tank sized for a range of 300 to 400 miles.

Because of these factors, the committee does not expect wide use of fuel cell vehicles before 2025.

FINDINGS

Finding 6.1: The degree of hybridization can vary from minor stop-start systems with low incremental costs and modest reductions in fuel consumption (i.e., the most basic stop-start systems may have a fuel consumption benefit of up to about 4 percent at an estimated incremental retail price equivalent (RPE) cost of $670 to $1,100) to complete vehicle redesign (e.g., Prius) and downsizing of the SI gasoline engine at a high incremental RPE cost ($3,000 to $9,000) and with significant reductions in fuel consumption. A significant part of the improved fuel consumption of production hybrid vehicles comes from vehicle modifications such as low-rolling-resistance tires, improved aerodynamics, and the use of smaller, more efficient SI engines.

Finding 6.2: In the next 10 to 15 years, improvements in hybrid vehicles will occur primarily as a result of reduced costs for hybrid power train components and improvements in battery performance such as higher power per mass and volume, increased number of lifetime charges, and wider allowable state-of-charge ranges.

Finding 6.3: During the past decade, significant advances have been made in lithium-ion battery technology. When the cost and safety issues associated with Li-ion batteries are resolved, they will replace NiMH batteries in HEVs and PHEVs. A number of different Li-ion chemistries are being studied, and it is not yet clear which ones will prove most beneficial.

Finding 6.4: Given the high level of activity in lithium-ion battery development, plug-in hybrid electric vehicles will be commercially viable and will soon enter at least limited production. However, improving the cost-effectiveness of PHEVs depends on the cost of fuel and whether significant reductions in battery cost are achieved.

[6] See http://www.reuters.com/article/pressRelease/idUS238743+09-Sep-2009+PRN20090909.

Finding 6.5: The practicality of full-performance battery electric vehicles (i.e., with driving range, trunk space, volume, and acceleration comparable to those of internal combustion-powered vehicles) depends on a battery cost breakthrough that the committee does not anticipate within the time horizon considered in this study. However, it is clear that small, limited-range, but otherwise full-performance battery electric vehicles will be marketed within that time frame.

Finding 6.6: Although there has been significant progress in fuel cell technology, it is the committee's opinion that fuel cell vehicles will not represent a significant fraction of on-road light-duty vehicles within the next 15 years.

REFERENCES

Amine, K. 2007. Advanced high power chemistries for HEV applications. Presentation to the National Research Council Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, November 27, Washington, D.C.

Andermann 2007. Lithium-ion batteries for hybrid electric vehicles: Opportunities and Challenges. Presentation to the National Research Council Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, October 25, Washington, D.C.

California Air Resources Board. 2009. DriveClean. Available at http://www.driveclean.ca.gov. Accessed June 29, 2009.

Fushiki, S., and B. Wimmer. 2007. Perspectives from Toyota. Presentation to the National Research Council Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, November 27, Washington, D.C.

Grewe, T.H., B.M. Conlon, and A.G. Holmes. 2007. Defining the General Motors 2-mode hybrid transmission. SAE Paper 2007-01-0273. SAE International, Warrendale, Pa.

Iijima, T. 2006. Development of hybrid system for 2006 compact sedan. SAE Paper 2006-01-1503. SAE International, Warrendale, Pa.

Kalhammer, F.R., B.M. Kopf, D.H. Swan, V.P. Roan, and M.P. Walsh. 2007. Status and Prospects for Zero Emissions Vehicle Technology. Report presented to ARB Independent Expert Panel, April 13, State of California Air Resources Board, Sacramento.

Nelson, P., K. Amine, and H. Yomoto, 2007. Advanced lithium-ion batteries for plug-in hybrid-electric vehicles. Paper presented at 23rd International Electric Vehicle Symposium, December, Anaheim, Calif.

NRC (National Research Council). 2008. Transitions to Alternative Transportation Technologies: A Focus on Hydrogen. The National Academies Press, Washington, D.C.

Reilly, B. 2007. Battery Technologies. Presentation to the National Research Council Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, October 25, Washington, D.C.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for the U.S. Environmental Protection Agency. EPA420-R-08-004. Contract No. EP-C-06-003. Work Assignment No. 1-14. Ann Arbor, Mich. Available at http://www.epa.gov/oms/technology/420r08004a.pdf. Accessed June 29, 2009.

Rousseau, A., N. Shidore, R. Carlson, and P. Nelson. 2007. Research on PHEV battery requirements and evaluation of early prototypes. Paper presented at the Advanced Automotive Battery Conference, May 17, Long Beach, Calif.

Tate, E.D., M.O. Harpster, and P.J. Savagian. 2009. The electrification of the automobile: From conventional hybrid, to plug-in hybrids, to extended-range electric vehicles. SAE International 1(April):156-166.

Tesla Motors, Inc. 2009. Tesla Roadster Spec Sheet. Available at http://www.teslamotors.com/display_data/teslaroadster_specsheet.pdf. Accessed June 29, 2009.

Transmission Technology International. 2008. ZF eight-speed hybrid. September, p. 10.

ANNEX

TABLE 6.A.1 Performance of Production Hybrid Vehicles from 2009 CAFE Certification Data

				Volume	EPA Fuel Economy (unadjusted mpg)			EPA Test	Acceleration (Consumer Reports)			Edmund's MSRP
Make	Type	Model	Drive	Trunk	City	Comb.	Hwy	Car Weight	0 to 30 mph, sec.	0 to 60 mph, sec.	45 to 65 mph, sec.	Price
Toyota	Split	Highlander Hybrid	4WD	NA	35	35	35	5000	3.4	8.2	5	$34,700
Toyota		Highlander	4WD	NA	21	25	31	4750	3	8	5.1	$29,050
Toyota	Split	Prius	FWD	16	67	66	65	3250	3.8	10.6	6.2	$22,000
Toyota		Corolla	FWD	12	35	40	49	2875	3.6	9.9	5.9	$16,150
Toyota		Camry	FWD	15	27	33	44	3750	3.7	9.6	6	$20,195
Toyota		Yaris	FWD	13	37	42	49	2625	4.1	11.4	6.9	$13,765
Toyota	Split	Camry Hybrid	FWD	11	44	46	48	4000	3.5	8.5	5.1	$26,150
Toyota		Camry	FWD	15	27	33	44	3750	3.7	9.6	6	$20,195
Toyota		Camry	FWD	15	25	30	40	3875	3.3	7.1	4.4	$24,215
Ford	Split	Escape Hybrid	FWD	NA	45	44	43	4000	NA	NA	NA	$29,645
Ford		Escape	FWD	NA	26	30	39	3625	NA	NA	NA	$21,645
Ford		Escape	FWD	NA	23	27	36	3625	NA	NA	NA	$24,465
Ford	Split	Escape Hybrid	4WD	NA	37	37	37	4250	4.1	10.7	5.8	$31,395
Ford		Escape	4WD	NA	24	28	35	3875	3.3	10	6.4	$23,395
Ford		Escape	4WD	NA	22	26	33	3875	3	7.9	5.2	$26,215
Saturn	Parallel	Aura Hybrid	FWD	16	33	39	48	NA	NA	NA	NA	$26,325
Saturn		Aura	FWD	16	28	34	47	4000	3.4	9.4	6.9	$22,655
Saturn		Aura	FWD	16	21	26	36	4000	2.8	6.6	4.3	$27,250
Saturn		Vue Hybrid	FWD	NA	32	37	45	4000	4.2	10.9	7.3	$28,160
Saturn		Vue	FWD	NA	24	28	37	4000	NA	NA	NA	$23,280
Saturn		Vue	FWD	NA	21	25	33	4250	NA	NA	NA	$26,435
Honda	Parallel	Civic Hybrid	FWD	10	55	59	65	3125	4.4	11.7	7.3	$23,650
Honda		Civic	FWD	12	33	39	51	3125	3.6	10.1	6	$16,305
Nissan	Parallel	Altima Hybrid	FWD	10	47	47	47	3750	3.1	7.6	4.4	$26,650
Nissan		Altima	FWD	15	29	34	43	3500	3.2	8.1	5	$19,900
Mazda	Split	Tribute Hybrid	FWD	NA	45	44	43	NA	NA	NA	NA	$28,175
Mazda		Tribute	FWD	NA	26	30	39	NA	NA	NA	NA	$21,790
Mazda		Tribute	FWD	NA	23	27	36	NA	NA	NA	NA	$23,055
Mazda	Split	Tribute Hybrid	4WD	NA	37	37	37	NA	4.1	10.7	5.8	$29,925
Mazda		Tribute	4WD	NA	24	28	35	NA	3.3	10	6.4	$23,545
Mazda		Tribute	4WD	NA	22	26	33	NA	3	7.9	5.2	$24,805
Mercury	Split	Mariner Hybrid	FWD	NA	45	44	43	NA	NA	NA	NA	$30,090
Mercury		Mariner	FWD	NA	26	30	39	NA	NA	NA	NA	$22,650
Mercury		Mariner	FWD	NA	23	27	36	NA	NA	NA	NA	$23,660
Mercury	Split	Mariner Hybrid	4WD	NA	37	37	37	NA	4.1	10.7	5.8	$31,840
Mercury		Mariner	4WD	NA	24	28	35	NA	3.3	10	6.4	$24,400
Mercury		Mariner	4WD	NA	22	26	33	NA	3	7.9	5.2	$25,410

continued

TABLE 6.A.1 Continued

				Volume	Official EPA (unadjusted mpg)			EPA Test	Acceleration (Consumer Reports)			Edmund's MSRP
Make	Type	Model	Drive	Trunk	City	Comb.	Hwy	Car Weight	0 to 30 mph, sec.	0 to 60 mph, sec.	45 to 65 mph, sec.	Price
Chevrolet	Parallel	Malibu Hybrid	FWD	15	33	39	48	3875	4.1	10.3	6.9	$25,555
Chevrolet		Malibu	FWD	15	27	33	43	3750	3.4	9.4	7	$21,605
Chevrolet		Malibu	FWD	15	23	28	40	NA	3	8.1	5.1	NA
Lexus	Split	RX 400h Hybrid	2WD	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lexus		RX 350	2WD	NA	20	22	25	4250	NA	NA	NA	$37,700
Lexus		RX 350	2WD	NA	20	22	25	NA	NA	NA	NA	NA
Lexus	Split	RX 400h Hybrid	4WD	NA	NA	NA	NA	NA	2.9	7.4	4.6	NA
Lexus		RX 350	4WD	NA	22	26	32	4500	NA	NA	NA	$39,100
Lexus		RX 350	4WD	NA	22	26	32	NA	2.7	7.3	4.8	NA
Lexus	Split	GS 450h Hybrid	RWD	9	28	31	35	4500	2.5	5.9	3.9	$56,550
Lexus		GS 350	RWD	13	24	28	37	4000	NA	NA	NA	$45,000
Lexus	Split	LS 600h L	AWD	12	25	27	30	5500	NA	NA	NA	$106,035
Chevrolet	Split	Tahoe Hybrid	RWD	NA	27	28	30	6000	NA	NA	NA	$50,455
Chevrolet		Tahoe	RWD	NA	15	19	27	6000	NA	NA	NA	Premium
Chevrolet		Tahoe	RWD	NA	17	20	27	5500	NA	NA	NA	$39,315
Chevrolet	Split	Tahoe Hybrid	4WD	NA	27	28	30	6000	3.9	9.6	5.5	$53,260
Chevrolet		Tahoe	4WD	NA	15	18	26	6000	3.4	9	5.7	$41,025
Chevrolet	Split	Silverado Hybrid	RWD	NA	27	28	30	NA	NA	NA	NA	$38,020
Chevrolet		Silverado	RWD	NA	17	21	27	5500	NA	NA	NA	NA
Chevrolet		Silverado	RWD	NA	18	21	27	5000	NA	NA	NA	$26,915
Chevrolet	Split	Silverado Hybrid	4WD	NA	27	28	30	NA				$41,170
Chevrolet		Silverado	4WD	NA	17	20	27	5500				NA
Chevrolet		Silverado	4WD	NA	18	21	27	5250	3	7.9	5.1	$30,065
GMC	Split	Yukon Hybrid	RWD	NA	27	28	30	NA	NA	NA	NA	$50,920
GMC		Yukon	RWD	NA	15	19	27	NA	NA	NA	NA	Premium
GMC		Yukon	RWD	NA	17	20	27	NA	NA	NA	NA	$39,970
GMC	Split	Yukon Hybrid	4WD	NA	27	28	30	NA	3.9	9.6	5.5	$53,730
GMC		Yukon	4WD	NA	17	20	27	NA	3.4	9	5.7	$41,765
GMC	Split	Sierra Hybrid	RWD	NA	27	28	30	NA	NA	NA	NA	$38,390
GMC		Sierra	RWD	NA	17	21	27	5500	NA	NA	NA	NA
GMC		Sierra	RWD	NA	18	21	28	NA	NA	NA	NA	$26,915
GMC	Split	Sierra Hybrid	4WD	NA	27	28	30	NA	NA	NA	NA	$41,540
GMC		Sierra	4WD	NA	17	20	27	NA	NA	NA	NA	NA
GMC		Sierra	4WD	NA	18	21	27	6000	3	7.9	5.1	$30,065
Dodge	Split	Durango Hybrid	4WD	NA	25	27	30	NA	NA	NA	NA	$45,040
Dodge		Durango	4WD	NA	17	20	26	NA	2.8	7.4	5.2	NA
Chrysler	Split	Aspen Hybrid	4WD	NA	25	27	30	NA	NA	NA	NA	$45,270
Chrysler		Aspen	4WD	NA	17	20	26	NA	2.8	7.4	5.2	NA
Cadillac	Split	Escalade Hybrid	2WD	NA	27	28	30	NA	NA	NA	NA	$73,135

7

Non-Engine Technologies

INTRODUCTION

This chapter focuses on reducing fuel consumption with non-power-train technologies. These technologies affect engine performance either directly or indirectly in a manner that reduces fuel consumption. For example, a significant portion of this chapter discusses the state of readiness, cost, and impact of reducing vehicle mass. Reducing mass reduces the energy necessary to move a vehicle, and thus reduces fuel consumption. The complexity of substituting advanced, lightweight materials affects the redesign of a part or a subsystem, component manufacturing (including tooling and production costs), and joining, and raises interface issues that mixing different materials can pose. The term *material substitution* oversimplifies the complexity of introducing advanced materials, because seldom does one part change without changing others around it. Advanced lightweight materials show great promise for reducing mass throughout a vehicle's body structure and interior. Low-rolling-resistance tires and reduction of aerodynamic drag are also discussed as technologies that can lower tractive force and result in reduced fuel consumption. Improvements in energy-drawing devices such as air conditioner compressors and power steering can reduce fuel consumption either by electrification or by improving their efficiency. New transmissions with more gears or that are continuously variable improve power train efficiency. All these options either reduce the demand for power from the engine or enable operating the engine at a more efficient point to reduce fuel consumption.

NON-ENGINE TECHNOLOGIES CONSIDERED IN THIS STUDY

The committee considers car body design (aerodynamics and mass), vehicle interior materials (mass), tires, vehicle accessories (power steering and heating, ventilation, and air conditioning [HVAC] systems), and transmissions as areas of significant opportunity for achieving near-term, cost-effective reductions in fuel consumption. These will be considered in some detail below.

Aerodynamics

As discussed in Chapter 2, the force required to overcome drag is represented by the product of the drag coefficient, the frontal area, and the square of speed. The actual formula is F = ½ Cd AV2 where A is the vehicle frontal area, V is velocity, and Cd is the drag coefficient. Cd typically ranges from about 0.25 to 0.38 on production vehicles and depends on several factors with the primary influence coming from vehicle shape and smaller influences from other factors, such as external mirrors, rear spoilers, frontal inlet areas, wheel well covers, and the vehicle underside. Vehicles with higher Cd values (greater than .30) may be able to reduce the Cd by up to 10 percent at low cost without affecting the vehicle's interior volume. In trying to reduce fuel consumption, certain vehicles achieved very low drag coefficients, for example, GM's EV1 had a Cd of 0.19, and the third-generation Prius has a Cd of 0.25.[1] In the committee's judgment a Cd of less than 0.25 would require significant changes that could include the elimination of outside rear view mirrors, total enclosure of the car underbody, and other modifications that may be very costly. Vehicles that exist today with a low Cd (below 0.25) are usually specialty vehicles (e.g., sports cars and high-mileage vehicles like the Prius). The 2010 Mercedes E-class is the only production vehicle with a Cd as low as 0.25. However, this is a luxury-class vehicle and retails for $50,000 (or more). Some costs are incurred from incorporating aerodynamic features such as the integrated front spoiler, an option that may not be possible for lower-cost vehicle classes. Further reducing Cd for lower-cost vehicles is expensive and perhaps beyond a point of diminishing returns. Vehicles with higher Cd (e.g., trucks,

[1] See http://www.greencar.com/articles/20-truths-gm-ev1-electric-car.php and http://pressroom.toyota.com/pr/tms/toyota/all-new-prius-reveal.aspx, respectively.

vans, and box-like vehicles such as the Scion and Flex) can reduce Cd, although vehicle functionality is diminished. If the functionality is compromised, then the vehicle's appeal to the consumer would be reduced.

As noted above, the aerodynamic drag is the product of the drag coefficient Cd, the vehicle frontal area, and speed. Reduction in the frontal area, reducing vehicle size, and lower speed limits would also improve fuel consumption; however, exploring these options is outside the committee's statement of task.

Car Body Design and Interiors

Optimized car body design focuses on a balance between structural stiffness, noise/vibration/harshness (NVH), safety (crashworthiness), comfort (space), and mass. Today's priority of reducing fuel consumption places an emphasis on mass reduction, with the assumption that other performance criteria will not be unduly compromised. Vehicle mass can be reduced without compromising size, crashworthiness, and NVH, although countermeasures are often required to restore NVH performance when mass is reduced.

The majority of vehicle mass can be attributed to the body structure, closure panels (doors, hood, and deck lid), interior seating and trim components, glass, power train components (engine, transmission, etc.), and the chassis (axles, wheels, brakes, suspension, etc.). Steel, cast iron, fiber/reinforced composites, glass, and aluminum have been the dominant materials for these components, with steel accounting for the majority of mass. Estimates for the amount of these materials in today's average, high-volume vehicles are listed in Table 7.1 (Carpenter, 2008). The typical baseline vehicle used for comparison is described as a 3,600-lb model-year 2009 comparable to a Toyota Camry or Chevrolet Malibu.

High-volume vehicle manufacturing is generally associated with the production of more than about 100,000 vehicles per year (although some might say 50,000). Low volume might be under 25,000 vehicles per year. This is important because different materials become cost competitive at different volumes. Higher-cost materials (composites, aluminum, and magnesium) become more cost competitive at lower volumes because the forming tools in most cases have a lower investment cost offsetting the higher material cost. Steel requires high-cost forming tools but has a lower materials cost, making steel competitive at higher volumes. For example, for some non-structural applications, steel becomes cost competitive vis-à-vis plastic at around 50,000 units.

Two key strategies for achieving mass reduction are changing the design to require less material, or substituting lighter-weight materials for heavier materials. Assuming that the car size is essentially fixed, there are design techniques that can reduce mass. Several different body architectures are described below. Material substitution relies on replacing a heavier material with a lighter one while maintaining performance (safety and stiffness). For example, high-strength steel can be substituted for mild steel (and therefore a thinner gauge can be used), aluminum can be substituted for steel, plastic can be substituted for aluminum, and magnesium can be substituted for aluminum. It is often a misnomer to refer to this as material substitution. The part (or subsystem) often has to be redesigned, and the fabrication process may change and the assembly process may be different. In fact, the material cost differential may be insignificant relative to the costs associated with the changes in fabrication and assembly.

Body Design and Material Selection

The great majority of vehicles produced today are unibody design. The unibody design is a construction technique that uses the internal parts as the principal load-bearing structure. While the closure panels (doors, hood, and deck lid) provide important structural integrity to the body of the vehicle, the outer skin panels, defined as the metal outer panels on the entire automobile that are painted and visible to the consumer, do not. This design has replaced the traditional body-on-frame design primarily because it is a lighter. Body-on-frame designs, where an independent body structure (with its own structural integrity) sits on top of a separate frame (with its own structural integrity), still prevail on some heavier vehicles such as pickup trucks and larger SUVs because of its overall superior strength and stiffness. Another design, the space frame, was recently developed to accommodate aluminum. The forming and joining of aluminum cannot easily or cheaply be replicated in a steel unibody design. A typical space frame is composed of extruded metal connected at the ends, which are referred to as nodes. Both the unibody and the space frame have "hang-on" panels where the skin panels have little to no structural load. A final design architecture, the monocoque, relies on the outer skin surface as a principal load-bearing surface. The

TABLE 7.1 Distribution of Materials in Typical Vehicle (e.g., Toyota Camry and Chevrolet Malibu)

Material	Comments	Approximate Content in Cars Today, by Weight (percent)
Iron and mild steel	Under 480 Mpa	55
High-strength steel	≥ 480 Mpa (in body structure)	15
Aluminum	No aluminum closure panels; aluminum engine block and head and wheels	10
Plastic	Miscellaneous parts, mostly interior trim, light lenses, facia, instrument panel	10
Other (magnesium, titanium, rubber, etc.)	Miscellaneous parts	10

monocoque is seen in very low volumes because there are few applications where it is structurally and economically viable. Generally, these three designs are associated with the following materials:

- *Unibody*—steel-based structure (mostly steel stampings) usually with steel skin panels but sometimes plastic or aluminum skin panels. This design has high investment (engineering and tooling) costs and is designed for high volume.
- *Space frame*—usually an aluminum-based structure (aluminum castings, extrusions, and sheet). This design is less complex than the unibody and has lower investment costs, which are typically offset by higher material costs. Because of the high material costs (that are variable with volume), this is typically a low-volume design.
- *Monocoque*—reinforced resin/composite body structure using the skin to bear loads. Today, this architecture is uncommon for passenger automobiles and more common for aircraft or ships.

The space frame and monocoque structures are associated today with niche vehicle markets, whereas the unibody with its steel-based structure is common (perhaps found in more than 99 percent of today's automobiles). These design approaches differ from the body-on-frame design that is well suited for heavier "working" vehicles like trucks and SUVs. Body-on-frame readily achieves all the desired design criteria, except that it is heavy because of the large frame components.

Reducing Mass Using Alternative Materials

There are several methods to make steel structures lighter, regardless of their design construction:

- Substitute higher-strength steel for lower-strength steel. Higher-strength steel can be down-gauged (made thinner). There are, however, forming and joining issues with higher-strength steel that limit where it can be applied, and down-gauging can reduce the ability to meet stiffness criteria.
- Substitute sandwich metal material for conventional steel. Sandwich material has layers of steel or aluminum (usually three), often with the internal layer in the form of honeycomb or foam. Other layered materials can include bonded steel with plastic/polymers. This cladding material can achieve high stiffness and strength levels with low mass. Sandwich material is light, is very stiff, and can be formed for many parts. On the downside, joining it to other parts can be difficult, its availability is limited today, and it is expensive to produce.
- Introduce new steel designs that are available, such as with laser welded blanks and hydro-formed tubes or hydro-formed sheet metal. The use of tubes and laser blanks can make more optimal use of metal (steel or aluminum) and result in less mass in the structure without compromising design criteria. These methods may increase or decrease costs depending on the application.

Most steel and mixed-material vehicles (e.g., steel and aluminum) today are unibody, and aluminum-intensive vehicles tend to be space frame designs, but these are low volume due to cost. The unibody design was developed primarily for steel, and the conventional vehicle today is composed of about 65 percent steel (both mild and high strength). Various components of a unibody can have alternative lightweight materials, including high-strength steel, polymers/composites, and aluminum directly substituted on a part-by-part basis to help reduce mass on a limited basis. Sheet molding compound (SMC plastic) body panels are sometimes used for fenders or exterior closure panels to save weight, and in the case of low-volume vehicles, to save costs. The ability to substitute alternative materials, however, can be limited because of forming (part shape), joining, and interface issues between mixed materials. Steel unibody designs can accommodate polymer/composite or aluminum closure panels because these parts can be easily isolated from the remainder of the structure since they are fastened onto the structure. Many unibody steel-based vehicles made in North America have aluminum hoods and deck lids, but steel doors. Hoods and deck lids are simpler designs than doors (they are flatter and have fewer parts, and therefore are less expensive and less complex to switch over to aluminum). Steel doors could also be converted to aluminum in many cases, as is often done in Europe, but in North America their size and geometry would make this conversion relatively expensive.

The mass savings by introducing high-strength steel results from the ability to down-gauge the thickness over mild steel while maintaining the same strength as the thicker mild steel part. Down-gauging reduces stiffness, and so this is not a solution in some cases where stiffness is important. Also, as the strength of steel increases, its ability to be formed into different shapes is reduced (its allowable percent elongation is reduced). This reduced formability also limits where high-strength steel can be applied. The outside panels (skin panels) on a unibody are predominantly non-structural and subject to dents, thus also limiting the ability to down-gauge these panels. The tools that form high-strength steel parts cost more, require greater maintenance because they are subject to wear, and require greater forming pressures in production. In most cases, high-strength steel parts cost more than comparable mild steel parts. New, advanced high-strength steels are being developed to give high-strength steel greater formability and weldability. These advanced high-strength steels, expected to be available within a few years, can reduce mass on some compatible parts by around 35 percent. This is achieved by using high-strength steel to reduce part thickness by 35 percent (e.g., replacing 1.8-mm-thick mild steel with 1.2-mm-thick high-strength steel). Factors such as part geometry and subsystem stiffness can limit viable applications of high-strength steel or constrain the reduction in thickness.

An aggressive approach to introducing aluminum into the structure may dictate a totally different body design approach, such as shifting from a unibody to a space frame structure. The space frame design has been developed recently for aluminum-intensive structures. The structure is composed of aluminum castings, extrusions, and sheet. This design is lighter than a comparable steel design and is in production today, but is used only on lower-volume, higher-end vehicles because of its high cost. Introducing an aluminum-intensive structure would necessitate a complete vehicle redesign, requiring several years at extremely high development costs (see the product development process discussion in the section "Timing Considerations for Introducing New Technologies" below in this chapter).

Polymer-matrix composites (PMCs) are beginning to be introduced into higher-volume vehicles. Viable options for PMC are for it to be reinforced with glass fibers, natural fibers, or carbon fiber to give it strength. Glass- and natural-fiber-reinforced PMCs are lower cost than carbon fiber, but they have less strength. Since they incur lower cost, it is likely that these applications will be seen on higher-volume vehicles before there is significant use of carbon fiber composites. Carbon fiber is a promising lightweight material for many automotive components. Much like plastic, PMC can be molded into complex shapes, thus integrating several steel or aluminum parts into a single PMC part that reduces complexity and tooling costs. Conservative estimates are that carbon fiber PMC can reduce the mass of a steel structure by 40 to 50 percent (Powers, 2000). Both its strength and its stiffness can exceed that of steel, making it easy to substitute for steel or aluminum while offering equal or better structural performance. The greatest challenges with PMC are cost and carbon fiber availability. Also challenging is connecting composite parts with fasteners, which has delayed the introduction of the latest Boeing 787 Jet.

The price of carbon fiber is extremely volatile, with material cost typically in excess of $10/lb. Carbon fiber exceeds the cost of steel and aluminum by approximately 20-fold and 7-fold, respectively. Steel and aluminum can also be formed with high-speed stamping, which is much less costly than forming PMC, which typically involves a fairly slow autoclave process. Research at Oak Ridge National Laboratory (ORNL) is aimed at developing lignin-based carbon fiber to help reduce material cost and improve supply (Compere et al., 2001). This research in conjunction with the FreedomCar program at the United States Council for Automotive Research (USCAR) indicates that the price of carbon fiber has to fall to $5 to $7 per pound (about 50 percent) before it can be cost competitive for high-volume automobiles (Carpenter, 2008). Lignin-based carbon fiber will also help ensure a greater supply of the base material of PMC. One expert stated that carbon fiber will see wider use in the future, but primarily on lower-volume (fewer than 100,000 vehicles per year), higher-performance vehicles (Carpenter, 2008).

The cost differential (by pound) varies significantly for alternative materials. High-strength steel might cost double the price of mild steel ($0.80 versus $0.40 per pound), and aluminum might cost four or five times that of steel (per pound). Other materials such as magnesium and titanium are also expensive and have volatile price fluctuations.

It is important to recognize that the comparison of different materials is complicated by many factors, making a cost analysis difficult. Tooling costs and parts fabrication costs differ significantly for different materials.

- The amount of material (pounds) needed by the lightweight material is different from the incumbent material.
- Because of part fabrication, the optimal design with the lightweight material may be very different from the design of the original part. For example, some steel parts cannot be formed exactly the same out of aluminum because of formability constraints. Also, if you substitute a material that is cast (magnesium) instead of stamped (steel), the forming cost and the part design are different.
- The tooling to form the alternative material is likely to be different than the tooling for the incumbent material, and may cost more or less.
- The processing (part fabrication) process will likely run differently, and may operate much slower than that for the incumbent material (e.g., molding is much slower than stamping, sometimes by a factor of 10).

USCAR and the U.S. Department of Energy continue to research reducing body mass by substituting new materials, such as high-strength steel, advanced high-strength steel, aluminum, magnesium, and composites for current materials. The material industries also conduct significant research to advance new materials (for example, through the Auto-Steel Partnership, the American Iron and Steel Institute, the Aluminum Association, and the American Chemistry Council). Increased costs for lighter and stronger parts result from higher material costs and higher costs for component fabrication and joining. Estimates for the body-mass reduction that can be achieved in the near term vary from 10 percent (with mostly conventional and high-strength steels) to 50 percent (with a mostly aluminum/composite structure). Even greater reductions are feasible, but these require very expensive and aggressive use of aluminum, magnesium, and composite structures involving materials such as carbon fiber.

Non-Body Mass Reduction

Vehicle interiors also offer opportunities to reduce vehicle mass. Some opportunities can be implemented for little cost, whereas others entail significant costs. For example, composite-intensive instrument panels, recycled seating materials, and lighter-weight trim panels can reduce mass by tens of pounds at virtually no cost. However, unlike the car body for which the consumer cannot easily detect what materials are used, the interior is aesthetically critical and closely scrutinized by the consumer. Costs may be incurred by covering over the appearance of some parts. There are quality concerns, such as fit-up of panels, part texture, and appearance issues that constrain interior cockpit design alternatives. Some isolated components can have mass reduced with material substitution such as headlamps (with new resins) and wheels (with new aluminum grades) that actually enhance aesthetics but often increase cost. Non-visual parts, however, also present an opportunity, such as seat belt reinforcements, seating frames/brackets, and fire wall panels. Most non-structural applications that can be light-weighted with plastic already have been. Glass-reinforced sheet molding compound (SMC) is low cost and inexpensive to form but lacks sufficient strength to replace most structural applications responsible for much of the weight.

Isolated components on the vehicles are also candidates for aluminum, magnesium, or advanced high-strength steel substitution, such as wheels, engine cylinder heads, suspension arms, transmission cases, brake calipers, steering knuckles, and engine blocks, although many OEMs have already made these substitutions, especially in cylinder blocks and heads. Aluminum heads are more common than aluminum blocks because of performance issues in the block, but other materials including hybrid materials (both aluminum and cast iron) are being applied to the blocks. An even more aggressive approach to introducing aluminum into the structure itself will likely involve aluminum-intensive substructures (e.g., axle assemblies, engine compartment, etc.), and such components are also now starting to penetrate the new-vehicle population.

Car glass (windshield, side windows, rear window, mirrors, and sun roofs) is also heavy, and there are opportunities to reduce mass by substituting polycarbonate. Polycarbonate can be coated to provide a durable finish, and this has been applied to non-windshield glass panels where scratching is less a concern.

Rolling Resistance

Tire rolling resistance is one of many forces that must be overcome in order for a vehicle to move (see discussion in Chapter 2). When rolling, a tire is continuously deformed by the load exerted on it (from the vehicle mass). The repeated deformation during rotation causes energy loss known as rolling resistance. Rolling resistance is affected by tire design (for example, materials, shape, and tread design) and inflation. Underinflated tires increase rolling resistance. The opportunity to improve fuel economy by reducing rolling resistance is already used by OEMs to obtain better "EPA numbers," and so original equipment tires tend to have lower rolling resistance than consumer-replaced tires because typical values for the coefficient of rolling resistance (r_o) values differ between them (NRC, 2006). This represents an interesting value tradeoff. The OEMs are more interested in getting low-rolling-resistance tires to show improved fuel economy, and people buying replacement tires are more interested in low cost and durability. Therefore the total opportunity for fuel consumption reduction is defined by the fraction of the tires on the road that falls into each category. Education of the public on the subject of low-rolling-resistance tires for replacement tires and the continued introduction of tire pressure monitoring systems, which is discussed below, may help improve in-use performance of tires for fuel consumption reduction.

There are performance tradeoffs involving tires that tire manufacturers consider during design and manufacturing. These tradeoff variables include, for example, tread compound, tread and undertread design, bead/sidewall, belts, casing, and tire mass. Important tire performance criteria affected by design and manufacturing include rolling resistance, tire wear, stopping distance (stopping distance or grip can be evaluated over different surfaces, such as wet or dry), and cornering grip. Wear and grip are closely correlated to tread pattern, tread compound (e.g., softer compounds grip better but wear faster), and footprint shape.

The impact of emphasizing one performance objective (such as low rolling resistance) over other performance criteria is inconclusive. Some studies have shown that tires with low rolling resistance do not appear to compromise traction, but may wear faster than conventional tires. Another study in 2008 by Consumers Union and summarized by *Automotive News* (Automotive News, 2008) concluded that there may be a reduction in traction, because of low-rolling-resistance tires, that increases stopping distance. The study is not rigorously controlled, and other influences may confound the results. The response by one tire manufacturer, Michelin (Barrand and Bokar, 2008), argues that low-rolling-resistance tires can be achieved without sacrificing performance factors by balancing the design and manufacturing process variables. Tire makers are continuing to research how to get optimal performance (including fuel economy) without sacrificing other criteria such as safety or wear. Goodyear points out that performance tradeoffs between rolling resistance, traction, and tread wear can be made based on materials and process adjustments, which also affect cost (Goodyear Tire & Rubber Company, 2009). The incremental cost for low-resistance tires may not be significant, but the cost-benefit tradeoff with increased stopping distance, wear, and possibly noise, vibration, and harshness issues are important for the consumer.

Rolling resistance can also be affected by brakes. Low-drag brakes reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotating rotor. Most new vehicles have low-drag brakes. The impact over conventional brakes may be about a 1 percent reduction of fuel consumption.

Rolling resistance is also affected by tire inflation, and so any technology that affects inflation levels can also affect fuel economy. Reducing tire inflation levels increases rolling resistance, which in turn increases fuel consumption. A tire pressure monitoring system (TPMS) can be set to different pressure thresholds, and the average deviation from the recommended inflation level would be 1/2 the threshold level. For example, if the threshold is set at 10 psi, the average deviation from the recommended level would be 5 psi. Michelin believes that an accurate TPMS with an appropriately set threshold could reduce fuel consumption by up to 0.7 percent (J. Barrand, personal communication, May 12, 2009).

Vehicle Accessories

Some automakers are beginning to introduce electric devices (such as motors and actuators) that can reduce the mechanical load on the engine, reduce weight, and optimize performance, resulting in reduced fuel consumption. Of course, the electrical power used by these devices must be furnished by the engine driving the alternator. Thus the most advantageous opportunities for converting mechanical devices to electrical are devices that operate only intermittently, such as power steering and air-conditioning compressor. The benefits from electric and/or electro-hydraulic power steering and greater efficiency in air-conditioning (A/C) are not credited by current EPA fuel economy tests (since neither operates during the test), and so manufacturers are reluctant to implement them because of added costs. With the new EPA test procedures, some of the benefits will be reflected in the "sticker," and improvements in these areas are relatively "low hanging fruit."

- *Heating, ventilating, and air-conditioning (HVAC).* A more efficient system starts with (larger) heat exchangers that transfer high heat more effectively and a thermal expansion valve that controls the evaporator temperature. The compressor uses the majority of the energy of the A/C system, and variable displacement piston compressors are available and in use that significantly reduce fuel use over fixed displacement compressors. There are many other technologies, such as increased use of recirculated air, elevation of evaporator temperature, use of pulse-width modulated blower speed controllers, and internal heat exchangers, that can further reduce fuel usage.

Further reductions in fuel use can be achieved by decreasing A/C load through the use of low-transmissivity glazing (reducing both heat and ultraviolet penetration), reflective "cool" paint, and cabin ventilation while parked. Suppliers are investigating the use of directly cooling the seat either through ducting or by thermoelectric materials. Although this may increase comfort, it is not clear whether this will significantly improve fuel economy (Rugh et al., 2007).

- *Exhaust heat recovery.* Recent improvements in thermoelectric materials for HVAC and exhaust energy recovery appear promising. Research is directed primarily at new materials with higher "thermoelectric figure of merit" (Heremans et al., 2008; Hussain et al., 2009). This is accomplished by increasing the thermoelectric effect (Seebeck coefficient) and reducing the thermal conductivity. Good results have been obtained with nanomaterial processing, but at this time these are costly. Improvements in potentially low-cost bulk materials are needed for automotive applications. BMW has announced a planned introduction on production vehicles in the 2012/2013 model year.[2] It presented a model of an application at the 2006 DEER Conference[3] and in the press.[4] A DOE presentation gave more information on this vehicle and presented a rather optimistic view of energy recovery.[5] In the view of the committee significant improvements need to be made in the performance of bulk materials and in the processing of nanomaterials before thermoelectric heat recovery from the exhaust can be applied in mass production. The committee thinks that this will not happen in the 10-year horizon considered here.

Transmission Technologies

Transmission technologies can reduce fuel consumption in two ways, first by moving engine operation to more efficient regions of the engine map (cf. Figure 2.3 in Chapter 2) and second by continued reduction of the mechanical losses within transmissions. Of these two, moving engine operation to more efficient regions of the engine map (e.g., higher torque (or brake mean effective pressure; BMEP) and lower speeds) offers the largest potential gains. The major approaches to achieving this movement are by increasing the number of speeds in the transmission (whether manual, automatic, or continuously variable) and lowering final drive ratio.

Five-speed automatic transmissions are already a standard for many vehicles; 6-, 7-, and 8-speed automatic transmissions have been available on luxury cars and are penetrating into the non-luxury market. This new wave of automatic transmissions has been enabled by new power flow configurations and improved controls capability that are enabling larger numbers of speeds to be achieved at a lower cost increment over 4-speed automatics than would be the case for adding speeds to previous automatic transmission designs.

[2]See http://www.motorward.com/2009/02/new-details-on-next-generation-bmw-5-series/.

[3]See http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2006/session6/2006_deer_lagrandeur.pdf.

[4]See http://www.autobloggreen.com/2008/09/25/bmw-wins-koglobe-2008-award-for-thermoelectric-generator/.

[5]See http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2006/session6/2006_deer_fairbanks.pdf.

This cost improvement resulted from transmission gear train synthesis optimization studies using computational tools that uncovered gear trains requiring fewer discrete elements because some of the elements (e.g., planetary gear trains) are utilized for multiple speeds. However, increasing the number of speeds always adds some components and their associated cost. Along with higher numbers of transmission speeds, which allow operating engines in more efficient parts of their fuel consumption map, transmission internal losses are also being reduced, thus further improving power train efficiencies.

In addition to planetary-based automatic transmissions, advanced versions of manual transmissions are also being introduced that can be more efficient than automatics since torque converters are replaced by computer-controlled clutches, which slip less than torque converters. These new clutches not only are used to launch the vehicle from a stop but also enable rapid automated shifting of the manual gears since one clutch can start engagement before the other clutch has completely released. This class of manuals is called dual-clutch automated manual transmissions (DCTs).[6] With this concept, new-design manual transmissions are arranged with two parallel gear trains, one for odd-numbered speeds and the other for even-numbered speeds: for a 6-speed DCT, one gear train would contain the first, third, and fifth speed gears while the other gear train would include the second, fourth, and sixth speed gears. DCTs are then coupled to the engine through two clutches integrated into the transmission, one linking the odd-speed gear train to the engine and the other clutch linking the even-speed gear train to the engine. Finally, the clutches are actuated with electro-hydraulic systems calibrated to provide smooth launch and rapid and smooth shifting, making them automatic in their interface to the driver. In most of the current implementations of these clutches, they are immersed in transmission oil, thus providing the cooling necessary for acceptable durability. Dry-clutch versions are now also being developed for vehicles with lower torque requirements, making oil cooling unnecessary. Dry-clutch DCT designs are expected to be less costly to produce and lighter than their wet-clutch counterparts. In addition, dry-clutch DCTs will be more efficient through elimination of the hydraulic pump work to cool the wet clutches.

Both automatic and DCT transmissions feature a discrete number of gear ratios that determines the ratio of engine speed to vehicle speed. In contrast, a continuously variable transmission (CVT) offers a theoretically infinite choice of ratios between fixed limits, which allows engine operating conditions to be optimized for minimizing fuel consumption. CVT technology has tended to be used in lower-horsepower vehicles because of maximum-torque limitations with the most common metal-belt design. A few OEMs offer CVTs that utilize other drive schemes allowing usage with larger engines. CVTs have achieved some penetration into the market, but recent trends suggest that their usage may not grow further due to higher than expected costs and lower than expected internal efficiencies (EPA, 2008).

The issues discussed above generally apply to both SI and CI engines. However, the effects of moving engine operating points to lower-speed and higher-torque regions of the engine map are more beneficial for SI engines than for CI engines because intake throttling losses are reduced for SI engines, whereas CI engines are not throttled. Nonetheless, for both CI and SI engines, fuel consumption is reduced by moving to higher-torque and lower-speed regions of the engine maps because the relative effect of engine friction losses is reduced.

Another important transmission issue difference between SI and CI engines is their peak torque. As noted in Chapter 5, CI engines produce higher maximum torques than do SI engines. Maximum torque capacity is one of the most important criteria for durable transmission design, and so CI engines generally are mated with different, higher-torque-capacity transmissions than SI engines even in the same vehicle platform. Sometimes, a given transmission used for SI engines can be upgraded to higher torque capacity by more extensive and more expensive heat treating of the gears and clutch upgrading, but frequently, different transmissions originally designed for higher maximum torque capacity must be used with CI engines, thus increasing cost, weight, and to some extent internal losses.

Another transmission-related technology that is applicable to both SI and CI engines is called idle-stop. This technology is useful primarily for operation in cities and involves turning off the engine at idle. Benefits from idle-stop involve eliminating most of the idle fuel consumption during the idle-stop period. Since idle fuel consumption is relatively large for SI engines due to throttling losses and the use of ignition retard for smooth operation when accessories turn on and off, FC reductions on the Federal Test Procedure (FTP) driving cycle range from 3 to 5 percent. The real-world gain for congested city driving (e.g., New York City) could be as high as 10 percent since engines would be idled much more than on the FTP test cycle. All idle fuel consumption losses are not eliminated since some accessories may need to operated while the engine is stopped (e.g., A/C in hot climates), which not only consumes some fuel but also increases component cost by the necessity of replacing belt-driven accessories with electrically driven ones. For the CI diesel vehicle, idle-stop benefits are smaller than those attained with idle-stop for SI gasoline vehicles because diesel engines have much lower idle FC than their gasoline counterparts. The estimated gain on the U.S. cycle for CI vehicles is about 1 percent, although the real-world gain for congested city driving (e.g., in New York City) could be much higher.

Other studies of vehicle fuel consumption (e.g., NRC, 2002) have generally considered potential gains from transmission technologies in a separate category from engine efficiency technologies. In the present study, potential gains

[6]See http://www.dctfacts.com/hmStory1b.asp.

from transmission technologies are considered together with those for engines. This choice was made for the following reasons. For SI engines, the major opportunity for reducing fuel consumption (as is discussed extensively in Chapter 4) is reducing pumping losses. Many of the technology measures discussed in Chapter 4 reduce pumping losses in one way or another. As noted above, the major impact of transmission technologies toward reducing fuel consumption is to move the operation of the engine toward higher torque (or BMEP) and lower speeds at which pumping losses will be reduced. As a result, there are significant interactions between engine technologies that reduce pumping losses (e.g., valve event modulation) and transmission changes that also move engine operation to lower speeds and loads, such as increasing the number of ratios and the associated ratio spread.[7] A good example of these interactive effects is cylinder deactivation, as discussed in Chapter 4. When cylinder deactivation is used, the benefit of moving the engine operating point to lower speeds and higher torques and higher BMEP is reduced compared to engines not using cylinder deactivation, because the working cylinders are already running at higher BMEP, thereby reducing pumping losses. Thus the fuel consumption reductions possible from increasing the number of transmission ratios from 4 to 6, for example, would be lower for engines using cylinder deactivation than for those not using cylinder deactivation. This demonstrates how transmission-derived fuel reductions of fuel consumption cannot readily be separated from engine-technology-derived fuel consumption reductions. This choice is reflected in the technology paths discussed in Chapter 9.

FUEL CONSUMPTION BENEFITS OF NON-ENGINE TECHNOLOGIES

The tractive force that is needed to propel a vehicle can be written simply as the sum of three forces:

$$F_{TR} = F_m + F_r + F_a$$

where F_m accelerates the mass, F_r overcomes rolling resistance, and F_a overcomes aerodynamic drag. The integral of this force over a given driving cycle gives the amount of energy required at the wheels. Using typical values in Equation 2.1 one can calculate that for the EPA combined cycle about one-third of the tractive energy goes into each of these three components (see Table 2.7). However, as Table 2.7 shows for the urban cycle, F_m is around 60 percent of the total and for the highway cycle, F_a is about half. Before giving estimates of the benefits of fuel-saving technologies, it is necessary to make two important points.

Merely reducing tractive energy does not translate into a directly proportional reduction of fuel consumption because of (1) the accessory load and (2) the possibility that the power train may then operate at worse efficiency points. To take care of the power train efficiency it is necessary, at the same time, to downsize the engine and/or change transmission shift points, because with a lighter load, the efficiency of the power train is reduced, especially with SI engines that will then operate with more throttling. Unfortunately, many studies on the impact of reducing F_m and F_a do not change the engine operating points. For example, Barrand and Bokar (2008) do an excellent job of investigating the effect of rolling coefficient by changing tires without changing the power train. Only an OEM designing a vehicle with low-rolling-resistance tires, for example, can fully take advantage of rolling-resistance changes by reoptimizing the power train.

Theoretically reducing any one of the three components by, say, 10 percent should reduce fuel consumption by roughly 3.3 percent since, as stated above, each component accounts for roughly one-third of the total tractive energy. In fact the size of the engine is determined by acceleration performance requirements, as well as the tractive energy. Therefore all that can be said for certain is that reduction of all three components by an amount (say, *X* percent) would result in a reduction in fuel consumption by roughly the same amount (*X* percent), assuming the power train were reoptimized.

Aerodynamics

As discussed above, vehicles with higher C_d values (over .30) may be able to have the C_d reduced by 5 percent or so (up to 10 percent) at low cost. The associated impact on fuel consumption and fuel economy could be 1 to 2 percent, and this assumes that the engine operating regime is not modified. If lower acceleration can be tolerated and the engine operates at the same efficiency, the improvement with a 10 percent reduction of aerodynamic drag could be as high as 3 percent (10 percent × 0.3). Argonne calculations for the improvement in fuel consumption show that without engine modifications a 10 percent reduction in aerodynamic drag would result in about a 0.25 percent reduction in fuel consumption for the urban cycle and a 2.15 percent change for the highway cycle.

Car Body Design and Interiors

It is well established that a reduction in vehicle mass reduces fuel consumption. The specific relationship between mass reduction and fuel consumption, however, is complex and depends on many factors:

- Amount of mass reduction,
- Driving cycle,
- Type of engine, and
- Secondary benefits, such as whether or not other vehicle systems are redesigned to match the new vehicle

[7]Ratio spread is defined as the ratio of first gear divided by the ratio of the top gear. As an example, for a typical 6-speed automatic transmission, the low-gear ratio would be 4.58:1 while that of the sixth gear would be 0.75:1. The ratio spread would then be 4.58/0.75, which equals 6.1.

mass, as with, for example, engine downsizing, retuned transmission, and reduced components for crash management, braking, fuel storage, and so on.

A midsize car body structure with closure panels (no trim or glass) can weigh approximately 800 pounds (about 25 percent of the vehicle's total curb weight). Should the mass reduction be significant, a secondary benefit can accrue from reducing the size of the needed power train, braking systems, and crash management structures. These secondary benefits are difficult to estimate but can potentially approach an additional 30 percent reduction in mass, and these secondary benefits can help offset the cost of the initial effort (IBIS Associates, 2008).

A basic estimate of the relationship between fuel economy and mass is provided by the Department of Energy (Carpenter, 2008) and also by the Laboratory for Energy and Environment at the Massachusetts Institute of Technology (Cheah et al., 2007). A rule of thumb is a 6 to 8 percent improvement in fuel economy (or, equivalently, a reduction of 5.7 to 7.4 percent in fuel consumption) for every 10 percent drop in weight when secondary benefits are included that indirectly accrued from having lower mass.

In a study conducted by Ricardo, Inc. (2007), and sponsored by the Aluminum Association, this relationship was simulated for several vehicles loaded with from 2 to 5 passengers. The gasoline-powered vehicles simulated are listed in Table 7.2.

Two scenarios for these vehicles were simulated. The first scenario evaluated the impact on fuel economy when everything about the vehicle remained unchanged except for a reduction in vehicle mass. The second scenario resized the engine to reflect comparable vehicle performance (the benefits of other reductions in mass such as a smaller gas tank, smaller brakes, etc. were not included). In this scenario, the engine required less power because of the reduction in mass, and therefore, fuel economy was further improved. The vehicle type was not a major differentiator of fuel economy impact; Table 7.3 shows the range of impact on fuel economy for all types.

Table 7.3 shows the results of the Ricardo, Inc., simulation calculating the potential impact on fuel consumption from reduction of mass. The range shown in the results is due to summarizing a composite of simulation runs for different vehicle models and power trains. This discrepancy (range of fuel economy impact) in fuel economy improvement increases for different vehicle types as the reduction in mass increases from 5 to 20 percent. However, if the engine is resized to match each level of mass reduction (to maintain original vehicle performance), the range of fuel economy improvement across the vehicle classes is fairly small. This observation points to the importance of matching engine performance to vehicle mass. For small (under 5 percent) changes in mass, resizing the engine may not be justified, but as the reduction in mass increases (greater than 10 percent), it becomes more important for certain vehicles to resize the engine and seek secondary mass reduction opportunities.

Physical vehicle testing has confirmed the reductions in fuel consumption associated with reductions in vehicle mass. For an internal combustion engine, the effect of mass reduction is greater with a city driving cycle versus a highway cycle because of the frequent acceleration/deceleration of mass. For example, vehicles (combination of compact, midsize, and SUV classes) powered by internal combustion engines can reduce fuel consumption approximately as follows (Pagerit et al., 2006): 0.1 gallon per 100 miles driven can be saved with, approximately,

- 190 pounds mass reduction—city cycle, and
- 285 pounds mass reduction—highway cycle.

As discussed in Pagerit et al. (2006) and further supported by the Ricardo, Inc., study, the improvement gained from reduction of mass (expressed as fuel consumption and not miles per gallon) is the same regardless of the weight of the vehicle. Unlike changes in rolling resistance and aerodynamics, re-

TABLE 7.2 Vehicle Mass Assumptions for Ricardo, Inc. (2007) Study to Assess Effects of Mass Reduction on Fuel Economy

Type of Vehicle	Initial Weight (lb)	Load Weight (lb)	5% Reduction (lb)	10% Reduction (lb)	20% Reduction (lb)
Small car	2,875	300	3,031	2,888	2,600
Midsize car	3,625	450	3,894	3,713	3,350
Small SUV	4,250	550	4,588	4,735	3,950
Large SUV	5,250	750	5,738	5,475	4,950

NOTE: The 5 percent, 10 percent, and 20 percent mass reduction applies to the initial vehicle weight and not the load.

TABLE 7.3 Impact on Fuel Consumption Due to Reduction of Mass in Study by Ricardo, Inc. (2007)

Vehicle Mass Reduction from Baseline Vehicle	5% Mass Reduction	10% Mass Reduction	20% Mass Reduction
Mass reduction only	1-2%	3-4%	6-8%
Mass reduction and resized engine	3-3.5%	6-7%	11-13%

ducing mass not only reduces the amount of tractive energy needed but also permits a reduction in power train (engine downsized or transmission shift changes) without adversely affecting performance (acceleration). A 10 percent reduction in mass and power for the reference vehicle should reduce fuel consumption by about 5.7 to 7.4 percent (or 6 to 7 percent). In a conventional vehicle, the energy used to accelerate the mass is mostly dissipated in the brakes, whereas in a hybrid, a significant fraction of this braking energy is recovered, sent back to the battery, and reused. Thus, mass reduction in hybrid vehicles is less important than in conventional vehicles. The complexity of mass reduction increases when a conventional vehicle is compared with either a hybrid (which incurs additional battery mass) or a CI engine (which has greater power train mass). While reducing mass will always provide a fuel economy benefit, changing technology pathways (between SI, CI, or hybrid designs) has to recognize the impact that the new technology has on mass.

Rolling Resistance

A report on tires and fuel economy (NRC, 2006) estimates that a 10 percent reduction in rolling resistance will reduce fuel consumption by 1 to 2 percent. This reduction, however, is without changes in the power train. If the power train could be adjusted to give the same performance, then the benefit of a 10 percent reduction would be on the order of as much as 3 percent. Underinflated tires that are 20 percent below recommended inflation pressure (say, 35 psi) increase rolling resistance by 10 percent, and thus increase fuel consumption by 1 to 2 percent (Goodyear Tire & Rubber Company, 2009).

Again as discussed above under "Aerodynamics," if a reduction in rolling resistance is combined with a reduction in aerodynamics and mass, the power train can be significantly modified to improve efficiency. As indicated in Chapter 2, rolling resistance accounts for about a third of the energy going to the wheels for the city as well as the highway cycles. Reducing mass, aerodynamics, and rolling resistance by 10 percent reduces fuel consumption by about 10 percent with power train resizing and other drive train adjustments (e.g., changes in transmission shift points, axle ratios). As noted earlier, vehicle mass reduction for a hybrid is not as effective since some of the energy going to the brakes is recovered.

Vehicle Accessories

The opportunity may exist to decrease fuel consumption (in gallons per 100 miles driven) by about 3 to 4 percent with a variable-stroke HVAC compressor and better control of the amount of cooling and heating used to reduce humidity (Table 7.4). Estimates for further reductions that can be achieved by decreasing air conditioner load through the use of low-transmissivity glazing, reflective "cool" paint, and cabin ventilation while parked have not been determined. According to a Deutsche Bank report, electro-hydraulic power steering (EHPS) would reduce fuel consumption by 4 percent with an incremental cost of $70, while electric power steering could improve 5 percent with an incremental cost of $120, but there is little information on how this estimate was obtained (Deutsche Bank, 2008). A TRW study (Gessat, 2007) showed that while a conventional hydraulic power steering system consumed 0.35 L/100 km, the best TRW electro-hydraulic steering system consumed 0.07 and an electric power steering system 0.02. These figures are relative to a small vehicle with a 1.6-L engine. In its study of CO_2-reducing technologies for the EPA (EPA, 2008), Ricardo, Inc., found that electric power steering (EPS) reduced combined fuel consumption by about 3 percent based on FSS calculations. From this and the estimates provided in recent regulatory activities by NHTSA and EPA, the committee estimated that EPS reduces combines fuel consumption by about 1 to 3 percent on the EPA 55/45 combined cycle, which is the basis for the CAFE standard. However, the committee recognizes that the reduction of fuel consumption could be as high as 5 percent under in-use driving conditions.

Transmission Technologies

Fuel consumption reductions generally increase with additional transmission speed ratios, although interaction effects between engine technologies that reduce pumping losses and increase the number of transmission speeds are important, as noted earlier. However, since the costs also increase and the marginal gain for each additional speed gets smaller, there are diminishing returns. Table 7.5 lists the transmission technologies and estimated reductions in fuel consumption. The basis of this table is baseline engines

TABLE 7.4 Potential Reduction of Fuel Consumption with the Use of Vehicle Accessories

Vehicle Accessory	Reduction in Fuel Consumption (%)	Comments
Variable-stroke HVAC compressor	3-4	Improved cooling, heating, and humidity control
Low-transmissivity glazing, cool paint, parked-vehicle ventilation	~1	Lower heat buildup in vehicle decreases air-conditioning load
Electrohydraulic power steering	4	Combined electric and hydraulic power for midsize to larger vehicles reduces continuous load on engine
Electric power steering	1-5	Electric power steering for smaller vehicles reduces continuous load on engine—smaller benefits (1-3%) estimated for the FTP

without significant valve event modulation technologies or cylinder deactivation.

TIMING CONSIDERATIONS FOR INTRODUCING NEW TECHNOLOGIES

The timing for introducing new fuel consumption technologies can significantly influence cost and risk. The maturity of a technology affects its cost and reliability. Automobile companies have sophisticated *product and process validation procedures* that must be adhered to before products can be scaled up for mass production, or they expose themselves to large warranty or product liability concerns. Many vehicle changes are timed for implementation around the product development process to minimize cost and quality concerns. Lower-volume and higher-end vehicles often have new technologies applied first for several reasons. The lower volumes mitigate the exposure to risk, and the higher-end vehicles can bear the higher initial early cost of a new technology. During this period, competition brings the technology cost down while the supply chain develops for higher volumes in the future.

An important consideration for introducing new technologies that have broad impact concerns the product development process of new vehicles. Aggressive use of lightweight materials to obtain secondary benefits; power train modifications; and body shape modifications (to improve aerodynamics), for example, may have to be timed with future product development phases. Although material substitution for components can occur throughout the life cycle of a car in many cases, the mass saved in this way is relatively minor. Considering how to reduce mass to achieve greater energy savings requires a broad systems evaluation and reengineering of the vehicle. Once a vehicle has been validated and tooled for a specific design and production has begun, new development costs are planned for future model changes. Most significant modifications have to occur around various phases of the vehicle's production life.

Automobile manufacturers differ significantly in their approach to introducing new products. Manufacturers based in Asia, for example, are known for having shorter product life cycles but often implementing lower levels of engineering redesign at changeover. Manufacturers based in Europe and North American have traditionally had longer product cycles with a greater amount of engineering applied at changeover. There are always exceptions to these generalities even within a manufacturer, depending on the vehicle model. The strategy to implement engineering changes on a regional vehicle (e.g., North America only) versus a global platform can greatly impact timing and cost. Entire textbooks have been written around product timing for manufacturers, and so a discussion here can at best only introduce the inherent issues that affect cost and timing for any manufacturer.

Generally, 2 to 3 years is considered the quickest time frame for bringing a new vehicle to market. A significant amount of carryover technology and engineering from other models (or previous vehicle models) is usually required to launch a new vehicle this quickly. In some cases, so much of the vehicle is replicated that the new vehicle is considered a "freshened" or "re-skinned" model. The ability to significantly influence vehicle performance (e.g., through light-weighting, changing power trains, etc.) is minimal because so much of the vehicle is unchanged. More substantial changes to the vehicle occur over longer periods of time. Newly styled, engineered, and redesigned vehicles can take from 4 to 8 years, each with an increasing amount of new content.

Automobile producers generally have product development programs (PDPs) spanning at least 15 years. PDPs are extremely firm for 3 to 5 years due to the need for long-lead-time items such as tooling or supplier development requirements, and the need for extensive testing of major items such as those required for fuel economy, emissions, and safety regulations, and confirmation of reliability and durability. In general, model changeovers can be categorized into five areas (freshen, re-skin, restyle, reengineer,

TABLE 7.5 Transmission Technologies and Estimated Reductions in Fuel Consumption

Technology	Fuel Consumption Reduction[a] (%)	Comments
Five-speed automatic transmissions	2-3	Technology can also improve vehicle performance
Six-speed automatic transmissions	3-5	
Seven-speed automatic transmissions	5-7	
Eight-speed automatic transmissions	6-8	
Dual-clutch automated manual transmissions (6-speed) (DCT)	6-9	Original automatic transmissions with conventional manual transmissions supplemented with electro-hydraulic clutch and shift actuators have been replaced with DCTs
Continuously variable transmissions	1-7	Some issues related to differences in feel and engine noise; improvements depend on engine size

NOTE: Values based on EEA (2007) with adjustments to reflect range of values likely to occur.
[a]Improvements are over a 2007 naturally aspirated SI-engine vehicle with 4-speed automatic transmission of similar performance characteristics.

and redesign; see *Automotive News,* July 14, 2008, p. 28). These five categories and their potential for effecting fuel consumption improvements are described in Table 7.6. It is not accurate to say that every vehicle progresses through every one of these phases. It is possible to skip a re-skin and jump to a restyle, for example. Also, not every vehicle will be redesigned in 6 to 8 years because many factors affect this timing (market demand, finances, etc.). The potential for impacting fuel consumption is only a rough approximation, and none of these estimates consider the inclusion of hybrid or alternative power trains. The estimates for reducing fuel consumption shown in Table 7.6 are not additive (from previous changeover phases). Fuel consumption estimates also assume comparable vehicles of the same size and performance (including crash worthiness, electronic content, and other factors that are often adjusted with new vehicles).

The engine development process often follows a path separate from those of other parts of the vehicle. Engines have longer product lives, require greater capital investment, and are not as critical to the consumer in differentiating one vehicle from another as are other aspects of the car. Also, consumer-driven changes for styling change faster than the need to introduce new power train technologies. The power train development process evolves over closer to a 15-year cycle, although refinements and new technologies will be implemented throughout this period. Also, because of the complexity, costs, and resources required to launch a new power train, it is unusual to launch a new engine-related transmission simultaneously. The development of new technologies over a 15-year life cycle can be substantial, and the performance improvement for fuel consumption can be substantial with a new power train.

The estimates in Table 7.6 are based on business as usual. The "frequency" is the time from concept through prototyping, production vehicle design, tooling release, verification testing on preproduction vehicles, and start of full-scale production. Shorter time frames are possible, especially if more vehicle content is carried over between PDPs to reduce engineering, testing, etc., but this limits the degree of model changeover. Urgency to introduce new vehicles (e.g., smaller and more fuel efficient vehicles) can accelerate the nominal duration of each PDP phase, but the investment cost will grow.

Modest improvements in fuel consumption can be achieved early in the PDP cycle (e.g., freshen and re-skin stages) by introducing more aerodynamic designs and low-rolling-resistance tires. A greater impact on reducing fuel consumption can come from changes in engine, transmission, and mass reduction later in the PDP when the vehicle is redesigned or reengineered. Restyled vehicles allow for material substitution on a part-by-part basis, but without changing entire subassembly structures. Often, the substitution might be for a higher-strength metal with a thinner gage in place of the current material. Tooling and assembly processes may be altered somewhat to accommodate the new material. A reengineered vehicle allows for changing the design of major subassemblies (engine compartment, closure panels, body sides, etc.), thus allowing for entirely new approaches to reducing mass. Reengineered vehicles normally require crashworthiness testing

TABLE 7.6 Vehicle Product Development Process (non-power train) and Timing Implications to Effect Fuel Economy Changes

Type of Model Change	Frequency (Years)	Description	Fuel Consumption Reduction	Opportunities to Impact Fuel Consumption	Investment Cost
Freshen	2-3	Sheet metal untouched, may include new grille, fascia, headlights, taillights, etc.	Little to none (≤3%)	Minor impact on mass; possible impact with aerodynamics and tires	Low
Re-skin	3-5	Minor changes to sheet metal	Little to none (≤5%)	Same as above and vehicle accessories	Modest
Re-style	4-8	Extensive changes to exterior and interior	Minimal (5-8%)	Some impact on mass (mostly interior components); possible impact with aerodynamics, tires, and vehicle accessories	High
Re-engineer	4-8	Extensive makeover of vehicle's platform, chassis, and components to reduce noise, vibration, and harshness and improve qualities such as ride, handling, braking, and steering (this degree of change or the next may require recertification and crash testing), body restyling often concurrent with this phase	Moderate (7-14%)	Mass reduction opportunity with part-by-part material substitution (e.g., aluminum or high-strength steel); possible impact with aerodynamics, tires, and vehicle accessories	Very high
Redesign A	6-8	New platform, new interior and exterior styling; engine and transmission carried over; some structural subsystems possibly reengineered	Significant (13-18%)	Entire vehicle structure—opportunity to introduce lightweight materials throughout entire vehicle; impact from aerodynamics, tires, and vehicle accessories	Very high

and incur significant additional costs because of the reengineered designs. The redesigned vehicles start with a "clean sheet" affording the benefits of a reengineered vehicle, along with more optimal matching of the power train to the lighter-weight structure. In general, a redesign results in a new vehicle platform that in many cases replaces existing vehicles.

Aerodynamics

Reductions of drag coefficient Cd by 5 percent or so (up to 10 percent) have been taking place and will continue. A 5 percent reduction in aerodynamics can be achieved with minimal cost through vehicle design, and larger reductions can be achieved by sealing the undercarriage and installing covers/shields (e.g., in the wheel well areas and underbody). Elimination of outside rear view mirrors will require changes in safety regulations and improvement in vision systems. Since these changes can be costly, they are unlikely to be implemented soon except on high-end vehicles. In the longer term (about 10 years), 5 to 10 percent reductions in aerodynamic drag are plausible, but this may come with some compromise in vehicle functionality.

Car Body Design and Interiors

Reductions in weight have been taking place and will continue in the near term with reductions from 10 percent (with mostly conventional and high-strength steels) to 25 percent (with high-strength steel structures, aluminum closure panels, and body/interior components made from various lightweight materials). Table 7.7 provides an overview of the timelines for the introduction of new materials for various vehicle components. Today's new vehicles already are composed of upward of 40 to 50 percent high-strength steel (over 480 MPa yield strength), but higher-strength steels (advanced high-strength steels) are being developed (up to 1,000 MPa) that could replace even the current high-strength steel. Various vehicle components for which isolated material substitution can take place will also be the norm. For example, Ford recently indicated that aluminum calipers replaced steel ones, thus saving 7.5 pounds per vehicle. Also, aluminum wheels replaced steel wheels, resulting in 22 pounds saved per vehicle. More aggressive application of aluminum to car doors can also save another 20 pounds per door, but at a higher cost. Substitution of material in other components can also be expected, including the wiring harness. Substituting copper-clad aluminum wiring for all copper wiring can save 10 or more pounds per vehicle, but usually at a higher cost.

More aggressive reduction of mass is feasible at higher cost if aggressive targets of greater than 25 percent are set. Reduction of mass at the 50 percent level can be attained in the body with a mostly aluminum structure (probably using a space frame design), but this approach will be cost prohibitive under most conditions for high-volume vehicles.

The use of composite structures involving materials such as carbon fiber will need significant cost reduction and supply chain development over the next 15 years. The committee does not expect to see significant inroads in this time frame by this technology except in low-volume (specialized applications), high-performance vehicles. Other polymer/reinforced composites, etc. will continue to make inroads in the vehicle interior where steel or aluminum is used currently for strength. For example, all-polymer/reinforced composite instrument panels (without rear steel reinforcements) are likely to make it to production soon.

As production processes continue to be developed, broader application of both magnesium and titanium can be expected, such as for magnesium engine blocks that weigh approximately 30 pounds less than aluminum ones (see Table 7.7). Magnesium will likely make inroads for component parts such as suspension arms and interior dash panels and seating brackets. Titanium will continue to find application in suspension springs, valve springs, valves, connecting rods, and exhaust systems, resulting in 35 to 40 percent savings in mass over steel components.

Rolling Resistance

Low-rolling-resistance tires are already used by OEMs. The committee does not expect significant additional improvements without sacrificing performance. Since replacement tires are on most vehicles on the road today, a campaign to educate purchasers of replacement tires of the possibility of fuel savings is a good way to reduce fuel consumption. More vehicles today are being offered with low-tire-pressure monitors to warn the driver of underinflated tires for safety and fuel economy.

Vehicle Accessories

Variable stroke compressors and reduction of subcooling are being developed and should appear in vehicles in the next 3 to 5 years. Because the current duty cycle measuring fuel consumption does not recognize HVAC systems, there is no motivation to introduce these systems because they incur additional costs. However, the proposed new EPA test procedure may cause new interest in introducing this technology.

COSTS OF NON-ENGINE TECHNOLOGIES

Aerodynamics

A 5 percent reduction in aerodynamics can be achieved with minimal cost through vehicle design. Slightly more aggressive reductions can be achieved by sealing the undercarriage and installing covers/shields (e.g., in the wheel well areas and underbody) costing in the tens of dollars. A 10 percent reduction in aerodynamics may be aggressive, calling for wind deflectors (spoilers) and possibly elimination of rear view mirrors, which would cost a few hundred dollars.

TABLE 7.7 Estimated Timeline for Introduction of New Materials by Type of Component

Timing	High-Strength Steel	Aluminum	Magnesium	Plastics and Polymer—Composites
Current or near term (3-5 years)	Body rails, door sills, B-pillar, side roof rails, underbody, front suspension subframe, bumper beams, cross-members, brackets and reinforcements, exterior body panels, body side ring, longitudinal rails, wheels	Hood, deck lid, engine block and cylinder lining, front suspension subframe, bumper beams, rear suspension knuckles, steering hanger beam, power train components (castings), condenser/radiator wiring harness	Instrument panel, seat components Brackets Crash structures Intake manifold	Truck box Outer skin panels (doors, fenders, etc.) Instrument panel Bumpers Trim Engine parts (intake manifold, cover, etc.)
Future (5-10 years)	Same as above, only with higher-strength steels	Doors, exterior body panels (fender, roof)	Door, inner Engine block	Body side ring Roof Side pillar (B or C) Underbody Seat components Sound dampening Glass (polycarbonate)
Long term (>10 years)	New steels with greater formability allowing application to more complex part shapes and exterior panels; less steel overall in the vehicle	Increased applications (depending on material cost); subassemblies such as engine compartment, chassis, instrument panels; overall, more aluminum in the vehicle	Limited increase in applications; possibly transmission parts	New materials will be developed with higher strength, allowing them to be applied to more structural parts. Mixed-material bonding will be developed. Overall, more plastics/polymers will be in the vehicle.

Car Body Design and Interiors

The term "material substitution" often misrepresents the complexity and cost comparison when one material is substituted for another one. The cost to change materials in the vehicle, from an incumbent material to a lighter-weight material, is a function of capital and variable costs:

Fixed Costs (up-front investment costs)
- Design and engineering
- Prototype development and testing
- Tooling: fabrication, dimensional measurement, and assembly

Variable Costs (a function of the volume of production)
- Production and assembly labor cost
- Production equipment
- Material
- Joining (welding, adhesive, sealing, riveting, etc.)

An added complexity results with material substitution because part design is material dependent, and the redesigned part may provide (and often does) different functionality than the original part. For example, a molded plastic part can take on more complexity than a formed steel part, and so the direct comparison should also take the difference in functionality into account. Also, two or more parts may get integrated into a single part with one material versus that of another, and so the subsystem of parts has to be evaluated for a cost and performance comparison.

Most cost-effective materials today for reducing mass are high-strength steel and aluminum. Both materials can replace many incumbent steel parts or assemblies, and the structural components that are among the heaviest parts offering the greatest opportunity will be targeted. Plastics, composites, and other metals (magnesium and titanium) will be used on a somewhat limited basis because of cost.

In recent years, reductions in mass have been realized in the body, interior, and power train by introducing new materials such as high-strength (and advanced high-strength) steels, plastics (not including carbon fiber), and aluminum. Magnesium has also been used to reduce mass, but to a much lesser extent. In the near future (5 years), the committee expects continued mass reduction following the same pattern; through continued introduction of more and higher-strength steels, aluminum, plastics/polymers, and to a lesser extent other materials such as magnesium.

Although there are research and development costs to develop new high-strength steels and new manufacturing processes for them, once developed they have minimal net long-term incremental cost over mild steel. Tooling, fabrication, and joining costs tend to be higher for these materials because of the material strength, which has to be added to the net cost difference. Although the cost per pound of high-strength steel is higher than mild steel, less of it is needed. Hence, a 10 or 20 percent material cost premium will be offset by using 10 to 20 percent thinner steel. As high-strength steels are introduced, their net incremental cost approaches zero after a period of maturity. The DOE estimates that, on average, substituting high-strength steel for mild steel results in about a net increase in material cost of 10 percent (see Carpenter, 2008).

The cost to reduce mass (cost per pound of mass reduced) *increases* as the amount of reduced mass increases. The "low hanging fruit" of mass reduction using high-strength steel in basic applications can result in less than a 10 percent cost premium. However, increasingly aggressive reduction of mass requires more difficult parts and materials whose cost exceeds the 10 percent premium. For example, a 1 percent reduction in mass can generally be achieved at a multiplier of 1.0 to 1.1. More aggressive applications likely require more expensive materials or more expensive fabrication and joining methods, or affect the costs of other parts in the vehicle. As the aggressiveness increases (to 5 percent, 10 percent, or even 20 percent), more materials and processing options need to be considered that further increase cost. The committee believes that a 10 percent reduction in mass is achievable with a mix of materials (high-strength steels, aluminum, composites, and other metals) for approximately $2.00 per pound of mass eliminated (see Table 7.8). More aggressive reductions will cost more than $2.00 per pound.

Aluminum costs more than steel and has some forming and joining limitations that prevent its use in some applications. An incremental cost of aluminum over steel body parts in the range of 30 to 100 percent has been estimated (Carpenter, 2008; Bull, 2008). The Aluminum Association estimates that the average increment is 30 percent at the low end (premium cost per pound of mass eliminated). At the mid-point of this range, the incremental cost is $1.65/pound of mass eliminated. Higher costs will be incurred (approaching $2.00/lb cost premium) as more aggressive reduction of mass reduction is attempted.

The body of a baseline vehicle (mostly steel) weighs approximately 800 pounds. An aluminum-intensive body weighs approximately 45 percent less, or 440 pounds. The estimated cost for this savings in weight is in the range of $468 ($1.30/lb) to $594 ($1.65/lb). Mass reduction in other vehicle systems such as power train, wheels, chassis, and interior would typically come at similar or slightly higher incremental cost per pound saved. Vehicle interiors (including seats, door trim, headliners, instrument panel components, etc.) constitute approximately one-third of the vehicle mass (1,000 pounds in a 3,000-pound vehicle). By using lightweight materials, Byron Foster at Johnson Controls plans to eliminate 30 percent of the interior mass (Forbes, 2008). If the same incremental cost used for the body is assumed, approximately 300 pounds eliminated would cost $390 ($1.30/lb) to $495 ($1.65/lb).

Other opportunistic components in the vehicle include the power train, chassis, and wheel components. Many of these components have been light-weighted already with high-strength steel and aluminum where practical. One next step would be to transition to more magnesium, which comes with a cost premium of perhaps 50 percent or more over that for aluminum.

Secondary Savings Benefits

An important consideration with mass reduction is that its effects on fuel consumption can cascade. As the mass of a vehicle is reduced in, say, the body or interior, other components of the vehicle can be reduced in size as a consequence. For example, brakes, fuel system, power train, and even crash-management structures can all be downsized for a lighter vehicle. In the study conducted by Ricardo, Inc., (2007) for the Aluminum Association, the rule of thumb generated was that for every pound eliminated in the vehicle structure, an additional 0.30 lb (30 percent) of mass could be reduced in other areas of the vehicle. If this rule of thumb is applied and mass reduction comes at a cost of $1.65/lb, then at an additional 30 percent of secondary mass savings (0.3 lb) the net cost per pound becomes $1.65/1.3 lb, which becomes $1.27/lb. It is important to note that achieving secondary savings typically requires reengineering one or more systems on the vehicle, and this would likely be performed according to the product development timing plan (see above the section "Timing Considerations for Introducing New Technologies"). So the 30 percent secondary benefit is achieved in the long term and not necessarily when the initial reduction in mass is achieved.

Rolling Resistance

The incremental cost for low-rolling-resistance tires is estimated to be $2 to $5 per tire, but there is some evidence that suggests that these tires may slightly compromise stopping distance. One tire manufacturer suggested that tires that do not compromise stopping distance or tread wear could cost 10 to 20 percent more than conventional tires. (Note: The uncertainty about low-rolling-resistance tires with respect to increased tread wear and stopping distance is the reason for increasing the estimated cost beyond the $1.00 per tire cost cited in NRC (2006). The NRC (2006) study recognized that an acceptable increase in tread wear and stopping distance might occur. However, to eliminate this increase, additional costs can be expected over the $1.00 estimate.)

TABLE 7.8 Committee's Estimate of Cost to Reduce Vehicle Mass (based on 3,600-lb vehicle)

Mass Reduction (%)	Low Cost/lb ($)	High Cost/lb ($)	Average Cost/lb ($)	Mass Saved (lb)	Low Total Cost ($)	High Total Cost ($)
1	1.28	1.54	1.41	36	46.08	55.30
2	1.33	1.60	1.46	72	95.76	114.91
5	1.50	1.80	1.65	180	270.00	324.00
10	1.80	2.16	1.98	360	648.00	777.60

Vehicle Accessories

Table 7.9 shows the committee's estimates of the costs for vehicle accessories that could improve the fuel consumption of light-duty vehicles.

Transmission Technologies

The estimated retail price equivalent for each transmission technology is provided in Table 7.10. As was the case for the engine technology chapters (e.g., Chapters 4 and 5), the baseline for transmission costs is the 4-speed automatic typical of 2007 model-year vehicles. Cost estimates are from the two sources considered (EEA, 2007; Martec Group, Inc., 2008). As can be seen from Table 7.10, the cost estimates for the 5-, 6-, 7-, and 8-speed automatic transmission replacements for the baseline 4-speed automatic have a considerable numerical range. In addition to the cost estimates, Table 7.10 also includes cost estimates converted to RPE using the RPE multiplier of 1.5. Besides the estimates for 5-, 6-, 7-, and 8-speed automatic transmission replacements, estimates are also included for DCTs and CVTs. The DCT estimates reflect an even wider numerical range than those for the automatics. For example, the 6-speed automatic cost estimates range from $133 to $215, whereas the estimates for the wet-clutch, 350 N-m torque capacity range from $140 to $400.

Although DCT units have been in high-volume production for a number of years, until recently only the VW-Audi group, working closely with one supplier, has produced such a transmission. As a result, the number of cost estimates available to the committee was limited. When additional information was sought by the committee, the results reflected the still-emerging knowledge base about this transmission type. One estimate, based on a detailed teardown study conducted by FEV, Inc., for the EPA, estimated the cost of 6-speed DCTs with 350 N-m torque capacity and wet clutches at over $147 less than that for a 6-speed automatic (Kolwich, 2010). However, OEMs considering tooling up their own equivalent units had also made careful estimates of the high-volume piece cost increase of DCT6s. These OEM estimates were that high-volume DCT6s would cost nearly $200 more than 6-speed automatics. Thus, the range between estimates was approximately $350. At the present time, insufficient information is available to narrow this wide range.

SUMMARY

There is a range of non-engine technologies with varying costs and impacts to consider. Many of these technologies are continually being introduced to new vehicle models based on the timing of the product development process. Coordinating the introduction of many technologies with the product development process is critical to maximizing their impact and minimizing their cost. Relatively minor changes that do not involve reengineering the vehicle can be implemented within a 2- to 4-year time frame. This could include efforts such as aiming for minor reductions

TABLE 7.9 Estimated Incremental Costs for Vehicle Accessories That Improve Fuel Consumption

Description	Source of Cost Estimate	Estimate
HVAC—variable stroke, increased efficiency (humidity control, paint, glass, etc.)	U.S. Environmental Protection Agency[a]	$70-$90
Electric and electric-hydraulic power steering	Deutsche Bank	$70-$120
Thermoelectric energy recovery		Several hundred dollars

[a]The U.S. EPA has estimated the cost associated with improving the energy efficiency of the A/C system and reducing refrigerant leakage from the system at less than $110 to the consumer (ANPR-HQ-OAR-2008-0318; FRL 8694-2). With an RPE of 1.75 the cost to the original equipment manufacturer would be just over $60.

TABLE 7.10 Estimates of Replacement Costs for Transmission Technologies Relative to 2007 4-Speed Automatic Transmissions

Transmission Type	$Cost (EEA, 2007)	$RPE (EEA, 2007)	$Cost (Martec, 2008)	$RPE (Martec, 2008)
5-speed automatic	133	200	—	—
6-speed automatic	133	205	215	323
7-speed automatic	170	255	—	—
8-speed automatic	—	—	425	638
DCT (dry clutch, 250 N-m)	—	—	300	450
DCT (wet clutch, 350 N-m)	140	210	400	600
CVT (engine <2.8 liter)	160	240	—	—
CVT (engine >2.8 liter)	253	380	—	—

NOTE: RPE values were determined using a cost multiplier of 1.5.

in mass (material substitution), improving aerodynamics, or switching to low-rolling-resistance tires. More substantive changes require longer-term coordination with the PDP because reengineering and integration with other subsystems are necessary. This could include resizing the power train/transmission or aggressively reducing mass (e.g., changing the body structure). Substantive changes like this will take 4 to 8 years to adopt. The cost estimates provided in this chapter all assume coordination with the PDP to help contain costs and achieve maximum impact.

Two important technologies impacting fuel consumption addressed in this chapter are light-weighting and transmissions. Light-weighting has almost unlimited potential because vehicles can be made very light with exotic materials, albeit at potentially high cost. The incremental cost to reduce a pound of mass from a vehicle tends to increase as the total amount of reduced mass increases, leading to a curve with diminishing returns. About 10 percent of vehicle mass can be eliminated at a cost of roughly $700 (or about $2.00/lb; see Table 7.11). If the aggressiveness to reduce mass increases much beyond 10 percent, it is necessary to begin addressing body structure design (such as considering an aluminum-intensive car), and the cost per pound increases. A 10 percent reduction in mass over the next 5 to 10 years appears to be within reach for the typical automobile, considering the current baseline.

Transmission technology has significantly improved and, like other vehicle technologies, shows a similar curve of diminishing returns. Planetary-based automatic transmissions can have five, six, seven and eight speeds, but with incremental costs increasing faster than their impact on fuel consumption. Continuously variable transmissions have been available on the market for a number of years, but their rate of implementation seems to have flattened out, suggesting that future new implementations will be limited in number. DCTs are in production by some vehicle OEMs (e.g., VW/Audi DSG), and new DCT production capacity has been announced by other vehicle OEMs and suppliers. It is therefore expected that the predominant trend in transmission design will be conversion both to 6- to 8-speed planetary-based automatics and to DCT automated manuals, with CVTs remaining a niche application. Because of the close linkage between the effects of fuel-consumption-reducing engine technologies and those of transmission technologies, the present study has considered primarily the combined effect of engines and transmission combinations rather than potential separate effects.

TABLE 7.11 Summary of the Committee's Findings on the Costs and Impacts of Technologies for Reducing Light-Duty Vehicle Fuel Consumption

Fuel Consumption Technology	Description and Approximate Manufacturing Cost	Impact on Fuel Consumption (%)	Comments
Mass reduction (assume 3,600-pound vehicle)	1% (36 lb); $46-$55	0.25	Material substitution
	5% (180 lb); $270-$324	3-3.5[a]	Material substitution
	10% (360 lb); $648-$778	6-7[a]	Aggressive material substitution
	20% (720 lb); $1,600+	11-13[a]	Redesigned body with aluminum and composite-intensive structures
Transmission	Five-speed automatic transmissions; $133	2-3	Can also improve vehicle performance
	Six-speed automatic transmissions; $133-$215	3-5	Can also improve vehicle performance
	Seven-speed automatic transmissions; $170-$300	5-7	Can also improve vehicle performance
	Eight-speed automatic transmissions; $425	6-8	Can also improve vehicle performance
	Dual-clutch automated (DCT) manual transmissions (6/7 speed); $300 (dry clutch), –$14-$400 (wet clutch <350 N-m)	6-9	DCTs have replaced original automated manual transmissions
	Continuously variable transmissions; $150 (<2.8 L), $263 (>2.8 L)	1-7	Possible engine noise; not applicable to large engines
Aerodynamics	5 to 10% reduction in C_d (coefficient of drag); $40-$50	1-2	Wheel well and underbody covers, body shape, mirrors, etc.; bigger impact on highway drive cycle
Rolling resistance	Low-rolling-resistance tires; approximately $10 apiece ($30-$40)	1-2[b]	Stopping distance and durability can be compromised with inferior materials; optimal materials drive up costs
	Tire-inflation monitor; becoming standard equipment	0.7	Depends on monitor settings and driver behavior
	Low-drag brakes; becoming standard equipment	1	Most cars equipped already today
Electrical accessories	HVAC—variable stroke, increased efficiency (humidity control, paint, glass, etc.); $70-$90	3-4	Current FTP does not capture benefit (benefits reduced to 0.5-1.5% within Table 9.1)
	Electric and electric-hydraulic power steering; $70-$120	1-5	Electric for small cars, electric-hydraulic for bigger cars—benefits for the FTP are smaller (1-3%).

[a]With resized power train.
[b]Three percent may be feasible with resized power train.

Accessories are also being introduced to new vehicles to reduce the power load on the engine. Higher-efficiency air-conditioning systems are available that more optimally match cooling with occupant comfort. This includes, for example, humidity control, air recirculation, and increased compressor efficiency using a variable-stroke compressor. Electric and electric-hydraulic power steering also reduces the load on the engine by demanding power (electric) only when the operator turns the wheel, whereas the older technology relied on hydraulic power supplied by the engine all the time. An important motivating factor affecting the introduction of these accessories is whether or not their impact is measured during the official CAFE certification tests. The certification test currently does not take the air conditioner into account, and so there is little motivation to improve its efficiency and incur added cost; however, this situation may change with newly proposed test procedures.

Estimates for these technologies and several others are summarized in Table 7.11. The fuel consumption estimates assume ideal conditions, and there are important interaction effects among different technologies. Generally, it is not possible to apply two or more of the technologies in Table 7.11 and algebraically add the impacts on fuel consumption. The typical impact from multiple technologies will be less than the sum of their individual fuel consumption estimates.

FINDINGS

Finding 7.1: *Refresh/redesign.* With respect to reducing fuel consumption, recognition of product development process timing is important for minimizing the cost of implementing many new vehicle technologies. Only relatively modest changes can be made when vehicles are restyled, and secondary benefits from mass reduction are unlikely. The reengineering or redesign phases of product development offer the greatest opportunity for implementing new fuel-saving technologies, and this can occur from 4 to 8 years after initial introduction. Significant changes to power train and vehicle structure and materials can be made more easily at this time.

Finding 7.2: *Mass reduction.* Reduction of mass offers the greatest potential to reduce vehicle fuel consumption. To reduce mass, vehicles will continue to evolve with a broad mix of replacement materials that include high-strength steels, aluminum, magnesium, and reinforced plastics. These materials will be introduced on a component-by-component basis as companies move up the learning curve and continue to design for them. More aggressive efforts to reduce mass (by, say, 5 to 10 percent) will require system solutions (as opposed to material substitution solutions). Achieving a mass reduction of greater than 10 percent (as high as 20 percent) will require a significant change in vehicle design (such as a shift to an aluminum-intensive body or aggressive use of other higher-cost materials like carbon fiber) and will incur a significant increase in costs. The uncertainty and instability of commodity prices (e.g., for carbon fiber, resins, and aluminum versus steel) increase the risk to the vehicle manufacturer of adopting these new materials.

Finding 7.3: *Transmissions.* Another promising technology for reducing vehicle fuel consumption is transmissions with an increased ratio spread between the low and the high gears (e.g., 6-8 speeds) and dual-clutch transmissions that eliminate torque converters.

Finding 7.4: *Lower-energy-loss accessories.* A collection of relatively low-cost vehicle technologies can have a positive impact on reducing fuel consumption. Low-rolling-resistance tires, improvements to vehicle aerodynamics, and electric power steering can all cost less than $200 in total while reducing fuel consumption by about 10 percent, if HVAC is included as a component of real-world driving. Other technologies that can yield incremental reductions in fuel consumption are increased HVAC compressor efficiency, ultraviolet filtering, glazing, and cool/reflecting paints, but these technologies are not currently pursued very aggressively because they are not taken account of in the official CAFE certification tests. It would take more than the addition of HVAC in one of the five test schedules used to report fuel economy on the vehicle sticker to have a significant impact on the penetration of these technologies.

REFERENCES

Automotive News. 2008. A big fuel saver: Easy rolling tires (but watch braking). July 21.

Barrand, J., and J. Bokar. Reducing tire rolling resistance to save fuel and lower emissions. SAE Paper 2008-01-0154. SAE International, Warrendale, Pa.

Bull, M. 2008. Efficacy, cost, and applicability of lightweight structures to fuel economy. Presentation to the Committee for the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, June 3, Washington, D.C.

Carpenter, Jr., J., U.S. Department of Energy, Washington, D.C. 2008. Challenges to automotive composites. Presentation to American Chemistry Council, Plastics Division, Arlington, Virginia, May 20.

Cheah, L., C. Evans, A. Bandivadekar, and J.B. Heywood. 2007. Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035. Laboratory for Energy and Environment, Massachusetts Institute of Technology, October.

Compere, A.L., W.L. Griffith, C.F. Leitten, and S. Petrovan. 2001. Improving the Fundamental Properties of Lignin-Based Carbon Fiber for Transportation Applications. Oak Ridge National Laboratory. Available at http://www.ornl.gov/~webworks/cppr/y2001/pres/120145.pdf.

Deutsche Bank. 2008. Electric cars: Plugged in. Deutsche Bank Global Markets Research Report. June 9.

EEA (Energy and Environmental Analysis, Inc.). 2007. Update for Advanced Technologies to Improve Fuel Economy of Light Duty Vehicles—Final Report. Prepared for U.S. Department of Energy. October.

EPA (U.S. Environmental Protection Agency). 2008. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. Ann Arbor, Mich.

Forbes. 2008. Automakers' natural appeal, Forbes Magazine, September 26.

Gessat, J. 2007. Electrically powered hydraulic steering systems for light commercial vehicles. SAE Paper 2007-01-4197. SAE International, Warrendale, Pa.

Goodyear Tire & Rubber Company. 2009. Letter from Donald Stanley, Vice President, Product Quality and Plant Technology, April 13, 2009; e-mail exchanges with Donald Stanley, January, 28, 2009, and February 25, 2009.

Heremans, J.P., V. Jovovic, E.S. Toberer, A. Saramat, K. Kurosaki, A. Charoenphakdee, S. Yamanaka, and G.J. Snyder. 2008. Enhancement of thermoelectric efficiency in PbTe by distortion of the electronic density of states. Science 321:554.

Hussain, Q., C. Maranville, and D. Brigham. 2009. Thermoelectric exhaust heat recovery for hybrid vehicles. SAE Paper 2009-01-1327. SAE International, Warrendale, Pa.

IBIS Associates. 2008. Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Power Train Technologies in Automobiles. IBIS, Waltham, Mass.

Kolwich, G. 2010. Light-Duty Technology Cost Analysis—Report on Additional Case Studies. Prepared for U.S. Environmental Protection Agency. FEV, Inc., Auburn Hills, Mich.

Martec Group, Inc. 2008. Variable Costs of Fuel Economy Technologies. Prepared for Alliance of Automobile Manufacturers. June 1; amended September 26 and December 10.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Washington, D.C.: National Academy Press.

NRC. 2006. Tires and Passenger Vehicle Fuel Economy: Informing Consumers, Improving Performance—Special Report 286. Washington, D.C.: The National Academies Press.

Pagerit, S., A. Rousseau, and P. Sharer. 2006. Fuel economy sensitivity to vehicle mass for advanced vehicle powertrains. SAE Paper 2006-01-0665. SAE International, Warrendale, Pa.

Powers, W. 2000. Automotive materials in the 21st century. Advanced Materials and Processes, May.

Ricardo, Inc. 2007. Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures. Prepared for the Aluminum Association, Inc.

Rugh, J.P., L. Chaney, J. Lusbader, J. Meyeer, M. Rustagi, K. Olson, and R. Kogler. 2007. Reduction in vehicle temperatures and fuel use from cabin ventilation, solar-reflective paint, and a new solar-reflective glazing. SAE Paper 2007-01-1194. SAE International, Warrendale, Pa.

8

Modeling Improvements in Vehicle Fuel Consumption

INTRODUCTION

The potential of technology to reduce fuel consumption can be estimated in three basic ways. One approach involves constructing an actual prototype vehicle with the technologies in question, performing the Environmental Protection Agency (EPA) city and highway dynamometer tests repeatedly, and then measuring the fuel consumption. Although there is some variability from test to test, this method is the most accurate but is also prohibitively expensive. A second approach is to construct a computer model that represents all of a vehicle's components and their interactions, including representations of the technologies for reducing fuel consumption, and to simulate the behavior of the vehicle over the federal test procedures. This method, which the committee refers to as full system simulation (FSS), is now the state of the art throughout the automotive industry for modeling fuel consumption. Although it is less expensive, FSS still requires very large expenditures of time and money if it is used to calibrate models to the 1,000 or so different vehicle configurations offered for sale in the United States each model-year and to test all relevant combinations of technologies. The third alternative is to construct an algorithm that adds discrete technologies to the set of base-year vehicle configurations and that then calculates their cumulative impact while attempting to account for interactions between them by means of adjustment factors. The committee refers to this third method as partial discrete approximation (PDA). The simplicity of the third approach allows fuel consumption impacts to be calculated for thousands of vehicles and tens of thousands of technology combinations. The key question is whether the third method can be executed with sufficient accuracy to support fuel economy regulation. The Volpe Model (Van Schalkwyk et al., 2009), used by the National Highway Traffic Safety Administration (NHTSA) in its rulemaking analyses, and the EPA's OMEGA model, used by the EPA in its rulemaking analysis (EPA and NHTSA, 2009), are PDA models that use data on technology costs and fuel consumption impacts from a variety of sources, including FSS models.

This chapter evaluates methods of estimating the potential to decrease automotive fuel consumption by changing vehicle design and technology. It begins with some general observations on modeling technologies' potential for reducing fuel consumption. Because of the technological complexities of vehicle systems, predicting how combinations of technologies might perform in new vehicle designs involves uncertainty. The present committee summarizes and discusses the method used by the National Research Council (NRC) Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards in its 2002 report (NRC, 2002). It then goes on to compare and evaluate the two most widely used approaches to estimating the technological potential for reducing fuel consumption—PDA and FSS. Both methods are described in detail, and applications of the two methods to various types and configurations of vehicles are compared. Although it was able to make useful comparisons between modeling methods, the committee found that information comparing the results of either the FSS or the PDA method to real-world vehicles is scarce. The committee also comments briefly on the methodology used by the NHTSA in its 2011 Final Rule.

Recognizing the limitations of all modeling approaches, the committee considers the FSS method to be the state of the art and therefore the preferred method for estimating the potential of technologies to reduce fuel consumption. However, given the cost of FSS modeling at present, the committee believes that the PDA method, properly executed and supplemented with estimates of technology interaction effects developed by FSS or lumped parameter modeling, can be a reasonably accurate method for assessing the potential for reducing light-duty vehicle fuel consumption over a time horizon on the order of 10 years.

CHALLENGES IN MODELING VEHICLE FUEL CONSUMPTION

Along with the many potential benefits of using computer models to understand vehicle systems come limitations as well. In addition to enabling insight into how an overall vehicle system might operate, vehicle system modeling can also help measure the interactions between vehicular subsystems and how they affect overall vehicle performance. An understanding of the physics underlying these interactions is important when trying to estimate how future vehicles might perform with different combinations of technologies. All models are inherently simplifications of reality; the physics of real processes will always be considerably more complicated than that reflected in a model. In the end, impacts can only be known with certainty when a technological concept is realized in a real vehicle, and even then realizations of the same technological concept can differ from one vehicle to another. The meaningful question is whether any given model or methodology has sufficient fidelity to competent executions of the technological concept to achieve the goals for which the model has been developed.

With even the most complex and comprehensive models, there are challenges when modeling a *known* vehicle configuration, and even greater challenges when trying to predict the behavior of future vehicles using new combinations of technologies. When modeling a known or existing vehicle the principal problems are in capturing the desired dynamics to a sufficient level of detail or fidelity, and in collecting and inputting representative parameters or boundary conditions. The advantage of modeling a known vehicle is that data on the vehicle's actual performance are usually available to the modeler, and the data can be used to tune or validate the model's performance. Even for existing vehicles, however, experimental data sets are frequently sparse and may not include the precise performance situations of interest.

Detailed computer modeling of vehicle systems can be very expensive. Developing sufficient data on the performance of engines and other components, data that are not generally available in the open literature, is a major source of the expense of FSS modeling. An automobile company might spend many times the resources available to the committee to develop dynamic models to help answer the kinds of questions posed to the committee. On the order of 1,000 different vehicle configurations undergo fuel consumption testing each model year. FSS modeling of even the most promising combinations of advanced technologies for such a large number of vehicles would be expensive for federal agencies. PDA modeling, on the other hand, can be implemented in simplified algorithms that can estimate fuel consumption potentials for thousands of vehicles or more, considering virtually all logical combinations of technologies.

There are at least six sources of error in estimating the potential to reduce vehicle fuel consumption:

1. Differences between the attributes of the representative or typical vehicle being analyzed and the actual vehicles it represents;
2. Inaccuracies in the characterization of the base vehicle, especially its energy flows;
3. Inaccurate assessment of technology impacts, including the inability to fully represent the physics of a new technology in FSS modeling;
4. Differences in the implementation of a given technology from vehicle to vehicle;
5. Changes in the nature of a technology over time; and
6. Inaccurate estimation of the synergies among technologies and how they contribute to the overall end result of their combined application.[1]

In general, rigorous, quantitative assessments of these potential sources of error and their impacts on the potential to reduce vehicle fuel consumption are scarce.

In this chapter comparisons of the results of FSS and PDA (with lumped parameter modeling) are presented. In addition, the committee contracted with Ricardo, Inc., to perform a statistical analysis of FSS modeling. The goal was to determine whether a limited number of FSS runs could be used to generate accurate data on the main effects of technologies and their interactions, which could then be used as basic input data for PDA modeling. The results of the analysis support the feasibility of this concept. Unfortunately, scientific data about the accuracy of either modeling method in comparison to actual vehicles are very limited.

METHODOLOGY OF THE 2002 NATIONAL RESEARCH COUNCIL REPORT

The 2002 NRC report *Effectiveness and Impact of Corporate Average Fuel Economy Standards* used a type of PDA method to estimate the potential future reductions of fuel consumption by light-duty vehicles. The 2002 committee recognized the existence of synergies among technologies applied to reduce fuel consumption but did not provide explicit estimates of the effects of such interactions. Technologies were implemented in defined sequences called paths, and the impacts of technologies on fuel consumption were adjusted to account for interactions with other technologies previously adopted.

[1] In this report the committee chose to use the term *synergies* as defined in the joint EPA and NHSTA "Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards" (EPA and NHTSA, 2009). Two or more technologies applied together might be negatively synergistic, meaning that the sum of their effects is less than the impact of the individual technologies (contributes less to reducing fuel consumption, in this case), or might be positively synergistic, meaning that the sum of the technologies' effects is greater than the impact of the individual technologies (in this case, contributes more to reducing fuel consumption).

> Technology changes modify the system and hence have complex effects that are difficult to capture and analyze. It is usually possible, however, to estimate the impacts of specific technologies in terms of a percentage savings in fuel consumption for a typical vehicle without a full examination of all the system-level effects. (NRC, 2002, p. 33)

> For each technology assessed, the committee estimated not only the incremental percentage improvement in fuel consumption . . . but also the incremental cost that applying the technology would add to the retail price of a vehicle. (NRC, 2002, p. 35)

The 2002 NRC committee grouped technologies into three categories: engine technologies, transmission technologies, and vehicle technologies. Vehicles were grouped into 10 classes. Table 8.1 is the 2002 committee's list of technologies for passenger cars, including ranges for the estimated incremental reductions in fuel consumption and for incremental RPE impacts.

For each vehicle class three different sequences of technology implementation, called "production development paths," were mapped out. Figure 8.1 shows impacts of the technologies included in the three paths for passenger cars, as noted in Table 8.1, on the fuel consumption of a midsize car. The paths were intended to provide a logical sequence of implementation of the various technologies and to ensure that the incremental fuel consumption reductions from a given technology could be estimated conditional on the technologies that had preceded it. Paths 1 and 2 comprised proven technologies that could be introduced within the next 10 years (from 2002), with Path 2 including some more costly technologies than Path 1. Path 3 included additional emerging technologies the 2002 committee believed would become available within the next 15 years. The list of emerging technologies included several technologies that are now in use (intake valve throttling, automated manual transmission, advanced continuously variable transmissions (CVTs), integrated starter/generator, electric power steering) and several that are still not available (camless valve actuation, variable compression ratio engine). In addition, the 2002 committee judged that the potential for diesels to meet tighter emissions standards was highly uncertain and also excluded hybrids from its quantitative assessment due to uncertainty about their future potential. However, both technologies are now available on mass market vehicles in the United States.

In estimating the potential reduction in fuel consumption (gallons per 100 miles) of each technology, the 2002 committee drew on a variety of sources of information, from published reports to presentations to the committee by experts and consultations with automotive manufacturers and suppliers. Having studied the available information, the 2002 committee used its own expertise and judgment to decide on ranges of estimates for each technology. The ranges were intended to reflect uncertainties with respect to the technology of the baseline vehicle, effectiveness of the implementation, and possible tradeoffs with other vehicle attributes. Ranges were given for costs in order to reflect manufacturer-specific conditions, market uncertainties, and the potential for evolutionary costs reductions for new technologies. The 2002 committee did not specify a confidence interval for the ranges, nor did it explicitly address interdependencies or synergies of performance or cost, except via the incremental effects of sequential application in the technology paths.

The incremental fuel consumption improvement and retail price equivalent estimates in Table 8.1 are additive but only for a particular technology path. The technologies included in a path are indicated by an "X" in the columns labeled 1, 2, and 3. Technologies not contained in a path were not to be added to that path. A range of estimates is provided for both fuel consumption and cost impacts. However, only the midpoints of those estimates can be directly accumulated (as illustrated in Figure 8.1), since accumulation of all the high-end or low-end estimates without adjustment would produce misleading results.

The 2002 NRC committee's method received some criticism for being overly simplistic. One notable critique (Patton et al., 2002) cited three major issues:

1. Failure to examine system-level effects;
2. Inaccurate fuel consumption estimates for individual technologies; and
3. Overcounting of fuel consumption reductions.

The first point chiefly faulted the 2002 committee for multiplying together the impacts of individual technologies as if they were independent. It observed that when technologies address different energy-loss mechanisms, their impacts generally are independent, but when technologies address the same energy-loss mechanism (e.g., engine pumping losses), the aggregate effect may be more complex. The committee believed that it had addressed this issue by estimating the incremental effects of technologies implemented in a specified order. However, that committee neglected to quantify the energy losses addressed by each technology and did not separately quantify the interactions among technologies.

The second critique covered a variety of points including the degree of optimism in studies cited to support the committee's estimates and inadequate attention to the dependence of fuel consumption impacts on the characteristics of the vehicle to which they are applied.

> An example of this is cylinder deactivation. According to the report, cylinder deactivation is "applied to rather large engines (>4.0 L) in V8 and V12 configurations." Yet the report applies the same fuel consumption reduction factor for cylinder deactivation to vehicles with six and four cylinder engines, where the actual benefit would be smaller. (Patton et al., 2002, p. 10)

However, the 2002 committee applied cylinder deactivation only to large passenger cars, midsize and larger sport

TABLE 8.1 Fuel Consumption Technology Matrix: Passenger Cars

Baseline: overhead cams, 4-valve, fixed timing, roller finger follower	Fuel Consumption Improvement (%)	Retail Price Equivalent ($)		Subcompact			Compact			Midsize			Large		
		Low	High	1	2	3	1	2	3	1	2	3	1	2	3
Production-intent engine technology															
Engine friction reduction	1-5	35	140	X	X	X	X	X	X	X	X	X	X	X	X
Low-friction lubricants	1	8	11	X	X	X	X	X	X	X	X	X	X	X	X
Multivalve, overhead camshaft (2-V vs. 4-V)	2-5	105	140												
Variable valve timing (VVT)	2-3	35	140	X	X	X	X	X	X	X	X	X	X	X	X
Variable valve lift and timing	1-2	70	210		X	X		X	X		X	X		X	X
Cylinder deactivation	3-6	112	252											X	
Engine accessory improvement	1-2	84	112	X	X	X	X	X	X	X	X	X	X	X	X
Engine supercharging and downsizing	5-7	350	560									X			X
Production-intent transmission technology															
Five-speed automatic transmission	2-3	70	154	X			X			X	X		X	X	
Continuously variable transmission	4-8	140	350		X	X		X	X			X			X
Automatic transmission w/aggressive shift logic	1-3	—	70	X			X			X			X		
Six-speed automatic transmission	1-2	140	280								X		X	X	
Production-intent vehicle technology															
Aero drag reduction	1-2	—	140					X	X		X	X		X	X
Improved rolling resistance	1-1.5	14	56	X	X	X	X	X	X	X	X	X	X	X	X
Safety technology															
Safety weight increase	−3 to −4	0	0	X	X	X	X	X	X	X	X	X	X	X	X
Emerging engine technology															
Intake valve throttling	3-6	210	420		X			X			X			X	
Camless valve actuation	5-10	280	560			X			X			X			X
Variable compression ratio	2-6	210	490			X			X			X			X
Emerging transmission technology															
Automatic shift/manual transmission (AST/AMT)	3-5	70	280								X			X	
Advanced CVTs—allows high torque	0-2	350	840									X			X
Emerging vehicle technology															
42-V electrical system	1-2	70	280			X			X		X	X		X	X
Integrated starter/generator (idle off-restart)	4-7	210	350			X			X			X			X
Electric power steering	1.5-2.5	105	150			X			X		X	X		X	X
Vehicle weight reduction (5%)	3-4	210	350												

NOTE: An X means the technology is applicable to the particular vehicle. Safety weight added (EPA baseline + 3.5%) to initial average mileage/consumption values.
SOURCE: NRC (2002), Table 3.1.

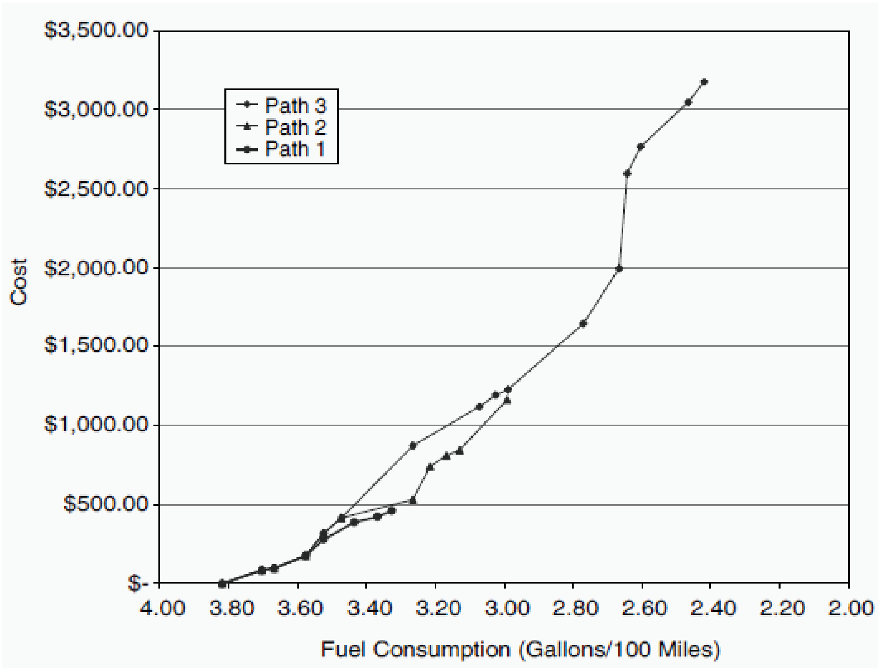

FIGURE 8.1 Estimated cost of fuel consumption reduction in model-year 1999 midsize cars. SOURCE: NRC (2002), Figure 3.6.

utility vehicles (SUVs), minivans, and pickup trucks. Nearly all of these vehicles have engines with six or more cylinders. Cylinder deactivation is applied today to six-cylinder engines. Nonetheless, the 2002 committee's characterization of baseline vehicles was based solely on the typical attributes of the 10 vehicle classes. Using the average characteristics of 10 classes of vehicles will lead to a certain degree of error if the resulting estimates are applied to the vehicles of specific manufacturers.

The criticism of inadequate attention to individual vehicle characteristics can also be leveled at the 2002 NRC committee's costs estimates. The costs of fuel consumption technologies in the 2002 NRC report were the same for all vehicle classes. In fact, the costs of many technologies scale directly with measurable vehicle attributes such as weight or cylinder count.

The third critique is that the 2002 NRC committee's estimates overstated the potential benefits of technologies that primarily addressed pumping losses because the methodology did not take into account the theoretical limits of pumping loss reduction.[2]

Using their own judgments about the allocation of the benefits of technologies to reduction of pumping losses, Patton et al. (2002) divided the 2002 committee's fuel consumption benefit estimates into six categories of energy losses. Patton et al. (2002) attributed essentially all of the 2002 committee's 4 to 8 percent benefit to reduction in pumping loss (and even added an additional 0.5 to 1.0 percent to pumping loss reduction that compensated for reduced transmission efficiency). Only a 0.0 to 0.5 percent benefit was assigned to increased thermal efficiency, presumably due to operating the engine in a more efficient portion of the engine map more of the time. Likewise, most of the benefits of 5-speed and 6-speed automatic transmissions (versus 4-speed) were attributed to reducing pumping losses with no benefits for engine thermal efficiency. Similarly, 4.0 to 6.0 percent of the committee's estimated 5.0 to 7.0 percent benefits of engine boosting and downsizing was attributed to reduced pumping losses. The 2002 committee, on the other hand, judged that the technology derives much of its benefits from increased engine efficiency at light load due to engine downsizing and, when possible, reduced friction due to reduced cylinder count at equivalent power. The 2002 committee asserted that the energy efficiency benefits of multivalve, overhead camshaft engines derived from four different sources:

> The application of single and double overhead cam designs, with two, three or four valves per cylinder, offers the potential for reduced frictional losses (reduced mass and roller followers), higher specific power (hp/liter), engine downsizing, somewhat increased compression ratios, and reduced pumping losses. (NRC, 2002, p. 36)

Patton et al. (2002) disagreed, assigning 2.0 to 5.0 percent of the committee's estimated 2.0 to 5.0 percent

[2]Patton et al. (2002) estimated the theoretical limits at between a 13 percent and 17 percent reduction in fuel consumption, depending on the vehicle in question. The U.S. EPA (2008b) estimated pumping plus friction losses at between 10 percent and 13 percent for actual vehicles, assuming a gross indicated engine efficiency of 37 percent.

improvement to reduced pumping losses, while adding a 0.5 to 1.0 percent benefit in thermal efficiency, offset by a −0.5 to −1.0 percent efficiency *loss* due to *increased* friction.

While the benefits of variable valve timing and lift (VVT + L) are largely reductions in pumping losses, they also include improved power, and the benefits of cylinder deactivation include increased engine load (operation in a more efficient region of the engine map) as well as reduced pumping losses. Estimates of the benefits of the aforementioned technologies generated by FSS models have produced results consistent with the 2002 NRC committee's estimates. Recent estimates from the DOT/NHTSA (2009) and the EPA (2008a) are compared with the 2002 NRC committee's estimates in Table 8.2. The chief area of disagreement is the benefit of cylinder deactivation applied to multivalve, overhead camshaft engines with VVT and discrete or continuous lift control. The NHTSA estimated a benefit of 0.0 to 0.5 percent, whereas the NRC and the EPA estimated benefits of 3 to 6 percent.

The critics of the 2002 NRC report's methodology make an important and valid point in calling attention to the lack of a rigorous relation between the estimates of fuel consumption reduction and the physical energy flows in a vehicle. As a consequence, the plausibility of the 2002 NRC estimates relied heavily on the expert judgment of the committee members. The 2002 NRC study's method also did not explicitly account for the current use of the identified fuel economy technologies in existing vehicles. Practitioners of the PDA method can and often do account for energy constraints using simplified modeling methods called "lumped parameter" models, based on methods developed by Sovran and Bohn (1981) and extended by Sovran and Blaser (2003, 2006) and reviewed in Chapter 2 of this report. FSS models inherently account for energy flows and ensure that physical limits will not be violated.

MODELING USING PARTIAL DISCRETE APPROXIMATION METHOD

The PDA method incrementally adds discrete fuel-consumption-reducing technologies to a baseline vehicle until certain criteria are met. The method is sometimes applied to individual vehicles but more often assumes that the fuel consumption impact and cost of a technology will be approximately the same for all vehicles within at least a subset (or class) of light-duty vehicles. In a presentation to the committee, K.G. Duleep of Energy and Environmental Analysis, Inc. (EEA) identified three important areas in which the PDA method, and especially its application in the 2002 NRC study, had come under criticism (Duleep, 2008).

1. Adequate definition of baseline vehicles;
2. Order of implementation of fuel consumption technologies; and
3. Accounting for synergies among fuel consumption technologies.

The chief disadvantage of the PDA method is that it is entirely empirically based and therefore does not explicitly represent the interactions among any set of technologies. Synergies among technologies are estimated by engineering judgment or by means of simplified analytical tools, such as lumped parameter models of vehicle energy use (Duleep, 2008; Sovran and Blaser, 2003, 2006). Computational simplicity and the ability to quickly and economically process information on thousands of individual vehicles and dozens of alternative combinations of technologies are the method's chief advantages.

The main steps in the PDA process are the following:

1. Identify discrete technologies with fuel consumption reduction potential.

TABLE 8.2 Comparison of Benefits of Valve Train Technologies as Estimated by NRC (2002), NHTSA's Final Rule for 2011, and the EPA

Technology	NRC (2002) (%)	Midpoint (%)	NHTSA[a] (%)	Midpoint (%)	EPA (%)	Midpoint (%)
Multivalve OHC	2-5	3.5	1-2.6	1.8	NA	NA
Variable valve timing	2-3	2.5	3-5	4	2-4	3
Variable valve lift and timing	1-2	1.5	1.5-3.5	2.5	3-4	3.5
Cylinder deactivation	3-6	4.5	0.0-0.5	0.25	6	6
Subtotal		**12**		**8.5**		**12.5**
Intake valve throttling[b]	3-6	4.5	1.5-3.5	2.5	1-2	1.5
Total		**16.5**		**11**		**14**
Camless valves[c]	5-10	7.5	NA	NA	5-15	10

[a]NHTSA's fuel consumption benefits are path dependent. The path shown here is for dual overhead camshaft engines.

[b]In NHTSA's terminology IVT is continuously variable valve lift (CVVL) and is a substitute for discrete variable valve lift (DVVL). NHTSA argues that cylinder deactivation applied to CVVL has little benefit since pumping losses have already been greatly reduced. Others argue that this misses the benefit of increased engine efficiency at higher load when a six-cylinder engine is operated on only three cylinders.

[c]Effect of camless valve actuation is incremental to variable valve lift and timing not to intake valve throttling. The two are mutually exclusive.

SOURCE: Based on data in NRC (2002), DOT/NHTSA (2009), and EPA (2008a).

2. Determine the applicability of each technology.
3. Estimate each technology's impact on fuel consumption and cost.
4. Determine implementation sequences based on
   a. Cost-effectiveness and
   b. Engineering and manufacturing considerations.
5. Identify and estimate synergistic effects
   a. Based on empirical data and expert judgment,
   b. Using a simplified model of vehicle energy flows (e.g., lumped-parameter model), or
   c. Using estimates from FSS models.
6. Determine the "optimal" fuel consumption level by
   a. Using a computer algorithm that sequentially applies technologies,
   b. Using fuel consumption cost curves.

Identifying Technologies That Reduce Fuel Consumption

The PDA method, like the FSS method, begins with the identification of distinct technologies that have the potential to reduce vehicle fuel consumption at a realistic cost.[3] The list of all possible technologies with some potential to reduce fuel consumption could range from lower-rolling-resistance tires and improved engine lubricants to human-powered vehicles and the compressed air engine. When the purpose is regulatory rulemaking, not all possible fuel consumption technologies should be included. The world record for automotive fuel economy is held by the Pac Car II, a fuel-cell-powered vehicle that won the 2005 Shell Ecomarathon in Ladoux, France, with a gasoline equivalent fuel economy of 12,666 miles per gallon.[4] The three-wheel vehicle accommodates one small passenger, who must drive lying down. The 0.57-m wide, 0.61-m high, 2.78-m long carbon-fiber body has no room for cup holders, not to mention air conditioning. It is a zero-emission vehicle, but meeting safety standards was not a design consideration. Clearly much of the PAC Car II's fuel economy was achieved by making unacceptable tradeoffs with other vehicle attributes. The CAFE law requires that fuel economy standards must be technologically feasible and economically practicable. This is ultimately a matter of expert judgment, yet there is remarkable agreement among diverse studies on the list of relevant technologies. Most assessments assume no reduction in size or power-to-weight ratios as a premise.

In general, studies of fuel consumption potential intended to inform the regulatory process and using the PDA method select technologies that meet all of the following three criteria:

1. Technologies already incorporated in at least one mass-produced vehicle somewhere in the world or preproduction technologies judged to have a strong likelihood of widespread adoption within the next decade;
2. Technologies having no significant negative impact, or a beneficial impact on attributes that are valued by consumers or that are necessary to meet safety and emissions regulations; and
3. Technologies whose cost does not far exceed the potential value of fuel savings and other private and social benefits.

For example, all but a few of the technologies considered by the 2002 NRC study were already in mass production. In general, PDA studies are most reliable when they are limited to technologies already in production. However, the farther one must look into the future the less tenable this constraint becomes.

Determining Applicability

Not every technology will be applicable to every vehicle. Torque limitations, for example, have so far prevented the use of CVTs in the largest, most powerful light-duty vehicles. Engine downsizing by reducing the number of cylinders with turbo-charging may be considered applicable to six-cylinder engines but less so to four-cylinder engines due to vibration and harshness considerations. Applicability appears to be largely a matter of expert judgment, determined on a case-by-case basis. The applicability step reduces the full set of technologies to only those that can be used on the baseline vehicle being considered.

Estimating Fuel Economy and Cost Impacts

Fuel consumption impacts are estimated for each technology and each class of vehicles (or each individual vehicle) to which it is applicable. Practitioners of the PDA method derive their estimates from a variety of sources. Unlike FSS, the PDA method, by itself, is not able to produce fuel consumption impact estimates for individual technologies. It is a method of aggregating the fuel consumption impacts of various technologies and must obtain the individual technology benefit estimates from other sources. In its report to the committee, EEA cited three principal sources of information on fuel economy benefit.

> First, the trade press, engineering journals and technical papers presented at engineering society meetings provide detailed information on the types of technologies available to improve fuel economy and the performance, when applied to current vehicles. Second, most of the technologies

[3]The CAFE guidance states that fuel economy standards should be set at the maximum feasible level, taking into consideration technological feasibility, economic practicability, the effect of other federal motor vehicle standards on fuel economy, and the need of the nation to conserve energy (Motor Vehicle Information and Cost Saving Act, Title V, Chapter 329, Section 32902[a]).

[4]Details about the competition, the car, and its design can be found at http://www.paccar.ethz.ch/.

> considered in this report have been introduced in at least a few vehicles sold in the marketplace, and actual test data on fuel economy can be used. Third, the world's largest automanufacturers have research and development staff with detailed knowledge of the attributes of each technology, and their inputs in an unconstrained situation can be used to estimate the benefits of technologies. (EEA, 2007, p. 9)

The EPA has provided a similar list of sources of information.

> These data sources included: vehicle fuel economy certification data; peer reviewed or publicly commented reports; peer reviewed technical journal articles and technical papers available in the literature; and confidential data submissions from vehicle manufacturers and automotive industry component suppliers. (EPA, 2008a, p. 2)

The EPA considers the vehicle certification test data to be an especially reliable source when a directly comparable vehicle is offered with and without a specific technology. In addition, the NHTSA's staff has access to proprietary data provided by vehicle manufacturers to directly support the rulemaking process.

Recently, FSS models have been extensively used to estimate the fuel economy impacts of individual technologies and combinations of technologies (e.g., Ricardo, Inc., 2008a,b; Sierra Research, Inc., 2008). A study done by Ricardo, Inc., for the committee and described below indicates that data on technologies' main and synergistic effects generated by FSS models can be used effectively in PDA analyses (Ricardo, Inc., 2009).

Sequencing Implementation

Sequences for implementing fuel economy technologies are usually determined by a combination of cost-effectiveness and engineering considerations. All else equal, it would be economically efficient to implement first the technology that offered the greatest reduction in fuel consumption per dollar of cost, followed by the technology with the second largest ratio, and so on. Engineering considerations may dictate a different sequence, however. For example, VVT for both intake and exhaust must come after VVT for intake only, regardless of cost-effectiveness.

Fuel consumption benefits must then be converted to incremental benefits, given the implementation sequence. For example, the benefit of a 6-speed transmission must be defined as incremental to that of a 5-speed transmission, even if the base vehicle has a 4-speed, assuming that the 5-speed will be implemented before the 6-speed.[5] Obvious incompatibilities (e.g., a vehicle cannot have both a 6-speed automatic transmission and a CVT at the same time) must also be taken into account.

Accounting for Synergies

Undoubtedly the most serious criticism of the PDA method is that it does not adequately account for synergies among fuel economy technologies. Whether or not the PDA approach is capable of appropriately accounting for synergies is one of the key issues addressed by the present committee.

Fuel economy technologies can have both positive and negative synergies (see footnote 1). In addition, the impacts of technologies applied to vehicle subsystems could potentially be significantly nonlinear, and therefore the effects of multiple technologies might not be accurately estimated by summing the effects of the individual technologies. Practitioners of the PDA method draw on three sources of information to estimate such synergistic effects (EEA, 2007). Because most of the technologies under consideration are in use in some mass-produced vehicle, it is occasionally possible to find models using a combination of several technologies. Comparing the actual fuel consumption performance of these vehicles to an estimate based on the sum of their individual effects can provide an estimate of the degree of synergy.

Second, simplified lumped parameter models of vehicle energy use (e.g., Sovran and Bohn, 1981) provide a means of avoiding the double counting of energy savings. Given a few key parameters, lumped parameter models allow the quantification of sources of energy loss and the components of tractive force requirements for a vehicle. By attributing the impacts of technologies to specific energy losses and tractive force requirements, analysts can check that the sequential application of technologies has plausible impacts on the factors determining energy use. A key question is whether the use of a lumped parameter model can sufficiently accurately account for synergistic effects or whether the FSS method must be used in all cases (Hancock, 2007). An analysis of this subject by Ricardo, Inc. (2009) commissioned by the committee, together with an assessment by the EPA considered below, indicates that a reasonably accurate accounting is possible.

The ability of lumped parameter models to accurately predict vehicle fuel use was first demonstrated by Sovran and Bohn (1981). In an updated version of the same methodology, Sovran and Blaser (2003) showed that despite major changes in automotive technology, lumped parameter models still predicted tractive energy requirements with a high degree of accuracy. Development of a lumped parameter model begins with the fundamental physics equations that determine the energy requirements of vehicles over fixed driving cycles, in particular the EPA urban and highway cycles (equations of the lumped parameter model are presented in Chapter 2). Any cycle can be divided into three regimes:

1. Times when tractive force (F_{TR}) is required from the engine;

[5] In the PDA method a leap from a 4-speed transmission directly to a 6-speed transmission would be calculated by combining the incremental costs and fuel consumption effects of the 4- to 5-speed transition and the 5- to 6-speed transition.

2. Times when deceleration force is greater than rolling resistance (R) and aerodynamic drag (D); and
3. Times when no tractive force is required (vehicle stationary or undergoing deceleration provided by R + D).

When tractive force is required on either cycle, it must equal the sum of forces required to overcome rolling resistance, aerodynamic drag, and inertia. The lumped parameter method simplifies the equation for tractive force and other equations for braking and idling modes by integrating over the drive cycles, as explained in detail in Chapter 2 of this report. Sovran and Blaser (2003) found that the lumped parameter model defined by Equations 2.2 and 2.3 could explain the tractive energy required at the wheels and hence indirectly the engine output of vehicles over either EPA test cycle with an $R^2 = 0.9999$.

The lumped parameter method allows changes in pumping losses, engine friction, accessory loads, and other factors to be related in a manner that can prevent double counting if done properly. It reduces the likelihood of overestimating the combined fuel consumption impacts of multiple technologies by requiring that the laws of physics controlling energy flows and tractive requirements be maintained. As such, it is a powerful tool for quantifying synergistic effects for use in the PDA method. The lumped parameter method cannot, however, predict the kind of synergistic effects that occur when two or more technologies alter each other's performance. This topic is taken up in detail in the following section.

FSS modeling more completely represents such synergistic effects and so it is useful to compare lumped parameter and FSS estimates to test the adequacy of PDA synergy estimates. The U.S. EPA (2008a) used both methods to estimate the fuel economy benefits of 26 technology packages applied to five vehicle types. For most packages they found close agreement between the two types of estimates (Figure 8.2). The EPA's general conclusion was that both methods were valuable and that the use of lumped parameter modeling in PDA estimation gave reasonable estimates of synergies.

> Based on this, EPA concludes that the synergies derived from the lumped parameter approach are generally plausible (with a few packages that garner additional investigation). (EPA, 2008b, p. 44)

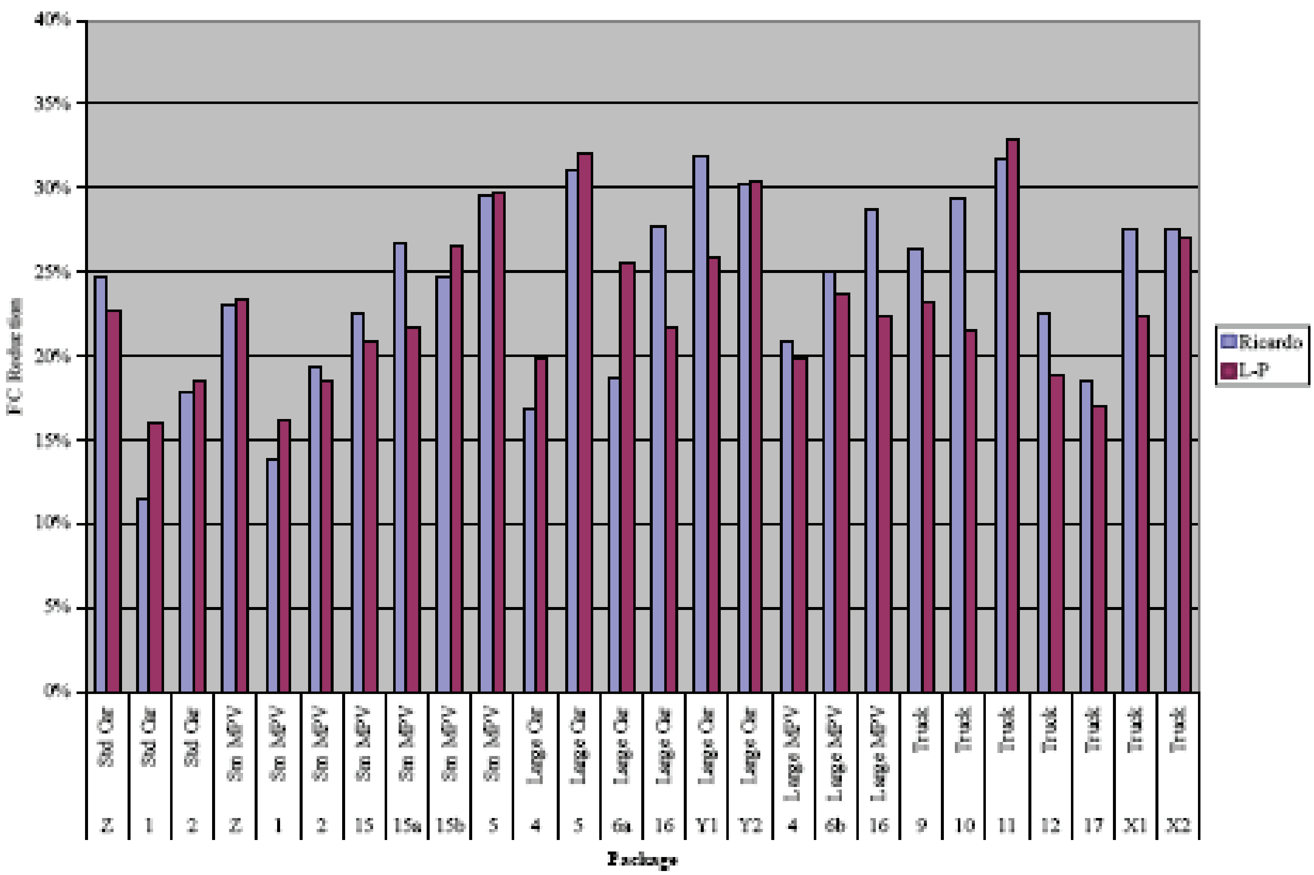

FIGURE 8.2 EPA's comparison of full vehicle simulation model (Ricardo, Inc.) and lumped parameter (L-P) PDA model results. SOURCE: EPA (2008a), Figure 3.3-1.

In 10 cases, significant differences were found (EPA, 2008b). For Standard Car Package 1 and Small MPV Package 1, the lumped parameter method estimated a larger fuel economy improvement. The difference was traced to the CVT component. The Ricardo, Inc., FSS CVT representation had a lower efficiency than assumed in the lumped parameter model. Two other cases involved turbo-charging with engine downsizing. The lumped parameter model estimate was also much higher in the case of Large Car Package 6a, involving continuously variable valve lift. In the case of Large Car Package 4, the lumped parameter model estimated a large benefit, but in the case of Truck Package 10, the FSS model produced the higher benefit estimate. For the packages including cylinder deactivation and coordinated cam phasing (Large Car 16, Large MPV, and Truck 12), the FSS modeling results were consistently higher. FSS estimates were also higher for the cases involving camless valve trains (Large Car Y1, Truck X1). The EPA staff is still investigating reasons for the differences but had identified at least some cases in which the comparison between the two methods led to the discovery of inadvertent errors in the FSS modeling. For example, EPA judged that Ricardo's modeling of cylinder deactivation and coupled cam phasing was incorrect because it did not account for cylinder deactivation's effect of approximately doubling brake mean effective pressure (BMEP) in the firing cylinders. The EPA staff suggested that conducting both FSS and lumped parameter analysis was a wise strategy since the discrepancies between the two methods had led to the discovery of correctable errors.

Twenty-three of the 26 packages evaluated by Ricardo were also estimated by EEA, Inc. (Duleep, 2008) for comparison. EEA was not able to estimate the packages including homogeneous charge compression ignition (HCCI) due to the novelty of the technology. The FSS method requires an externally provided representation of the physics of a device in order to estimate its impact on fuel consumption. While the FSS method itself cannot characterize the physics of technologies, it can produce impact estimates given such characterizations. The PDA method, on the other hand, must be given estimates of impacts for novel technologies. In 16 of the 23 comparisons the two methods produced estimates with relative differences of less than 5 percent. In two cases involving CVT transmissions the Ricardo estimate was much lower. In the committee's discussions with Ricardo and EEA, it was determined that this was due to Ricardo's estimated efficiency of the CVT being much lower than EEA's. This instance illustrates how both methods depend on assumptions about the performance of key technologies. In the remaining five cases, Ricardo's FSS estimates were higher but there appeared to be no common technology that could explain the differences. One of these cases was again the Truck Package 10 involving a turbo-charged gasoline direct injection engine: EEA's lumped parameter PDA method estimated a fuel economy benefit of 26.4 percent, whereas the Ricardo estimate was 42 percent.

Determining the "Optimal" Level of Fuel Economy

Calculation of fuel economy potential and its cost can be accomplished by algorithms that decide which technologies to apply and in what order, or by the use of fuel economy cost curves. The algorithmic approach relies on predefined technology implementation sequences (decision trees or pathways) and is the basis of the Department of Transportation's Volpe Model (Van Schalkwyk et al., 2009) and the Energy Information Administration's NEMS model's Manufacturers' Technology Choice Submodule (DOE/EIA, 2007). The decision tree methodology is described below. Cost curves developed by the NRC (2002) CAFE study and in a number of other studies have been reviewed in Greene and DeCicco (2000).

A PDA Algorithm: The NHTSA's Volpe Model

The NHTSA's Volpe model contains a compliance simulation algorithm that simulates the response of manufacturers to various forms of fuel economy standards. Data are put into the model describing a "CAFE scenario," a combination of definitions of vehicles included in the program, definitions of vehicle classes, levels of fuel economy standards that must be met each year, and the structure of the standards. The structure comprises several elements, the mathematical formulation (e.g., sales-weighted harmonic mean), the functional form (e.g., footprint metric function), the classes of vehicles to which it applies (e.g., foreign or domestic manufacture), and provisions for trading credits over time and among firms. In the description below, the focus is the determination of a manufacturer's "optimal" fuel economy level for a given CAFE scenario.

The algorithm begins with a list of vehicles expected to be available during the future period being evaluated. This is typically a narrow window of three to five model years, beginning 2 years in the future. Vehicles are distinguished by make, model, engine, and transmission, as in the EPA test car list. Many other vehicle attributes are in the vehicles data base, including sales volumes, prices, and specifications. The compliance algorithm applies technologies to each vehicle in the database individually. In the past, the technologies were largely taken from the NRC 2002 report's three technology path lists, but for the 2011 Fuel Economy Rule, the NHTSA developed a new technology list with the assistance of Ricardo, Inc. The new list adds diesel and hybrid power trains (including plug-in hybrids) and materials substitution to reduce vehicle weight. It represents other technologies at a greater level of detail. It also provides a table of estimated pair-wise synergies between technologies. However, the synergies used in the final rule appear to be the same for all vehicles classes. The analysis done for the committee by Ricardo, Inc., described below, indicates that synergy effects can vary across applications to different classes of vehicles (Ricardo, Inc., 2009).

The algorithm evaluates the applicability of each technology to each individual vehicle based on timing of availability and whether or not it is included in decision trees for that vehicle class. The Volpe model's decision trees are analogous to the 2002 NRC study's "paths" except that there are separate decision trees for internal combustion engines, transmissions, electrical accessories, material substitution, dynamic load reduction, aerodynamic drag reduction, and hybrid electric technology. The engine technology decision tree is shown in Figure 8.3. After low-friction lubricants and engine friction reduction are accomplished, the tree splits into three paths depending on camshaft configuration. This allows the NHTSA to tailor the technology sequencing to the base vehicle's engine attributes. If fuel economy is pushed to higher levels the three paths then converge on the stoichiometric, gasoline direct-injection engine. A table of notes can be used to "override" the algorithm's logic and determine applicability in special cases (e.g., as in Table 4, DOT, 2005).

In the committee's judgment, it is not necessary to have separate decision trees for engines and transmissions. This view is supported by the Ricardo, Inc. (2009) analysis, which demonstrates that the important across, or inter-decision-tree, synergies are between engines and transmissions (Ricardo, Inc., 2009). These inter-tree synergies can be transformed to incremental improvements by combining engines and transmissions into a single power train decision tree. Once this has been done, nearly all important synergies can be addressed by adjusting technology impacts to account for interactions with technologies previously implemented in the decision tree, or pathway.

In the Volpe model, the cost and fuel economy impact of each technology vary by vehicle class. Previously the 10 vehicle classes of the 2002 NRC report were used, but the 2011 rule is based on 12 vehicle classes that include 4 performance-based classes:

1. Small light truck (including SUVs and pickups),
2. Midsize light truck (including SUVs and pickups),
3. Large light truck (including SUVs and pickups and full-size vans),
4. Minivans,
5. Subcompact cars,
6. Subcompact performance cars,
7. Compact cars,
8. Compact performance cars,
9. Midsize cars,
10. Midsize performance cars,
11. Large cars, and
12. Large performance cars.

The sequence in which the technologies are applied to any given vehicle is determined by an optimization algorithm. Technologies already in use in a given vehicle are "carried over" from the previous year so that they are not duplicated.

The algorithm then begins an iterative process of determining a manufacturer's compliance with the CAFE standards. If a manufacture is not in compliance, the algorithm selects the next-best technology to add to the vehicle.[6] A technology is selected from the next steps on each of the applicable decision trees. The single technology that has the lowest "effective cost" is chosen for implementation. Effective cost is defined as the total retail price equivalent (RPE) cost of implementing the technology (the change in RPE times the number of vehicles affected), plus any change in the manufacturer's potential CAFE fine, minus the total discounted value of fuel saved by the increase in fuel economy, all divided by the number of vehicles affected. Fines are calculated so as to take account of credits for exceeding standards on some vehicles that can be transferred to other vehicles. Some manufacturers are assumed not to be willing to pay fines and so for them that option is removed. The current version of the model calculates credits or deficits (negative credits) generated by exceeding or failing to meet the standard in any given year. It does not, however, attempt to model credit trading either within a manufacturer over time or among manufacturers. The algorithm continues considering and implementing next-best technologies for all vehicle classes until a manufacturer either achieves compliance with the standard, exhausts all available technologies, or finds that paying fines is more cost-effective than increasing fuel economy (Van Schalkwyk et al., 2009, p. 2).

In a joint EPA and NHTSA (2009) notice of proposed rulemaking (NPRM) the EPA introduced its optimization model for reducing emissions of greenhouse gases from automobiles (OMEGA) model. Like the Volpe model, OMEGA is based on the PDA method and although the logic of the two models is fundamentally the same, there are some notable differences. The Volpe model operates on individual vehicle configurations (on the order of 1,000 make, model, engine, and transmission combinations), taking into account the existing or planned use of fuel economy technologies on each one. The OMEGA model deals with approximately 200 vehicle platforms broken down by engine size (EPA and NHTSA, 2009). For the purpose of estimating technology impacts the 200+ platforms are divided into 19 vehicle types that attempt to distinguish among power trains and market intent. Each of the 19 vehicle types are grouped into five vehicle classes (small car, large car, minivan, small truck, and large truck) for the purpose of scaling cost estimates. In general, the EPA's baseline vehicle is defined as one with a port-fuel-injected, naturally aspirated gasoline engine with two intake and two exhaust valves and fixed valve timing and lift, and a 4-speed automatic transmission. For the NHTSA's Volpe model the baseline is the actual configuration of each

[6]The Volpe model allows manufacturers to opt for non-compliance if paying a fine is less costly than missing the standards, and if a switch set in input data files allows such non-compliance. This option is not discussed here for the sake of brevity.

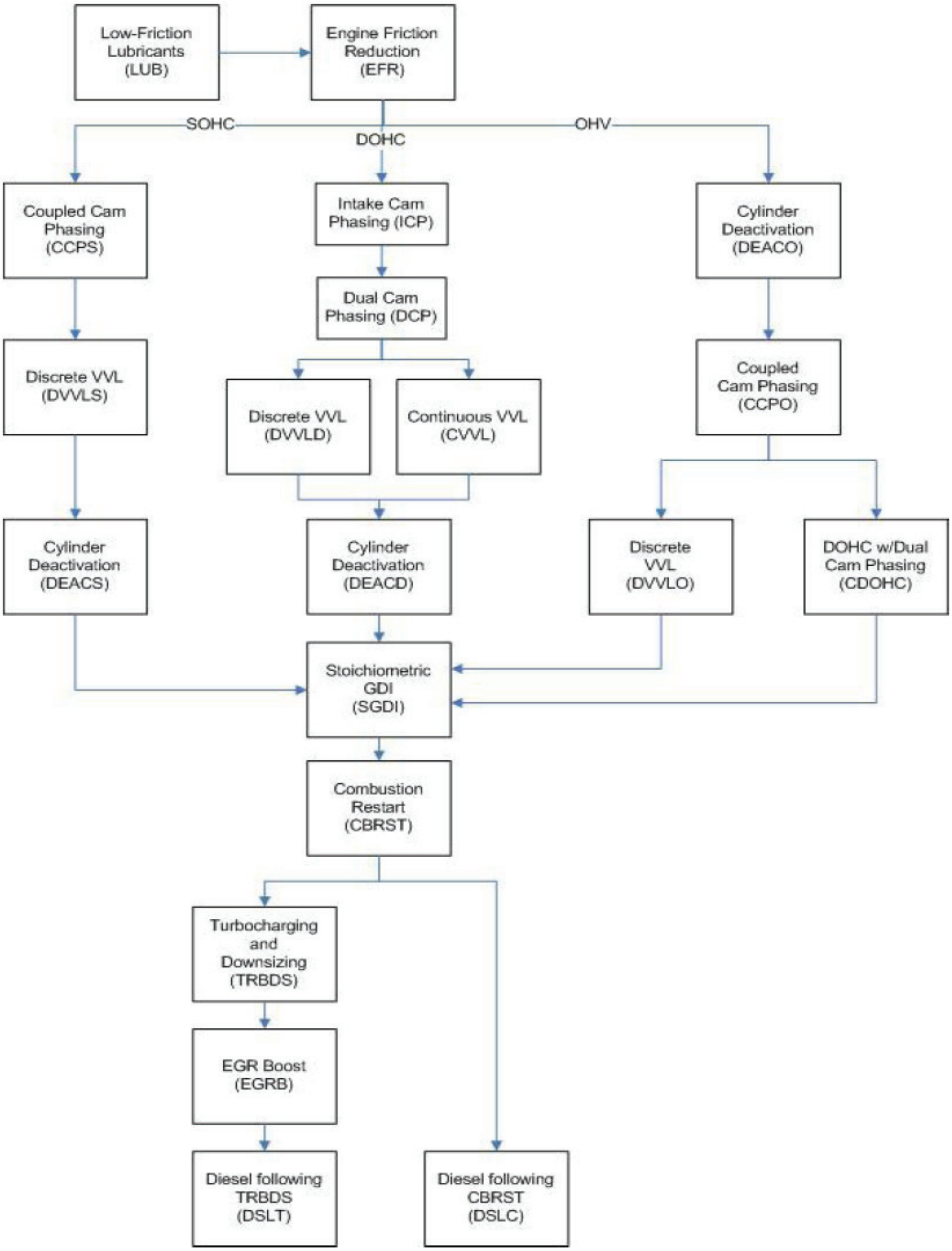

FIGURE 8.3 Volpe model engine technology decision tree.

vehicle configuration as it exists or is predicted to exist in the baseline fleet.

The Volpe model applies individual technologies one at a time in a sequential algorithm, whereas the OMEGA model applies predefined packages of technologies that have been ranked by cost-effectiveness for each vehicle type. However, the packages are assembled from individual technology impact estimates, with synergies between technologies within a package incorporated in the technology package impact estimates. The EPA used the lumped parameter method to determine the adjustment factors (EPA and DOT, 2009, p. 171).

Because neither the Volpe CAFE Compliance and Effects Modeling System nor the EPA's OMEGA model make use of cost curves but rather employ computer algorithms, neither NHTSA nor EPA require cost curves but rather a list of fuel economy technologies including cost, applicability, and synergy estimates. This committee's method is based on implementation pathways that are analogous to the Volpe model's decision trees and the OMEGA model's packages. Therefore, this committee determined that it was not necessary for this study to produce cost curves as such.

Aggregating to Estimate Manufacturers' Fleet Average Fuel Economy

Because fuel economy standards are enforced on automobile manufacturers, both the FSS and PDA methods require a means of inferring the fuel economy potential of an OEM from the fuel economy potential of individual vehicles or vehicle classes. The FSS method is sufficiently computationally intensive that it has not been practical to carry out simulations for all thousand or so vehicles in the EPA test car database for all relevant combinations of technologies. Using the PDA method, a manufacturer's fuel economy potential can be calculated using data on individual configurations (make, model, engine, transmission, i.e., a single entry in the test car database) or using data on classes of vehicles. The NHTSA's Volpe model, for example, calculates a manufacturer's fuel economy target using individual vehicle data since each vehicle has its own fuel economy target as a function of its footprint. The model also calculates each manufacturer's fuel economy potential at the test car list level of detail. Estimates based on vehicle classes can also be computed but they will only be approximately equal to estimates based on individual configurations.

Assume that the optimal level of fuel economy for a single vehicle configuration j has been determined to include technologies $k = 1$ to n_j (given a technology implementation sequence and fuel economy impacts adjusted for implementation order and synergies). The cumulative fuel economy impact is calculated by summing the fractional fuel economy (miles per gallon) improvements, adding one, and multiplying by the base fuel economy MPG_{0j}. If the sales of vehicle configuration j are s_j, then the fuel economy for manufacturer k selling configurations $j = 1$ to N_k is the following:

$$\left(\sum_{j=1}^{N_k} \frac{s_j}{\sum_{j=1}^{N_k} s_j} \left[MPG_j \left(1 + \sum_{i=1}^{n_j} \Delta_{ij} \right) \right]^{-1} \right)^{-1} \qquad \text{Equation 1}$$

If the calculation is done in terms of fuel consumption, or gallons per mile (GPM), the corresponding equation for the manufacturer's fuel consumption target is the following:

$$\sum_{j=1}^{N_k} \frac{s_j}{\sum_{j=a}^{N_k} s_j} \left[GPM_j \prod_{i-1}^{n_j} \left(1 - \delta_{ij} \right) \right] \qquad \text{Equation 2}$$

Equations 1 and 2 make two strong assumptions. First, they assume that the relative fuel consumption impact of a technology will not vary from vehicle to vehicle. Because impacts will vary depending on the initial design of each vehicle, some error will be introduced for each vehicle. In addition, it is assumed that, for a given implementation sequence, any interactions (synergies) among technologies have already been accounted for in the Δ or δ terms. Given information on technology synergies generated by FSS models, equations 1 or 2 could be modified to include synergistic effects as each technology is added. Summing relative fuel economy increases as in equation 1 produces a smaller estimate than sequentially multiplying one plus the relative fuel economy increases. Most fuel economy impact estimates have been determined with the expectation that they will be added to obtain the overall fuel economy benefit. Likewise, multiplying the terms in equation 2 will produce a smaller estimated change in fuel consumption than adding the δ_i, which could erroneously lead to negative fuel consumption. In either case, adding fuel economy impacts or multiplying fuel consumption impacts is intended to produce an approximation to the true impact in a way that reduces the chances of overestimating fuel consumption benefits.

Aggregation over Vehicles in a Class

The PDA method can be applied to an individual vehicle or to a representative vehicle (e.g., a midsize passenger car). For an individual vehicle, it is necessary to know the existing technology makeup of the vehicle so that incompatibilities are avoided and technologies are not applied twice. In the case of a representative vehicle, it is necessary to know the market shares of fuel economy technologies for vehicles in its class. In general, the exact distribution of all combinations of technologies within the vehicle class is not known. Instead, the total market shares of each technology are used, in effect assuming that their distributions are independent. This introduces a further element of approximation into the estimation.

Let $s_{ij,0}$ be the initial market share of technology i in the vehicle class j, and let $s_{ij,\max}$ be the maximum market share for technology i. The estimated change in fuel economy (MPG) by application of the full set of technologies is given by equation 3:

$$D_{j\max} = \sum_{i=1}^{n_j} \left(s_{ij,\max} - s_{ij,0} \right) \Delta_{ij} \qquad \text{Equation 3}$$

The estimated change in fuel consumption by application of the full set of technologies is given by equation 4:

$$d_{j\max} = GPM \left(\prod_{i=1}^{n_j} \left(1 - \left(s_{ij,\max} - s_{ij,0} \right) \delta_{ij} \right) \right) \qquad \text{Equation 4}$$

The cost of the above fuel economy increase is calculated similarly, where C_i is the cost of technology i in retail price equivalent:

$$C_{j\max} = \prod_{i=1}^{n_j} \left(s_{ij,\max} - s_{ij,0} \right) C_{ij} \qquad \text{Equation 5}$$

Although equation 3 approximates the share-weighted harmonic mean change in fuel economy for a class of vehicles with a mixture of technologies it does not precisely equal it. Even performing the calculations in terms of fuel consumption, as in equation 4, will not produce the exact harmonic mean fuel economy, in general.

MODELING USING FULL SYSTEM SIMULATION

The FSS approach to modeling vehicle fuel consumption involves capturing the physics or characteristics of subsystems of the vehicle in software, assembling these subsystems by passing relevant operational variables between these subsystems, and choosing preferred input variables and trajectories to simulate desired vehicle operation. The overall goal is to have the subsystem models work in a synergistic way to reflect the actual performance of the vehicle in various maneuvers. Because of the complexity and nonlinearity of these vehicle subsystems, it is often difficult to anticipate the synergistic effects, especially during transients, and this approach usually provides this useful information to some degree of accuracy. FSS modeling has been used by the automotive industry since the 1970s, and is a proven method of estimating the impacts of existing and new technologies on vehicle systems (Waters, 1972; Blumberg, 1976). More recently, regulatory agencies and other groups outside the automotive industry are undertaking efforts to develop and utilize FSS in their analysis (NESCCAF, 2004; Rousseau, 2007; EPA, 2008a).

Although modeling approaches differ, all FSS models are based on the time integration of Newton's second law (i.e., F = m·a) over some driving maneuver, in this case over the FTP and highway driving cycles. The boundary and initial conditions for this integration are based on a description of the vehicle (mass, frontal area, drag coefficient, etc.), the components that compose the driveline (engine and transmission, etc.), accessories (pumps, fans, generators, etc.), and a specification of the drive cycle, or vehicle speed trace, the vehicle is to perform. Components are represented by computer modules and may be described by performance maps represented by tables or equations. All energy flows among components are accounted for by equations linking the modules. FSS models may be backward-looking or forward-looking. Backward-looking models assume that the drive cycle's velocity and acceleration trajectory will be met, calculate the force required at the wheels, and then work backward to the resulting engine speed, and the necessary throttle and brake commands. Forward-looking models choose throttle and brake commands in order to achieve the specified trace. Some models use a combination of both strategies (see, e.g., Markel et al., 2002).

Modeling can have the potential benefit of helping one to understand these synergies and better predict future performance, either through the careful analysis of available vehicle data, or through creating dynamic models of the vehicles and analyzing the performance of these virtual vehicles. In addition to the synergies within various subsystems of the vehicle, many subsystems within the vehicle exhibit nonlinear behavior. Considering the performance of individual subsystems independently, even if this performance is well known and understood, can therefore result in misleading conclusions for the overall system. When an understanding of each subsystem can be represented by a computer model to an appropriate level of detail, and the interconnectivity or physical communication between each of these subsystems can also be adequately represented, the synergistic and nonlinear effects can be included and analyzed in the behavior of the entire system. Computer modeling of vehicle systems is widely used in the industry for this purpose, as well as to help predict future performance or performance under various conditions. Manufacturers use FSS in the product development process to optimize factors such as shift logic and final drive ratio.

For new technologies not implemented in any mass-produced vehicle, FSS model results are probably the most reliable source of estimates of synergistic effects. Historically, the PDA approach has generally not been used for estimating the fuel consumption impacts of novel vehicle systems for which there are no actual test data (Greene and DeCicco, 2000). Today FSS modeling is more widely used to estimate the potential for reducing fuel consumption than even 5 years ago. A number of studies are available that have used FSS to estimate the fuel consumption impacts of advanced technologies (e.g., Ricardo, Inc., 2008a,b, 2009; Kasseris and Heywood, 2007; Kromer and Heywood, 2007; Sierra Research, 2008). It should be noted, however, that sufficient knowledge of the technology package being investigated is necessary to allow its representation within the model to have an acceptable degree of accuracy. For an aggregate technology, this may take the form of a performance map describing its efficiency over a range of operating conditions. For a technology described by unique operation of an existing subcomponent, relevant performance insight in the corresponding new regime of operation would be necessary.

It is important to note that, although FSS models have the ability to estimate the absolute impacts of vehicle technologies due to their ability to model the physics of system components, they have limited ability to model the dynamic working of individual fuel efficiency technologies and generally rely on a limited set of input data. For novel technologies, many of the input parameters are assumptions based on engineering judgment and experience with related technologies. This emphasizes the fact stated at the outset of this chapter, that one cannot know with absolutely accuracy the impact of technologies until an actual vehicle is constructed and repeatedly tested.

Model Fidelity

An important consideration for FSS modeling is deciding what level of fidelity of the equations or look-up tables is required for the problem being addressed. No set of equations completely reflects the detailed physics of the actual process, so the choice of fidelity should be a conscious choice from a continuum of models of varying fidelity, all of which represent simplifications of the actual process. The objective is to achieve an appropriate balance of fidelity with modeling goals, modeling effort and resources, simulation speed, and available data that specifically characterizes the system being modeled. There is always a difference between the simulation and actual subsystem operation, known as the modeling error. The tolerable level of error depends upon the goals of the simulation.

Unfortunately, data on the predictive accuracy of FSS models are scarce. In part this is because some models and more often the representation of their components are proprietary to firms that use them in their own research or consulting. The committee is not aware of any rigorous study evaluating the accuracy of models for various applications. The few comparisons the committee has seen indicate that for known vehicles, simulation models can reproduce fuel consumption and performance with a high degree of accuracy. Data provided by Ricardo, Inc., based on its research for the EPA indicated a range of error in predicting fuel consumption of 1 to 3 percent for five vehicles (Figure 8.4). For this modeling, the EPA chose a specific representative vehicle for each of the five classes: the Toyota Camry for the standard car, the Saturn Vue for the small MPV, the Chrysler 300 for the full-size car, the Dodge Grand Caravan for the large MPV, and the Ford F150 for the truck. Ricardo, Inc., (2008a) attributed any discrepancies between the simulation results and the actual vehicle data to the use of generic input data for that vehicle class instead of actual data for a specific vehicle. Of course, these are known vehicles so that component representations and the overall model can be calibrated. Prediction errors for truly novel technologies for which no vehicle exists to calibrate to would presumably be larger. In any event, it is the change in fuel consumption from the implementation of a technology that is of most interest. The absolute error of a predicted change can be smaller when prediction errors similarly exist in both the "before" and "after" simulations (i.e., the modeling errors of the before and after cases are strongly correlated). Still, relative errors for a predicted change are likely to be greater. The accuracy of FSS models in predicting fuel consumption changes in actual vehicles deserves additional study. Note that such an accuracy study is made more difficult by the fact that the

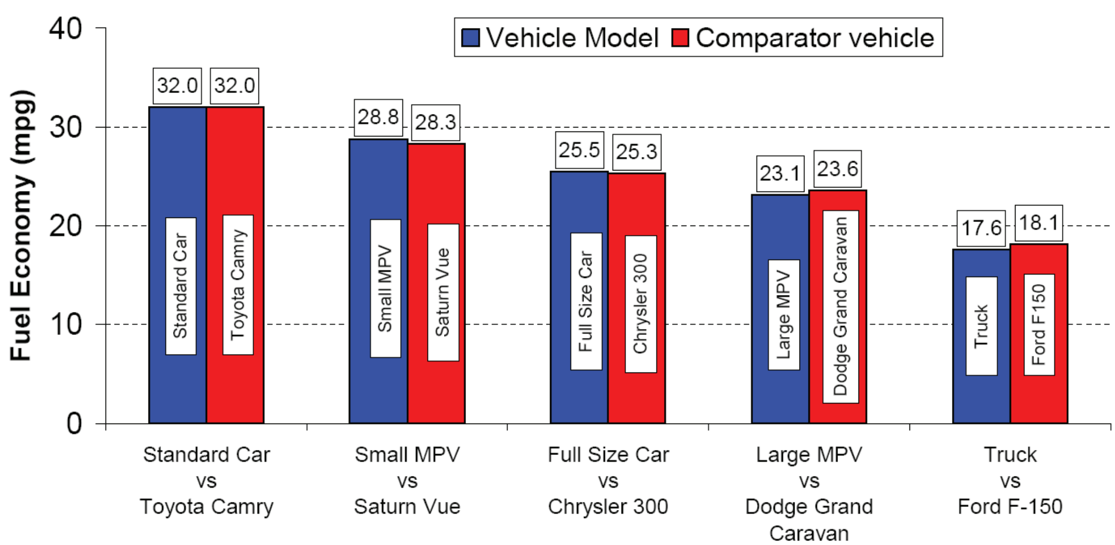

FIGURE 8.4 Comparison of actual vehicle combined fuel economies and Ricardo simulated fuel economies for five vehicles. SOURCE: Ricardo, Inc. (2008a).

accuracy of FSS estimations depends significantly on the experience and skill of the FSS practitioner.

The flexibility, rigor, and comprehensiveness of the FSS approach to vehicle modeling are significant advantages. Subsystem models may be as simple as a single parameter or table based on steady-state operation, or a detailed, nonlinear, multivariable representation of the dynamics of the subsystem, including transient operation. The choice of how to represent each subsystem model is not only based on modeling error considerations discussed above, but also on balancing fidelity between subsystem models, in order to use computational resources as effectively as possible. One way of looking at balancing fidelity between subsystems is to consider the filtering properties or bandwidth of these subsystems. If one subsystem model has a level of fidelity that generates details in an output variable that are filtered out by a subsequent system, then the effort in generating those details is mostly wasted if the intermediate variables between the subsystems are not of interest. This balance of fidelity within an overall FSS model is a judgment call that is typically developed through experience or trial and error, although the effects can be clearly seen by looking carefully at the content of the variables that are passed between subsystems to see what effects are preserved or eliminated.

An example of these considerations can be seen by examining a typical system model of a turbocharger. In many dynamic system models, the characteristics of both the turbocharger compressor and turbine are simulated based on steady-state maps. However, the rotational dynamics of the rotor is simulated based on Newton's second law (i.e., a differential equation reflecting dynamic or transient operation). The rationale for choosing and combining these two different types of models is based on the idea that the time constants for the gas dynamics in the compressor and turbine are considerably shorter (i.e., faster) than the time constant of the rotor. If much more detailed dynamic models of the gas dynamics were included in the model when the rotational speed of the rotor is the desired output variable, almost all of the gas dynamic effects would be filtered out by the rotor inertia or rotational bandwidth. This combination of steady-state and dynamic models to represent the turbocharger usually provides an effective dynamic model of its rotational dynamics and transient operation in relation to the rest of the engine. However, if the goal is to capture the pulsed gas dynamics in the turbine or compressor, this choice of subsystem models may not be appropriate (for that specific goal). The important point is that more detail is not necessarily better, but fidelity and balance should be conscious decisions reflecting modeling goals.

Model Validation

An effective way of carrying out model validation, given available data on the system operation, is to subdivide the data into at least two sets covering different operating conditions. One set of data can be used to determine parameters or tune the subsystem models, and a separate and distinct set of data can be used to test the predictive capabilities of the model in different situations after it has been tuned or calibrated. The model should not be tested using the same set of data that was used to calibrate the model.

FSS Model Example

An example of an FSS compression-engine model is illustrated in Figure 8.5 in order to give the reader a better visual idea of a possible subdivision of subsystems within the overall system model, as well as possible choices of fidelity within each subsystem. The overall goal of this model is to represent engine transient performance within the vehicle power train, including cylinder-by-cylinder rotational dynamic effects as well as first order intake and exhaust dynamics that affect turbocharger transient effects on the engine. Some simple emission transient predictive capability is included but is not comprehensive for all constituents.

This model was developed using the MATLAB/Simulink modeling software, and its overall structure is presented by the block diagram structure of MATLAB/Simulink in hierarchical form. Most of the subsystem models are identified for the reader. The core of the model is the engine map that provides brake-specific fuel consumption as a function of engine speed and load. Numerous other modules are necessary to represent the many interacting components of the engine system. Most of these components must be calibrated to the specific engine system of interest.

AN ANALYSIS OF SYNERGISTIC EFFECTS AMONG TECHNOLOGIES USING FULL SYSTEM SIMULATION

At the request of the committee, Ricardo, Inc. (2009) undertook a study to quantify the synergistic effects captured by FSS models. It is important to note that the study is based solely on the predictions of Ricardo, Inc.'s FSS models and therefore can quantify only the synergies those models can represent. In its report, Ricardo estimated the accuracy of its models for predicting fuel economy at 1 percent for well-characterized vehicle systems (systems for which nearly all model subsystems have been calibrated to the actual components) and 3 percent for novel vehicle systems. However, each estimate of accuracy was based on a single data point and so cannot be considered definitive.

Ricardo's approach was to simulate the technologies contained in five different packages of technologies it had previously modeled for the EPA (2008a) as applied to five different types of vehicles. The technologies were applied one at a time and in combinations according to a rigorously defined design of experiments. The results were then fitted by a response surface model using a neural network method. The response surface model fit the data with maximum errors of 1 percent using terms no higher than second order (Figure 8.6).

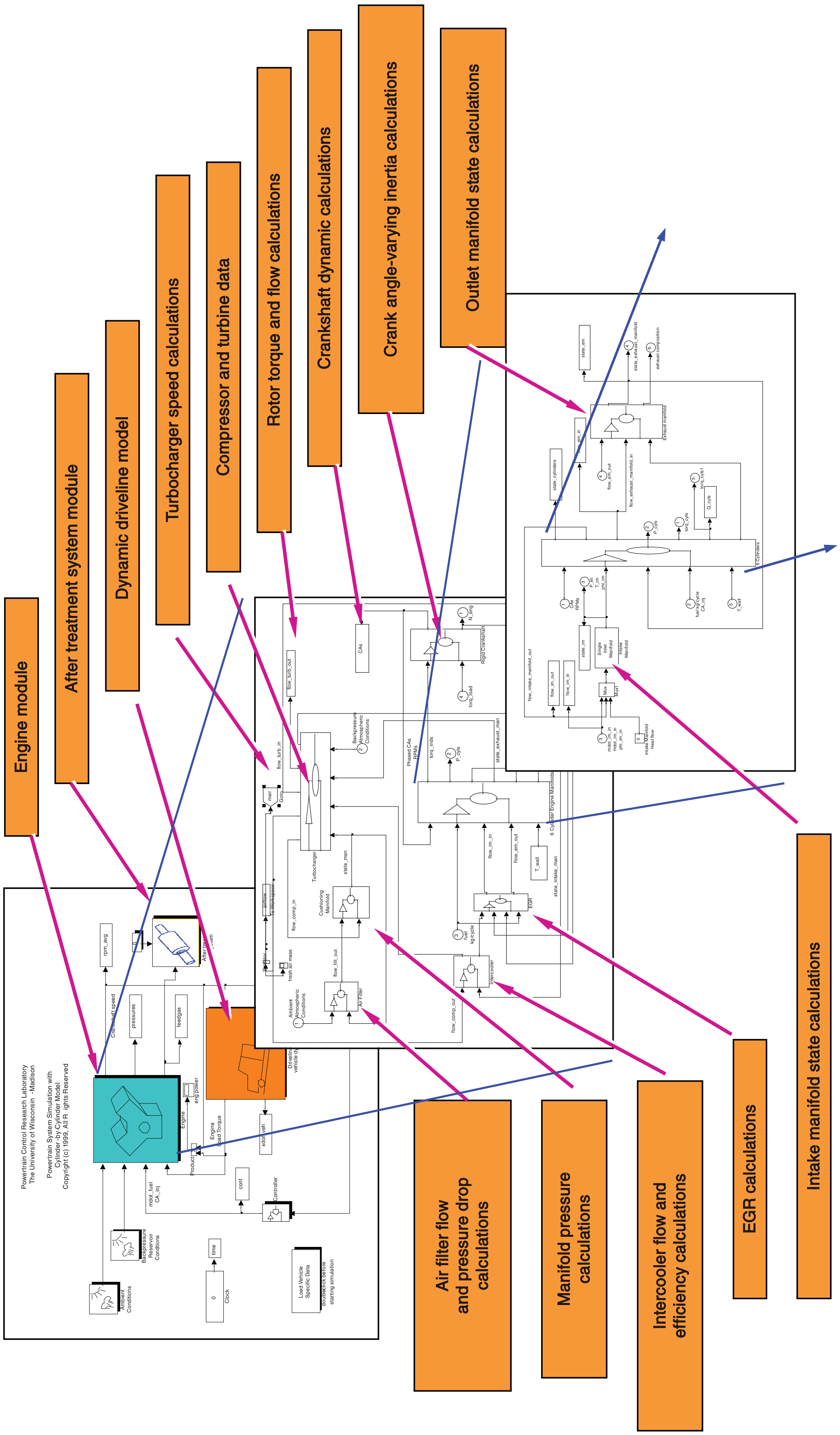

FIGURE 8.5 An example structure for a full system simulation diesel engine dynamic model. SOURCE: Reprinted with permission from John J. Moskwa, Powertrain Control Research Laboratory, University of Wisconsin, Madison, Wisc.

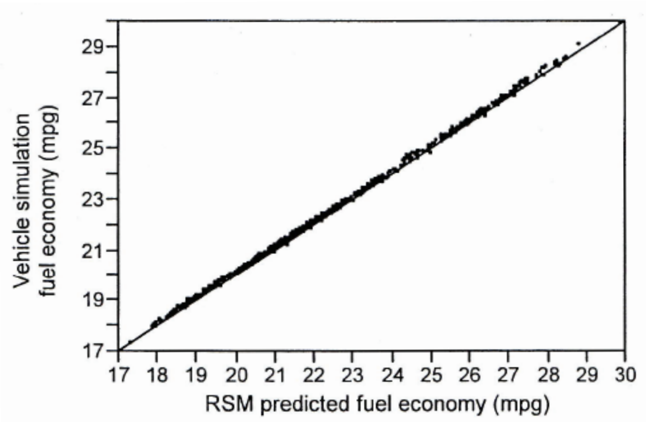

FIGURE 8.6 Ricardo, Inc., statistical (response surface model [RSM]) predictions versus full system simulation model predictions. SOURCE: Ricardo, Inc. (2009), Figure 3-2.

> This shows that a relatively simple 2nd order regression model provides a very suitable representation of the more complex vehicle simulation output with maximum RSM (Response Surface Model, ed.) residual errors of about 1 percent, or that higher order effects (3rd order and above) account for less than 1 percent of the vehicle simulation output characteristics. (Ricardo, Inc., 2009, p. 13)

This finding is significant in that it indicates that important synergistic effects (as represented by the FSS models) are of no higher order than two-way interactions. It is also generally consistent with the ability of a much simpler lumped parameter model to accurately estimate fuel economy over the federal test cycles with Sovran and Blaser (2006).

The next step was to carry out an analysis of variance (ANOVA) to quantify the first-order (main) and second-order effects. The ANOVA estimated that main effects of technologies accounted for 80 to 86 percent of the fuel economy increase. Interaction effects, taken together, accounted for 14 to 20 percent. Ricardo, Inc., concluded that simplified models that did not properly account for interaction effects could have estimation errors of up to 20 percent. However, 20 percent not only is the upper bound on estimation error but also assumes that the error in estimating interaction effects is 100 percent (for example, if they were all estimated to be 0). Interaction effects estimated using lumped parameter models, for example, are likely to be much smaller.

Even more importantly, the interaction effects include second-order main effects and incremental effects. Second-order main effects represent the interaction of a technology with itself and are introduced to account for nonlinear effects in the linear ANOVA model. Thus, they do not depend on the presence or absence of other technologies and so are not synergies in the sense that is of interest. Incremental effects include some true synergistic effects and some purely incremental effects. Purely incremental effects reflect the fact that when technologies are applied in sequence the fuel consumption impact of a technology depends on which technologies have been previously applied. For example, given a base vehicle with a 4-speed transmission, the impact of a 6-speed transmission will be smaller if a 5-speed transmission has been previously applied. The PDA method explicitly recognizes this kind of interaction by ordering technologies for interaction and using only incremental impacts, given that ordering, to estimate the total fuel consumption impact. But incremental effects, as defined in the Ricardo ANOVA, also include true synergistic effects, such as when a 42-volt electrical system is implemented together with electric accessories (e.g., electric power steering). Most PDA modelers attempt to take such interactions into account, but the accuracy with which they do so will depend on the available data sources and the engineering judgment of the analyst.

There are additional synergies of interest that Ricardo terms "inter-tree" or "true" synergies. These are the interactions among technologies that are neither second-order main effects nor incremental effects. PDA modeling cannot, in general, account for this type of synergy. According to the results of Ricardo's study, these effects are quite small. For example, adding up the synergy (inter-tree) effects for Small MPV Package 5 (allowing positive and negative effects to cancel) results in a total synergy effect of −1.3 percent of the total fuel economy impact of the technology package. Adding up the inter-tree synergies produces a positive synergy of 4.6 percent for Small MPV Package 15, a positive synergy of 2.8 percent for Large MPV Package 16, and a positive synergy of 10.3 percent of the total fuel economy impact for Truck Package 11. These are percentages of the total fuel economy change and so suggest that errors due to completely ignoring inter-tree synergies are on the order of 10 percent or less for the total fuel economy impact. The size of these effects is roughly consistent with the discrepancies EPA (2008b) found in its comparison of lumped parameter and FSS modeling.

Ricardo, Inc. (2009) concluded that PDA modeling, such as that used in the NHTSA's Volpe model, if informed by rigorously designed FSS modeling of the kind represented in its study, can produce accurate estimates of fuel consumption reduction potential. This conclusion, however, is conditional on the accuracy of FSS models for predicting EPA test cycle fuel economy. Given the scarcity of evidence on this subject and its importance to validating Ricardo's conclusion, it merits further investigation.

FINDINGS

Finding 8.1: The state of the art in estimating the impacts of fuel economy technologies on vehicle fuel consumption is full system simulation (FSS) because it is based on integration of the equations of motion for the vehicle carried out over the speed-time representation of the appropriate driving or test cycle. Done well, FSS can provide an accurate assessment (within +/–5 percent or less) of the impacts on fuel consumption of implementing one or more technologies. The validity of FSS modeling depends on the accuracy of representations of system components (e.g., engine maps). Expert judgment is also required at many points (e.g., determining engine warm-up rates or engine control strategies) and is critical to obtaining accurate results.

Finding 8.2: The partial discrete approximation (PDA) method relies on other sources of data for estimates of the impacts of fuel economy technologies. Unlike FSS, the PDA method cannot be used to generate estimates of the impacts of individual technologies on vehicle fuel consumption. Thus, the PDA method by itself, unlike FSS, is not suitable for estimating the impacts on fuel consumption of technologies that have not already been tested in actual vehicles or whose fuel consumption benefits have not been estimated by means of FSS. Likewise, the effects of technology interactions must be determined from external estimates or approximated by a method such as lumped parameter modeling. Even FSS, however, depends directly on externally generated information on the performance of individual technology components.

Finding 8.3: Comparisons of FSS modeling and PDA estimation (within the range of cases where the PDA method is applicable) supported by lumped parameter modeling to eliminate double counting of energy efficiency improvements have shown that the two methods produce similar results when similar assumptions are used. In some instances, comparing the estimates made by the two methods has enhanced the overall validity of estimated fuel consumption impacts by uncovering inadvertent errors in one or the other method. In the committee's judgment both methods are valuable, especially when used together, one providing a check on the other. However, more work needs to be done to establish the accuracy of both methods relative to actual motor vehicles. In particular, the accuracy of applying class-specific estimates of fuel consumption impacts to individual vehicle configurations needs to be investigated. The magnitude of the errors produced when such estimates are aggregated to calculate the potential of individual automobile manufacturers to reduce fuel consumption should also be analyzed.

Finding 8.4: The U.S. Department of Transportation's Volpe National Transportation Systems Center has developed a model for the NHTSA to estimate how manufacturers can comply with fuel economy regulations by applying additional fuel savings technologies to the vehicles they plan to produce. The model employs a PDA algorithm that includes estimates of the effects of technology synergies. The validity of the Volpe model, and probably also the OMEGA model, could be improved by making use of main effects and interaction effects produced by the FSS methodology described in this chapter. In particular, research done for the committee has demonstrated a practical method for using data generated by FSS models to accurately assess the fuel consumption potentials of combinations of dozens of technologies on thousands of vehicle configurations. A design-of-experiments statistical analysis of FSS model runs demonstrated that main effects and first-order interaction effects alone could predict FSS model outputs with an R^2 of better than 0.99. Using such an approach could appropriately combine the strengths of both the FSS and the PDA modeling methods. However, in Chapter 9 the committee recommends an alternate approach that would use FSS to better assess the contributory effects of technologies applied for the reduction of vehicle energy losses and to better couple the modeling of fuel economy technologies to the testing of such technologies on production vehicles.

REFERENCES

Blumberg, P.N. 1976. Powertrain simulation: A tool for the design and evaluation of engine control strategies in vehicles, SAE Technical Paper Series 760158. SAE International, Warrendale, Pa. February 23.

DOE/EIA (U.S. Department of Energy/Energy Information Administration). 2007. Transportation sector module of the National Energy Modeling System: Model documentation 2007, DOE/EIA-M070(2007). Office of Integrated Analysis and Forecasting, Washington, D.C.

DOT (U.S. Department of Transportation). 2005. CAFE compliance and effects modeling system. Volpe Systems Center, Cambridge, Mass., July 19.

DOT/NHTSA (U.S. Department of Transportation/National Highway Traffic Safety Administration). 2009. Average fuel economy standards, passenger cars and light trucks, model year 2011: Final rule, RIN 2127 AK-29, Docket No. NHTSA 2009-0062, Washington, D.C., March 23.

Duleep, K.G. 2008. EEA-ICF analysis update, Presentation to the Committee on Technologies for Improving Light-Duty Vehicle Fuel Economy, April 1, Washington, D.C.

EEA (Energy and Environmental Analysis, Inc.). 2007. Technologies to improve light-duty vehicle fuel economy, Draft report to the National Research Council Committee on Fuel Economy of Light-Duty Vehicles, Arlington, Va., September.

EPA (U.S. Environmental Protection Agency). 2008a. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008, Ann Arbor, Mich.

EPA. 2008b. EPA's technical review of Ricardo simulations, Presentation to the Committee on Technologies for Improving Light-Duty Vehicle Fuel Economy, March 31, 2008, Detroit, Mich.

EPA and DOT (U.S. Environmental Protection Agency and U.S. Department of Transportation). 2009. Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. August 24. Washington, D.C.

EPA and NHTSA (U.S. Environmental Protection Agency and National Highway Traffic Safety Administration). 2009. Draft Joint Technical Support Document: Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, EPA-420-D-09-901, September.

Greene, D.L., and J. DeCicco. 2000. Engineering-economic analysis of automotive fuel economy potential in the United States. Annual Review of Energy and the Environment 25:477-536.

Hancock, D. 2007. Assessing fuel economy. Presentation to the Committee on Fuel Economy of Light-Duty Vehicles, National Research Council, September 10, Washington, D.C.

Kasseris, E.P., and J.B. Heywood. 2007. Comparative analysis of automotive powertrain choices for the next 25 years. SAE Technical Paper Series No. 2007-01-1605. SAE International, Warrendale, Pa.

Kromer, M.A., and J.B. Heywood. 2007. Electric powertrains: opportunities and challenges in the U.S. light-duty vehicle fleet. Publication No. LFEE 2007-02 RP. Sloan Automotive Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

Markel, T., A. Brooker, T. Hendricks, V. Johnson, K. Kelly, B. Kramer, M. O'Keefe, S. Sprik, and K. Wipke. 2002. ADVISOR: A systems analysis tool for advanced vehicle modeling. Journal of Power Sources 110(2):255-266.

Moskwa, J. 2008. Powertrain Control Research Laboratory, University of Wisconsin, Madison, Wisc.

NESCCAF (Northeast States Center for a Clean Air Future). 2004. Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles. March.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy Standards. National Academy Press, Washington, D.C.

Patton, K.J., A.M. Sullivan, R.B. Rask, and M.A. Theobald. 2002. Aggregating technologies for reduced fuel consumption: A review of the technical content in the 2002 National Research Council Report on CAFE. SAE Paper 2002-01-0628. SAE International, Warrendale, Pa.

Ricardo, Inc. 2008a. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for the U.S. Environmental Protection Agency, EPA420-R-08-004, Contract No. EP-C-06-003, Work Assignment No. 1-14, Ann Arbor, Mich.

Ricardo, Inc. 2008b. A study of potential effectiveness of carbon dioxide reducing vehicle technologies. Presentation to the Committee on Fuel Economy of Light-Duty Vehicles, National Research Council, January 24.

Ricardo, Inc. 2009. A Study of Interaction Effects Between Light Duty Vehicle Technologies. Prepared for the NRC Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy by Ricardo Inc., Van Buren, Mich., February 27.

Rousseau, A. 2007. Designing advanced vehicle powertrains using PSAT. Presentation to the Committee on Fuel Economy of Light-Duty Vehicles, National Research Council, September 10.

Sierra Research, Inc. 2008. Technology and retail price implications of HR6 CAFE standards based on vehicle simulation modeling (preliminary results). Presentation to the committee by James M. Lyons, January 24.

Sovran, G., and D. Blaser. 2003. A contribution to understanding automotive fuel economy and its limits. SAE Paper 2003-01-2070. SAE International, Warrendale, Pa.

Sovran, G., and D. Blaser. 2006. Quantifying the potential impacts of regenerative braking on a vehicle's tractive-fuel consumption for the U.S., European, and Japanese driving schedules. SAE Paper 2006-01-0664. SAE International, Warrendale, Pa.

Sovran, G., and M.S. Bohn. 1981. Formulae for the tractive-energy requirements of vehicles driving the EPA schedules. SAE Paper 810184. SAE International, Warrendale, Pa.

Van Schalkwyk, J., W. Gazda, K. Green, D. Pickrell, and M. Shaulov. 2009. Corporate average fuel economy compliance and effects modeling system documentation. DOT HS 811 012. U.S. Department of Transportation, Research and Innovative Technology Administration, Energy Technology Division, John A. Volpe National Transportation Systems Center, Cambridge, Mass., April.

Waters, W.C. 1972. General purpose automotive vehicle performance and economy simulator. SAE Paper 720043. January 10. SAE International, Warrendale, Pa.

9

Application of Vehicle Technologies to Vehicle Classes

INTRODUCTION

In conducting its assessment of technology applicability to different vehicle classes, the committee was guided by the following question included in the statement of task: "What are the estimated cost and potential fuel economy benefits of technology that could be applied to improve fuel economy of future passenger vehicles, given the constraints imposed by vehicle performance, functionality, and safety and emission regulations?" Note that applying technology to improve fuel economy and reduce fuel consumption should not be interpreted to mean simply attaching a component or subsystem that then achieves a subsequent reduction in fuel consumption. Such reductions in fuel consumption typically evolve through an incremental, evolutionary application of components, subsystems, and new power train or vehicle technologies.

Previous chapters of this report have provided technical summaries of current and advanced technologies that are currently being applied to vehicles, or developed for future vehicle applications. Other reports from the National Research Council (NRC) have also looked at the impacts of technologies for reducing fuel consumption—Appendix H provides a summary of other recent NRC studies related to light-duty vehicle technologies. Many of these technologies could, in principle, be applied to almost any vehicle. However, the intended use of the vehicle, its price range, consumer characteristics, emissions and safety standards compliance, and packaging constraints influence which technologies will see market penetration on different vehicle types.

Many of the technologies have already seen significant penetration into European or Asian markets where regulatory and market pressure, including significant taxation that results in high fuel prices for consumers, have encouraged early adoption. Others, such as turbocharged, direct-injection gasoline engines, have gained significant attention in the United States because fuel consumption can be reduced with minimal redesign of the total vehicle system.

DEVELOPING BASELINE VEHICLE CLASSES

The concept of dividing U.S. passenger vehicles into so-called classes is both an outcome of regulatory segmentation for the purpose of varying standards and a means whereby vehicle sales categories are differentiated by vehicle size, geometry, and intended use. The NRC CAFE report segmented U.S. passenger vehicle sales into 10 classes that were a subset of the larger number of type and weight classes that the U.S. EPA uses as part of its vehicle certification process (NRC, 2002). These 10 classes are as follows:

1. Small SUV,
2. Medium SUV,
3. Large SUV,
4. Minivans,
5. Small pickups,
6. Large pickups,
7. Subcompact cars,
8. Compact cars,
9. Midsize cars, and
10. Large cars.

The statement of task directs the current committee to evaluate these vehicle classes and update the technology outlook for future model introduction. However, shifts in consumer preference and vehicle sales have been significantly influenced by the recent instability in fuel prices, vehicle financing costs, U.S. and global economic conditions, and regulatory uncertainty. Significant shifts in vehicle sales between 2002 and 2007 showed a continuing increase in SUV sales, with sales of small pickups essentially disappearing (EPA, 2008a). However, in 2008, large increases in fuel price (above $4 per gallon of gasoline) resulted in a greater than 50 percent reduction in the sale of midsize and large SUVs. Subsequent U.S. and global instability in the financial markets, followed by a period of recession, has resulted in an overall reduction of vehicle sales in the United States of more than 20 percent from 2008 to 2009.

Therefore, the choice of vehicle classes for future consideration as part of this assessment of potential fuel economy technologies should focus on vehicle size, weight, interior passenger volume, intended use, and the potential for implementation of next-generation power trains, including hybrid electrics. Based on various factors outlined below, the following classification of light-duty vehicles in the United States was determined by the committee to be an appropriate basis for future technology development and introduction into production.

1. *Two-seater convertibles and coupes*—Small vehicles by interior volume whose function is high-performance and handling. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 6-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
2. *Small cars*—Mini-, sub-, and compact cars, standard performance, mostly four-cylinder, mostly front-wheel drive (FWD), including small station wagons. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a four-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 6-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
3. *Intermediate and large cars*—Standard performance, mostly FWD, mostly six-cylinder, including large station wagons with less than 0.07 hp/lb of vehicle weight. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 4-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
4. *High-performance sedans*—Passenger cars with greater than or equal to 0.07 hp/lb of vehicle weight that are not two-seaters. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 6-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
5. *Unit-body standard trucks*—Non-pickup trucks with unibody construction and hp/lb of vehicle weight ratios of under 0.055 including crossover vehicles, SUVs, and minivans. Most vehicles employ front-wheel drive. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 6-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
6. *Unit-body high-performance trucks*—Crossover vehicles, SUVs, and minivans with hp/lb of vehicle weight ratios of 0.055 or greater. Most have rear-wheel drive (RWD) or all-wheel drive (AWD) and unibody construction, and most are luxury vehicles. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, four-valve, dual overhead cam engine with intake cam phasing and a 6-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
7. *Body-on-frame small and midsize trucks*—Pickups less than or equal to 1,500 lb payload capacity (CEC class 14) and SUVs of up to 175 cubic feet of passenger volume plus cargo volume with RWD or AWD. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: a six-cylinder, two-valve, single overhead cam engine with a 5-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.
8. *Body-on-frame large trucks*—Pickups of greater than 1,500 lb payload but less than 10,000 lb GVW, and SUVs with 175 cubic feet or greater of passenger plus cargo volume with RWD or AWD, including all standard vans, cargo and passenger. The average 2007 model-year vehicle for this class was developed from EPA (2008a) and has the following characteristics: an eight-cylinder, two-valve, overhead valve engine with a 4-speed automatic transmission. The average vehicle for this class is used as the base vehicle in the estimation of fuel consumption reductions for multiple technologies as discussed later in this chapter.

These eight classes allow an evaluation of similar base vehicles designs, where the vehicle size, baseline chassis configuration, aerodynamic characteristics, vehicle weight and type of drive train (FWD, RWD, and AWD) are similar. This grouping should result in vehicle classes where similar calibration criteria are associated with similar vehicle performance characteristics. A greater number of classes would also be possible if there was a desire to narrow the variability in vehicle characteristics in each class.

ESTIMATION OF FUEL CONSUMPTION BENEFITS

Incremental reductions in fuel consumption through the application of technologies were estimated by the committee. As discussed earlier in this report, input came from many sources including component suppliers, vehicle manufacturers, and the review of many published analyses conducted by, or for, the U.S. Department of Transportation National Highway Traffic Safety Administration (NHTSA), U.S. Environmental Protection Agency (EPA), California Air Resources Board (CARB), and other agencies or trade associations. The committee also contracted with several consultants to provide input.

Relative reductions in fuel consumption can result from several factors, many of which are interrelated:

- Reduction in the tractive force needed to propel the vehicle (reduced rolling resistance, aerodynamic drag, vehicle weight, etc.);
- Improvement in the energy conversion efficiency of the fuel in the engine into maximum usable energy through increased thermal efficiency (compression ratio increase for gasoline engines, lean combustion, diesel, etc.);
- Reductions in the engine and power train energy losses that consume portions of the available energy before and after combustion (gas exchange losses, power train friction, accessory losses, etc.);
- Optimization of operational parameters that allow the engine to run in regions of highest efficiency (increased number of transmission gears, CVTs, improved lugging characteristics, aggressive shift logic, etc.); and
- Some form of hybridization that allows other forms of energy capture, storage, and management to reduce the total energy consumed over the driving cycle.

The committee thinks that the most accurate method of analyzing potential reductions in fuel consumption, which considers the extent to which any of the efficiency improvements or energy loss reductions identified above can be realized while maintaining energy balance criteria, utilizes full system simulation (FSS). This analysis technique, as described in Chapter 8, represents the state of the art in predicting vehicle performance, fuel consumption, direct CO_2 emissions, and other regulated and non-regulated emissions. However, FSS analyses require detailed vehicle, engine, transmission, accessory, and other subsystem data, typically expressed in the form of data maps that quantify power, torque, fuel consumption, and exhaust emissions over the complete range of operation. Historically, such data (which may not yet exist for the most advanced technologies) have been considered proprietary by automobile manufacturers (referred to as original equipment manufacturers; OEMs) and suppliers, such that only those companies associated with the design, development, and production of such systems have had the data to conduct such analyses. However, partnerships currently exist between the automotive industry and the U.S. government such that more complete experimental data will be made available in the future.

Another factor in successfully modeling full vehicle systems is the need to understand and capture the tradeoffs that OEMs must make in developing final production calibrations of vehicles and their power trains. Calibration is the process of power train and vehicle performance optimization that focuses on achieving predetermined performance, drivability, fuel consumption, durability, fuel octane sensitivity, and many other parameters while still complying with statutory requirements such as those for levels of emissions, onboard diagnostics (OBD), and safety standards. In particular, many potential technologies that can be applied for improving fuel consumption could influence performance parameters such as 0-60 mph acceleration times, vehicle passing capability, towing capability, transmission shift quality, or noise and vibration characteristics. Different manufacturers must thus determine their customer-preferred compromises and calibrate the vehicle control algorithms accordingly. Based on the number of potential parameters that may be varied in modern passenger car engines, tens of thousands of combinations are possible. Therefore, manufacturers and calibration service companies have developed optimization strategies and algorithms to fine-tune these variables while achieving an OEM's criteria for performance and drivability within the constraints of emissions, fuel economy, and other standards. Calibration logic is normally a highly confidential process that requires the experience of companies involved in the production release of vehicles (OEMs, Tier 1 suppliers, production engineering services companies, etc.) to accurately assess the necessary performance, fuel consumption and exhaust emission, and drivability tradeoffs for accurate modeling.

Partial discrete approximation (PDA) and lumped parameter modeling techniques, as described in Chapter 8, examine and estimate incremental reduction in fuel consumption associated with applications of discrete technologies or subsystems and their effect on reducing energy losses. They represent a more time- and cost-effective method of estimating potential reductions in fuel consumption and may incorporate routines that attempt to tabulate or account for aggregation of energy-loss reductions that focus on fluid mechanical losses, frictional losses, and heat transfer losses. However, the ultimate accuracy of such analyses relies on a sufficiently broad set of empirical or system-simulation data that do not necessarily provide enough detail to understand the base test vehicle distribution of energy losses. Calibration of such models against actual test vehicles provides a benchmark of the modeler's attempt to match performance data, but does not provide the same level of explanation of the subsystem contribution to total vehicle energy losses that is accomplished in the FSS cases. Furthermore, the influences of variations in calibration strategies owing to such factors as driver comfort; noise, vibration, and harshness (NVH)-related issues; and performance/emissions tradeoffs are typically not considered in such analyses.

With either modeling approach, it is imperative to understand the role that any previously applied technologies play in reducing energy losses and/or improving the thermodynamic efficiency of the power train.

APPLICABILITY OF TECHNOLOGIES TO VEHICLE CLASSES

Not all of the technologies identified in Chapters 4 through 7 of this report can be justifiably applied to all vehicle types. Applicability of the technologies to the various vehicle classes requires an analysis of parametric tradeoffs which considers functionality, intended use, impact on warranty, ease of implementation, product cycle timing, market demand, cost-effectiveness, and many other factors. Some technologies may be discounted for technical reasons, for example, the limitations of continuously variable transmissions (CVTs) in transmitting high torque on vehicle classes with larger engines where towing or off-road capability is a primary product feature. Others may be excluded based on the intended purpose of the vehicle. For example, low-rolling-resistance tires appear to be a cost-effective means of reducing fuel consumption, potentially justifying their use on all vehicles. However, in higher performance classes of vehicles, where tire grip is an important product feature or for SUV applications where the vehicle may travel off-road, the use of such tires is likely restricted.

Table 9.1 shows the committee's estimation of incremental reductions in fuel consumption that may be expected from the application of different technologies and ranges associated with the reductions. In general, the committee estimated what it considered to be the average fuel consumption reduction for a technology before it attempted to estimate the range. These data, shown in the form of ranges, are in some cases dependent upon the level of technology applied to a vehicle before the next increment is taken. As identified above, these data represent estimates by the committee developed from evaluating published data, and analyses conducted by the NHTSA, the EPA, and others. Appendix I contains results from some of these other studies, although the reader should refer to the original source for the assumptions and study approaches used in these other studies. The expert judgment of members of the committee whose careers have focused on vehicle and power train design and development were also incorporated in the estimates. Examination of the data in Table 9.1 suggests that significant variations in estimates of the potential for reducing fuel consumption are due to the lack of detailed simulation data on actual or theoretically modeled vehicles or power trains against which to refine the estimates. This variability in estimates for fuel consumption reductions also reflects the fact that different OEMs may obtain different benefits from the same technology due to differences in implementation and calibration. Also, positive benefits may vary depending on the particular engine/transmission/vehicle architecture. These factors have been considered by the committee in its range of estimates or its decision to include or exclude the potential application of technologies into different technology paths. Note that the ranges associated with these technologies do not reflect the possibility that, over time, the average fuel consumption benefit could tend toward the high end of the range as the lessons learned from the best examples of the technology spread across the industry and as the impacts of higher CAFE standards increase. Although the committee recognizes that the implementation of these technologies with fuel consumption benefits at the higher end of the ranges could occur, it is difficult to assert that this will occur or to what degree this would impact the average consumption benefit over time.

The issue of how multiple technologies might interact when used to reduce fuel consumption is critical. FSS analyses conducted by Ricardo, Inc., for the EPA and for the committee shed some light on the issue of synergistic interaction of multiple technologies that may attempt to reduce energy losses of a similar type, such as pumping losses (Ricardo, Inc., 2008, 2009). These analyses show the need to carefully understand the contribution of technologies in reducing losses whose impact may be only a 1 to 2 percent reduction in fuel consumption. The Ricardo, Inc., analyses also show that the type of vehicle and power train influences the extent to which different technologies reduce fuel consumption, especially between vehicles of different classes with different intended uses. This effect is discussed in Chapter 8, where the primary effect of synergies was shown to dominate the potential for improvement. Accordingly, secondary effects of influences that interact across technology improvement paths were found to be minor.

ESTIMATING INCREMENTAL COSTS ASSOCIATED WITH TECHNOLOGY EVOLUTION

Chapter 3 describes the methodologies used for the estimation of incremental costs associated with the introduction of advanced technology for reducing fuel consumption. A range of estimated costs was also prepared and is outlined in the technology sections presented in Chapters 4 through 7. Table 9.2 shows the collection of these cost estimates for all technologies included in this report. The cost estimates represent estimates for the current (2009/2010) time period to about 5 years in the future. As with the data on fuel consumption reductions, incremental cost information was provided to the committee by OEMs, Tier 1 suppliers, and studies published by trade associations, governmental agencies, manufacturing consultants, and earlier NRC reports. Appendix I

TABLE 9.1 Committee's Estimates of Effectiveness (shown as a percentage) of Near-Term Technologies in Reducing Vehicle Fuel Consumption

Technologies		Incremental values - A preceding technology must be included								
		I4			V6			V8		
Spark Ignition Techs	Abbreviation	Low	High	AVG	Low	High	AVG	Low	High	AVG
Low Friction Lubricants	LUB	0.5	0.5	**0.5**	0.5	0.5	**0.5**	0.5	0.5	**0.5**
Engine Friction Reduction	EFR	0.5	2.0	**1.3**	0.5	2.0	**1.3**	1.0	2.0	**1.5**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.5	3.0	**2.3**	1.5	3.0	**2.3**	2.0	3.0	**2.5**
Cylinder Deactivation, SOHC	DEAC	NA	NA	NA	4.0	6.0	**5.0**	5.0	10.0	**7.5**
VVT - In take Cam Phasing (ICP)	ICP	1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.5	2.0	**1.8**
VVT - Dual Cam Phasing (DCP)	DCP	1.5	2.5	**2.0**	1.5	3.0	**2.3**	1.5	3.0	**2.3**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Continuously Variable Valve Lift (CVVL)	CVVL	3.5	6.0	**4.8**	3.5	6.5	**5.0**	4.0	6.5	**5.3**
Cylinder Deactivation, OHV	DEAC	NA	NA	NA	4.0	6.0	**5.0**	5.0	10.0	**7.5**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.5	3.0	**2.3**	1.5	3.5	**2.5**	2.0	4.0	**3.0**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	1.5	2.5	**2.0**	1.5	3.0	**2.3**	2.0	3.0	**2.5**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.5	3.0	**2.3**	1.5	3.0	**2.3**	1.5	3.0	**2.3**
Turbocharging and Downsizing	TRBDS	2.0	5.0	**3.5**	4.0	6.0	**5.0**	4.0	6.0	**5.0**
Diesel Techs										
Conversion to Diesel	DSL	15.0	35.0	**25.0**	15.0	35.0	**25.0**	NA	NA	NA
Conversion to Advanced Diesel	ADSL	7.0	13.0	**10.0**	7.0	13.0	**10.0**	22.0	38.0	**30.0**
Electrification/Accessory Techs										
Electric Power Steering (EPS)	EPS	1.0	3.0	**2.0**	1.0	3.0	**2.0**	1.0	3.0	**2.0**
Improved Accessories	IACC	0.5	1.5	**1.0**	0.5	1.5	**1.0**	0.5	1.5	**1.0**
Higher Voltage/Improved Alternato	HVIA	0.0	0.5	**0.3**	0.0	0.5	**0.3**	0.0	0.5	**0.3**
Transmission Techs										
Continuously Variable Transmission (CVT)	CVT	1.0	7.0	**4.0**	1.0	7.0	**4.0**	1.0	7.0	**4.0**
5-spd Auto. Trans. w/ Improved Internals		2.0	3.0	**2.5**	2.0	3.0	**2.5**	2.0	3.0	**2.5**
6-spd Auto. Trans. w/ Improved Internals		1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.0	2.0	**1.5**
7-spd Auto. Trans. w/ Improved Internals		2.0		**2.0**	2.0		**2.0**	2.0		**2.0**
8-spd Auto. Trans. w/ Improved Internals		1.0		**1.0**	1.0		**1.0**	1.0		**1.0**
6/7/8-spd Auto. Trans. w/ Improved Internals	NAUTO	3.0	8.0	**5.5**	3.0	8.0	**5.5**	3.0	8.0	**5.5**
6/7-spd DCT from 4-spd AT	DCT	6.0	9.0	**7.5**	6.0	9.0	**7.5**	6.0	9.0	**7.5**
6/7-spd DCT from 6-spd AT	DCT	3.0	4.0	**3.5**	3.0	4.0	**3.5**	3.0	4.0	**3.5**
Hybrid Techs										
12V BAS Micro-Hybrid	MHEV	2.0	4.0	**3.0**	2.0	4.0	**3.0**	2.0	4.0	**3.0**
Integrated Starter Generator	ISG	29.0	39.0	**34.0**	29.0	39.0	**34.0**	29.0	39.0	**34.0**
Power Split Hybrid	PSHEV	24.0	50.0	**37.0**	24.0	50.0	**37.0**	24.0	50.0	**37.0**
2-Mode Hybrid	2MHEV	25.0	45.0	**35.0**	25.0	45.0	**35.0**	25.0	45.0	**35.0**
Plug-in hybric	PHEV	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vehicle Techs										
Mass Reduction - 1%	MR1	0.3		**0.3**	0.3		**0.3**	0.3		**0.3**
Mass Reduction - 2%	MR2	1.4		**1.4**	1.4		**1.4**	1.4		**1.4**
Mass Reduction - 5%	MR5	3.0	3.5	**3.3**	3.0	3.5	**3.3**	3.0	3.5	**3.3**
Mass Reduction - 10%	MR10	6.0	7.0	**6.5**	6.0	7.0	**6.5**	6.0	7.0	**6.5**
Mass Reduction - 20%	MR20	11.0	13.0	**12.0**	11.0	13.0	**12.0**	11.0	13.0	**12.0**
Low Rolling Resistance Tires	ROLL	1.0	3.0	**2.0**	1.0	3.0	**2.0**	1.0	3.0	**2.0**
Low Drag Brakes	LDB	1.0		**1.0**	1.0		**1.0**	1.0		**1.0**
Aero Drag Reduction 10%	AERC	1.0	2.0	**1.5**	1.0	2.0	**1.5**	1.0	2.0	**1.5**

NOTE: Some of the benefits (highlighted in green) are incremental to those obtained with preceding technologies shown in the technology pathways described in Chapter 9.

contains results from some of these other studies, although, again, the reader should refer to the original source for the assumptions and study approaches used in these other studies. During the data gathering process, it became clear that the estimated incremental cost ranges were, in many cases, very large, depending on the boundary conditions identified by the organization offering the information. Generally, the committee notes that cost estimates are always more uncertain than the fuel consumption impact estimates, and the estimates presented here should be considered very uncertain until more detailed studies are completed. A boundary condition in the cost estimations is an assumption of long-term, high-volume production, whereby analysts attempt to normalize all incremental costs into a scenario where the capitalized development cost becomes a small portion of the final unit production cost. This is accomplished by assuming that production volumes are several hundred thousand units per year and remain in production for many years.

Although this assumption may be quite appropriate to normalize overall annual societal costs, it does not necessarily recognize the initial development-based costs and quality hurdles that may prevent a manufacturer from pursuing new product or technology areas. For example, such analyses would not consider factors that may inhibit or prevent the

TABLE 9.2 Committee's Estimates of Technology Costs in U.S. Dollars (2008)

NRC 2009 Costs													
Technologies		Incremental Values - A preceding technology must be included											
		I4				V6				V8			
Spark Ignition Techs	Abbreviation	Low	High	AVG	AVG w/1.5 RPE	Low	High	AVG	AVG w/1.5 RPE	Low	High	AVG	AVG w/1.5 RPE
Low Friction Lubricants	LUB	3	5	**4**	**6**	3	5	**4**	**6**	3	5	**4**	**6**
Engine Friction Reduction	EFR	32.0	52.0	**42**	**63**	48	78	**63**	**94.5**	64	104	**84**	**126**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	130	160	**145**	**217.5**	180	210	**195**	**292.5**	280	320	**300**	**450**
Cylinder Deactivation, SOHC	DEAC	NA	NA	**NA**	**NA**	340	400	**370**	**555**	357	420	**388.5**	**582.75**
VVT - In take Cam Phasing (ICP)	ICP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
VVT - Dual Cam Phasing (DCP)	DCP	35		**35**	**52.5**	70		**70**	**105**	70		**70**	**105**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	130	160	**145**	**217.5**	180	220	**200**	**300**	260	300	**280**	**420**
Continuously Variable Valve Lift (CVVL)	CVVL	159	205	**182**	**273**	290	310	**300**	**450**	350	390	**370**	**555**
Cylinder Deactivation, OHV	DEAC	NA	NA	**NA**	**NA**	220	250	**235**	**352.5**	255		**255**	**382.5**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	35		**35**	**52.5**	35		**35**	**52.5**	35		**35**	**52.5**
Discrete Variable Valve Lift (DVVL), OH\	DVVL	130	160	**145**	**218**	210	240	**225**	**338**	280	320	**300**	**450**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	117	195	**156**	**234**	169	256	**213**	**319**	295	351	**323**	**485**
Turbocharging and Downsizinc	TRBDS	370	490	**430**	**645**	-144	205	**31**	**46**	525	790	**658**	**986**
Diesel Techs													
Conversion to Diesel	DSL	2154	2632	**2393**	**3590**	2857	3491	**3174**	**4761**	NA	NA	**NA**	**NA**
Conversion to Advanced Diese	ADSL	520	520	**520**	**780**	683	683	**683**	**1025**	3513	4293	**3903**	**5855**
Electrification/Accessory Techs													
Electric Power Steering (EPS)	EPS	70	120	**95**	**143**	70	120	**95**	**143**	70	120	**95**	**143**
Improved Accessories	IACC	70	90	**80**	**120**	70	90	**80**	**120**	70	90	**80**	**120**
Higher Voltage/Improved Alternator	HVIA	15	55	**35**	**53**	15	55	**35**	**53**	15	55	**35**	**53**
Transmission Techs													
Continuously Variable Transmission (CVT)	CVT	150	170	**160**	**240**	243	263	**253**	**380**	243	263	**253**	**380**
5-spd Auto. Trans. w/ Improved Internals		133		**133**	**200**	133		**133**	**200**	133		**133**	**200**
6-spd Auto. Trans. w/ Improved Internals		133	215	**174**	**262**	133	215	**174**	**262**	133	215	**174**	**262**
7-spd Auto. Trans. w/ Improved Internals		170	300	**235**	**353**	170	300	**235**	**353**	170	300	**235**	**353**
8-spd Auto. Trans. w/ Improved Internals		425		**425**	**638**	425		**425**	**638**	425		**425**	**638**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	137	425	**281**	**422**	137	425	**281**	**422**	137	425	**281**	**422**
6/7-spd DCT from 6-spd AT	DCT	-147	185	**19**	**29**	-147	185	**19**	**29**	-147	185	**19**	**29**
6/7-spd DCT from 4-spd AT	DCT	-14	400	**193**	**290**	-14	400	**193**	**290**	-14	400	**193**	**290**
Hybrid Techs													
12V BAS Micro-Hybrid	MHEV	450	550	**500**	**665**	585	715	**650**	**865**	720	880	**800**	**1064**
Integrated Starter Generator	ISG	1760	2640	**2200**	**2926**	2000	3000	**2500**	**3325**	3200	4800	**4000**	**5320**
Power Split Hybrid	PSHEV	2708	4062	**3385**	**4502**	3120	4680	**3900**	**5187**	4000	6000	**5000**	**6650**
2-Mode Hybrid	2MHEV	5200	7800	**6500**	**8645**	5200	7800	**6500**	**8645**	5200	7800	**6500**	**8645**
Series PHEV 40	PHEV	8000	12000	**10000**	**13300**	9600	14400	**12000**	**15960**	13600	20400	**17000**	**22610**
Vehicle Techs													
Mass Reduction - 1%	MR1	37	45	**41**	**61**	48	58	**53**	**80**	68	82	**75**	**113**
Mass Reduction - 2%	MR2	77	93	**85**	**127**	100	121	**111**	**166**	142	170	**156**	**234**
Mass Reduction - 5%	MR5	217	260	**239**	**358**	283	339	**311**	**467**	399	479	**439**	**659**
Mass Reduction - 10%	MR10	520	624	**572**	**859**	679	815	**747**	**1120**	958	1150	**1054**	**1581**
Mass Reduction - 20%	MR20	1600	1700	**1650**	**2475**	1600	1800	**1700**	**2550**	1600	1900	**1750**	**2625**
Low Rolling Resistance Tires	ROLL	30	40	**35**	**53**	30	40	**35**	**53**	30	40	**35**	**53**
Aero Drag Reduction 10%	AERO	40	50	**45**	**68**	40	50	**45**	**68**	40	50	**45**	**68**

introduction of diesel technology into passenger vehicles due to the significant investment and general lack of familiarity of North American automotive OEMs and suppliers in the production of small, light-duty diesels and the durability of necessary exhaust aftertreatment systems. This serves as a reminder that, while overall costs to the industry of new technologies is an important consideration, it is the individual manufacturers that bear the risk in adapting a technology to a specific vehicle and this risk may not be fully captured in a metric of overall industry costs.

The committee was briefed on the very detailed and transparent teardown cost assessment methodology being utilized by the EPA as part of the process for estimating the cost of fuel economy technologies. Cost estimation using the teardown approach is discussed in Chapter 3. The committee finds this approach an improvement over one where cost estimates are developed through expert knowledge and surveys of suppliers and OEMs, which have been the basis for most published studies and the majority of this report. Furthermore, the committee recommends that the use of teardown studies be expanded for future assessments when cost-effectiveness is an important evaluation criterion.

ASSESSING POTENTIAL TECHNOLOGY SEQUENCING PATHS

When manufacturers consider a strategy for implementing technologies that reduce fuel consumption, a normal business decision process must tradeoff many different parameters, including cost-effectiveness (fuel consumption reduction versus production cost), the ability to be integrated into product planning cycles, intended product use, reliability, impact on vehicle performance characteristics, and customer acceptance. To conduct the current assessment, the committee employed a method whereby cost-effectiveness (fuel consumption reduction divided by high-volume production incremental cost), vehicle intended use, base power train configuration, and technology state of readiness were considered in estimating potential technology paths for the eight vehicle classes described earlier.

As previously stated, an attempt to perform FSS on every vehicle model with all combinations of technologies is not practicable. Such a process would necessitate the analysis of (at least) tens of thousands of vehicle and power train technology combinations. It would require potentially confidential engine, transmission, accessory, and hybrid power train system maps; vehicle data such as friction as a function of vehicle speed; aerodynamic parameters; and many others parameters that are either proprietary or would require significant vehicle testing to generate for all of the combinations that are possible.

In some published studies, OEMs have supported such analyses for a limited number of vehicles that were chosen as sufficiently representative for discussion of the technology benefits and associated costs. For example, Sierra Research, in its report for the Alliance of Automobile Manufacturers (Auto Alliance), used the DOE-supported VEHSIM model to estimate fuel consumption reduction for various technologies using a composite of engine maps provided by manufacturers. Although the committee recommends a more practical approach to apply FSS for future regulatory actions, which is discussed later in this chapter, the exclusive use of FSS simulation for the assessment of all technologies considered under this study was not possible. The committee believes that sufficient experimental data can be gathered by the government to support future analysis and regulatory activities through consortia that include both regulatory agencies and automotive manufacturers and suppliers.

With this background, the committee evaluated potential technology paths that could be considered by a manufacturer, depending upon the manufacturer's actual state of technology and production capability. Rather than creating decision trees from which an extremely large number of possible technology combinations could be created for each vehicle class, the committee estimated possible technology evolution paths for each class that develop from the average baseline vehicle. These pathways are summarized in Figures 9.1 to 9.5.

The baseline attributes were determined on a class-by-class basis using the 2007 EPA test list. If 51 percent of the vehicles in a given class had variable valve timing (VVT), then the baseline, class-representative vehicle was given VVT, and this technology would not be added in the path. Because the characteristic vehicle in each class represents the average attributes for that class, there will be some vehicles in that class that have more or less technology content. The below-average vehicles may require additional technologies and associated costs to address future standards while the above-average vehicles may not. Using the average attributes should provide a good overall representation of technology benefits relative to the baseline fleet within a class of vehicles. The technologies of the baseline vehicles are listed in the title bar of each technology path.

In the absence of a very large number of FSS analyses, but guided by a limited number of FSS runs performed for the committee by Ricardo, Inc. (2009), the committee evaluated possible sequences of technology implementation for different classes of vehicles. The development of the technology sequences shown in Figures 9.1 to 9.5 also was done with input from OEMs, Tier 1 suppliers, other published analyses, and the expert judgment of committee members. In developing the ranges of fuel consumption reduction, the committee recognized that the potential reduction for each incremental step is highly dependent on the extent to which system losses could have been reduced by previous technologies. These pathways attempt to include such factors as cost-effectiveness (percent fuel consumption reduction/incremental cost), logical sequencing based upon preexisting technology, technical limitations, and ease of implementation (requirements for major or minor manufacturing changes, including production line considerations). Subjective judgment by the committee also played a role in the pathway definition process.

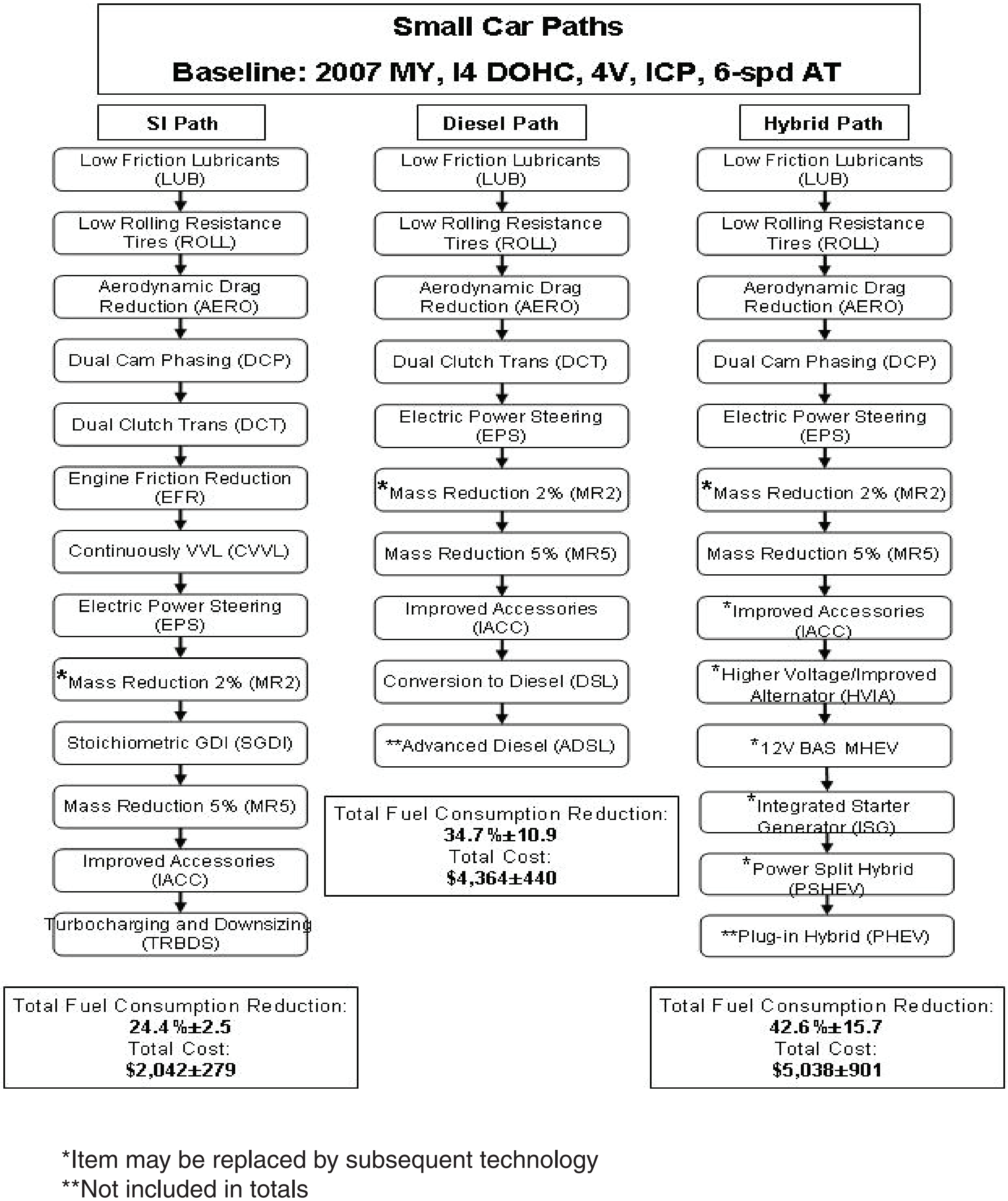

FIGURE 9.1 Small-car pathways with estimated total fuel consumption reduction and cost shown.

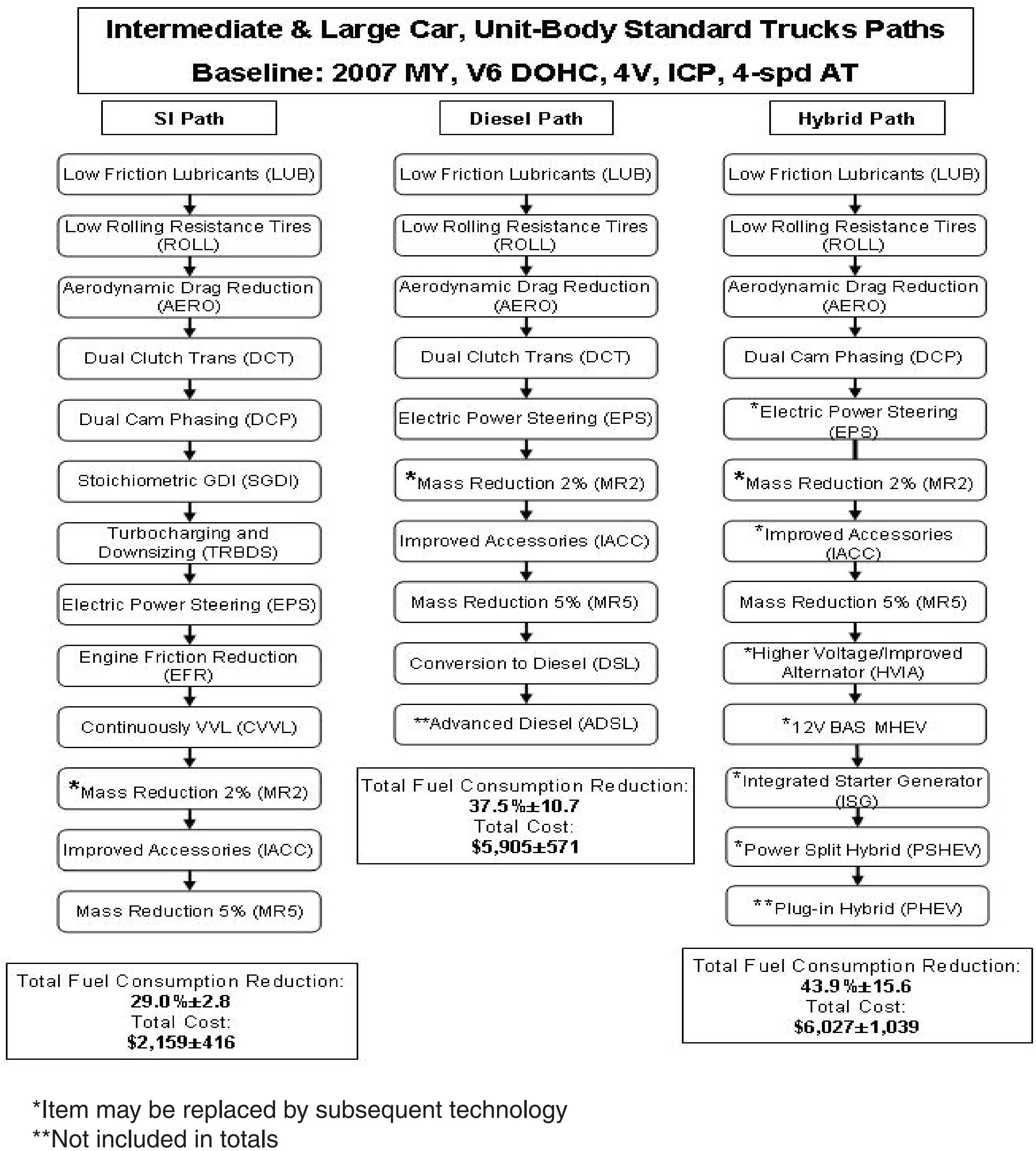

FIGURE 9.2 Intermediate- and large-car and unit-body standard truck pathways with estimated total fuel consumption reduction and cost shown.

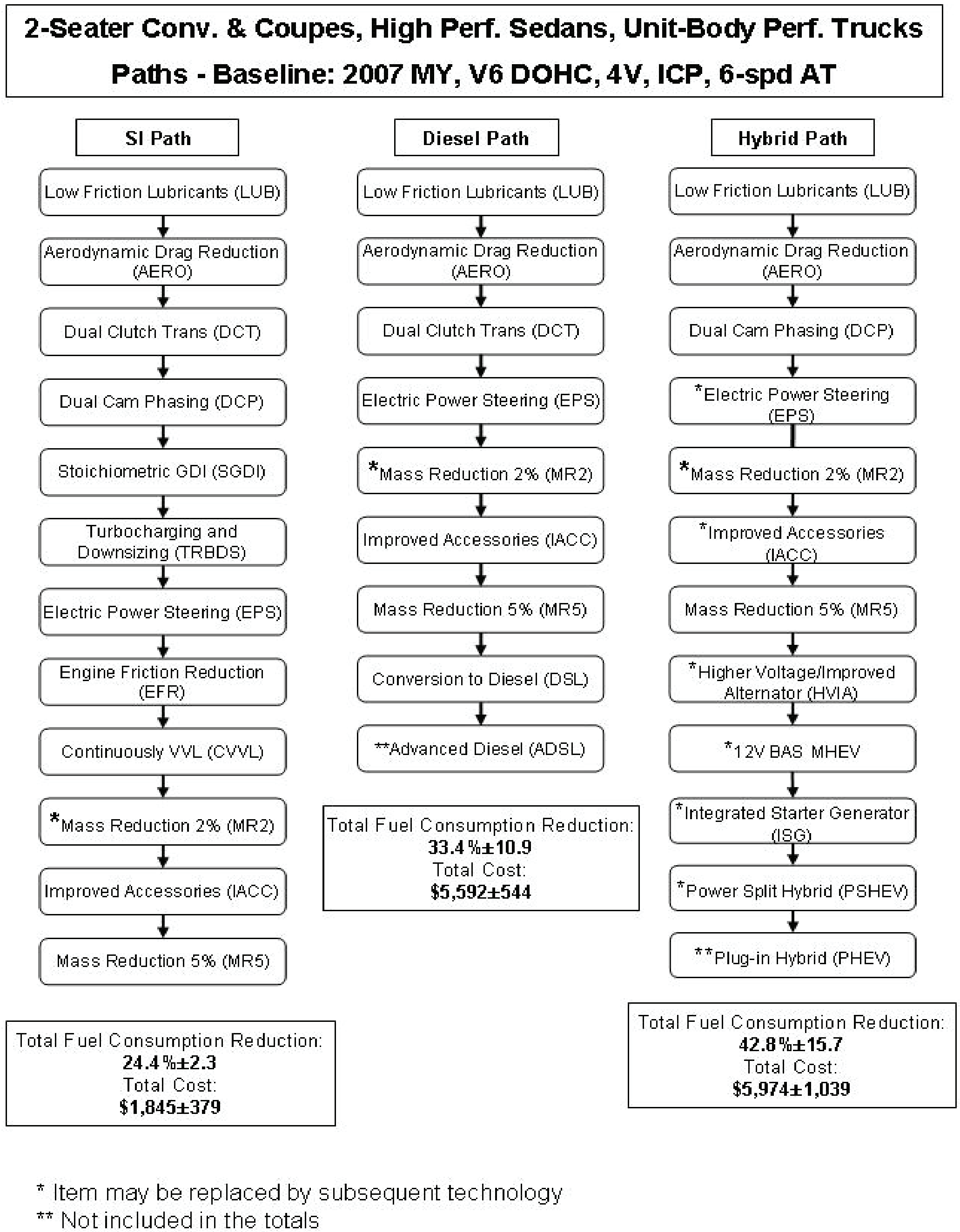

FIGURE 9.3 Two-seater convertible and coupe, high-performance sedan, and unit-body performance truck pathways with estimated total fuel consumption reduction and cost shown.

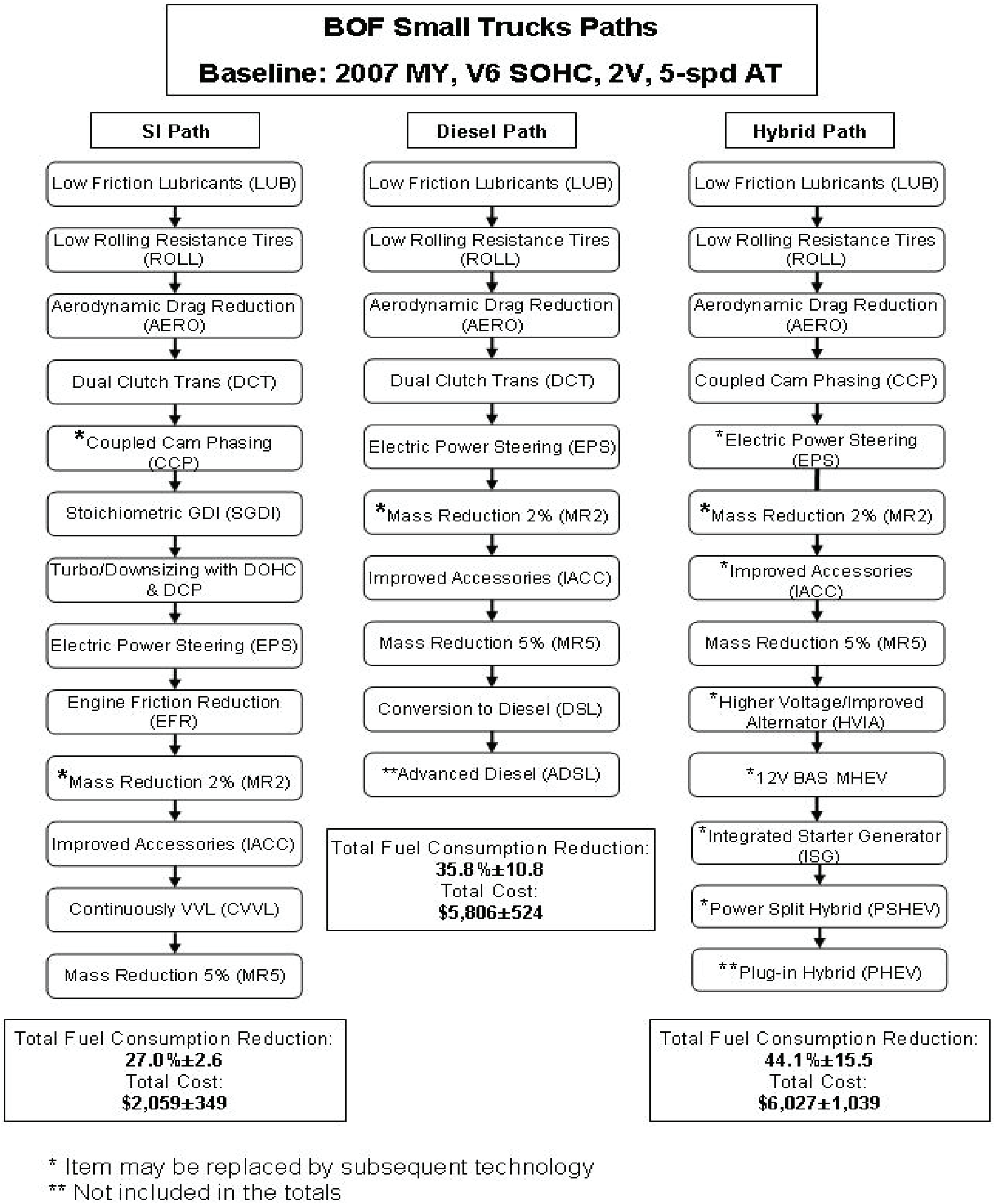

FIGURE 9.4 Body-on-frame small-truck pathways with estimated total fuel consumption reduction and cost shown.

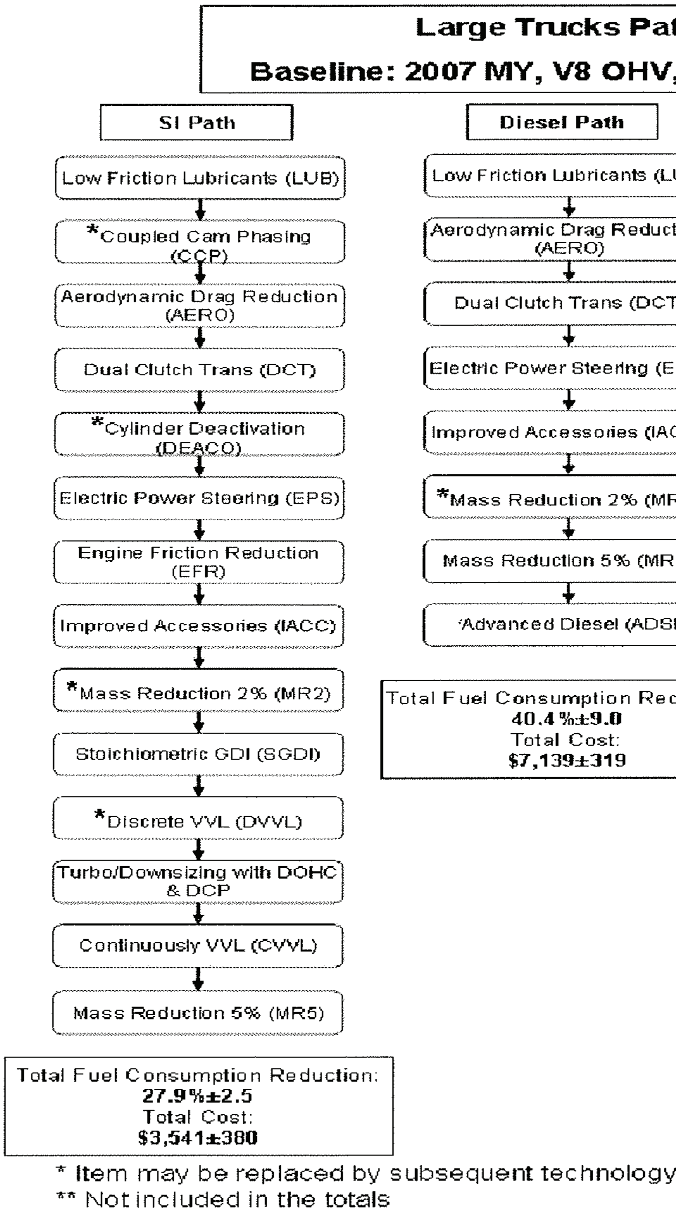

FIGURE 9.5 Large-truck pathways with estimated total fuel consumption reduction and cost shown.

Although the committee believes that some potential reduction is possible with each of the technologies considered, the extent to which a system energy loss can be reduced is highly dependent on all of the system interactive effects, the extent to which the baseline technology package has already reduced different categories of energy losses, and the production calibration parameters chosen by each manufacturer for the final release of each vehicle. Evaluating the energy losses associated with these technology pathways is discussed later in this chapter.

Review of Figures 9.1 through 9.5 shows that in certain cases (intermediate and large cars; unit-body standard trucks; two-seater convertibles, coupes, and high-performance sedans; unit-body performance trucks) the technology pathways are the same because of the similar base vehicle power train. However, the tradeoffs made as a result of varying performance metrics as these vehicle types go through their product evolution would result in different levels of fuel consumption improvement depending on the specific vehicle application.

Each range in potential fuel consumption reduction is an attempt by the committee to estimate the potential variation in energy loss reduction that might be possible when applying the technology to different power train and vehicle packages, taking into consideration known system features that will likely be optimized for different classes of vehicles with different intended uses. An example would be the bias inherent in production calibration of light-duty trucks or SUVs where reasonable towing capability is required.

A simple, multiplicative aggregation of the potential fuel consumption reduction is presented below each path in Figures 9.1 through 9.5 as a means to roughly estimate the total potential that might be possible. A probabilistic methodology based on the mean square rule was applied to estimate the confidence intervals for the aggregation of fuel consumption improvements and costs. Appendix J provides the mathematical explanation for this methodology. It assumes that the confidence intervals on each individual estimate of technology effectiveness or cost are the same. It also assumes that ranges in estimates are independent of each other and that errors are normally distributed. The approach then maintains a confidence interval for the aggregation of the low or high ends of the estimates that is equal to the confidence intervals estimated for the individual technologies. The committee assumes that the ranges for the individual costs and effectiveness represent a 90 percent confidence level. As such, the ranges were increased in technical areas where, in the opinion of the committee, more uncertainty existed with initial estimates.

It should also be noted that when the combination of fuel consumption improvement predictions and associated incremental costs is considered, the probability drops to 81 percent that any actual production technology introduction would fall within the ranges bounded by both the fuel consumption and cost ranges. This reduction is due to the (multiplicative) product of two 90 percent probabilities. *Although prepared in response to the committee's statement of task, these data are approximate in nature and as such should not be used as input to analyses where modeling accuracy is important. They are provided here as rough estimates that can be used in a qualitative comparative sense when comparing the relative cost-benefits of spark-ignition (SI)-related technologies that are potential candidates for FSS analyses. The committee's estimates can also be used for a qualitative comparison of SI-related technologies to other candidates such as light-duty diesel or hybrid vehicles.*

The results show that significant reductions in fuel consumption are possible with technologies that are already in production in U.S., European, or Asian markets. For example, for the intermediate car, large car, and unibody standard truck classes, the average reduction in fuel consumption for the SI path is 29 percent at a cost of approximately $2,200; the average reduction for the compression-ignition (CI) engine path is 38 percent at a cost of approximately $5,900; and the average reduction for the hybrids path is about 44 percent at an average cost of approximately $6,000. In general, diesel engine and hybrid vehicle technology options offer greater improvement potential compared to the SI pathway, but at a higher incremental cost. However, as evidenced by the increasingly wide range in estimated fuel consumption reduction and incremental cost, actual fuel consumption improvement can vary significantly depending on an individual manufacturer's product strategy. Further, it may be that the needs to reduce vehicle fuel consumption as mandated by recent legislation will result in OEMs implementing these technologies in such a way that the benefits fall toward the high end of the range. It should be noted that among its provisions related to fuel economy, the Energy Independence and Security Act (EISA) of 2007 required periodic assessments by the NRC of automobile vehicle fuel economy technologies and their costs. Thus, follow-on NRC committees will be responsible for responding to the EISA mandates, including the periodic evaluation of costs and fuel consumption benefits of individual technologies and the combined impacts of multiple technologies.

When developing the effectiveness numbers, attempts were made by the committee to incrementally adjust the effectiveness numbers of certain technologies that would normally be preceded by another technology. This process allowed the committee to approximate the inclusion of the synergistic effects resulting from the combination of certain technologies that were deemed to usually be packaged together. In an attempt to evaluate the incremental effectiveness numbers for the SI pathway derived by the committee, comparisons were conducted using the FSS data from the Ricardo report prepared for the committee (Ricardo, Inc., 2009), the EPA-provided lumped parameter model, and various other SAE papers where combinations of technologies were assessed. A comparison to the Ricardo data is shown in Figure 9.6. Packages involving CVTs were excluded because the committee agrees with the EPA (EPA, 2008b) that

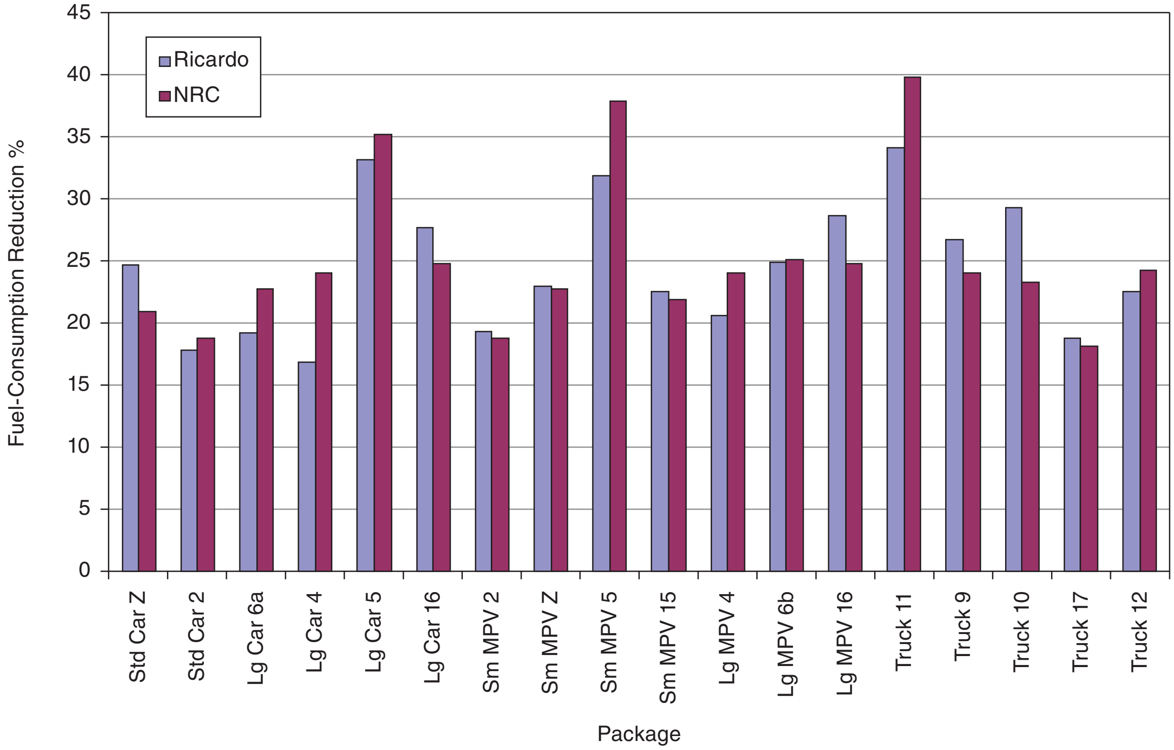

FIGURE 9.6 NRC estimates of effectiveness in reducing the fuel consumption of various light-duty vehicles compared with Ricardo, Inc. (2009) estimates based on data obtained with full system simulation.

Ricardo, Inc., used an abnormally small fuel consumption effectiveness value for this type of transmission.

As can be seen in Figure 9.6, the packages' fuel consumption reduction results generally follow the relative comparisons between the packages analyzed by Ricardo, Inc. This is likely due to the engineering judgment of the members of the committee whose experience in power train engineering could be applied to the assessment. However, the absolute levels of potential improvement can vary significantly between the committee estimates and Ricardo analyses. Furthermore, a comparison of the step-by-step incremental estimates that would result from the application of single technologies was not conducted. Therefore, it is not possible to determine whether the demonstrated correlations were a result of accurate incremental estimates, or whether a combination of over- and underestimates resulted in a rough approximation, where such occurs.

In any case, the Ricardo, Inc., packages represent only a subset of the greater number of technology combinations that would result from proceeding down the entire pathway evaluated by the committee. This underscores the importance of using FSS to account for the larger number of technology synergies and ensure that system loss reduction is not overstated.

Due to the approximate nature of the estimates of incremental improvements in fuel consumption, the committee recognizes the potential to overestimate the potential reduction in energy losses, despite consideration given to the total system energy consumers. Therefore, as another check on the predicted aggregation of potential technologies, the committee contracted with EEA to apply its lumped parameter modeling approach to evaluate the committee's estimates. Simplified lumped parameter models of vehicle energy use (e.g., Sovran and Bohn, 1981) provide a means of evaluating whether the fuel consumption benefits estimate for combinations of technologies by the multiplication methods result from forcing categories of energy losses (pumping and friction) to physically impossible levels. Appendix K provides a description of the EEA lumped parameter model as well as a description of the results in terms of the tractive energy requirements and the engine efficiency for the SI and diesel test cycles. These results indicate that the results from the multiplication method used here likely do not greatly overstate the benefits because this method does not explicitly take into account the theoretical limits of pumping loss reduction.

Figures 9.7 and 9.8 show the model results versus the committee estimates for eight cases (four for SI paths, and four for diesel paths). The model estimates for incremental improvements are relatively close to those of the committee, with the committee's estimates generally exceeding those of the EEA model by a small amount. These comparisons are made between the average level of the committee's estimates and the EEA data with no range presented. It should also be

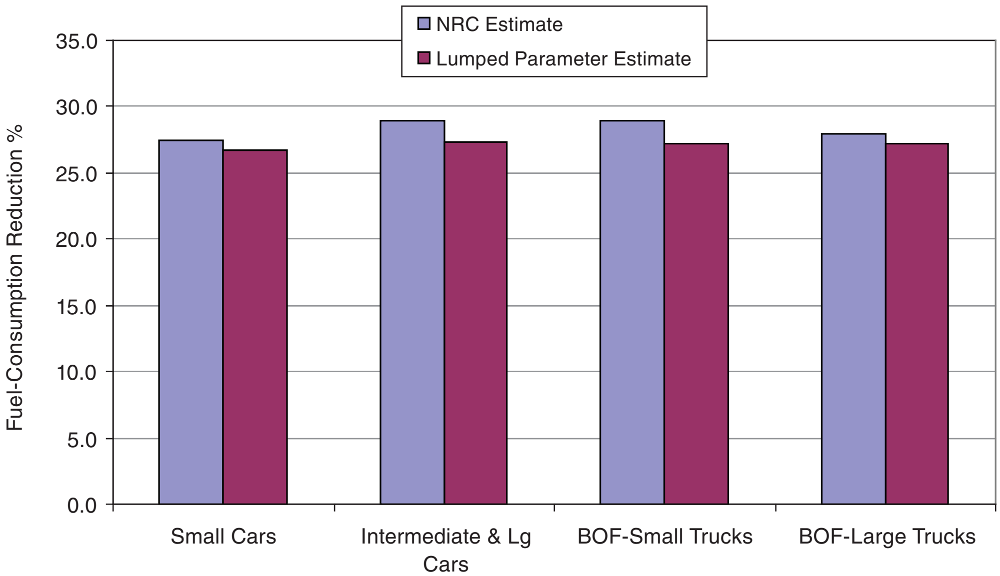

FIGURE 9.7 NRC estimates of effectiveness in reducing fuel consumption in spark-ignition engine pathways compared to EEA model outputs.

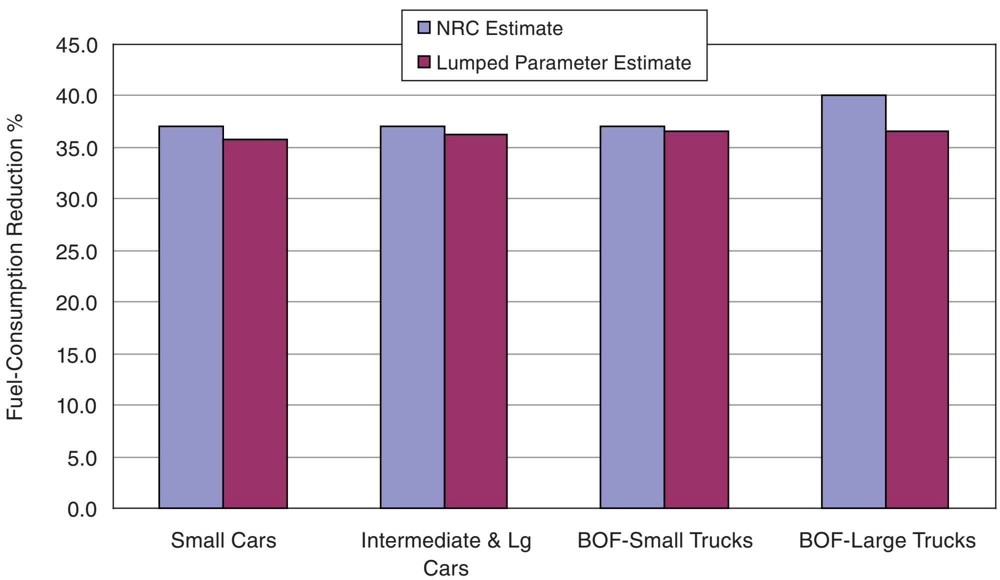

FIGURE 9.8 NRC estimates of effectiveness in reducing fuel consumption in diesel engine pathways compared to EEA model outputs.

noted that a baseline 4-speed automatic was used for both the committee's and EEA estimates because these comparisons were conducted prior to the committee's decision to utilize the average class transmission from the 2007 EPA test data in the technology paths.

One might conclude that the EEA modeling does, in fact, suggest that the committee's estimates slightly overpredict the estimate. However, the same general method of comparison with known production vehicles and estimating the potential levels of energy loss reduction are employed in both the EEA lumped parameter approach and the expert opinion of the committee members. The EEA model does employ an algorithm to account for incremental reductions of energy losses, as predicted by an industry-derived set of equations (see Chapter 8). Therefore, it is not surprising that the estimations are relatively close.

However, the applications of the EEA's or the committee's estimation approach is done without a detailed understanding of the actual levels of thermal efficiency of a subject vehicle's engine, the influence of combustion chamber design on the fuel conversion efficiency, the actual levels of gas exchange or frictional losses, and all of the other parameters for which additional technologies can be applied to reduce fuel consumption. This is only possible through a combination of experimental and analytical analyses, which are necessary to predict the absolute level of fuel consumption.

Stated another way, in the opinion of the committee, neither the lumped parameter approaches evaluated by the committee nor the committee's aggregated estimates define the actual level of energy efficiencies and/or losses of a randomly chosen vehicle with sufficient accuracy to allow accurate predictions of future technology introductions. Furthermore, this inaccuracy further degrades as an increasing number of technologies is employed. Therefore, the committee believes that a physics-based, FSS, in combination with experimentally generated data, is required for such predictions, especially if technology that is not currently in production is considered.

IMPROVEMENTS TO MODELING OF MULTIPLE FUEL ECONOMY TECHNOLOGIES

The application of FSS, in which the engine load, thermodynamic efficiency, operational losses of energy, and accessory loads are varied as a function of vehicle operational performance, offers the best opportunity to evaluate the effectiveness of incremental application of vehicle systems in reducing vehicle energy losses, thereby improving overall operational cycle efficiency and reducing fuel consumption. However, since different technologies may be attempting to reduce the same type of loss, for instance, pumping loss, it is necessary to evaluate the contribution of each incremental technology in reducing the different losses in each step along a potential product improvement path. Through the application of incremental technologies, one at a time, and then optimizing the predicted overall vehicle performance and fuel economy tradeoffs, it is possible to understand and quantify, at least for the vehicle model being evaluated, the interactive or synergistic effects that result. These may be positive or negative synergies, as outlined in the Ricardo report prepared for this committee (Ricardo, Inc., 2009) and discussed in Chapter 8 of this report. An example of these synergistic effects is presented in Table 9.3.

Table 9.3 shows that the total improvement in fuel consumption is gained from a combination of primary benefits attributed to a technology pair and a synergistic benefit (or detriment) as a result of the energy losses that are targeted for reduction. If one considers the engine and transmission combination, benefits in reduced pumping losses occur if a downsized, higher-specific-power engine is applied. Additional benefits can be gained from a more efficient transmission with reduced hydraulic losses or reduced friction. However, when these two are applied, there are additional benefits that arise from the ability to run the engine at a lower operating speed for a given power level, thereby increasing the brake mean effective pressure in the cylinders and further reducing the pumping losses. This contributes to the 2.17 percent improvement outlined in Table 9.3. However, it is important to note that the absolute level and relative levels of improvement outlined in Table 9.3 may vary significantly, depending on the application of the same technology sequence to another vehicle application.

As evidenced by the Ricardo, Inc., FSS analyses conducted for the committee, different vehicle types, with differing intended uses, demonstrate different optimization-of-performance characteristics. Therefore, when attempting to estimate the incremental benefits from the application of discrete technologies, the vehicle class, intended use, and associated performance metrics must be considered. Furthermore, the positive or negative synergistic effects of multiple vehicle energy-loss-reducing technologies will vary depending on the vehicle class and intended performance.

As outlined in Chapter 8 of this report, the current NHTSA method of applying technologies to vehicles applies them incrementally and individually to each vehicle in the NHTSA database, starting from the experimentally deter-

TABLE 9.3 Fuel Consumption Synergy Values for Inter-tree Technology Pairs—Results for Truck Package 11

Inter-tree Technology Pair	Fraction of Total Fuel Consumption Impact Attributed to Inter-tree Technology Pair (%)	Synergy Value—Impact on Total Fuel Consumption Reduction from Synergy of Technology Pair (%)
Engine–transmission	6.62	2.17
Final drive ratio–engine	2.81	0.88
Aggressive shift logic–engine	−1.28	−0.39
Electric accessories–engine	0.88	0.27
Aerodynamic drag–engine	0.44	0.13
Aerodynamic drag–transmission	0.36	0.11
Aerodynamic drag–final drive ratio	0.23	0.07
Aerodynamic drag–electric accessories	0.21	0.06
Aggressive shift logic–aerodynamic drag	0.14	0.04

NOTE: The modeling included three decision trees or families of technologies, one for engine technologies, one for transmission technologies, and a third for vehicle technologies. The results shown are for Truck Package 11 (Ricardo, Inc., 2009) mined value for combined fuel economy as demonstrated in the EPA vehicle exhaust emission certification process. One potential flaw in this methodology results from the process in which the lumped parameter model is used to predict the magnitude of energy loss reduction through the application of discrete technologies on an actual vehicle-by-vehicle basis. Without knowing the starting point in terms of how much the energy losses have been already been reduced, the ability to accurately project further reductions in such system energy losses, and therefore fuel consumption, can be highly erroneous.

Stated another way, it appears most logical to begin any predictive analysis with actual vehicle experimental data, if they are available, as is the case with all vehicles certified under the EPA Test Car List. However, without knowing how successful each manufacturer has been on a vehicle-by-vehicle basis in an ongoing attempt to reduce such energy losses, it is not possible, without detailed vehicle and power train experimental methods, to determine the extent to which any such loss can be further reduced, with a reasonable level of accuracy, on an actual vehicle model.

With an understanding of the potential errors that will result from the approximation method presented above, or other lumped parameter approaches where insufficient information is known about the level of energy loss reduction that has previously occurred on a particular vehicle, the committee proposes an alternative method whereby the potential for fuel consumption reduction and its associated costs can be assessed. This proposed method would determine a characteristic vehicle that would be defined as a reasonable average representative of a class of vehicles. This representative vehicle, whether real or theoretical, would undergo sufficient FSS, combined with experimentally determined and vehicle-class-specific system mapping, to allow a reasonable understanding of the contributory effects of the applied technologies in the reduction of energy losses. The reference to a "theoretical" vehicle suggests that if, during the regulatory process, the NHTSA and the EPA conclude that a vehicle may be characterized to represent a class that may not be in production, FSS models may still be created using physics-based vehicle models combined with experimentally generated engine maps.

In any full system simulation, the engine/power train/vehicle system is defined by input data that are generated by other physics-based analyses, engineering judgment, or experimentally or empirically derived tests. Experimentally measured data for engine maps can incorporate manufacturer-predetermined calibration parameters that have taken into consideration production operational factors such as knock-preventing spark timing or air/fuel ratio adjustments, which are used to protect from component temperature extremes. Physics-based engine maps, generated from engine combustion models, may also be used, but calibration-specific parameters must also be incorporated into such models to achieve best possible predictive results. The use of such models may be necessary when evaluating advanced technologies, such as variable compression ratio, that may not be readily available from production vehicles.

Vehicle-related data, such as data on frontal area, rolling resistance, and weight also are required input for modeling of vehicle performance and fuel economy. However, these data are more readily approximated based upon simplified physics-based calculations or are published in accordance with vehicle certification testing. Therefore, although physics-based engine simulation models are available, the use of experimental engine data, as described above, greatly improves the accuracy of the modeling.

Experimental methods used to understand the effects of different technologies in an attempt to reduce system energy losses have been developed under the United States Council for Automotive Research (USCAR) Benchmarking Consortium. Actual production vehicles are subjected to a battery of vehicle, engine, and transmission tests in sufficient detail to understand how each is applied and how they contribute to the overall performance and fuel consumption factors in light-duty vehicles. Combining such experimental methods with FSS modeling, wherein all simulation variables and subsystem maps would be transparent to all interested parties (both the regulatory agencies and automotive manufacturers, for example), would allow, in the opinion of the committee, the best opportunity to define a technical baseline against which potential improvements could be more accurately and openly analyzed than the current methods employed.

The advantages of such a method include the ability to explicitly account for all energy loss categories, the ability to directly estimate fuel consumption (as opposed to the percent change in fuel consumption), and the ability to represent new technologies and combinations of technologies. It also recognizes the increasingly common utilization of FSS models by regulatory agencies and other entities outside the automotive industry. Finally, the method proposes a procedure whereby engine and vehicle experimental data can be obtained without reliance on proprietary data, such as engine maps, that have posed a barrier to effective utilization of FSS models by non-OEMs in the past.

The steps in the recommended process are as follows:

1. Develop a set of baseline vehicle classes from which a characteristic vehicle can be chosen to represent each class. The vehicle may be either real or theoretical and will possess the average attributes of that class as determined by sales-weighted averages.
2. Identify technologies with a potential to reduce fuel consumption.
3. Determine the applicability of each technology to the various vehicle classes.
4. Estimate the technology's preliminary impact on fuel consumption and cost.

5. Determine the optimum implementation sequence (technology pathway) based on cost-effectiveness and engineering considerations.
6. Document the cost-effectiveness and engineering judgment assumptions used in step 5 and make this information part of a widely accessible database.
7. Utilize modeling software (FSS) to progress through each technology pathway for each vehicle class to obtain the final incremental effects of adding each technology.

If such a process were adopted as part of a regulatory rule-making procedure, it could be completed on 3-year cycles to allow regulatory agencies sufficient lead time to integrate the results into future proposed and enacted rules.

Based on the eight new vehicle classes proposed by the committee, an average vehicle, either real or theoretical, would be chosen that possessed the average attributes of the vehicles in that class. It would be of average weight, footprint, engine displacement, and other characteristics. The resulting vehicle would serve as the baseline for FSS analysis. This would also allow a very important starting point for the vehicle systems from which potential improvements could be evaluated. Using detailed benchmark data, defined levels of energy losses would be used as input into the simulation model. The data used to choose the vehicle consists of the following specifications available from the EPA test car list:

- Footprint,
- Weight,
  Engine (displacement, cylinder count, horsepower, torque),
- Valve train configuration (OHV, SOHC, DOHC),
- Valve event modulation technology (VVT, VVL),
- Combustion technology (SI, CI, HCCI),
- Fuel injection method and fuel type (SEQ, GDI, DFI, gasoline, diesel),
- Aspiration method (natural, supercharged, turbocharged),
- Number of occupants,
- Power/vehicle weight ratio,
- Transmission type and gear ratio spread,
- Driveline (FWD, RWD, AWD), and
- EPA vehicle class.

FINDINGS AND RECOMMENDATION

Finding 9.1: Many vehicle and power train technologies that reduce fuel consumption are currently in or entering production or are in advanced stages of development in European or Asian markets where high consumer prices for fuel have justified their commercialization. Depending on the intended vehicle use or current state of energy-loss minimization, the application of incremental technologies will produce varying levels of fuel consumption reduction.

Finding 9.2: Data made available to the committee from original equipment manufacturers and Tier 1 suppliers and found in various published studies suggest a very wide range in estimated incremental cost that makes assessments of cost-effectiveness very approximate. Generally, the committee notes that estimates of cost are always more uncertain than estimates of impact on fuel consumption, and the estimates presented here should be considered very uncertain until more detailed studies are completed. As noted in Chapter 3, estimates based on teardown cost analysis, currently being utilized by the EPA in its regulatory analysis for light-duty vehicle greenhouse gas emissions standards, should be expanded for developing cost impact analyses.

Finding 9.3: In response to the statement of task, the committee estimated possible technology evolution paths for each vehicle class that arise from the average baseline vehicle. A very simple, multiplicative aggregation of potential for reducing fuel consumption is presented as a means to roughly estimate the total potential that might be possible. The results from this analysis show that, for the intermediate car, large car, and unibody standard truck classes, the average reduction in fuel consumption for the SI path is about 29 percent at a cost of approximately $2,200; the average reduction for the CI path is about 38 percent at a cost of approximately $5,900; and the average reduction for the hybrids path is about 44 percent at a cost of $6,000. However, unless calibrated methods are used to accurately consider the synergistic effects of applying several technologies—effects that may reduce the same sources of power train and vehicle energy losses—these results are extremely approximate in nature and, in the committee's opinion, should not be used as input to analyses for which modeling accuracy is important. In general, the technology tables that present incremental data for percent reduction in fuel consumption and estimated incremental cost cannot be used in their current form as input into lumped parameter-type models without methods to accurately consider the synergistic effects of applying several technologies and without significant expertise in vehicle technologies to fully understand integration issues.

Recommendation 9.1: As noted in Chapter 8, full system simulation (FSS), based on empirically derived power train and vehicle performance and fuel consumption data maps, offers what the committee believes is the best available method to fully account for system energy losses and synergies and to analyze potential reductions in fuel consumption as technologies are introduced into the market. FSS analyses conducted for the committee show that synergy effects between differing types of energy-loss-reducing technologies vary greatly from vehicle application to vehicle application.

The committee proposes a method whereby FSS analyses are used on class-characterizing vehicles, so that synergies and effectiveness in implementing multiple fuel economy technologies can be evaluated with what should be greater accuracy. This proposed method would determine a characteristic vehicle that would be defined as a reasonable average representative of a class of vehicles. This representative vehicle, whether real or theoretical, would undergo sufficient FSS, combined with experimentally determined and vehicle-class-specific system mapping, to allow a reasonable understanding of the contributory effects of the technologies applied to reduce vehicle energy losses. Data developed under the United States Council for Automotive Research (USCAR) Benchmarking Consortium should be considered as a source for such analysis and potentially expanded. Under the USCAR program, actual production vehicles are subjected to a battery of vehicle, engine, and transmission tests in sufficient detail to understand how each candidate technology is applied and how it contributes to the overall performance and fuel consumption of light-duty vehicles. Combining the results of such testing with FSS modeling, and thereby making all simulation variables and subsystem maps transparent to all interested parties, would allow the best opportunity to define a technical baseline against which potential improvements could be analyzed more accurately and openly than is the case with the current methods employed.

The steps in the recommended process are as follows:

1. Develop a set of baseline vehicle classes from which a characteristic vehicle can be chosen to represent each class. The vehicle may be either real or theoretical and will possess the average attributes of that class as determined by sales-weighted averages.
2. Identify technologies with a potential to reduce fuel consumption.
3. Determine the applicability of each technology to the various vehicle classes.
4. Estimate each technology's preliminary impact on fuel consumption and cost.
5. Determine the optimum implementation sequence (technology pathway) based on cost-effectiveness and engineering considerations.
6. Document the cost-effectiveness and engineering judgment assumptions used in step 5 and make this information part of a widely accessible database.
7. Utilize modeling software (FSS) to progress through each technology pathway for each vehicle class to obtain the final incremental effects of adding each technology.

If such a process were adopted as part of a regulatory rulemaking procedure, it could be completed on 3-year cycles to allow regulatory agencies sufficient lead time to integrate the results into future proposed and enacted rules.

BIBLIOGRAPHY

EPA (U.S. Environmental Protection Agency). 2008a. Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008. EPA420-R-08-015. September.

EPA. 2008b. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. Ann Arbor, Mich.

NHTSA (National Highway Traffic Safety Administration). 2009. Average fuel economy standards, passenger cars and light trucks, model-year 2011: final rule, RIN 2127 AK-29, Docket No. NHTSA 2009-0062. Washington, D.C., March 23.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. EPA420-R-08-004. Prepared for the U.S. Environmental Protection Agency, Contract No. EP-C-06-003, Work Assignment No. 1-14. Ann Arbor, Mich.

Ricardo, Inc. 2009. A Study of Interaction Effects Between Light Duty Vehicle Technologies. Prepared for the NRC Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy by Ricardo Inc., Van Buren, Mich., February 27.

Sovran, G., and M.S. Bohn. 1981. Formulae for the tractive energy requirements of vehicles driving the EPA schedule, SAE Paper 810184. February.

Appendixes

A

Committee Biographies

Trevor O. Jones (NAE), *Chair* is founder, chairman, and chief executive officer (CEO) of ElectroSonics Medical, Inc. Before that, he was founder, chairman, and CEO of Biomec, Incorporated, a biomedical device company. He was formerly chairman of the board of Echlin, Incorporated, a supplier of automotive components, primarily to the aftermarket. Dr. Jones is also chairman and CEO of the International Development Corporation, a private management consulting company that advises automotive supplier companies on strategy and technology. He was chair, president, and CEO (retired) of Libbey-Owens-Ford Company, a large manufacturer of glass for automotive and construction applications. Previously, he served as vice president of engineering in the Automotive Worldwide Sector of TRW, Incorporated, and as group vice president, Transportation Electronics Group. Before joining TRW, he was employed by General Motors (GM) in many aerospace and automotive executive positions, including director of GM Proving Grounds; of the Delco Electronics Division, Automotive Electronic, and Safety Systems; and director of the GM Advanced Product Engineering Group. Dr. Jones is a life fellow of the Institute of Electrical and Electronics Engineers (IEEE) and has been cited for leadership in the application of electronics to the automobile. He is also a fellow of the Society of Automotive Engineers (SAE), a fellow of the British Institution of Electrical Engineers, a fellow of the Engineering Society of Detroit, a registered professional engineer in Wisconsin, and a chartered engineer in the United Kingdom. He holds many patents and has lectured and written on automotive safety and electronics. He is a member of the National Academy of Engineering (NAE) and a former commissioner of the National Research Council (NRC) Commission on Engineering and Technical Systems. Dr. Jones has served on several other NRC study committees, including the Committee for a Strategic Transportation Research Study on Highway Safety. He chaired the NAE Steering Committee on the Impact of Products Liability Law on Innovation and the Committee on Review of the Research Program of the Partnership for a New Generation of Vehicles for six reviews. He holds a higher national certificate in electrical engineering from Aston Technical College and an ordinary national certificate in mechanical engineering from Liverpool Technical College. Cleveland State University awarded Dr. Jones an honorary doctorate of science and cited him for contributions in the development of fuel cells and biomedical devices.

Thomas W. Asmus (NAE) is a retired senior research executive of DaimlerChrysler Corporation. He has also held positions at Mead Corporation, as an adjunct faculty member of mechanical engineering at the University of Michigan, and as a professor of physical chemistry at the University of Guadalajara, in Mexico. He has more than 30 years of experience and has played a leadership role in nearly all aspects of internal combustion engine and fuels research and development, focusing mainly on fuel consumption and exhaust emissions reduction. His entry into the field was initially based on his background in combustion and emissions formation mechanisms for both gasoline and diesel engines, but with time and circumstances his activities expanded to include gas exchange processes, controls, lubrication, many types of fault diagnoses, and heat management. New-concept analysis has become routine for Dr. Asmus. Besides having been a member of the NAE, he is a fellow of the SAE and was a recipient of the Soichiro Honda Lecture Award recipient in 1999. He has a B.S. in paper science and engineering from Western Michigan University and an M.S. and a Ph.D. in physical chemistry from Western Michigan University.

Rodica Baranescu (NAE) is a professor in the College of Engineering, Department of Mechanical and Industrial Engineering, University of Illinois at Chicago. Before that, she was manager of the fuels, lubricants, and engine group of the International Truck and Engine Corporation, at Melrose Park, Illinois. She is an internationally sought after public speaker on technical issues related to mobility technology, environmental control, fuels, and energy. She has extensive expertise in diesel engine technology and was elected to the NAE in 2001 for research leading to effective and environmentally sensitive diesel and alternative-fuel engines and leadership in automotive engineering. She is a fellow of SAE International and was its president in 2000. In 2003 she received the Internal Combustion Engine Award of the American Society of Mechanical Engineering (ASME). Dr. Baranescu received her M.S. and Ph.D. degrees in mechanical engineering in 1961 and 1970, respectively, from the Politechnica University in Bucharest, Romania, where she served as assistant professor (1964-1968), lecturer (1970-1974), and associate professor (1974-1978).

Jay Baron is president of the Center for Automotive Research (CAR) and the director of its Manufacturing, Engineering and Technology Group. Dr. Baron's recent research has focused on developing new methods for the analysis and validation of sheet metal processes, including die making, tool and die tryout, and sheet metal assembly processes. He also developed functional build procedures that result in lower tooling costs and shorter development lead times, while improving quality—particularly with sheet metal assemblies. He also has been researching new technologies in the auto industry, including looking at body shop design and flexibility and evaluating the manufacturing capability of evolving technologies. He recently completed investigations on state-of-the-art tailor-welded blank technologies, the economics of weld-bond adhesives, and the analysis of car door quality and construction methods. Before becoming first the director of manufacturing systems at CAR and then president, Dr. Baron was the manager of manufacturing systems at the Office for the Study of Automotive Transportation at the University of Michigan Transportation Research Institute. He also worked for Volkswagen of America in quality assurance and as staff engineer and project manager at the Industrial Technology Institute in Ann Arbor and at the Rensselaer Polytechnic Institute's Center for Manufacturing Productivity in Troy, New York. Dr. Baron holds a Ph.D. and a master's degree in industrial and operations engineering from the University of Michigan and an M.B.A. from Rensselaer Polytechnic Institute.

David Friedman is the research director of the Clean Vehicles Program of the Union of Concerned Scientists (UCS), Washington, D.C. He is the author or coauthor of more than 30 technical papers and reports on advancements in conventional, fuel cell, and hybrid electric vehicles and alternative energy sources with an emphasis on clean and efficient technologies. Before joining UCS in 2001, he worked for the University of California, Davis, in the fuel cell vehicle modeling program, developing simulation tools to evaluate fuel cell technology for automotive applications. He worked there on University of California's FutureCar team to build a hybrid electric family car that doubled its fuel economy. He also once worked at Arthur D. Little researching fuel cell, battery electric, and hybrid electric vehicle technologies, as well as photovoltaics. He served as a member of the NRC Panel on the Benefits of Fuel Cell R&D of the Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs, Phase 1, and is currently a member of the NRC Committee on National Tire Efficiency. He earned a bachelor's degree in mechanical engineering from Worcester Polytechnic Institute and is a doctoral candidate in transportation technology and policy at the University of California, Davis.

David Greene is a corporate fellow at the Oak Ridge National Laboratory (ORNL). He has spent more than 20 years researching transportation and energy policy issues. His research interests include energy demand modeling, economic analysis of petroleum dependence, modeling market responses to advanced transportation technologies and alternative—fuels, economic analysis of policies to mitigate greenhouse gas emissions from transportation, and developing theory and methods for measuring the sustainability of transportation systems. After joining ORNL in 1977, he founded the Transportation Energy Group in 1980 and in 1987 established the Transportation Research Section. Dr. Greene spent 1988 to 1989 in Washington, D.C., as a senior research analyst in the Office of Domestic and International Energy Policy, at the Department of Energy (DOE). He has published more than 150 articles in professional journals, written contributions to books and technical reports, and given congressional testimony on transportation and energy issues. From 1997 to 2000 Dr. Greene served as the first editor-in-chief of the *Journal of Transportation and Statistics*, the only scholarly periodical published by the U.S. Department of Transportation. He currently serves on the editorial boards of *Transportation Research D*, *Energy Policy*, *Transportation Quarterly*, and the *Journal of Transportation and Statistics*. Active in the Transportation Research Board (TRB) and the NRC, Dr. Greene has served on several standing and ad hoc committees. He is past chairman and member emeritus of TRB's Energy Committee, was past chair of the Section on Environmental and Energy Concerns, and was a recipient of TRB's Pyke Johnson Award. Dr. Greene received a B.A. degree from Columbia University in 1971, an M.A. from the University of Oregon in 1973, and a Ph.D. in geography and environmental engineering from the Johns Hopkins University in 1978.

Linos Jacovides (NAE) recently retired as director, Delphi Research Labs, a position he held from 1998 to 2007. Dr. Jacovides joined General Motors Research and Development in 1967 and became department head of electrical engineering in 1985. He is a fellow of the IEEE. His areas of research were the interactions between power electronics and electrical machines in electric vehicles and locomotives. He later transitioned to Delphi with a group of researchers from GM to set up the Delphi Research Laboratories. He received a B.S. in electrical engineering and a master's in machine theory from the University of Glasgow, Scotland. He received a Ph.D. in generator control systems from the Imperial College, University of London, in 1965.

John H. Johnson is a presidential professor emeritus in the Department of Mechanical Engineering-Engineering Mechanics at Michigan Technological University (MTU) and a fellow of the SAE and the ASME. His experience spans a wide range of analysis and experimental work on advanced engine concepts, diesel and other internal engine emissions studies, fuel systems, and engine simulation. He was previously project engineer at the U.S. Army Tank Automotive Center, and chief engineer in applied engine research at the International Harvester Company before joining the MTU mechanical engineering faculty. He served as chairman of the MTU mechanical engineering and engineering mechanics department from 1986 to 1993. He has served on many committees related to engine technology, engine emissions, and health effects—for example, committees of the SAE, the NRC, the Combustion Institute, the Health Effects Institute, and the Environmental Protection Agency—and consults to a number of government and private sector institutions. In particular, he served on many NRC committees, including the Committee on Fuel Economy of Automobiles and Light Trucks, the Committee on Advanced Automotive Technologies Plan, the Committee on the Impact and Effectiveness of Corporate Average Fuel Economy (CAFE) Standards, and the Committee to Assess Fuel Economy for Medium and Heavy-Duty Vehicles. He chaired the NRC Committee on Review of DOE's Office of Heavy Vehicle Technologies and the NRC Committee on Review of the 21st Century Truck partnership. He received his Ph.D. in mechanical engineering from the University of Wisconsin.

John G. Kassakian (NAE) is professor of electrical engineering and director of the Massachusetts Institute of Technology's (MIT's) Laboratory for Electromagnetic and Electronic Systems. His expertise is in the use of electronics for the control and conversion of electrical energy, industrial and utility applications of power electronics, electronic manufacturing technologies, and automotive electrical and electronic systems. Before joining the MIT faculty, he served in the U.S. Navy. Dr. Kassakian is on the boards of directors of a number of companies and has held numerous positions with the IEEE, including founding president of the IEEE Power Electronics Society. He is a member of the NAE, a fellow of the IEEE, and a recipient of the IEEE's William E. Newell Award for Outstanding Achievements in Power Electronics (1987), the IEEE Centennial Medal (1984), and the IEEE Power Electronics Society's Distinguished Service Award (1998). He has served on a number of NRC committees, including the Committee on Review of the Research Program of the Partnership for a New Generation of Vehicles and the Review of the FreedomCAR and Fuel Research Program. He has an Sc.D. in electrical engineering from MIT.

Roger B. Krieger is currently an adjunct professor at the engine research center of the University of Wisconsin, Madison. Before that, he was laboratory group manager, Compression Ignition Engine Systems Group at the Powertrain Systems Research Laboratory. He also held a position at the Institut Francais du Petrôle, Applications Division, Rueil-Malmaison, in France. Dr. Krieger has approximately 35 years of research and development experience in internal combustion engines, especially diesel engines and combustion. He holds approximately 10 patents related to engine and emissions control technologies. He served as vice-chair and chair of the Diesel Engine Committee, SAE. He has a B.S. and a Ph.D. in mechanical engineering from the University of Wisconsin-Madison.

Gary W. Rogers is president, chief executive officer, and sole director, FEV, Inc. His previous positions included director, Power Plant Engineering Services Division, and senior analytical engineer, Failure Analysis Associates, Inc.; design development engineer, Garrett Turbine Engine Company; and Exploration Geophysicist, Shell Oil Company. He has extensive experience in research, design, and development of advanced engine and powertrain systems, including homogeneous and direct-injected gasoline engines, high-speed direction injection passenger car diesel engines, heavy-duty diesel engines, hybrid vehicle systems, gas turbines, pumps, and compressors. He provides corporate leadership for a multinational research, design, and development organization specializing in engines and energy systems. He is a member of the SAE, is an advisor to the Defense Advanced Research Projects Agency on heavy-fuel engines, and sits on the advisory board to the College of Engineering and Computer Science, Oakland University, Rochester, Michigan. He served as a member of the NRC Committee on Review of DOE's Office of Heavy Vehicle Technologies Program, the NRC Committee on the Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, and the NRC Panel on Benefits of DOE's Light-Duty Hybrid Vehicle R&D Program. He also recently supported the Department of Transportation's National Highway Traffic Safety Administration by conducting a peer review of the NHTSA CAFE Model. He has a B.S.M.E. from Northern Arizona University.

Robert F. Sawyer (NAE) is the Class of 1935 Professor of Energy Emeritus at the University of California, Berkeley. He is a member of the NAE and recently served as chair of the California Air Resources Board. His previous positions include research engineer and chief, Liquid Systems Analysis, U.S. Air Force Rocket Propulsion Laboratory; member of the research staff, Princeton University; member, California Air Resources Board; and chair, Energy and Resources Group, University of California, Berkeley. He is a past president of the Combustion Institute. His research includes combustion chemistry, pollutant formation and control, engine emissions, toxic waste incineration, alternative fuels, and regulatory policy. Dr. Sawyer served on numerous National Research Council committees, including the Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program, the Committee to Review EPA's Mobile Source Emissions Factor (MOBILE) Model, and the Committee on Adiabatic Diesel Technology, among others. He holds a B.S. and an M.S. (mechanical engineering) from Stanford University and an M.A. (aeronautical engineering) and a Ph.D. (aerospace science) from Princeton University.

B

Statement of Task

The committee formed to carry out this study will provide updated estimates of the cost and potential efficiency improvements of technologies that might be employed over the next 15 years to increase the fuel economy of various light-duty vehicle classes. Specifically, the committee shall:

1. Reassess the technologies analyzed in Chapter 3 of the NRC report, *Impact and Effectiveness of Corporate Average Fuel Economy (CAFE) Standards* (2002), for efficacy, cost, and applicability to the classes of vehicles considered in that report. In addition, technologies that were noted but not analyzed in depth in that report, including direct injection engines, diesel engines, and hybrid electric vehicles, shall be assessed for efficacy, cost and applicability. Weight and power reductions also shall be included, though consideration of weight reductions should be limited to advances in structural design and lightweight materials. The assessments shall include the effects of "technology sequencing"—in what order manufacturers might conceivably incorporate fuel economy technologies, and how such ordering affects technology cost and applicability.
2. Estimate the efficacy, cost, and applicability of emerging fuel economy technologies that might be employed over the next 15 years. The assessments shall include the effects of technology sequencing as defined in (1) above.
3. Identify and assess leading computer models for projecting vehicle fuel economy as a function of additional technology. These models would include both:

   - Lumped parameter (or Partial Discrete Approximation) type models, where interactions among technologies are represented using energy partitioning and/or scalar adjustment factors (also known as synergy factors), and
   - Full vehicle simulation, in which such interactions are analyzed using explicit drive cycle and engine cycle simulation, based on detailed vehicle engineering characteristics (*e.g.*, including engine maps, transmission shift points, etc.).

   Check the models against current, known fuel economy examples and select one of each type to perform the analyses of the effects of the technologies in 1 and 2 above.

4. Develop a set of cost/potential efficiency improvement curves, as in Chapter 3 of the 2002 NRC report, that is guided by the following question: "What is the estimated cost and potential fuel economy benefit of technologies that could be applied to improve the fuel economy of future passenger vehicles, given the constraints imposed by vehicle performance, functionality, safety and emission regulations?" The ten vehicle classes considered in the 2002 report shall be analyzed, including important variants such as different engine sizes (e.g., 6 and 8 cylinders). Most analyses shall be performed with the lumped parameter model, but sufficient cases to ensure overall accuracy shall be checked with the engine mapping model.
5. Define and document the specific methodology(ies) and inputs used to estimate the incremental costs and benefits of the fuel economy technologies chosen by the committee, including the methods used to account for variations in vehicle characteristics (e.g., size, weight, engine characteristics) and to account for the sequential application of technologies. Use flow charts or similar methods to document sequencing upon which the committee's estimates of incremental costs and benefits are based. Although methodologies vary, the committee's report should detail all of its calculation methodology(ies), even those as basic as simple mathematical relationships (if used) and as complex as structural representations, such as decision trees (if used). It should do so to levels of specificity, clarity and completeness sufficient for implementation and inte-

gration into models that project the fuel economy capability of vehicles, fleets and manufacturers, including fleets specified at the level of individual vehicle models, engines, and transmissions. The report should also provide and document estimates of all input data required for implementation of these methodologies.

6. Assess how ongoing changes to manufacturers' refresh and redesign cycles for vehicle models affect the incorporation of new fuel-economy technologies.

The committee's analysis and methodologies will be documented in two NRC-approved reports. An interim report will discuss the technologies to be analyzed, the classes of vehicles which may employ them, the estimated improvement in fuel economy that may result, and the models that will be used for analysis. The final report will include the detailed specifications for the methodologies used and the results of the modeling, and will make use of the input from the interim report and any new information that is available.

C

List of Presentations at Public Committee Meetings

WASHINGTON, D.C., SEPTEMBER 10-11, 2007

Julie Abraham, National Highway Traffic Safety Administration, *Fuel Economy Technology Study*
William Charmley, EPA Office of Transportation and Air Quality representative, *Greenhouse Gases and Light-Duty Vehicles*
Coralie Cooper, Northeast States for Coordinated Air Use Management, *Technical Feasibility and Costs Associated with Reducing Passenger Car GHG Emissions*
John German, USA Honda, *Advanced Technologies, Diesels, and Hybrids*
Dan Hancock, GM Powertrain, *Assessing Powertrain Fuel Economy*
John Heywood, Massachusetts Institute of Technology, *Challenges in Estimating Future Vehicle Fuel Consumption*
Aymeric Rousseau, Argonne National Laboratory, *Designing Advanced Vehicle Powertrains Using PSAT*
Wolfgang Stütz, BMW of North America, *Fuel Economy of BMW Diesel Vehicles*

WASHINGTON, D.C., SEPTEMBER 27, 2007

K.G. Duleep, Energy and Environmental Analysis, Inc., *Approaches to Modeling Vehicle Fuel Economy*
Kevin Green, The Volpe Center, *CAFE Compliance and Effects Modeling System*
Marc Wiseman, Ricardo, Inc., *Potential Approaches to Modeling Fuel Economy Technologies: Engine Simulation Modeling Capabilities and Cost Analysis Capabilities*

WASHINGTON, D.C., OCTOBER 25-26, 2007

Manahem Anderman, Advanced Automotive Batteries, *Lithium-Ion Batteries for Hybrid Electric Vehicles: Opportunities and Challenges*
Mark Daroux, Stratum Technologies, Inc., *Lithium Ion Phosphate Batteries for Traction Application*
Tien Duong, U.S. Department of Energy, *Status of Electrical Energy Storage Technologies*
Michel Forissier, Valeo, *Fuel Economy Solutions*
Bart Riley, A123 Systems, *A123 Systems Battery Technologies*

WASHINGTON, D.C., NOVEMBER 27-28, 2007

Khalil Amine, Argonne National Laboratory, *Advanced High Power Chemistries for HEV Applications*
Paul Blumberg, Ethanol Boosting Systems, LLC, *Ethanol Turbo Boost for Gasoline Engines: Diesel and Hybrid Equivalent Efficiency at an Affordable Cost*
Frank Fodal, Chrysler LLC, *Fuel Economy/Fuels*
David Geanacopoulos, Volkswagen of America, Inc., *Diesel Technology for VW*
Johannes Ruger, Bosch, *Increasing Fuel Economy: Contribution of Bosch to Reach Future Goals*
Robert Wimmer and Shunsuke Fushiki, Toyota, *Toyota Hybrid Program*

WASHINGTON, D.C., JANUARY 24-25, 2008

Steve Albu, California Air Resources Board, *ARB Perspective on Vehicle Technology Costs for Reducing Greenhouse Gases*
Wynn Bussman, Consultant, *Study of Industry-Average Mark-up Factors Used to Estimate Retail Price Equivalents (RPE)*
K.G. Duleep, Energy and Environmental Analysis, Inc., *Analysis of Technology Cost and Retail Price*
Kevin McMahon, Martec Group, *Variable Costs of Fuel Economy Technologies*
James Lyons, Sierra Research, Inc., *Technology and Retail Price Implications of More Stringent CAFE Standards Based on Vehicle Simulation Modeling*

WASHINGTON, D.C., FEBRUARY 25-26, 2008

Julie Abraham, National Highway Traffic Safety Administration, *Update from NHTSA on Regulatory Activities and Other Analysis*

WASHINGTON, D.C., MARCH 31-APRIL 1, 2008

David Haugen and Matt Brustar, EPA Office of Transportation and Air Quality, *Discussion of EPA's Modeling of Fuel Economy*

K.G. Duleep, Energy and Environmental Analysis, Inc., *Assessment of Costs and Fuel Economy Benefits*

WASHINGTON, D.C., JUNE 3-4, 2008

Michael Bull, Aluminum Association, *Opportunities for Reducing Vehicle Mass*

Bruce Moor, Delphi Electronics and Safety, *Power Electronics Systems Solutions for HEV Architectures*

Huang-Yee Iu, Hymotion, *Hymotion Plug-in Hybrid Vehicle*

WASHINGTON, D.C., SEPTEMBER 9-10, 2008

Susan Yester, Chrysler, *Opportunities for Reducing Vehicle Mass*

Joseph Kubish, Manufacturers of Emissions, Control Equipment Association, *Aftertreatment Technologies and Strategies for Light Duty Vehicles with Emphasis on* NO_x *and Particulates*

Frank Fronczak, University of Wisconsin, *Hydraulic Hybrid Vehicle*

John Kargul, EPA Clean Automotive Technology Program, *EPA's Hydraulic Hybrid Program*

WASHINGTON, D.C., MARCH 16-18, 2009

EPA Office of Transportation and Air Quality, *Update from EPA on Analysis of RPE and Separate Ongoing Work on Estimates of Analysis of Direct Manufacturing Costs of Technologies*

D

Select Acronyms

AWD	all-wheel drive
BMEP	brake mean effective pressure
BOM	bill of materials
BSFC	brake specific fuel consumption
CAFE	corporate average fuel economy
CDPF	catalyzed diesel particulate filter
CI	compression ignition
CO_2	carbon dioxide
CR	compression ratio
CVVL	continuously variable valve lift
DCP	dual cam phasing
DCT	dual-clutch transmission
DI	direct injection
DISI	direct injection spark ignition
DOC	diesel oxidation catalyst
DOHC	dual overhead cam
DOT	U.S. Department of Transportation
DPF	diesel particulate filter
DVVL	discrete variable valve lift
E85	85 percent ethanol
EACC	electric accessories
ECU	engine control unit
EEA	Energy and Environmental Analysis, Inc.
EGR	exhaust gas recirculation
EPA	U.S. Environmental Protection Agency
EU	European Union
EVO	exhaust valve opening
FAME	fatty acid methyl ester
FC	fuel consumption
FE	fuel economy
FSS	full system simulation
FTP	Federal Test Procedure
FWD	four-wheel drive
GDI	gasoline direct injection
GHG	greenhouse gas
GM	General Motors Company
HC	hydrocarbon
HCCI	homogeneous-charge compression ignition
HEV	hybrid-electric vehicle
HWFET	highway fuel economy test schedule (or highway cycle)
I4	inline four-cylinder engine
IC	internal combustion
ICP	intake-cam phasing
IVC	intake-valve closing
LBL	low-viscosity lubricants
LDV	light-duty vehicle
LEV	low-emissions vehicle
LNT	lean NO_x traps
LP	low pressure
LTC	low-temperature combustion
LVL	low-viscosity lubricant
MBT	maximum brake torque
MPFI	multipoint fuel injection
mpg	miles per gallon
MSRP	manufacturer's suggested retail price
NA	North American
NESCCAF	Northeast States Center for a Clean Air Future
NHTSA	National Highway and Traffic Safety Administration
NO_x	nitrous oxides
NSC	NO_x storage and reduction catalyst
NRC	National Research Council
NVH	noise, vibration, and harshness
OBD	on-board diagnostics

OEM	original equipment manufacturer
OHV	overhead valve
PCCI	premixed charge compression ignition
PDA	partial discrete approximation
PFI	port fuel injection
PGM	platinum group metal
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
R&D	research and development
RPE	retail price equivalent
RWD	rear-wheel drive
SAE	Society of Automotive Engineers
SCR	selective catalytic reduction
SGDI	stoichiometric gasoline direct injection
SI	spark ignition
SOC	state of charge
SOHC	single overhead cam
SUV	sport utility vehicle
UDDS	urban dynamometer driving schedule
ULEV	ultralow-emissions vehicle
V6	six cylinder V engine
VEL	valve event and lift
VEM	valve-event modulation
VGT	variable geometry turbochargers
VVL	variable valve lift

E

Comparison of Fuel Consumption and Fuel Economy

Figure E.1 shows the relationship between fuel consumption (FC) and fuel economy (FE), including the slope of the curve that relates them (Johnson, 2009). The slope, which is negative, and the shape of this relationship are important. The slope indicates the change in FC relative to a change in FE—e.g., when the magnitude of the slope is high, such as at 10 mpg, there is large change in FC for a small change in FE. At 50 mpg, however, there is little change in FE since the magnitude of the slope is very low and approaching zero as indicated by the right-hand slope scale on Figure E.1. Fuel consumption decreases slowly after 40 mpg since the slope (lower curve and right-hand scale) of the fuel consumption versus fuel economy (Figure E.1) curve approaches zero. The slope rapidly decreases past 40 mpg since it varies as the inverse of the FE squared, which then results in a small decrease in FC for large FE increases. This fact is very important since fuel consumption is the metric in CAFE. Furthermore, the harmonic average[1] in the CAFE standards is determined as the sales-weighted average of the fuel consumption for the urban and highway schedules converted into fuel economy. Figure 2.2 was derived from Figures 2.1 and E.1 to show how the share of fuel consumption decrease is related to percent increase of fuel economy.[2] The curve in Figure 2.2 is independent of the value of fuel economy and is calculated by the equation in footnote 2. For example, the fuel consumption is 2.5 gal/100 mi at 40 mpg and 1.25 gal/100 mi at 80 mpg, which is a 40 mpg change in fuel economy (100 percent increase in FE) and a change in fuel consumption of only 1.25 gal/100 mi (50 percent decrease in FC), as shown by the lines on the FC vs. FE curve in Figure E.1. In going from 15 to 19 mpg, there is an approximate 1.25 gal/100 mile change in fuel consumption. The nonlinear relationship between fuel consumption and fuel economy gives significantly more weight to lower fuel economy vehicles (15-40 mpg—i.e., 6.5-2.5 gal/100 mi) than to those greater than 40 mpg. Going beyond 40 mpg there is a perception that fuel efficiency is improving faster than the actual change in fuel consumption. For a fleet that contains a large number of vehicles in the 15-35 mpg range, the vehicles with a fuel economy greater than 40 mpg contribute only a small amount to the weighted average CAFE fuel economy, assuming that there are fewer 40-mpg vehicles than 15- to 35-mpg vehicles.

Fuel consumption difference is also the metric that determines the yearly fuel savings in going from a given fuel economy vehicle to a higher fuel economy vehicle:

$$\text{Yearly fuel savings} = \text{yearly miles driven} \times (FC_1 - FC_2)/100 \qquad \text{(E.1)}$$

where FC_1 = fuel consumption of existing vehicle, gal/100 mi, and FC_2 = fuel consumption of new vehicle, gal/100 mi. The amount of fuel saved in going from 14 to 16 mpg for 12,000 miles per year is 107 gal. This savings is the same as a change in fuel economy for another vehicle in going from 35 to 50.8 mpg. Equation E.1 and this example again show how important fuel consumption is to judging yearly fuel savings.

[1]Harmonic average weighted CAFE = $\dfrac{\sum_1^n N_n}{\sum_1^n N_1 \dfrac{1}{FE_1} + \ldots + N_n \dfrac{1}{FE_n}}$

where N_n = number of vehicles in class n; FE_n = fuel economy of class n vehicles; and n = number of separate classes of vehicles.

[2]If $FE_f = (FE_2 - FE_1)/FE_1$ and $FC_f = (FC_1 - FC_2)/FC_2$ where FE_1 and FC_1 = FE and FC for vehicle baseline and FE_2 and FC_2 = FE and FC for vehicle with advanced technology, then, $FC_f = FE_f/(FE_f + 1)$ where FE_f = fractional change in fuel economy and FC_f = fractional change in fuel consumption. This equation can be used for any change in FE or FC to calculate the values shown in Figure 2.2. Also, $FE_f = FC_f/(1 - FC_f)$ and $\%FC = 100\, FC_f$, $\%FE = 100\, FE_f$.

REFERENCE

Johnson, J. 2009. Fuel consumption and fuel economy. Presentation to the National Research Council Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, April 7, Dearborn, Mich.

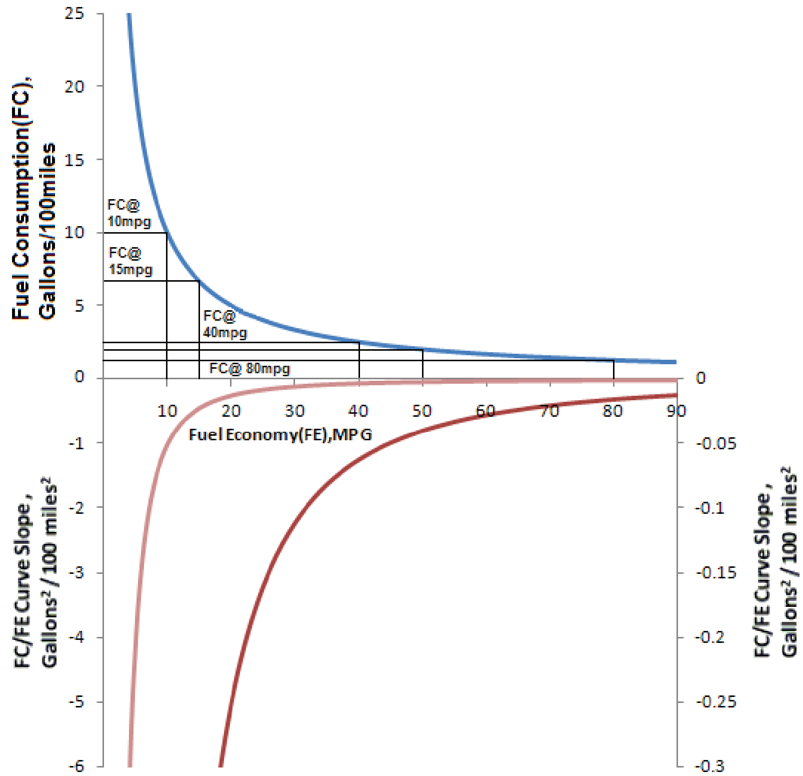

FIGURE E.1 Fuel consumption (FC) versus fuel economy (FE) and slope of FC/FE curve (two curves and two different scales). SOURCE: Johnson (2009). Reprinted with permission.

F

Review of Estimate of Retail Price Equivalent Markup Factors

Vyas et al. (2000) of Argonne National Laboratory (ANL) compared their own markup factors to estimates developed by Energy and Environmental Analysis, Inc. (EEA) and Borroni-Bird. Two different markup factors were compared: (1) the markup over direct manufacturing (variable) costs for components produced in house and (2) the markup for components purchased fully manufactured from outside suppliers. In the ANL analysis, costs of manufacture include materials, assembly labor, and other manufacturing costs but not depreciation, amortization, warranty, or R&D and engineering (Table F.1). Other costs borne by the original equipment manufacturer (OEM) are corporate overhead, benefits (retirement and health care), and distribution, marketing, and dealer costs, including dealer profits.

Because the cost categories used by Borroni-Bird and EEA differed from those used by the ANL study, an exact comparison is not possible (Table F.2). While Vyas et al. (2000) concluded that the three sets of estimates were quite close, the different definitions cloud the issue. For example, Vyas et al. (2000) assumed that half of the costs—shown by Borroni-Bird as transportation/warranty; amortization and depreciation; engineering R&D, pension and health, advertising, and overhead—would be borne by the outside supplier. In their own estimates they allocate all warranty, R&D/engineering, and depreciation and amortization costs to the supplier. Clearly, even components purchased fully manufactured from a Tier 1 supplier will incur costs just for their engineering into the vehicle system and are likely to lead to some warranty costs beyond those covered by the supplier. Still, the bottom-line markup over variable manufacturing costs is very similar: 2.05 for the Borroni-Bird analysis versus 2.00 for the ANL analysis.

The Vyas et al. (2000) memorandum also summarized the cost methodology used by EEA, Inc., in a study for the Office of Technology Assessment (OTA, 1995), although it should be noted that the auto industry has undergone dramatic changes since that time, and the continued applicability of the methodology is debatable. Again, the cost categories differ, but the bottom-line markup over variable manufacturing costs is similar although a bit higher: 2.14 (Table F.3). To get an idea of the markup over outsourced component costs, the ANL analysts again assumed that the supplier would bear the costs of warranty, R&D engineering, and depreciation and amortization. Since EEA methods do not separate warranty costs from manufacturing overhead, Vyas et al. (2000) assumed that warranty costs made up half of the overhead costs. With those assumptions they obtained a markup factor of 100/(33.6 + 6.5 + 6.5 + 10.3/2 + 12.1) = 1.56. This leaves only a bit more than 5 percent of the total retail price equivalent (RPE) for the costs of integrating components into the overall vehicle design, assembly, and other OEM assembly costs.

The ANL memorandum concludes that all three sources would result in very similar markup factors (Table F.4). However, for markups over Tier 1 supplier costs, the ANL decision on how to allocate the costs has a lot to do with the similarities. A less generous allocation of warranty, assembly, and manufacturing overhead costs to suppliers would result in higher markup factors for outsourced components. Despite these ambiguities, the ANL comparison reasons that the markup for in-house-made components would be about twofold rather than the 1.5-fold markup for components purchased from Tier 1 suppliers.

A markup factor of 1.5 was used by NHTSA (DOT/NHTSA, 2009, p. 173) in its final fuel economy rule for 2011. A somewhat lower RPE markup factor of 1.4 was used by NRC (2002) and by S. Albu, assistant chief, Mobile Source Division, California Air Resources Board, in his presentation to the committee (Albu et al., 2008), while the EPA has used a markup of approximately 1.3 (EPA, 2008).

A markup of approximately 2 over the direct manufacturing cost of parts manufactured in house by an OEM was also supported by Bussmann in a presentation, "Study of industry-average markup factors used to estimate retail price equivalents (RPE)," to the committee on January 24, 2008. In that briefing, Bussman cited a 2003 study of the global automotive industry by McKinsey Global Institute, which came up with a markup factor of 2.08, and his own analysis

TABLE F.1 Components of Manufacturer's Suggested Retail Price (MSRP) Equivalent RPE: ANL Method

Cost Category	Cost Contributor	Relative to Cost of Vehicle Manufacture	Share of MSRP (%)
Vehicle manufacture	Cost of manufacture	1.00	50.0
Production overhead	Warranty	0.10	5.0
	R&D engineering	0.13	6.5
	Depreciation and amortization	0.11	5.5
Corporate overhead	Corporate overhead, retirement, health	0.14	7.0
Selling	Distribution, marketing, dealers	0.47	23.5
Sum of costs		1.95	97.5
Profit	Profit	0.05	2.5
Total contribution to MSRP		2.00	100.0

SOURCE: Vyas et al. (2000).

TABLE F.2 Components of MSRP: Estimated by Borroni-Bird

Cost Category	Cost Contributor	Relative to Cost of Vehicle Manufacture	Share of MSRP (%)
Vehicle manufacture	Materials	0.87	42.4
	Labor, other manufacturing costs	0.13	6.3
Fixed cost	Transportation and warranty	0.09	4.4
Fixed cost	Amortization and depreciation, engineering R&D, pension and health care, advertising, and overhead	0.44	21.5
Selling	Price discounts	0.10	4.9
	Dealer markup	0.36	17.6
Sum of costs		1.99	97.1
Profit		0.06	2.9
MSRP		2.05	100.0

SOURCE: As reported by Vyas et al. (2000).

TABLE F.3 Components of Retail Price Equivalent: EEA, Inc., Method

Cost Category	Cost Contributor	Relative to Cost of Vehicle Manufacture	Share of MSRP (%)
Vehicle manufacture	Division costs	0.72	33.6
	Division overhead	0.14	6.5
	Assembly labor and overhead	0.14	6.5
Overhead	Manufacturing overhead	0.22	10.3
	Amortized engineering, tooling, and facilities	0.26	12.1
Selling	Dealer margin	0.49	22.9
Sum of costs		1.97	92.1
Profit		0.17	7.9
Total		2.14	100.0

SOURCE: EEA, Inc. (1995), as reported by Vyas et al. (2000).

TABLE F.4 Comparison of Markup Factors

Markup Factor for	ANL	Borroni-Bird	EEA
In-house components	2.00	2.05	2.14
Outsourced components	1.50	1.56	1.56

SOURCE: Vyas et al. (2000).

of Chrysler data for 2003-2004, which produced factors of 1.96-1.97. Since these markup factors apply to direct manufacturing costs, they are consistent with the estimates shown in Table F.4. Lyons (2008) used a markup factor of approximately 2.0 but was not specific about the cost components included in the estimate to which this factor was applied.

Information supplied to the committee in the presentation by Duleep on January 25, 2008, implies higher markup factors (Duleep, 2008). Assuming a reference cost of 1.00 for the variable factors used to produce a component (material, labor, energy, factory overhead), EEA calculates the Tier 1 supplier cost by applying multiplicative markups for supplier overhead and profit and an additive factor of 0.1 to 0.2 for tooling, facilities, and engineering (Table F.5). The range is intended to reflect the complexity of the component and the engineering effort required of the supplier to ensure its integration into the full vehicle system. Representing the variable costs by X, the total supplier price markup is given by equation 1:

$$\begin{aligned} SupplierRPE_{Low} &= X(1 + 0.20 + 0.05) + 0.10 = \\ &\quad 1.00(1.25) + 0.10 = 1.35 \\ SupplierRPE_{High} &= X(1 + 0.20 + 0.05) + 0.20 = \\ &\quad 1.00(1.25) + 0.20 = 1.45 \end{aligned} \tag{1}$$

In the EEA method, OEM costs include amortization of tooling, facilities and engineering, and overhead, profit and selling costs, which include marketing, distribution, and dealer costs. EEA assumes an average manufacturer profit of 8 percent, somewhat higher than the 5 percent assumed by ANL and the 6 percent assumed by Borroni-Bird. Amortized costs vary from 5 percent to 15 percent, again depending on the complexity of the part and the costs of integrating it into the vehicle system. Marketing, distribution, and dealer costs are multiplicative and add 25 percent to the OEM costs (Figure F.1).

$$\begin{aligned} RFE_{Low} &= SupplierCost_{Low}\,(1 + 0.20 + 0.08) + 0.05 = \\ &\quad 1.35(1.28) + 0.05 = 1.78 \\ RFE_{High} &= SupplierCost_{High}\,(1 + 0.20 + 0.08) + 0.15 = \\ &\quad 1.45(1.28) + 0.15 = 2.10 \end{aligned} \tag{2}$$

The resulting markup ranges are 2.22 to 2.51 for the markup over variable costs (corresponding to the ANL "vehicle manufacturing" costs) and 1.65 to 1.73 for the markup over Tier 1 supplier costs (corresponding to the ANL cost of outsourced components). The full breakdown of EEA markup estimates is shown in Table F.5. The markups are comparable to those proposed by Vyas et al. (2000) but higher by a meaningful amount, as shown in Figure F.2. In a note, EEA-ICF, Inc., argues that higher supplier amortized costs are generally associated with lower OEM amortized costs for any give™n part. However, this assertion was not applied here to develop the range of markup factors based on EEA data.

Average RPE factors can be inferred by costing out all the components of a vehicle, summing them to estimate OEM Tier 1 costs or fully burdened in-house manufacturing costs, and then dividing the sum into the selling price of the vehicle. The committee contracted with IBIS Associates (2008) to conduct such an analysis for two popular vehicles: (1) the Honda Accord sedan and (2) the Ford F-150 pickup truck. Current model year (2009) designs and base model trim levels (no nonstandard options) were chosen. Base models

TABLE F.5 Fuel Economy Technology Cost Markup Factors

Item	Cost Low	Cost High	Share Low %	Share High %
Supplier costs				
Factors (materials, labor, energy, factory overhead)	1.00	1.00	45	40
Supplier overhead	0.20	0.20	9	8
Supplier profit	0.05	0.05	2	2
Amortization of tooling + facilities + engineering	0.10	0.20	4	8
Supplier subtotal	1.35	1.45	61	58
Supplier markup	1.35	1.45		
OEM costs				
OEM overhead	0.20	0.20	12	12
OEM profit	0.08	0.08	5	5
Tooling + facilities + engineering amortization	0.05	0.15	2	6
OEM subtotal	1.78	2.01	80	80
OEM markup	1.32	1.38		
Marketing, transport, dealer markup	0.25	0.25	20	20
Total	2.22	2.51	100	100
RPE markup (over factors)	2.22	2.51		
RPE markup (over supplier price)	1.65	1.73		

SOURCE: EEA-ICF, Inc., as reported by Duleep in his presentation to the committee on January 25, 2008.

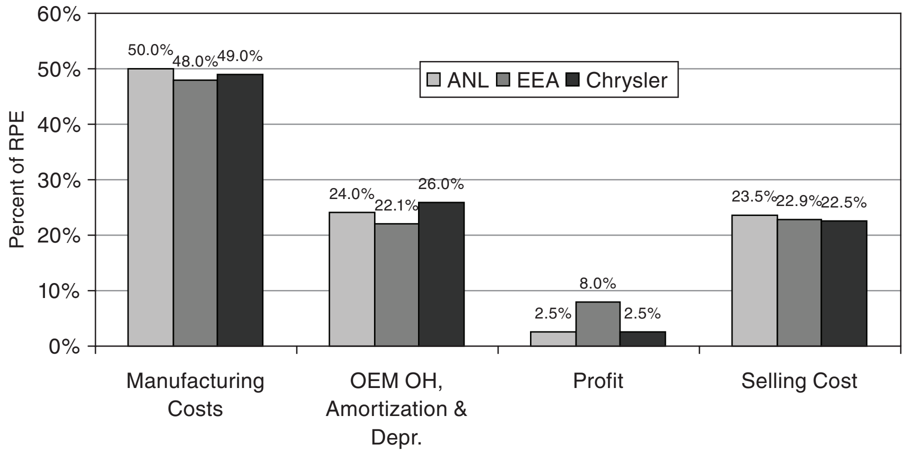

FIGURE F.1 Components of retail price equivalent (RPE) markup. SOURCE: Duleep (2008).

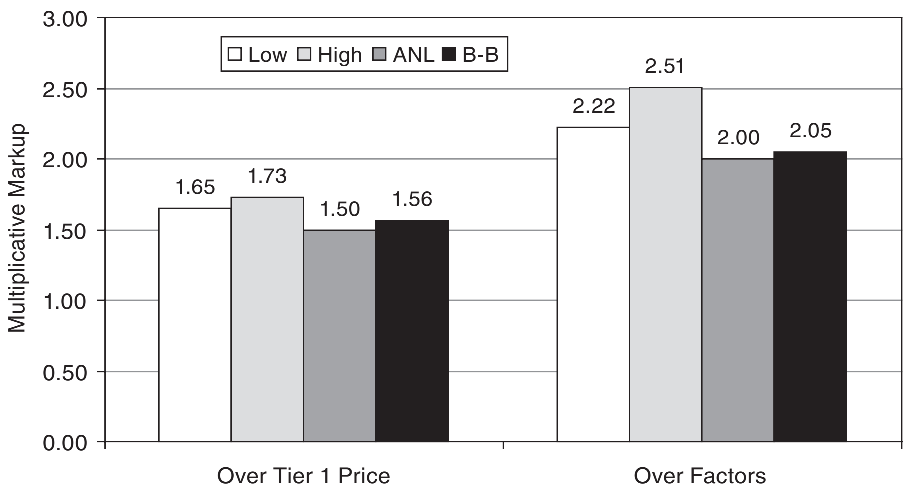

FIGURE F.2 Comparison of Duleep (2008) high/low, Argonne National Laboratory (ANL), and Borroni-Bird (B-B) cost markup factors.

were chosen to reduce the influence of market pricing decisions not driven by manufacturing costs.

Cost estimates were developed for subcomponents in terms of costs paid by OEMs for automotive components and subsystems in five broad systems. Although many of the components are manufactured in house, the costs of these components were estimated using the fixed or indirect manufacturing costs normally borne by a Tier 1 supplier. Results for the base Honda Accord are shown in Table F.6. The base vehicles are the four-door LX sedans produced in Marysville, Ohio, and Lincoln, Alabama. The curb weight of this vehicle is 3,230 lb, with a V6, 3.0-L, dual overhead cam engine, a five-speed manual transmission, and a stamped steel unibody with a lightweight aluminum subframe. Dealer invoice cost for the Accord is $18,830, MSRP is $20,755, and the average market transaction price is $19,370. The cost of all components plus assembly costs is estimated to be $14,564. This results in multipliers of 1.39 to market transaction price and 1.49 to MSRP. The multiplier to dealer invoice cost is 1.35, which means that dealer costs, including profit, amount to about 4 percent of manufacturing costs, not considering any dealer incentives offered by OEMs.

The base 2009 Ford F-150s are two-door XL Regular Cab Styleside short-bed, rear-wheel-drive pickups produced in Dearborn, Michigan, and Kansas City, Missouri. The curb weight of the vehicle is 4,743 lb, with a standard V8, 4.6-L, single overhead valve engine and a four-speed automatic transmission. The truck has a stamped steel body on frame construction. Dealer invoice cost for the F-150 is $20,055, MSRP is $21,565, and the average market transaction price is $21,344. The cost of all components plus assembly is $14,940, as shown in Table F.7. This means an RPE multiplier of 1.52 for market price and 1.54 for MSRP. The markup factor for the dealer invoice is 1.43, so that dealer costs and profit amount to about 9 percent of total manufacturing costs, not including any possible OEM incentives to dealers.

TABLE F.6 Cost Breakdown of Base 2009 Honda Accord LX

	Accord LX Base 2009		
	Mass (kg)	Cost ($)	Detail
Power train	609	6,677	
Engine	206	2,782	I4 2.4 DOHC AL/AL
Battery	20	58	Lead-acid, standard
Fuel storage and delivery	86	388	Gasoline, 18.5 gal
Transmission	70	621	Manual, 5-speed
Thermal management	23	150	
Driveshaft/axle	84	1,189	
Differential	26	203	
Cradle	25	161	Aluminum
Exhaust system	34	300	
Oil and grease	15	25	
Power train electronics	10	400	
Emission control electronics	10	400	
Body	451	2,234	
Body-in-white	307	1,006	Midsize steel unibody
Panels	60	197	Stamped steel midsize
Front/rear bumpers	10	30	Sheet steel
Glass	40	250	Conventional, 4 mm
Paint	12	450	Solvent-borne, average color
Exterior trim	10	50	
Hardware	10	226	
Seals and NVH control	2	24	
Chassis	181	1,643	
Corner suspension	30	217	Lightweight
Braking system	46	404	ABS
Wheels and tires	80	472	Alloy 16″
Steering system	26	549	
Interior	151	2,156	
Instrument panel	24	110	
Trim and insulation	22	429	
Door modules	25	220	
Seating and restraints	60	1,122	
HVAC	20	275	
Electrical	33	1,250	
Interior electrical	11	500	
Chassis electrical	11	500	
Exterior electrical	11	250	
Total components	1,426	13,959	
Final assembly	40	605	
Interior to body	5	140	
Chassis to body	10	90	
Power train to body	10	90	
Electronics to body	5	80	
Other systems to body	10	205	
Total manufacturing	1,466	14,564	

NOTE: DOHC, double overhead cam shaft; HVAC, heating, air conditioning, cooling; NVH, noise, vibration and, harshness; and ABS, automatic braking system.
SOURCE: IBIS (2009).

BIBLIOGRAPHY

Albu, S., California Air Resources Board. 2008. ARB perspective on vehicle technology costs for reducing greenhouse gas emissions. Presentation to the National Research Council Committee on Technologies for Improving Light-Duty Vehicle Fuel Economy on January 24.

Bussmann, W.V., and M.J. Whinihan. 2009. The Estimation of Impacts on Retail Prices of Regulations: A Critique of Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Prepared for the Alliance of Automobile Manufacturers, Southfield, Mich. May 6.

DOT/NHTSA (U.S. Department of Transportation/National Highway Traffic Safety Administration). 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2001: Final Rule. 49 CFR Parts 523, 531, 533, 534, 536, and 537, Docket No. NHTSA-2009-0062, RIN 2127-AK29. DOT/NHTSA, Washington, D.C. March 23.

Duleep, K.G. 2008. Analysis of technology cost and retail price. Presentation to the National Research Council Committee on Technologies for Improving Light-Duty Vehicle Fuel Economy, January 24.

TABLE F.7 Cost Breakdown of Base 2009 F-150

	F-150 Pickup XL Base		
	Mass (kg)	Cost ($)	Detail
Power train	922	7,666	
Engine	308	3,971	V8 4.6 L SOHC CI/AL
Battery	29	84	Lead-acid, standard
Fuel storage and delivery	102	440	Gasoline, 25 gal
Transmission	118	1,068	Auto 4 pickup truck
Thermal management	45	150	
Driveshaft/axle	150	608	Pickup truck 2WD steel
Differential	37	116	Light truck
Cradle	25	103	Hydroformed steel
Exhaust system	68	300	
Oil and grease	15	25	
Power train electronics	10	400	
Emission control electronics	16	40	
Body	672	2,258	
Body-in-white	500	1,020	Pickup truck body on frame
Panels	55	177	Stamped steel pickup truck
Front/rear bumpers	20	60	Medium truck
Glass	51	250	
Paint	12	450	Solvent-borne, average color
Exterior trim	12	50	
Hardware	13	226	
Seals and NVH control	10	24	
Chassis	348	1,719	
Corner suspension	119	413	Pickup truck 2WD
Braking system	79	520	Light truck ABS 4-wheel
Wheels and tires	105	334	Steel 17”
Steering system	44	453	Pickup truck
Interior	128	1,570	
Instrument panel	24	100	
Trim and insulation	28	350	
Door modules	22	156	
Seating and restraints	40	820	
HVAC	15	144	
Electrical	27	832	
Interior electrical	7	232	
Chassis electrical	10	400	
Exterior electrical	10	200	
Total components	2,098	14,045	
Final assembly	52	905	
Interior to body	10	200	
Chassis to body	10	150	
Power train to body	10	150	
Electronics to body	10	100	
Other systems to body	10	305	
Total manufacturing	2,150	14,950	

NOTE: SOHC, single overhead camshaft.
SOURCE: IBIS (2008).

EPA (U.S. Environmental Protection Agency). 2008. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. Ann Arbor, Mich.

IBIS Associates, Inc., Waltham, Mass. 2008. Data Collection and Analysis: Vehicle Systems Costs. Report to the National Research Council Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy. December.

Lyons, J.M., Sierra Research, Inc. 2008. Technology and retail price implications of HR6 CAFE standards based on vehicle simulation modeling (preliminary results). Presentation to the National Research Council Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, January 24.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

OTA (Office of Technology Assessment). 1995. Advanced Automotive Technology: Visions of a Super-Efficient Family Car. OTA-ETI-638. Washington, D.C.

Vyas, A., D. Santini, and R. Cuenca. 2000. Comparison of Indirect Cost Multipliers for Vehicle Manufacturing. Center for Transportation Research, Argonne National Laboratory. Argonne, Ill. April.

G

Compression-Ignition Engine Replacement for Full-Size Pickup/SUV

The analysis and discussion for the main part of Chapter 5 were based on two vehicle classes—namely, a midsize sedan such as the Accord, Camry, Fusion, or Malibu and a midsize SUV such as the Durango, Explorer, or Trailblazer. To enable projections for the entire range of vehicle classes discussed in Chapter 9, it was necessary to create an additional engine specification to provide a CI replacement for the 5.3- to 6.2-L V8 SI engines which would be found in full-size body-on-frame pickup trucks such as the F150, the Silverado, and the Ram 1500 and SUVs such as the Expedition and Tahoe. Table 5.5 in Chapter 5 described a V6 CI engine with displacement between 2.8 and 3.5 L appropriate for midsize SUVs and midsize pickup trucks. For cost reasons, there is a range of displacements for which OEMs would tend to design and build V6 rather than V8 engines since V6s require fewer parts. For CI engines, this V6 range would be from about 2.9 L to perhaps 4.5 L. It was therefore assumed in this additional analysis that the V8 SI engines typically used in full-size pickups would be replaced by a V6 CI engine as long as the torque and power required for equal performance could be achieved. With a base-level specification at a specific torque of 160 N-m/L, the displacement required for a CI V6 to replace an SI V8 of the displacement range 5.3-6.2 L would be 4.4-5.2 L, which is really too large for the V6 configuration. However, from a cost point of view, the V6 configuration would be preferable to a V8 if a V6 concept could be identified that meets the requirements. If no base-level configuration were considered, an advanced-level V6 of 3.5 L could easily provide sufficient torque to replace a 6.2-L SI V8 and could be manufactured with the same set of tooling as the V6 engine whose cost increments are described in Tables 5.5 and 5.8. Therefore, for the full-size pickup class of vehicles, it was assumed in this analysis that the CI replacement for SI V8 engines would be a V6 of displacement up to 3.5 L with advanced-level technology. Cost estimates for such an engine are shown in Tables G.1 to G.3.

TABLE G.1 Incremental CI-Diesel Engine Cost Estimations to Replace SI MPFI OHV Two-Valve 5.3- to 6.2-L V8 Engine in a Full-Size Body-on-Frame Pickup (e.g., Silverado and Ram) or SUV with a 3.5-L V6 DOHC CI

50-State Saleable ULEV II 3.5-L V6 DOHC CI-Diesel Engine, Baseline: SI Gasoline OHV 4-V 5.3- to 6.2-L V8	Estimated Cost Versus Baseline ($)
Common-rail 1,800 bar piezo-actuated fuel system with six injectors (@$75), high-pressure pump ($270), fuel rail, regulator and fuel storage upgrades plus high-energy driver upgrades to the engine control module. Credit for MPFI content deleted ($48).	911
Series sequential turbocharging: One VGT with electronic controls and one fixed-geometry turbocharger with active and passive bypass valves necessary to match high EGR rates at low load conditions ($750). Water-air charge air cooler, circulation pump, thermostat/valve, and plumbing. Engine downsizing credit from V8 ($200).[a]	830
Upgrades to electrical system: starter motor, alternator, battery, and 1.5-kW supplemental electrical cabin heater as is standard in Europe ($99).	167
Cam, crank, connecting rod, bearing, and piston upgrades, oil lines ($62) plus NVH countermeasures to engine ($47) and vehicle ($85).	194
High- and low-pressure EGR system to suppress NO_x at light and heavy loads. Includes hot-side and cold-side electronic rotary diesel EGR valves plus EGR cooler and all plumbing.	226
Add remaining components required for advanced-level technology (details in Table G.3).	308
Emissions control system including the following functionality: DOC, CDPF, selective catalytic reduction (SCR), urea dosing system ($363). Stoichiometric MPFI emissions and evaporative systems credit ($343).	1,040
On-board diagnostics (OBD) and sensing, including four temperature sensors (@$13), wide-range air/fuel ratio sensor ($30), NO_x sensor ($85), two-pressure sensing glow plugs (@$17), six glow plugs (@$3), and Delta-P sensor for DPF ($25). Credit for four switching O_2 sensors (@$9).	227
Total variable cost with credits for SI parts removed excludes any necessary transmission, chassis, or driveline upgrades.	3,903

NOTE: Aftertreatment system cost estimates reflect April 2009 PGM prices. Estimates derived from Martec (2008). CDPF, catalyzed diesel particulate filter; CI, compression ignition; DOC, diesel oxidation catalyst; DOHC, dual over head cam; DPF, diesel particulate filter; DPF, diesel particulate filter; EGR, exhaust gas recirculation; MPFI, multipoint fuel injection; NVH, noise, vibration, harshness; OBD, on-board diagnostics; OHV, over head valve; PGM, platinum group metals; SCR, selective catalytic reduction; SI, spark ignition; ULEV II, ultra-low-emissions vehicle; VGT, variable geometry turbocharger.

[a] Credit for downsizing from V8 to V6 referred to DOHC 4-V V8 downsized to DOHC 4V V6. In this case, credit used by Martec was reduced from $270 to $200 since the parts removed from an OHV 2-V V8 would cost less than those removed from a DOHC 4-V V8.

TABLE G.2 Cost Estimates of Exhaust Emissions Aftertreatment Technologies Capable of Enabling Tier 2, Bin 5 Compliance

Item	Midsize Car (e.g., Malibu), Catalytic Device Sizing Based on 2.0-L (April 2009 PGM prices) ($)	Midsize SUV (e.g., Explorer), Catalytic Device Sizing Based on 3.5- L (April 2009 PGM prices) ($)	Full-Size Pickup (e.g., Explorer), Catalytic Device Sizing Based on 4.4-L (April 2009 PGM prices) ($)
DOC 1			
Monolith and can	52	52	52
PGM loading	139	200	252
DOC 2			
Monolith and can	Not used	52	52
PGM loading	Not used	70	87
EGR catalyst			
Monolith and can	7	Not used	Not used
PGM loading	13	Not used	Not used
Coated DPF			
Advanced cordierite brick and can	124	270	270
PGM loading	131	26	33
NSC system			
Catalyst brick and can	114	Not used	Not used
PGM loading	314	Not used	Not used
SCR-urea system			
SCR brick and can	39	274	274
Urea dosing system	Passive SCR	363	363
Stoichiometric gasoline emissions and evaporative system credit	−245	−343	−343
Emissions system total	688	964	1,040

NOTE: This table complements Table 5.5. Compared to Table 5.5, the columns reflecting November 2007 PGM prices (Columns 2 and 4) have been removed and a new column, Column 4, was added. This column reflects the aftertreatment system cost estimate for the exhaust flow rates of a larger base-level V6 CI engine (i.e., 4.4 L) suitable for replacing 5.5- to 6.2-L two-valve OHV V8 SI engines with 3.5-L advanced-level technology CI engines. Note that, as discussed in Chapter 5, it was assumed that the aftertreatment component sizes for the 3.5-L advanced-level V6 are equal to those of a base-level 4.4-L V6 because the power levels for these two engines would be the same, thus requiring the same exhaust flow rates. All cost estimates are based on April 2009 PGM commodity prices. Column 4 provides the estimate used for the aftertreatment costs in Table G.1.

TABLE G.3 Estimates of Incremental Costs to Implement Developments Whose Estimated Fuel Consumption Reduction Gains Are Summarized in Table 5.2

Item	Midsize Car (e.g., Malibu) 1.6-L L4	Midsize SUV (e.g., Explorer) 2.8-L V6	Full-size Pickup (e.g., Ram 1500) 3.5-L V6	
Downsize engines 2-L L4 to 1.6 L, 3.5-L V6 to 2.8 L, 4.4-L V6 to 3.5 L	50	75	75	Higher load capacity rod bearings and head gasket for higher cylinder pressures (~$12.50/cylinder)
Two-stage turbocharger system	375	545	0[a]	Additional air flow control valves, piping, cost of additional turbo, water-to-air intercooler with control valve, separate pump
Dual-pressure oil pump	5	6	6	Switchable pressure relief valve for high or low oil pressure
Nonrecirculating LP fuel pump	10	12	12	Variable output LP pump controlled by HP pump output
Low-pressure EGR	—	95	95	Additional piping (~$20) and valves (e.g., integrated back pressure and LP EGR rate ~$75), much more difficult to package for V6 engine with underfloor DPF, cost for L-4 already included in Table 5.4
Direct-acting HP (maximum injection pressures > 2,000 bar) piezo injectors	80	120	120	$20/injector, benefits derived from combination of higher rail pressure and more injector controllability
Total	520	853	308	

NOTE: These developments are CI-diesel downsizing from base level to advanced level, thermodynamic improvements, friction reduction, and engine accessory improvements. Total for full-size body-on-frame pickup ($308 at bottom of Column 4) used in Table G.1. FC, fuel consumption.

[a]Two-stage turbo system already comprehended in Table G.1.

H

Other NRC Assessments of Benefits, Costs, and Readiness of Fuel Economy Technologies

The National Research Council (NRC) has conducted other studies to estimate benefits, costs, and readiness of fuel economy technologies for light-duty vehicles. Indeed, this committee's task is to update the estimates provided in one of the earlier studies, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,* which was issued in 2001. The committee discusses several other studies here. The *Review of the Research Program of the Partnership for a New Generation of Vehicles: Seventh Report* (NRC, 2001) assessed the fuel economy technologies and costs associated with three prototype vehicles built in connection with the Partnership for a New Generation of Vehicles (PNGV) research program to achieve up to three times the fuel economy of a 1994 family sedan. More recent NRC studies that have looked at different aspects of fuel economy technologies include *Transitions to Alternative Transportation Technologies—A Focus on Hydrogen* (NRC, 2008a), *Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report* (NRC, 2008b), and the report from the America's Energy Future (AEF) Panel on Energy Efficiency, *Real Prospects for Energy Efficiency in the United States* (NAS-NAE-NRC, 2010). Even though the recent report *Transitions to Alternative Transportation Technologies—Plug-In Hybrid Electric Vehicles* (NRC, 2009) was not strictly a report on fuel economy technology, it did address the costs and benefits of plug-in electric vehicles.

While the tasks required under each study are different, some of their analyses of costs, efficiencies, and prospects for the various technologies overlap and are reviewed here. However, the committee does not attempt to review the findings of any studies other than those of the NRC. It simply comments on them, as appropriate, to the degree that the NRC reports are based on them.

REVIEW OF THE RESEARCH PROGRAM OF THE PARTNERSHIP FOR A NEW GENERATION OF VEHICLES, SEVENTH REPORT

The task of the NRC Standing Committee to Review the Research Program of the PNGV (NRC PNGV committee) was to examine the research program, communicate the program's progress to government and industry participants, and identify barriers to the program's success. The PNGV program was a cooperative research and development program between the government and the United States Council for Automotive Research, whose members include the three original equipment manufacturers (OEMs) in the United States: DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation. The PNGV was envisioned to allow the parties to cooperate on precompetitive research activities that would ultimately result in the deployment of technologies to reduce our country's fuel consumption and emissions of carbon dioxide. The PNGV aimed to improve the competitiveness of the U.S. manufacturing base for future generations of vehicles and to introduce innovative technologies into conventional vehicles in order to improve fuel consumption or reduce emissions. The final goal of the PNGV program was to develop prototype vehicles that achieve up to three times the average fuel economy of a 1994 family sedan. It was recognized that these new vehicles would have to be sold in high volume in order to have an impact. For this reason, the strategy for the prototype vehicle was to develop an affordable family sedan with a fuel economy of up to 80 mpg that maintained the performance, size, and safety standards of the vehicles of that time. After 2002, the program transitioned to the FreedomCAR and Fuel Research (FreedomCAR) Program, discussed in the following section.

Each of the three automobile companies involved in the PNGV program built its own prototype concept vehicles since this could not be done in the context of precompetitive research. By the time of the seventh NRC report, all three companies had built prototypes that met the then-extant performance, comfort, cargo space, utility, and safety requirements. These prototype vehicles could not, however, meet the price target while simultaneously improving fuel economy to near 80 mpg. The DaimlerChrysler prototype foresaw a price premium of $7,500, while the other two did not announce any price premium associated with their vehicles. All three concept vehicles used hybrid electric power trains with small, turbocharged, compression-ignition direct-injection engines using diesel fuel. All three were start-stop hybrids that shut the engine off when idling. The report from the NRC PNGV committee estimated that dual-mode batteries would probably cost $1,000 to $1,500 per battery unit (1.5 kWh), or $670 to $1,000 per kWh (NRC, 2001). Each company took a different route to reduce the vehicle mass and aerodynamic drag and to supply power for auxiliary loads. The high cost of the lightweight materials and electronic control systems made the price target unattainable. In addition, the cost of the compression-ignition direct-injection engine was greatly increased by the exhaust-gas after-treatment systems to control emissions. In the middle of the PNGV program, the Tier 2 emission standard was promulgated, and the NRC PNGV committee believed that the ability of the diesel engine to meet emissions targets was not clear.

The NRC PNGV committee reported that the PNGV program had made significant progress in implementing desirable technologies as fast as possible. Each of the three automobile manufacturers in the PNGV demonstrated a hybrid electric vehicle before the end of the Partnership in 2004. They had developed the concept vehicles by 2000, but the goal of the development of a preproduction prototype by 2004 was not met because of the termination of the PNGV program. Indeed, the manufacturing and engineering innovations that came out of the PNGV program were implemented before 2000. In the end, the three OEMs demonstrated that a production medium-size passenger car could be produced that achieved 80 mpg, and one OEM (DaimlerChrysler) demonstrated that such a vehicle could be produced at a cost penalty of less than $8,000.

THE FREEDOMCAR AND FUEL RESEARCH PROGRAM REPORT

The task of the NRC Committee on Review of the FreedomCAR and Fuel Research Program (NRC FreedomCAR committee) is to assess the FreedomCAR and Fuel Partnership's management and the research and development activities overseen by the Partnership. The Partnership, started in 2002, built on the earlier PNGV program. FreedomCAR, like PNGV, is a collaboration between the government and industry to support a wide range of precompetitive research in automotive transportation. The Partnership's goal is to study technologies that will help the United States transition to an automotive fleet free from petroleum use and harmful emissions (NRC, 2005). The vision of the Partnership is to enable a transition pathway that starts with improving the efficiency of today's internal combustion (IC) engines, increasing the use of hybrid electric vehicles, and supporting research in fuel-cell-powered vehicles so that a decision can be reached in 2015 on the economic and technological viability of hydrogen-powered vehicles. In 2009, a greater emphasis began to be placed on plug-in hybrid electric vehicles (PHEVs). The NRC has thus far reviewed the FreedomCAR and Fuel Partnership twice, with reports published in 2005 and 2008. In the second of these reports, one of the NRC FreedomCAR committee's tasks was to comment on the balance and adequacy of the efforts and on the progress achieved since the 2005 report. The conclusions and recommendations of the second report focus on the Partnership's management and oversight but also provide the FreedomCAR committee's opinion on the readiness of new fuel economy technologies.

The NRC FreedomCAR committee report recognizes that more efficient IC engines will contribute the most to reducing fuel consumption and emissions in the near term. The Partnership focuses research on lean-burn, direct-injection engines for both diesel- and gasoline-fueled vehicles, specifically on low-temperature combustion engines and aftertreatment of the exhaust. The report recognizes that, after completing the research necessary to prove a technology's viability, there are typically several years of prototyping and developing manufacturing processes before the technology can be introduced into the vehicle fleet. Because of the urgent need to reduce vehicle fuel consumption, the development phase of these technologies has been accelerated while researchers are still studying the controlling thermochemistry of low-temperature combustion. The result is close coordination between those looking to expand the fundamental knowledge base and those investigating applications. The report from the NRC FreedomCAR committee recommends that the Partnership investigate the impact on emissions of combustion mode switching and transient operation with low-temperature combustion, and it questions how much exhaust energy can actually be recovered. Furthermore, the NRC FreedomCAR committee suggests the Partnership closely analyze the cost-effectiveness of the exhaust gas heat recovery research and the potential fuel efficiency benefits before deciding whether to pursue this research further.

Another goal of the FreedomCAR and Fuel Partnership is to develop, by 2015, battery storage for hybrid electric vehicles that has a 15-year life and a pulse power of 25 kilowatts (kW), with 1 kW of pulse power costing $20. This effort focuses on lithium (Li) ion batteries, which are simultaneously in both the research phase, as the knowledge base for specific electrochemical systems is expanded, and the development phase, as the batteries are built and tested. Significant progress had been made since the first FreedomCAR report (NRC, 2005, 2008b). The Partnership has demonstrated batteries that exceed the requirement for a 300,000-cycle lifetime, that have longer calendar lives, and that operate over a wider temperature range than earlier batteries. The NRC FreedomCAR committee recognized that cost is the primary barrier for introduction of the Li-ion battery to the market and commends the Partnership for researching lower cost materials for the cathode and the microporous separator. The report from the NRC

FreedomCAR committee recommended that the Partnership do a thorough cost analysis of the Li-ion batteries under development to account for recent process and materials costs and for increased production rate costs.

A 50 percent reduction in total vehicle weight at no additional cost is another key goal of the Partnership; it would rely on the widespread application of advanced high-strength steels, aluminum alloys, cast magnesium, and carbon-fiber-reinforced plastics. The NRC FreedomCAR committee concluded that the goal of price parity for the lightweight materials is insurmountable within the time frame of the Partnership (NRC, 2008b). However, the 50 percent weight reduction goal is critical for the Partnership's overall vision of a hydrogen-fueled car. The NRC FreedomCAR committee went beyond that, saying the weight reduction would be mandatory even with the associated cost penalty, because the alternative adjustments to the engine and batteries would cost more. The NRC report recommends maintaining the 50 percent weight reduction goal and analyzing cost-effectiveness to confirm that the added cost of weight reduction can be offset by modifying the fuel cell and battery goals.

THE HYDROGEN REPORT

The tasks of the Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies (the NRC hydrogen committee) was to establish the maximum practicable number of vehicles that could be fueled by hydrogen by 2020 and to discuss the public and private funding needed to reach that number. The NRC hydrogen committee assumed that (1) the technical goals for fuel cell vehicles, which were less aggressive than those of the FreedomCAR Partnership, are met; (2) that consumers would readily accept such vehicles; (3) that government policies would drive the introduction of fuel cell vehicles and hydrogen production and infrastructure at least to the point where fuel cell vehicles are competitive on the basis of lifecycle cost; and (4) that oil prices are at least \$100 per barrel by 2020 (NRC, 2008a). Thus, the scenarios developed in the hydrogen report are not projections but a maximum possible future market if all assumptions are met. The NRC hydrogen committee concluded that although durable fuel cell systems at significantly lower costs are likely to be increasingly available for light-duty vehicles over the next 5 to 10 years, the FreedomCAR Partnership goals for 2015 are not likely to be met. The NRC hydrogen committee also concluded that commercialization and growth of these hydrogen fuel cell vehicles could get under way by 2015 if supported by strong government policies. Those conclusions are more optimistic than the conclusions on fuel cells contained in this report, whose committee (though it did not consider the potential impact of policies on fuel cell market potential) does not expect progress on fuel cell costs and technology to be as rapid as expected by the NRC hydrogen committee. Further, one OEM that is aggressively pursuing fuel cell vehicles will probably not be in a position to begin significant commercialization until at least 2020, 5 years later than the target date assumed in the hydrogen study.

The task also called for the NRC hydrogen committee to consider whether other technologies could achieve significant CO_2 and oil reductions by 2020. The NRC hydrogen committee considered improvements to spark-ignition (SI) engines, compression-ignition (CI) engines, vehicle transmissions, and hybrid vehicle technologies as well as reductions in weight and other vehicle load reductions. Improvements also could come in the form of reductions in weight and similar improvements. The technical improvements that can be applied to SI engines include variable valve timing and lift, camless valve actuation, cylinder deactivation, the use of gasoline direct injection with turbocharging, and intelligent start-stop, which involves engine shutoff when the vehicle idles. Improvements in vehicle transmissions include the use of conventional 6/7/8-speed automatic transmissions and automated manual transmissions. This report repeats an estimate from Duleep (2007) that combining the projections for improvements in the engine, transmission, weight, parasitic loss (including friction losses, rolling resistance, and air drag), accessories, and idle-stop components could reduce fuel consumption in 2015 by 21 to 29 percent relative to today's vehicles and in 2025 by 31 to 37 percent. Table H.1 shows the improvements estimated for SI engines attributable to these approaches. The NRC hydrogen report also quotes studies by Heywood and colleagues at Massachusetts Institute of Technology (MIT) on the fuel efficiency of light-duty vehicles (Weiss et al., 2000; Heywood, 2007; Kasseris and Heywood, 2007; Kromer and Heywood, 2007). The fuel economy improvements noted in the MIT work result from changes to the engines and transmissions and appropriate reductions in vehicle weight. The MIT work assumes that the improvements are aimed entirely at reducing fuel consumption. Table H.2 shows the improvements in fuel economy compared to a 2005 SI engine vehicle that MIT estimates could be achieved by 2030, although the NRC hydrogen committee assumed that these levels of fuel economy would not be available as quickly.

TABLE H.1 Potential Reductions in Fuel Consumption (gallons per mile) for Spark-Ignition Vehicles Expected from Advances in Conventional Vehicle Technology by Category, Projected to 2025

	2006-2015 (%)	2016-2025 (%)
Engine and transmission	12-16	18-22
Weight, drag, and tire loss reduction	6-9	10-13
Accessories	2-3	3-4
Intelligent start-stop	3-4	3-4

NOTE: Values for 2016-2025 include those of 2006-2015.
SOURCE: Duleep (2007).

TABLE H.2 Comparison of Projected Improvements in Vehicle Fuel Consumption from Advances in Conventional Vehicle Technology

	Fuel Consumption (L/100 km)	Relative to 2005 Gasoline[a]	Relative to 2030 Gasoline[a]	Relative to 2005 Gasoline[b]	Relative to 2030 Gasoline[b]
2005 Gasoline	8.8	1.00			
2005 Diesel	7.4	0.84			
2005 Turbo	7.9	0.9			
2005 Hybrid	5.7	0.65			
2030 Gasoline	5.5	0.63	1.00		
2030 Diesel	4.7	0.53	0.85	0.61	1.00
2030 Turbo	4.9	0.56	0.89	0.45	0.77
2030 Hybrid	3.1	0.35	0.56	0.54	0.88
2030 Plug-in	1.9	0.21	0.34	0.38	0.615

[a]From Kromer and Heywood (2007).
[b]From Weiss et al. (2000).

Although the NRC hydrogen committee acknowledges the potential for hybrids outlined in Kromer and Heywood, it concluded that advances in hybrid technology are more likely to lower the cost of battery packs than to increase fuel economy significantly. This would increase their appeal to consumers relative to conventional vehicles and, thus, their market share (Kromer and Heywood, 2007). To simplify the analysis in the hydrogen report, the NRC hydrogen committee assumed that hybrids reduce fuel consumption a constant 29 percent annually relative to conventional vehicles, which also improve each year. This value is within the range of the potential for power split hybrids in the present report.

Thus, the NRC hydrogen committee judged that hybrid electric vehicles could, if focused on vehicle efficiency, consistently reduce fuel consumption 29 percent relative to comparable evolutionary internal combustion engine vehicles (ICEVs). Although this judgment is conservative compared to that of Kromer and Heywood, it still leads to a 60-mpg average for new spark-ignition hybrids by 2050. This means that hybrid technologies will have reached their greatest fuel consumption reductions by 2009 and that future improvements in hybrid vehicle fuel economy would be primarily attributable to the same technologies that reduce fuel consumption in conventional vehicles. Thus, hybrid vehicles reduce fuel consumption by 2.6 percent per year from 2010 through 2025, 1.7 percent per year in 2025-2035, and 0.5 percent per year between 2035 and 2050, the same as do evolutionary ICEVs.

PLUG-IN HYBRID ELECTRIC REPORT

After the publication of the NRC report *Transitions to Alternative Transportation Technologies—A Focus on Hydrogen* (NRC, 2008), the U.S. Department of Energy asked the Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies to expand its analysis to include plug-in hybrid electric vehicles. The committee reconvened to examine the issues associated with PHEVs and wrote *Transitions to Alternative Transportation Technologies—Plug-in Hybrid Electric Vehicles* (referred to here as the PHEV report) to that additional task (NRC, 2009).

In accordance with the committee's statement of task, the PHEV report does the following:

- Reviews the current and projected status of PHEV technologies.
- Considers the factors that will affect how rapidly PHEVs would enter the marketplace, including the interface with the electric transmission and distribution system.
- Determines a maximum practical penetration rate for PHEVs consistent with the time frame of the 2008 Hydrogen Report and other factors considered in that report.
- Incorporates PHEVs into the models used in the 2008 Hydrogen Report to estimate the costs and impacts on petroleum consumption and carbon dioxide (CO_2) emissions.

As in this report, the PHEV report considered two types of PHEVs, a PHEV10 with an all-electric range of 10 miles and a PHEV40 with an all-electric range of 40 miles. Both reports use the same architectures as this committee, which include a spark-ignited internal combustion engine, two electrical machines, power electronics, and a Li-ion battery. Only the first task relates to our report, and comparing the two, it is necessary to separate the current technology status and the projections. The assessment of current technologies in the PHEV report is in close agreement with the assessment of this committee. Both discuss the different battery chemistries and the advantages and problems of each and point out how PHEVs differ from batteries for

HEVs, because the critical parameter is the energy available as opposed to the power needs. The discussion of power electronics and motors and generators within the PHEV report again generally parallels what is in this report. There are some differences in terms of the technological needs. For example, the PHEV report assumes that liquid cooling is assumed to be required for the PHEV40 battery packs whereas this report assumes air cooling will be sufficient.

The PHEV report was required to project and analyze the technology costs to 2050, while this report stopped at 2025. The methodology used is similar, and in both cases the costs were built up by adding the costs of the new components needed compared to an internal combustion engine vehicle. Costs were deducted for components such as engine simplification and the elimination of the transmission. The information was obtained from OEMs and suppliers in a similar way. For the PHEV10 the cost estimates in this report are within 5 percent of those in the PHEV report and within 3 percent for the 2020 to 2030 time frame. For the PHEV 40 the committee's costs are significantly lower: by 45 percent for current costs and 42 percent for the 2020 to 2030 time frame. In view of the uncertainties of actual costs and how these would translate as retail price equivalents, the difference can be attributed to a difference in professional judgment.

A more difficult question is the rate at which the cost of the battery will come down, and what makes projections even harder is the injection of a substantial amount of capital by the administration and the enthusiasm of investors. Basically there are two ways of looking at future cost declines:

- People making these very large investments in both vehicles and lithium ion batteries must expect the market to take off. Since the success of vehicle electrification depends on reductions in the price of battery by factors of two or three, investors and the administration must be optimistic that large cost reductions will occur.
- A more pessimistic perspective is that lithium ion is a well-developed technology with billions of individual cells being produced.

How much improvement can one realistically expect in the 10-year horizon of the report? Both reports take a fairly conservative viewpoint in terms of the cost reductions of batteries over time and, taking into account developments in the last year, both reports may turn out to be overly conservative.

AEF ENERGY EFFICIENCY PANEL REPORT

The America's Energy Future Energy Efficiency Panel examined the technical potential for reducing energy demand by improving efficiency in transportation, lighting, heating, cooling, and industrial processes using existing technologies, technologies developed but not yet widely utilized, and prospective technologies. In its report, *Real Prospects for Energy Efficiency in the United States* (NAS-NAE-NRC, 2010), the panel estimated the current contributions and future potential of existing technologies. In addition, the energy efficiency panel estimated the potential for new technologies that could begin to be commercially deployed in the next decade, the associated impacts of these technologies, and the projected costs per unit of reduction in energy demand. The panel's work on light-duty vehicles is summarized in the following sections.

Gasoline SI Engine

Gasoline SI engine efficiency improvements contemplated by the NRC energy efficiency panel included engine friction reduction, smart cooling systems, variable valve timing (VVT), two- and three-step variable valve lift (VVL), cylinder deactivation, direct injection (DI), and turbocharging with engine downsizing. Most of these are already in low-volume production, and all could be deployed in large volumes in the next decade. In 15 to 20 years, technologies such as camless valve actuation, continuous variable valve lift (CVVL), and homogeneous-charge compression ignition (HCCI) could be deployed. The conclusions hoped for in connection with the deployment of camless valve actuation and HCCI are more optimistic than those anticipated for fuel cells in this report. The NRC energy efficiency panel survey shows the above technologies have the potential to reduce vehicle fuel consumption by 10 to 15 percent by 2020 and by an additional 15 to 20 percent by 2030 (EEA, 2007; Kasseris and Heywood, 2007; Ricardo, Inc., 2008; and NRC, 2008a).

Diesel CI Engine

Owing to high compression ratios and reduced pumping losses, turbocharged diesel engines offer a 20 to 25 percent efficiency advantage over gasoline SI engines when adjusted for the higher energy density of diesel fuel. The primary efficiency improvements in CI engines are likely to come from increased power density, improved engine system management, more sophisticated fuel injection systems, and improved combustion processes. New exhaust after-treatment technologies are emerging that reduce emissions of particulate matter and oxides of nitrogen to levels comparable to those of SI engines. One challenge for diesel engines noted by the NRC energy efficiency panel is the added costs and fuel economy penalties associated with the aftertreatment systems for reducing these emissions (Bandivadekar et al., 2008; Johnson, 2008; Ricardo, Inc., 2008).

Gasoline Hybrid Electric Vehicle

The primary efficiency benefits of a gasoline hybrid electric vehicle (HEV) noted by the NRC energy efficiency panel are realized by eliminating idling, including regenerative braking, downsizing the engine, and operating at more efficient engine conditions than current SI engines.

The NRC energy efficiency panel classifies hybrids on how well their electric motor and generator function. Belt-driven starter-generator systems eliminate engine idle to reduce fuel consumption by 4 to 6 percent. Integrated starter-generator systems that recover energy from regenerative braking, along with the start-stop function, can achieve a fuel consumption reduction of 10 to 12 percent. A parallel full hybrid with power assist, such as Honda's integrated motor assist system, can reduce fuel consumption by more than 20 to 25 percent, whereas more complex systems using two motors such as Toyota's hybrid synergy drive can reduce fuel consumption more than 30 percent. Some diesel HEV prototypes are now being developed. Diesel HEVs could be 10 percent more efficient than an equivalent gasoline hybrid, which translates to a 20 percent lower diesel fuel consumption when greater fuel density is factored in. A diesel HEV would be significantly more expensive than a gasoline HEV.

Vehicle Technologies and Transmission Improvements

The NRC energy efficiency panel notes that reducing the vehicle weight by 10 percent is commonly thought to reduce fuel consumption by 5 to 7 percent when accompanied by appropriate engine downsizing to maintain constant performance. Preliminary vehicle simulation results suggest that the relative benefits of weight reduction may be smaller for some types of hybrid vehicles (An and Santini, 2004; Wohlecker et al., 2007). In a conventional vehicle the energy used to accelerate the mass is mostly dissipated in the brakes, while in a hybrid a significant fraction of this braking energy is recovered, sent back to the battery, and reused. Thus weight reduction in hybrid vehicles has a much smaller effect on reducing fuel consumption than such reduction in non-hybrid vehicles. Additional weight reduction can be achieved by vehicle redesign and downsizing as well as by substituting lighter-weight materials in vehicle construction, For example, downsizing a passenger car by one EPA size-class can reduce vehicle weight by approximately 10 percent (Cheah et al., 2007). Additional sources of fuel consumption benefits noted by the NRC energy efficiency panel are from improvements in tires. A recent NRC report on tires and passenger vehicle fuel economy (NRC, 2006) agrees with estimates in the literature (Schuring and Futamura, 1990) that the vehicle fuel consumption will be reduced by 1 or 2 percent for a reduction of 0.001 in the coefficient of rolling resistance of passenger tires—equivalent to a 10 percent reduction in overall rolling resistance. The NRC energy efficiency panel also discussed transmission efficiency improvements likely in the next 10 to 20 years through an increase in the number of gears and through improvements in bearings, gears, sealing elements, and the hydraulic system. Table H.3 lists the efficiency improvements considered by the NRC energy efficiency panel that can be expected from different transmission systems in this time frame. Note that while a continuously variable transmission (CVT) allows the engine to operate near its maximum efficiency, the current estimates of CVT efficiency are lower than the corresponding efficiencies of 6- or 7-speed automatic transmissions. CVTs have been in low-volume production for well over a decade.

TABLE H.3 Expected Transmission System Efficiency Improvements

Transmission	Efficiency (%)
Current automatic transmission (4- and 5-speed)	84-89
Automatic transmission (6- or 7-speed)	93-95
Dual-clutch transmission (wet clutch)	86-94
Dual-clutch transmission (dry clutch)	90-95
Continuously variable transmission	87-90

SOURCE: NAS-NAE-NRC (2010), quoting Ricardo, Inc. (2008) and EEA (2007).

Summary and Costs of Potential Light-Duty Vehicle Efficiency Improvements

Table H.4 shows plausible levels of petroleum reduction potential through vehicle technology improvements estimated by the NRC energy efficiency panel. The NRC energy efficiency panel developed its estimates from a number of sources (An and Santini, 2004; Wohlecker et al., 2007; Cheah et al., 2007; NPC, 2007; and NRC, 2004). The estimates shown in Table H.4 assume that vehicle size and performance, such as the power-to-weight ratio and acceleration, are kept constant at today's levels. The evolutionary improvements briefly outlined above and discussed in more detail in the NRC energy efficiency panel report can reduce the fuel consumption of a gasoline ICE vehicle by up to 35 percent in the next 25 years. The diesel engine currently offers a 20 percent reduction in fuel consumption over a gasoline engine and, while the diesel engine will continue to evolve, the gap between gasoline and diesel vehicle fuel consumption is likely to narrow to a 15 percent improvement. Hybrid vehicles (including PHEVs) have a greater potential for improvement and can deliver deeper reductions in vehicle fuel consumption, although they continue to depend on petroleum (or alternative liquid fuels, such as biofuels). Battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) are two longer-term technologies.

The cost estimates developed by the NRC energy efficiency panel shown in Table H.4 represent the approximate incremental retail price of future vehicle systems, including emissions control costs, compared to a 2005 baseline gasoline ICE vehicle (NHTSA, 2007; EEA, 2007; Bandivadekar et al., 2008). The first column shown is for a midsize car; the second column is for a typical pickup truck or SUV. These retail prices are based on the costs associated with producing a vehicle at the manufacturing plant gate. To account for distribution costs and manufacturer and dealer profit margins, production costs were multiplied by a factor of

TABLE H.4 Plausible Reductions in Petroleum Use from Vehicle Efficiency Improvements over the Next 25 Years and Estimated Incremental Cost of Advanced Vehicles Relative to a Baseline 2005 Standard Gasoline Vehicle

	Petroleum Consumption (gasoline equivalent)		Incremental Retail Price (2007 dollars)	
Propulsion System	Relative to Current Gasoline ICE	Relative to 2035 Gasoline ICE	Car	Light Truck
Current gasoline	1	—	0	0
Current diesel	0.8	—	1,700	2,100
Current HEV	0.75	—	4,900	6,300
2035 gasoline	0.65	1	2,000	2,400
2035 diesel	0.55	0.85	3,600	4,500
2035 HEV	0.4	0.6	4,500	5,500
2035 PHEV	0.2	0.3	7,800	10,500
2035 BEV	None	—	16,000	24,000
2035 hydrogen FCV	None	—	7,300	10,000

NOTE: BEV, battery electric vehicle; FCV, fuel cell vehicle; HEV, hybrid electric vehicle; ICE, internal combustion engine.
SOURCE: Report from the NRC Panel on Energy Efficiency (NAS-NAE-NRC, 2010) quoting Bandivadekar et al. (2008).

1.4 to provide representative retail price estimates (Evans, 2008). The timescales indicated for these future technology vehicles are not precise. The rate of price reduction will depend on the deployment rate (Bandivadekar et al., 2008; Evans, 2008).

The results in Table H.4 show that alternative powertrains such as improved gasoline and diesel engines and hybrids entering the fleet today cost from 10 percent to 30 percent more than a current gasoline vehicle. This price difference is estimated to drop to 5 percent to 15 percent in the mid-term future. Longer-term options such as plug-in hybrid and FCVs are estimated to cost between 25 and 30 percent more than a future gasoline vehicle. Battery electric vehicles with standard vehicle performance and size remain costly, approaching double the cost of a future gasoline vehicle. A more plausible market opportunity for BEVs is small city cars with reduced range. However, these also will need significantly improved battery performance and battery costs to become competitive.

Based on the estimates in Table H.4, the NRC energy efficiency panel concludes that evolutionary improvements in gasoline ICE vehicles are likely to prove the most cost-effective way to reduce petroleum consumption. Since these vehicles will be sold in large quantities in the near term, it is critical that their efficiency improvements are directed toward reducing fuel consumption. While the current hybrids appear less competitive than a comparable diesel vehicle, they are likely to become more cost competitive over time. PHEVs, BEVs, and FCVs appear to be more costly alternatives for reducing petroleum consumption and greenhouse gas emissions. Among these three technologies, PHEVs are likely to become available in the near to midterm, whereas BEVs and FCVs are mid- to long-term alternatives.

BIBLIOGRAPHY

An, F., and D. Santini. 2004. Mass impacts on fuel economies of conventional vs. hybrid electric vehicles. SAE Technical Paper 2004-01-0572. SAE International, Warrendale, Pa.

An, F., J.M. DeCicco, and M.H. Ross. 2001. Assessing the Fuel Economy Potential of Light-Duty Vehicles. SAE International, Warrendale, Pa.

Bandivadekar, A.P. 2008. Evaluating the Impact of Advanced Vehicle and Fuel Technologies in the U.S. Light-Duty Vehicle Fleet. Ph.D. thesis. MIT Engineering Systems Division, Cambridge, Mass.

Bandivadekar, A., K. Bodek, L. Cheah, C. Evans, T. Groode, J. Heywood, E. Kasseris, K. Kromer, and M. Weiss. 2008. On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions. Massachusetts Institute of Technology (MIT) Laboratory for Energy and the Environment, Cambridge, Mass. July.

Cheah L., C. Evans, A. Bandivadekar, and J. Heywood. 2007. Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035. LFEE Report 2007-04 RP. MIT Laboratory for Energy and the Environment. Cambridge, Mass: Massachusetts Institute of Technology. Available at http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/cheah_factorTwo.pdf.

Duleep, K. 2007. The Hydrogen Transition and Competing Automotive Technology. Presentation to National Research Council Panel on Fuel Cell Vehicles and Hydrogen on April 18, Washington, D.C.

EEA (Energy and Environmental Analysis, Inc.). 2007. Update for Advanced Technologies to Improve Fuel Economy of Light Duty Vehicles. Draft Final Report. Submitted to U.S. Department of Energy. EEA, Washington, D.C. August.

Evans, C. 2008. Putting Policy in Drive: Coordinating Measures to Reduce Fuel Use and Greenhouse Gas Emissions from U.S. Light-Duty Vehicles. M.S. Thesis, Technology and Policy Program. June. Massachusetts Institute of Technology, Cambridge.

Heywood, J.B. 2007. Strategies to Reduce Transportation Petroleum Consumption and Greenhouse Gas Emissions. Presentation at FreedomCAR and Fuels Program Meeting.

Johnson, T. 2008. Diesel Emission Control Technology in Review. SAE Technical Paper 2008-01-0069. Society of Automotive Engineers, Warrendale, Pa. April.

Kasseris, E.P., and J.B. Heywood. 2007. Comparative Analysis of Automotive Powertrain Choices for the Next 25 Years. SAE International, Warrendale, Pa.

Kromer, M.A., and J.B. Heywood. 2007. Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet. MIT Laboratory for Energy and the Environment, Cambridge, Mass.

Lutsey, N. 2008. Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors. Ph.D. dissertation. University of California, Davis. May.

Lutsey, N., and D. Sperling. 2005. Energy efficiency, fuel economy, and policy implications. Transportation Research Record 1941:8-25.

NAS-NAE-NRC (National Academy of Sciences-National Academy of Engineering-National Research Council). 2010. Real Prospects for Energy Efficiency in the United States. The National Academies Press, Washington, D.C.

NPC (National Petroleum Council). 2007. Technologies for Transportation Efficiency. Topic paper of the Transportation Efficiency Subgroup. Council Committee on Global Oil and Gas. NPC, Washington, D.C. July.

NRC (National Research Council). 2001. Review of the Research Program of the Partnership for a New Generation of Vehicles, Seventh Report. The National Academies Press, Washington, D.C.

NRC. 2004. The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. The National Academies Press, Washington, D.C.

NRC. 2005. Review of the Research Program of the FreedomCAR and Fuel Partnership, First Report. The National Academies Press, Washington, D.C.

NRC. 2006. Tires and Passenger Vehicle Fuel Economy: Informing Consumers, Improving Performance—Special Report 286. The National Academies Press, Washington, D.C.

NRC. 2008a. Transitions to Alternative Transportation Technologies—A Focus on Hydrogen. The National Academies Press, Washington, D.C.

NRC. 2008b. Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report. The National Academies Press, Washington, D.C.

NRC. 2009. Transitions to Alternative Transportation Technologies—Plug-in Hybrid Electric Vehicles. The National Academies Press, Washington, D.C.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for EPA Office of Transportation and Air Quality. January. Available at http://www.epa.gov/OMS/technology/420r08004a.pdf. Accessed July 10, 2009.

Schuring, D., and S. Futamura. 1990. Rolling loss of pneumatic highway tires in the eighties. Rubber Chemistry and Technology 62(3):315-367.

Weiss, M.A., et al. 2000. On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies. Massachusetts Institute of Technology, Cambridge, Mass.

Wohlecker, R., M. Johannaber, and M. Espig. 2007. Determination of weight elasticity of fuel economy for ICE, hybrid and fuel cell vehicles. SAE Technical Paper 2007-01-0343. SAE International, Warrendale, Pa.

I

Results of Other Major Studies

Tables I.1 through I.8, which indicate the costs and fuel consumption benefits from other major studies, are included here to facilitate the comparison to other sources of technology cost and effectiveness. However, the reader is encouraged to look at the original source material to gain a better understanding of the different assumptions made in each study. For example, some sources consider incremental benefits, while others do not. Certain items, such as improved accessories, may include different technologies, which makes an apples-to-apples comparison difficult. Retail price equivalent factors also vary from source to source, reinforcing the need to review the original materials as well as the tables.

REFERENCES

DOT/NHTSA (U.S. Department of Transportation/National Highway Traffic Safety Administration). 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2001: Final Rule. 49 CFR Parts 523, 531, 533, 534, 536, and 537, Docket No. NHTSA-2009-0062, RIN 2127-AK29, March 23. Washington D.C.

EEA (Energy and Environmental Analysis, Inc.). 2007. Technologies to Improve Light-Duty Vehicle Fuel Economy. Draft report to the National Research Council Committee on Fuel Economy of Light-Duty Vehicles. EEA, Arlington, Va. September.

EPA (U.S. Environmental Protection Agency). 2008. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. EPA, Washington, D.C.

Martec Group, Inc. 2008. Variable Costs of Fuel Economy Technologies. Prepared for Alliance of Automobile Manufacturers. June 1; amended September 26 and December 10.

NESCCAF (Northeast States Center for a Clean Air Future). 2004. Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles. March.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. National Academy Press, Washington, D.C.

Ricardo, Inc. 2008. A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Prepared for the U.S. Environmental Protection Agency, EPA420-R-08-004, Contract No. EP-C-06-003, Work Assignment No. 1-14, Ricardo, Inc., Ann Arbor, Mich.

Sierra Research. 2008. Basic Analysis of the Cost and Long-Term Impact of the Energy Independence and Security Act Fuel Economy Standards. Sierra Research, Sacramento, Calif. April 24.

TABLE I.1 Technology Effectiveness, Incremental (Percent) Fuel Consumption Benefit from DOT/NHTSA (2009)

NHTSA - 2011 Rule																	
Technologies		Perf. SubcompactCar				Perf. Compact Car				Perf. Midsize Car				Perf. Large Car			
		I4				V6				V6				V8			
		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value	
Spark Ignition Techs	Abbreviation	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Low Friction Lubricants	LUB	0.5		-	-	0.5		-	-	0.5		-	-	0.5		-	-
Engine Friction Reduction	EFR	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Cylinder Deactivation, SOHC	DEAC	-	-	-	-	2.5	3.0	-	-	2.5	3.0	-	-	2.5	3.0	-	-
VVT - In take Cam Phasing (ICP)	ICP	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT - Dual Cam Phasing (DCP)	DCP	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Continuously Variable Valve Lift (CVVL)	CVVL	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-
Cylinder Deactivation, OHV	DEAC	-	-	-	-	3.9	5.5	-	-	3.9	5.5	-	-	3.9	5.5	-	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-
Conversion to DOHC with DCP	CDOHC	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.9	2.9	5.0	13.0	1.9	2.9	7.0	14.0	1.9	2.9	7.0	14.0	1.9	2.9	7.0	14.0
Turbocharging and Downsizing	TRBDS	4.5	5.2	11.0	17.0	2.1	2.2	11.0	17.0	2.1	2.2	11.0	17.0	2.1	2.2	11.0	17.0
Diesel Techs																	
Conversion to Diesel	DSL	15.0	15.3	21.2	25.9	12.3	13.1	21.2	25.9	11.1	12.0	20.2	24.9	11.1	12.0	20.2	24.9
Conversion to Diesel following TRBDS	DSL	6.6	7.7	21.2	25.9	6.6	7.7	21.2	25.9	5.3	6.5	20.2	24.9	5.3	6.5	20.2	24.9
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs																	
Electric Power Steering (EPS)	EPS	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
Improved Accessories	IACC	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
12V BAS Micro-Hybrid	MHEV	1.0	2.9	-	-	1.0	2.9	-	-	3.4	4.0	-	-	3.4	4.0	-	-
Higher Voltage/Improved Alternator	HVIA	0.2	0.9	-	-	0.2	0.9	-	-	0.2	0.6	-	-	0.2	0.6	-	-
Integrated Starter Generator	ISG	1.8	2.6	-	-	1.8	2.6	-	-	1.8	1.9	-	-	1.8	2.6	-	-
Transmission Techs																	
Continuously Variable Transmission (CVT)	CVT	0.7	2.0	-	-	0.7	2.0	-	-	0.7	2.0	-	-	-	-	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-
Dual Clutch Transmission (DCT)	DCT	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7
Hybrid Techs																	
Power Split Hybrid	PSHEV	14.6	15.2	21.0	26.5	14.6	15.0	21.0	26.5	13.1	14.6	21.0	26.5	13.7	15.7	21.0	26.5
2-Mode Hybrid	2MHEV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plug-in hybrid	PHEV	62.0	65.0	65.0	69.5	62.0	65.0	65.0	69.5	61.0	65.0	65.0	69.5	-	-	-	-
Vehicle Techs																	
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 5%	MR5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 10%	MR10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Secondary Axle Disconnect	SAX	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Aero Drag Reduction 10%	AERO	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-

continued

TABLE I.1 Continued

NHTSA - 2011 Rule																	
Technologies		Subcompact Car I4				Compact Car I4				Midsize Car I4				Large Car V6			
		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value	
Spark Ignition Techs	Abbreviation	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Low Friction Lubricants	LUB	0.5		-	-	0.5		-	-	0.5		-	-	0.5		-	-
Engine Friction Reduction	EFR	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Cylinder Deactivation, SOHC	DEAC	-	-	-	-	-	-	-	-			-	-	2.5	3.0	-	-
VVT - In take Cam Phasing (ICP)	ICP	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT - Dual Cam Phasing (DCP)	DCP	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Continuously Variable Valve Lift (CVVL	CVVL	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-
Cylinder Deactivation, OHV	DEAC	-	-	-	-	-	-	-	-	-	-	-	-	3.9	5.5	-	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-
Conversion to DOHC with DCP	CDOHC	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-
Stoichiometric Gasoline Direct Injection (GDI	SGDI	1.9	2.9	5.0	13.0	1.9	2.9	5.0	13.0	1.9	2.9	5.0	13.0	1.9	2.9	5.0	13.0
Turbocharging and Downsizing	TRBDS	4.5	5.2	11.0	17.5	4.5	5.2	11.0	17.5	4.5	5.2	11.0	17.5	2.1	2.2	11.0	17.5
Diesel Techs																	
Conversion to Diesel	DSL	15.0	15.3	21.2	25.9	15.0	15.3	21.2	25.9	13.8	14.2	20.2	24.9	11.1	12.0	20.2	24.9
Conversion to Diesel following TRBDS	DSL	6.6	7.7	21.2	25.9	6.6	7.7	21.2	25.9	5.3	6.5	20.2	24.9	5.3	6.5	20.2	24.9
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs																	
Electric Power Steering (EPS)	EPS	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
Improved Accessories	IACC	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
12V BAS Micro-Hybrid	MHEV	1.0	2.9	-	-	1.0	2.9	-	-	3.4	4.0	-	-	3.4	4.0	-	-
Higher Voltage/Improved Alternator	HVIA	0.2	0.9	-	-	0.2	0.9	-	-	0.2	0.6	-	-	0.2	0.6	-	-
Integrated Starter Generator	ISG	5.7	6.5	-	-	5.7	6.5	-	-	5.7	6.5	-	-	5.7	6.5	-	-
Transmission Techs																	
Continuously Variable Transmission (CVT	CVT	0.7	2.0	-	-	0.7	2.0	-	-	0.7	2.0	-	-	0.7	2.0	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-
Dual Clutch Transmission (DCT)	DCT	5.5	7.5	8.2	12.9	5.5	7.5	8.2	12.9	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7
Hybrid Techs																	
Power Split Hybrid	PSHEV	13.5	13.9	23.0	28.5	13.5	13.9	23.0	28.5	11.8	12.8	23.0	28.5	11.8	12.8	23.0	28.5
2-Mode Hybrid	2MHEV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plug-in hybrid	PHEV	61.0	63.0	65.0	69.5	61.0	63.0	65.0	69.5	60.0	63.0	65.0	69.5	-	-	-	-
Vehicle Techs																	
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 5%	MR5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 10%	MR10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Secondary Axle Disconnec	SAX	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Aero Drag Reduction 10%	AERO	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-

continued

TABLE I.1 Continued

NHTSA - 2011 Rule

Technologies		Minivan LT				Small LT				Midsize LT				Large LT			
		V6				I4				V6				V8			
		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value		Incremental Value		Net Value	
Spark Ignition Techs	Abbreviation	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Low Friction Lubricants	LUB	0.5		-	-	0.5		-	-	0.5		-	-	0.5		-	-
Engine Friction Reduction	EFR	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Cylinder Deactivation, SOHC	DEAC	2.5	3.0	-	-	-	-	-	-	2.5	3.0	-	-	2.5	3.0	-	-
VVT - In take Cam Phasing (ICP)	ICP	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-
VVT - Dual Cam Phasing (DCP)	DCP	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-	1.0	3.0	-	-
Continuously Variable Valve Lift (CVVL)	CVVL	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-	1.5	3.5	-	-
Cylinder Deactivation, OHV	DEAC	3.9	5.5	-	-	-	-	-	-	3.9	5.5	-	-	3.9	5.5	-	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-	0.5	2.6	-	-
Conversion to DOHC with DCP	CDOHC	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-	1.0	2.6	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.9	2.9	7.0	14.0	1.9	2.9	4.5	13.0	1.9	2.9	7.0	14.0	1.9	2.9	7.0	14.0
Turbocharging and Downsizing	TRBDS	2.1	2.2	11.0	17.5	4.5	5.2	11.0	17.5	2.1	2.2	11.0	17.5	2.1	2.2	11.0	17.5
Diesel Techs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conversion to Diesel	DSL	11.1	12.0	20.2	24.9	13.8	14.2	20.2	24.9	9.9	12.0	20.2	23.9	10.0	10.9	19.2	23.9
Conversion to Diesel following TRBDS	DSL	5.3	6.5	20.2	24.9	5.3	6.5	20.2	24.9	4.0	6.5	20.2	23.9	4.0	5.3	19.2	23.9
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electric Power Steering (EPS)	EPS	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	-	-	-	-
Improved Accessories	IACC	1.0	2.0	-	-	1.0	2.0	-	-	-	-	-	-	-	-	-	-
12V BAS Micro-Hybrid	MHEV	3.4	4.0	-	-	1.0	2.9	-	-	3.4	4.0	-	-	-	-	-	-
Higher Voltage/Improved Alternator	HVIA	0.2	0.6	-	-	0.2	0.9	-	-	0.2	0.6	-	-	-	-	-	-
Integrated Starter Generator	ISG	5.7	6.5	-	-	5.7	6.5	-	-	5.7	6.5	-	-	-	-	-	-
Transmission Techs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Continuously Variable Transmission (CVT)	CVT	0.7	2.0	-	-	0.7	2.0	-	-	-	-	-	-	-	-	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-	1.4	3.4	-	-
Dual Clutch Transmission (DCT)	DCT	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7	2.7	4.1	5.5	9.7
Hybrid Techs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Power Split Hybrid	PSHEV	11.8	12.8	23.0	28.5	13.5	13.9	23.0	28.5	13.3	16.2	23.0	28.5	-	-	-	-
2-Mode Hybrid	2MHEV	-	-	-	-	1.5	4.3	17.5	21.0	0.3	2.9	17.5	21.0	7.9	8.7	13.5	17.0
Plug-in hybrid	PHEV	-	-	-	-	61.0	63.0	65.0	69.5	-	-	-	-	-	-	-	-
Vehicle Techs		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	0.4		-	-	0.4		-	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	0.4		-	-	0.4		-	-
Mass Reduction - 5%	MR5	-	-	-	-	-	-	-	-	1.0		-	-	1.0		-	-
Mass Reduction - 10%	MR10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	1.0	2.0	-	-	1.0	2.0	-	-	1.0	2.0	-	-	-	-	-	-
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	0.5	1.0	-	-	0.5	1.0	-	-
Secondary Axle Disconnect	SAX	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-	1.0	1.5	-	-
Aero Drag Reduction 10%	AERO	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-	2.0	3.0	-	-

TABLE I.2 Technology Effectiveness, Incremental (Percent) Fuel Consumption Benefit from NRC (2002)

NRC - 2002				
Technologies				
Spark Ignition Techs	Abbreviation	Low	High	**AVG**
Low Friction Lubricants	LUB	1.0		**1.0**
Engine Friction Reduction	EFR	1.0	5.0	**3.0**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.0	2.0	**1.5**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	1.0	2.0	**1.5**
Cylinder Deactivation, SOHC	DEAC	-	-	**-**
VVT - In take Cam Phasing (ICP)	ICP	2.0	3.0	**2.5**
VVT - Dual Cam Phasing (DCP)	DCP	2.0	3.0	**2.5**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	1.0	2.0	**1.5**
Continuously Variable Valve Lift (CVVL)	CVVL	1.0	2.0	**1.5**
Cylinder Deactivation, OHV	DEAC	3.0	6.0	**4.5**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	2.0	3.0	**2.5**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	1.0	2.0	**1.5**
Conversion to DOHC with DCP	CDOHC	-	-	**-**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	-	-	**-**
Turbocharging and Downsizinc	TRBDS	5.0	7.0	**6.0**
Diesel Techs		**Non-incremental**		
Conversion to Diesel	DSL	-	-	**-**
Conversion to Diesel following TRBDS	DSL	-	-	**-**
Conversion to Advanced Diesel	ADSL	-	-	**-**
Electrification/Accessory Techs		**Non-incremental**		
Electric Power Steering (EPS)	EPS	1.5	2.5	**2.0**
Improved Accessories	IACC	1.0	2.0	**1.5**
12V BAS Micro-Hybrid	MHEV	-	-	**-**
Higher Voltage/Improved Alternator	HVIA	-	-	**-**
Integrated Starter Generator	ISG	4.0	7.0	**5.5**
Transmission Techs		**Non-incremental**		
Continuously Variable Transmission (CVT)	CVT	4.0	8.0	**6.0**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	1.0	2.0	**1.5**
Dual Clutch Transmission (DCT)	DCT	3.0	5.0	**4.0**
Hybrid Techs		**Non-incremental**		
Power Split Hybrid	PSHEV	-	-	**-**
2-Mode Hybrid	2MHEV	-	-	**-**
Plug-in hybrid	PHEV	-	-	**-**
Vehicle Techs		**Non-incremental**		
Mass Reduction - 1%	MR1	-	-	**-**
Mass Reduction - 2%	MR2	-	-	**-**
Mass Reduction - 5%	MR5	-	-	**-**
Mass Reduction - 10%	MR10	-	-	**-**
Mass Reduction - 20%	MR20	-	-	**-**
Low Rolling Resistance Tires	ROLL	1.0	1.5	**1.3**
Low Drag Brakes	LDB	-	-	**-**
Secondary Axle Disconnect	SAX	-	-	**-**
Aero Drag Reduction 10%	AERO	-	-	**-**

TABLE I.3 Technology Effectiveness, Incremental (Percent) Fuel Consumption Benefit from EPA (2008)

EPA 2008

Technologies		Small Car			Large Car		
		I4			V6		
Spark Ignition Techs	Abbreviation	Low	High	**AVG**	Low	High	**AVG**
Low Friction Lubricants	LUB	0.5		**0.5**	0.5		**0.5**
Engine Friction Reduction	EFR	1.0	3	**2.0**	1.0	3	**2.0**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	3.0	-	**3.0**	4.0	-	**4.0**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	4.0	-	**4.0**	3.0	-	**3.0**
Cylinder Deactivation, SOHC	DEAC	-	-	**-**	6.0	-	**6.0**
VVT - In take Cam Phasing (ICP)	ICP	2.0	-	**2.0**	1.0	-	**1.0**
VVT - Dual Cam Phasing (DCP)	DCP	3.0	-	**3.0**	4.0	-	**4.0**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	4.0	-	**4.0**	3.0	-	**3.0**
Continuously Variable Valve Lift (CVVL)	CVVL	5.0	-	**5.0**	6.0	-	**6.0**
Cylinder Deactivation, OHV	DEAC	-	-	**-**	6.0	-	**6.0**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	3.0	-	**3.0**	4.0	-	**4.0**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	4.0	-	**4.0**	4.0	-	**4.0**
Conversion to DOHC with DCP	CDOHC	-	-	**-**	-	-	**-**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.0	2.0	**1.5**	1.0	2.0	**1.5**
Turbocharging and Downsizin[1]	TRBDS	5.0	7.0	**6.0**	5.0	7.0	**6.0**
Diesel Techs		**Non-incremental**		**-**	**-**	**-**	**-**
Conversion to Diesel	DSL	25.0	35.0	**30.0**	30.0	40.0	**35.0**
Conversion to Diesel following TRBDS	DSL	-	-	**-**	-	-	**-**
Conversion to Advanced Diesel	ADSL	-	-	**-**	-	-	**-**
Electrification/Accessory Tech		**Non-incremental**		**-**	**-**	**-**	**-**
Electric Power Steering (EPS)	EPS	1.5	-	**1.5**	1.5	2.0	**1.8**
Improved Accessories[2]	IACC	1.0	2.0	**1.5**	1.0	2.0	**1.5**
12V BAS Micro-Hybrid	MHEV	-	-	**-**	-	-	**-**
Higher Voltage/Improved Alternator	HVIA	-	-	**-**	-	-	**-**
Integrated Starter Generato	ISG	30.0	-	**30.0**	25.0	-	**25.0**
Transmission Tech		**Non-incremental**		**-**	**-**	**-**	**-**
Continuously Variable Transmission (CVT) [3]	CVT	6.0	-	**6.0**	6.0	-	**6.0**
6/7/8-Speed Auto. Trans. with Improved Internals [3]	NAUTO	4.5	6.0	**5.3**	4.5	6.0	**5.3**
Dual Clutch Transmission (DCT [3]	DCT	9.5	14.5	**12.0**	9.5	14.5	**12.0**
Hybrid Techs		**Non-incremental**		**-**	**-**	**-**	**-**
Power Split Hybrid	PSHEV	35.0	-	**35.0**	35.0	-	**35.0**
2-Mode Hybrid	2MHEV	-	-	**-**	40.0	-	**40.0**
Plug-in hybrid	PHEV	58.0	-	**58.0**	58.0	-	**58.0**
Vehicle Techs		**Non-incremental**		**-**	**-**	**-**	**-**
Mass Reduction - 1%	MR1	-	-	**-**	-	-	**-**
Mass Reduction - 2%	MR2	-	-	**-**	-	-	**-**
Mass Reduction - 5%	MR5	-	-	**-**	-	-	**-**
Mass Reduction - 10%	MR10	-	-	**-**	-	-	**-**
Mass Reduction - 20%	MR20	-	-	**-**	-	-	**-**
Low Rolling Resistance Tire	ROLL	1.0	2.0	**1.5**	1.0	2.0	**1.5**
Low Drag Brakes	LDB	-	-	**-**	-	-	**-**
Secondary Axle Disconnect	SAX	1.0	-	**1.0**	1.0	-	**1.0**
Aero Drag Reduction 10%	AERO	-	-	**-**	-	-	**-**

TABLE I.4 Technology Effectiveness, Incremental (percent) Fuel Consumption Benefit from Ricardo, Inc. (2008), NESCCAF (2004), Sierra Research (2008), and EEA (2007)

Ricardo, Inc.

Technologies		Standard Car			Full Size Car		Small MPV			Large MPV		Truck	
		I4, 2.4L-4V, DCP, 5spd AT, 3.39 FDR			V6, 3.5L-4V, 5spd AT, 2.87 FDR		I4, 2.4L-4V, DCP, 4spd AT, 3.91 FDR			V6, 3.8L-2V, OHV, 4spd AT, 3.43 FDR		V8, 5.4L-3V, CCP, 4spd AT, 3.73 FDR	
Spark Ignition Techs	Abbreviation	from EPA report	from report for NAS	Low	from EPA report	from report for NAS	from EPA report	from report for NAS (pack 5)	(pack 15)	from EPA report	from report for NAS	from EPA report	from report for NAS
Low Friction Lubricants	LUB	2.0	-	-	2.0	-	-	-	-	2.0	-	2.0	-
Engine Friction Reduction	EFR		-	-		-		-	-		-		-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	-	-	-	-	-	-	-	-	-	-	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	-	-	-	-	-	-	-	-	-	-	-	-
Cylinder Deactivation, SOHC	DEAC	-	-	-	-	-	-	-	-	-	-	-	-
VVT - In take Cam Phasing (ICP)	ICP	-	-	-	-	-	-	-	-	-	-	-	-
VVT - Dual Cam Phasing (DCP)	DCP	-	-	-	5.0	-	-	-	-	5.0	-	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	2.0	1.5	-	-	-	-	-	-	-	-	-	-
Continuously Variable Valve Lift (CVVL)	CVVL	-	-	-	3.0	-	-	-	-	-	-	-	-
Cylinder Deactivation, OHV	DEAC	-	-	-	-	-	-	-	-	-	4.0	-	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-	-	-	-	-	-	-	-	2.5	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	-	-	-	-	-	-	-	-	-	-	-	-
Conversion to DOHC with DCP	CDOHC	-	-	-	-	-	-	-	-	-	-	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	-	-	-	2.0	-	2.0	-	-	3.0	2.8	-	-
Turbocharging and Downsizing	TRBDS	-	-	-	-	-	-	-	4.4	3.0	-	-	-
Diesel Techs													
Conversion to Diesel	DSL	-	-	-	-	-	-	12.8	-	-	-	16.0	11.4
Conversion to Diesel following TRBDS	DSL	-	-	-	-	-	-	-	-	-	-	-	-
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs													
Electric Power Steering (EPS)	EPS	-	-	-	-	-	-	-	-	-	-	-	-
Improved Accessories	IACC	-	-	-	-	-	-	1.7	1.4	-	-	-	-
12V BAS Micro-Hybrid	MHEV	3.0	3.0	-	-	-	3.0	-	-	-	2.0	-	-
Higher Voltage/Improved Alternator	HVIA	-	-	-	-	-	-	-	-	-	-	-	-
Integrated Starter Generator	ISG	-	-	-	-	-	-	-	-	-	-	-	-
Transmission Techs													
Continuously Variable Transmission (CVT)	CVT	-	-	-	-	-	-	-	-	-	-	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	-	-	-	-	-	-	-	-	2.0	2.4	-	-
Dual Clutch Transmission (DCT)	DCT	8.0	6.7	-	7.0	-	-	6.8	6.4	-	-	9.0	9.3
Hybrid Techs													
Power Split Hybrid	PSHEV	-	-	-	-	-	-	-	-	-	-	-	-
2-Mode Hybrid	2MHEV	-	-	-	-	-	-	-	-	-	-	-	-
Plug-in hybrid	PHEV	-	-	-	-	-	-	-	-	-	-	-	-
Vehicle Techs													
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 5%	MR5	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 10%	MR10	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	-	1.3	-	-	1.3	-	1.6	1.9	-	1.4	-	-
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	-	-	-	-
Secondary Axle Disconnect	SAX	-	-	-	-	-	-	-	-	-	-	-	-
Aero Drag Reduction 10%	AERO	-	-	-	-	-	-	-	-	-	-	2.0	1.4

continued

TABLE I.4 Continued

NESCCAF

Technologies		Small Car	Large Car	MiniVan	SmallTruck/SUV	Large Truck/SUV
		I4	V6	V6	V6	V8
Spark Ignition Techs	Abbreviation					
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	0.5	0.5	0.5	0.5	0.5
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	3.0	4.0	2.0	2.0	4.0
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	4.0	4.0	3.0	4.0	4.0
Cylinder Deactivation, SOHC	DEAC	-	6.0	5.0	6.0	4.0
VVT - In take Cam Phasing (ICP)	ICP	2.0	1.0	1.0	1.0	2.0
VVT - Dual Cam Phasing (DCP)	DCP	3.0	4.0	2.0	3.0	4.0
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	4.0	4.0	3.0	4.0	4.0
Continuously Variable Valve Lift (CVVL)	CVVL	5.0	6.0	4.0	5.0	5.0
Cylinder Deactivation, OHV	DEAC	-	6.0	5.0	6.0	4.0
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-	-	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	4.0	4.0	3.0	4.0	4.0
Conversion to DOHC with DCP	CDOHC	-	-	-	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	0.0	1.0	-1.0	-1.0	0.0
Turbocharging and Downsizin	TRBDS	6.0	8.0	6.0	6.0	-
Diesel Techs		-	-	-	-	-
Conversion to Diesel	DSL	-	-	-	-	-
Conversion to Diesel following TRBDS	DSL	-	-	-	-	-
Conversion to Advanced Diesel	ADSL	13.0	15.0	18.0	21.0	17.0
Electrification/Accessory Tech		-	-	-	-	-
Electric Power Steering (EPS)	EPS	1.0	-	-	-	1.0
Improved Accessories	IACC	3.0	-	-	-	2.0
12V BAS Micro-Hybrid	MHEV	-	-	-	-	-
Higher Voltage/Improved Alternator	HVIA	1.0	-	-	-	0.0
Integrated Starter Generator	ISG	-	-	-	-	-
Transmission Techs		-	-	-	-	-
Continuously Variable Transmission (CVT)	CVT	4.0	3.0	4.0	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	3.0	3.0	3.0	3.0	2.0
Dual Clutch Transmission (DCT	DCT	8.0	7.0	8.0	8.0	5.0
Hybrid Techs		-	-	-	-	-
Power Split Hybrid	PSHEV	53.0	53.0	53.0	53.0	53.0
2-Mode Hybrid	2MHEV	-	-	-	-	-
Plug-in hybrid	PHEV	-	-	-	-	-
Vehicle Techs		-	-	-	-	-
Mass Reduction - 1%	MR1	0.5	-	-	-	0.6
Mass Reduction - 2%	MR2	1.0	-	-	-	1.1
Mass Reduction - 5%	MR5	2.6	-	-	-	2.9
Mass Reduction - 10%	MR10	5.3	-	-	-	5.7
Mass Reduction - 20%	MR20	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	1.8	-	-	-	2.0
Low Drag Brakes	LDB	-	-	-	-	-
Secondary Axle Disconnect	SAX	-	-	-	-	-
Aero Drag Reduction 10%	AERO	1.7	-	-	-	1.9

continued

TABLE I.4 Continued

Sierra Research			
Technologies		**Midsize**	**Truck**
		- assume engine size adj. for constant acceleration	
Spark Ignition Techs	Abbreviation		
Low Friction Lubricants	LUB	0.5	0.5
Engine Friction Reduction	EFR	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	-	-
Cylinder Deactivation, SOHC	DEAC	7.5	8.8
VVT - In take Cam Phasing (ICP)	ICP	-	-
VVT - Dual Cam Phasing (DCP)	DCP	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	6.3	6.8
Continuously Variable Valve Lift (CVVL)	CVVL	11.4	12.4
Cylinder Deactivation, OHV	DEAC	7.5	8.8
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	-	-
Conversion to DOHC with DCP	CDOHC	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	5.9	6.2
Turbocharging and Downsizinç	TRBDS	-0.3	0.3
Diesel Techs			
Conversion to Diesel	DSL	-	-
Conversion to Diesel following TRBDS	DSL	21.3	18.6
Conversion to Advanced Diesel	ADSL	-	-
Electrification/Accessory Techs			
Electric Power Steering (EPS)	EPS	1.8	1.1
Improved Accessories	IACC	-	-
12V BAS Micro-Hybrid	MHEV	-	-
Higher Voltage/Improved Alternator	HVIA	0.9	0.6
Integrated Starter Generator	ISG	-	-
Transmission Techs			
Continuously Variable Transmission (CVT)	CVT	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	-	-
Dual Clutch Transmission (DCT)	DCT	4.0	4.4
Hybrid Techs			
Power Split Hybrid	PSHEV	28.7	22.1
2-Mode Hybrid	2MHEV	-	-
Plug-in hybrid	PHEV	-	-
Vehicle Techs			
Mass Reduction - 1%	MR1	-	-
Mass Reduction - 2%	MR2	-	-
Mass Reduction - 5%	MR5	-	-
Mass Reduction - 10%	MR10	-	-
Mass Reduction - 20%	MR20	-	-
Low Rolling Resistance Tires	ROLL	-	-
Low Drag Brakes	LDB	-	-
Secondary Axle Disconnect	SAX	-	-
Aero Drag Reduction 10%	AERO	-	-

continued

TABLE I.4 Continued

Technologies		EEA		
		-constant engine size		percent relative to PFI, fixed valve timing
		Values were converted to FC%		
Spark Ignition Techs	Abbreviation	Low	High	AVG
Low Friction Lubricants	LUB	0.9	1.1	**1.0**
Engine Friction Reduction	EFR	1.8	6.0	**3.9**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	1.3	1.9	**1.6**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	n/a	n/a	**n/a**
Cylinder Deactivation, SOHC	DEAC	5.3	7.1	**6.2**
VVT - In take Cam Phasing (ICP)	ICP	1.1	1.8	**1.4**
VVT - Dual Cam Phasing (DCP)	DCP	1.8	2.5	**2.2**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	2.9	3.8	**3.4**
Continuously Variable Valve Lift (CVVL)	CVVL	6.5	8.3	**7.4**
Cylinder Deactivation, OHV	DEAC	5.3	7.1	**6.2**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	1.3	1.9	**1.6**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	n/a	n/a	**n/a**
Conversion to DOHC with DCP	CDOHC	n/a	n/a	**n/a**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.9	3.8	**3.4**
Turbocharging and Downsizing	TRBDS	n/a	n/a	**n/a**
Diesel Techs				
Conversion to Diesel	DSL	24.8	30.1	**n/a**
Conversion to Diesel following TRBDS	DSL	n/a	n/a	**n/a**
Conversion to Advanced Diesel	ADSL	n/a	n/a	**n/a**
Electrification/Accessory Techs				
Electric Power Steering (EPS)	EPS	1.8	2.2	**2.0**
Improved Accessories	IACC	n/a	n/a	**n/a**
12V BAS Micro-Hybrid	MHEV	4.0	4.6	**4.3**
Higher Voltage/Improved Alternator	HVIA	0.3	0.7	**0.5**
Integrated Starter Generator	ISG	2.9	11.5	**7.2**
Transmission Techs				
Continuously Variable Transmission (CVT)	CVT	4.8	7.8	**6.3**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	4.0	5.5	**4.8**
Dual Clutch Transmission (DCT)	DCT	6.1	7.0	**6.5**
Hybrid Techs				
Power Split Hybrid	PSHEV	-	-	**-**
2-Mode Hybrid	2MHEV	-	-	**-**
Plug-in hybrid	PHEV	-	-	**-**
Vehicle Techs				
Mass Reduction - 1%	MR1	n/a	n/a	**n/a**
Mass Reduction - 2%	MR2	n/a	n/a	**n/a**
Mass Reduction - 5%	MR5	3.0	3.2	**3.1**
Mass Reduction - 10%	MR10	5.8	6.2	**6.0**
Mass Reduction - 20%	MR20	1.3	1.5	**-**
Low Rolling Resistance Tires	ROLL	n/a	n/a	n/a
Low Drag Brakes	LDB	n/a	n/a	**n/a**
Secondary Axle Disconnect	SAX	1.8	2.2	**n/a**
Aero Drag Reduction 10%	AERO	3.5	4.2	**3.8**

TABLE I.5 Incremental Costs ($) from DOT/NHTSA (2009)

NHTSA 2011																	
Technologies		Subcompact Car				Compact Car				Midsize Car				Large Car			
		I4				I4				I4				V6			
Spark Ignition Techs	Abbreviation	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net
Low Friction Lubricants	LUB	5.0		**5.0**	**-**	5.0		**5.0**	**-**	5.0		**5.0**	**-**	5.0		**5.0**	**-**
Engine Friction Reduction	EFR	52.0	196.0	**124.0**	**-**	52.0	196.0	**124.0**	**-**	52.0	196.0	**124.0**	**-**	78.0	294.0	**186.0**	**-**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	122.0	-	**122.0**	**-**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	306.0	-	**306.0**	**-**
Cylinder Deactivation, SOHC	DEAC	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	75.0	-	**75.0**	**-**
VVT - In take Cam Phasing (ICP)	ICP	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	122.0	-	**122.0**	**-**
VVT - Dual Cam Phasing (DCP)	DCP	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	122.0	-	**122.0**	**-**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	306.0	-	**306.0**	**-**
Continuously Variable Valve Lift (CVVL)	CVVL	306.0	-	**306.0**	**-**	306.0	-	**306.0**	**-**	306.0	-	**306.0**	**-**	432.0	-	**432.0**	**-**
Cylinder Deactivation, OHV	DEAC	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	306.0	-	**306.0**	**-**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	61.0	-	**61.0**	**-**	122.0	-	**122.0**	**-**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	201.0	-	**201.0**	**-**	76.0	-	**76.0**	**-**
Conversion to DOHC with DCP	CDOHC	373.0	-	**373.0**	**-**	373.0	-	**373.0**	**-**	373.0	-	**373.0**	**-**	590.0	-	**590.0**	**-**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	293.0	440.0	**366.5**	**-**	293.0	440.0	**366.5**	**-**	293.0	440.0	**366.5**	**-**	384.0	558.0	**471.0**	**-**
Turbocharging and Downsizing	TRBDS	1223.0	-	**1223.0**	**-**	1223.0	-	**1223.0**	**-**	1223.0	-	**1223.0**	**-**	822.0	-	**822.0**	**-**
Diesel Techs																	
Conversion to Diesel	DSL	2963.0	3254.0	**3108.5**	**4000.0**	2963.0	3254.0	**3108.5**	**4000.0**	2963.0	3254.0	**3108.5**	**4000.0**	4105.0	4490.0	**4297.5**	**5600.0**
Conversion to Diesel following TRBDS	DSL	1567.0	1858.0	**1712.5**	**4000.0**	1567.0	1858.0	**1712.5**	**4000.0**	1567.0	1858.0	**1712.5**	**4000.0**	3110.0	3495.0	**3302.5**	**5600.0**
Conversion to Advanced Diesel	ADSL	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Electrification/Accessory Techs															-		
Electric Power Steering (EPS)	EPS	105.0	120.0	**112.5**	**-**	105.0	120.0	**112.5**	**-**	105.0	120.0	**112.5**	**-**	105.0	120.0	**112.5**	**-**
Improved Accessories	IACC	173.0	211.0	**192.0**	**-**	173.0	211.0	**192.0**	**-**	173.0	211.0	**192.0**	**-**	173.0	211.0	**192.0**	**-**
12V BAS Micro-Hybrid	MHEV	372.0	-	**372.0**	**-**	408.0	-	**408.0**	**-**	453.0	-	**453.0**	**-**	490.0	-	**490.0**	**-**
Higher Voltage/Improved Alternator	HVIA	84.0	-	**84.0**	**-**	84.0	-	**84.0**	**-**	84.0	-	**84.0**	**-**	84.0	-	**84.0**	**-**
Integrated Starter Generator	ISG	1713.0	-	**1713.0**	**-**	2019.0	-	**2019.0**	**-**	2190.0	-	**2190.0**	**-**	2386.0	-	**2386.0**	**-**
Transmission Techs																	
Continuously Variable Transmission (CVT)	CVT	300.0	-	**300.0**	**-**	300.0	-	**300.0**	**-**	300.0	-	**300.0**	**-**	300.0	-	**300.0**	**-**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	323.0	-	**323.0**	**-**	323.0	-	**323.0**	**-**	323.0	-	**323.0**	**-**	323.0	-	**323.0**	**-**
Dual Clutch Transmission (DCT)	DCT	68.0	-	**68.0**	**500.0**	68.0	-	**68.0**	**500.0**	218.0	-	**218.0**	**600.0**	218.0	-	**218.0**	**600.0**
Hybrid Techs																	
Power Split Hybrid	PSHEV	1409.0	1462.0	**1435.5**	**4300.0**	1742.0	1795.0	**1768.5**	**4900.0**	2175.0	2228.0	**2201.5**	**5600.0**	2534.0	2587.0	**2560.5**	**6200.0**
2-Mode Hybrid	2MHEV	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Plug-in hybrid	PHEV	19648.0	19701.0	**19674.5**	**22500.0**	23670.0	23723.0	**23696.5**	**26700.0**	26702.0	26755.0	**26728.5**	**30000.0**	-	-	**-**	**-**
Vehicle Techs																	
Mass Reduction - 1%	MR1	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Mass Reduction - 2%	MR2	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Mass Reduction - 5%	MR5	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Mass Reduction - 10%	MR10	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Mass Reduction - 20%	MR20	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Low Rolling Resistance Tires	ROLL	6.0	9.0	**7.5**	**-**	6.0	9.0	**7.5**	**-**	6.0	9.0	**7.5**	**-**	6.0	9.0	**7.5**	**-**
Low Drag Brakes	LDB	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**
Secondary Axle Disconnect	SAX	117.0	-	**117.0**	**-**	117.0	-	**117.0**	**-**	117.0	-	**117.0**	**-**	117.0	-	**117.0**	**-**
Aero Drag Reduction 10%	AERO	60.0	116.0	**88.0**	**-**	60.0	116.0	**88.0**	**-**	60.0	116.0	**88.0**	**-**	60.0	116.0	**88.0**	**-**

continued

TABLE I.5 Continued

NHTSA 2011

Technologies		Performance Subcompact Car				Performance Compact Car				Performance Midsize Car				Performance Large Car			
		I4				V6				V6				V8			
Spark Ignition Techs	Abbreviation	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net
Low Friction Lubricants	LUB	5.0		**5.0**	-	5.0		**5.0**	-	5.0		**5.0**	-	5.0		**5.0**	-
Engine Friction Reduction	EFR	52.0	196.0	**124.0**	-	78.0	294.0	**186.0**	-	78.0	294.0	**186.0**	-	104.0	392.0	**248.0**	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	201.0	-	**201.0**	-	306.0	-	**306.0**	-	306.0	-	**306.0**	-	396.0	-	**396.0**	-
Cylinder Deactivation, SOHC	DEAC	-	-	**-**	-	75.0	-	**75.0**	-	75.0	-	**75.0**	-	75.0	-	**75.0**	-
VVT - In take Cam Phasing (ICP)	ICP	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
VVT - Dual Cam Phasing (DCP)	DCP	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	201.0	-	**201.0**	-	306.0	-	**306.0**	-	306.0	-	**306.0**	-	396.0	-	**396.0**	-
Continuously Variable Valve Lift (CVVL)	CVVL	306.0	-	**306.0**	-	432.0	-	**432.0**	-	432.0	-	**432.0**	-	582.0	-	**582.0**	-
Cylinder Deactivation, OHV	DEAC	-	-	**-**	-	306.0	-	**306.0**	-	306.0	-	**306.0**	-	400.0	-	**400.0**	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	201.0	-	**201.0**	-	76.0	-	**76.0**	-	76.0	-	**76.0**	-	76.0	-	**76.0**	-
Conversion to DOHC with DCP	CDOHC	373.0	-	**373.0**	-	590.0	-	**590.0**	-	590.0	-	**590.0**	-	746.0	-	**746.0**	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	293.0	440.0	**366.5**	-	384.0	558.0	**471.0**	-	384.0	558.0	**471.0**	-	512.0	744.0	**628.0**	-
Turbocharging and Downsizing	TRBDS	1223.0	-	**1223.0**	-	822.0	-	**822.0**	-	822.0	-	**822.0**	-	1229.0	-	**1229.0**	-
Diesel Techs																	
Conversion to Diesel	DSL	2963.0	3254.0	**3108.5**	**4000.0**	4105.0	4490.0	**4297.5**	**5600.0**	4105.0	4490.0	**4297.5**	**5600.0**	5125.0	5617.0	**5371.0**	**7000.0**
Conversion to Diesel following TRBDS	DSL	1567.0	1858.0	**1712.5**	**4000.0**	3110.0	3495.0	**3302.5**	**5600.0**	3110.0	3495.0	**3302.5**	**5600.0**	3723.0	4215.0	**3969.0**	**7000.0**
Conversion to Advanced Diesel	ADSL	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Electrification/Accessory Techs															-		
Electric Power Steering (EPS)	EPS	105.0	120.0	**112.5**	-	105.0	120.0	**112.5**	-	105.0	120.0	**112.5**	-	105.0	120.0	**112.5**	-
Improved Accessories	IACC	173.0	211.0	**192.0**	-	173.0	211.0	**192.0**	-	173.0	211.0	**192.0**	-	173.0	211.0	**192.0**	-
12V BAS Micro-Hybrid	MHEV	406.0	-	**406.0**	-	443.0	-	**443.0**	-	494.0	-	**494.0**	-	549.0	-	**549.0**	-
Higher Voltage/Improved Alternator	HVIA	84.0	-	**84.0**	-	84.0	-	**84.0**	-	84.0	-	**84.0**	-	84.0	-	**84.0**	-
Integrated Starter Generator	ISG	1789.0	1864.0	**1826.5**	-	2054.0	-	**2054.0**	-	2183.0	-	**2183.0**	-	2351.0	-	**2351.0**	-
Transmission Techs																	
Continuously Variable Transmission (CVT)	CVT	300.0	-	**300.0**	-	300.0	-	**300.0**	-	300.0	-	**300.0**	-	-	-	**-**	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	323.0	638.0	**480.5**	-	323.0	638.0	**480.5**	-	323.0	638.0	**480.5**	-	323.0	638.0	**480.5**	-
Dual Clutch Transmission (DCT)	DCT	97.0	218.0	**157.5**	**600.0**	97.0	218.0	**157.5**	**600.0**	97.0	218.0	**157.5**	**600.0**	97.0	218.0	**157.5**	**600.0**
Hybrid Techs																	
Power Split Hybrid	PSHEV	2838.0	2966.0	**2902.0**	**5900.0**	3144.0	3197.0	**3170.5**	**6400.0**	4093.0	4146.0	**4119.5**	**7500.0**	5467.0	5520.0	**5493.5**	**8800.0**
2-Mode Hybrid	2MHEV	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	**-**	-	-	**-**	-
Plug-in hybrid	PHEV	23736.0	23864.0	**23800.0**	**26800.0**	26790.0	26843.0	**26816.5**	**30100.0**	30110.0	30163.0	**30136.5**	**33600.0**	-	-	**-**	-
Vehicle Techs																	
Mass Reduction - 1%	MR1	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Mass Reduction - 2%	MR2	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Mass Reduction - 5%	MR5	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Mass Reduction - 10%	MR10	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Mass Reduction - 20%	MR20	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Low Rolling Resistance Tires	ROLL	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Low Drag Brakes	LDB	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-	-	-	**-**	-
Secondary Axle Disconnect	SAX	117.0	-	**117.0**	-	117.0	-	**117.0**	-	117.0	-	**117.0**	-	117.0	-	**117.0**	-
Aero Drag Reduction 10%	AERO	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-

continued

TABLE I.5 Continued

NHTSA 2011

Technologies		Minivan LT				Small LT				Midsize LT				Large LT			
		V6				I4				V6				V8			
Spark Ignition Techs	Abbreviation	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net	Low	High	AVG	Net
Low Friction Lubricants	LUB	5.0		**5.0**	-	5.0		**5.0**	-	5.0		**5.0**	-	5.0		**5.0**	-
Engine Friction Reduction	EFR	78.0	294.0	**186.0**	-	52.0	196.0	**124.0**	-	78.0	294.0	**186.0**	-	104.0	392.0	**248.0**	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	122.0	-	**122.0**	-	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	306.0	-	**306.0**	-	201.0	-	**201.0**	-	306.0	-	**306.0**	-	396.0	-	**396.0**	-
Cylinder Deactivation, SOHC	DEAC	75.0	-	**75.0**	-	-	-	-	-	75.0	-	**75.0**	-	75.0	-	**75.0**	-
VVT - In take Cam Phasing (ICP)	ICP	122.0	-	**122.0**	-	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
VVT - Dual Cam Phasing (DCP)	DCP	122.0	-	**122.0**	-	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	306.0	-	**306.0**	-	201.0	-	**201.0**	-	306.0	-	**306.0**	-	396.0	-	**396.0**	-
Continuously Variable Valve Lift (CVVL)	CVVL	432.0	-	**432.0**	-	306.0	-	**306.0**	-	432.0	-	**432.0**	-	582.0	-	**582.0**	-
Cylinder Deactivation, OHV	DEAC	306.0	-	**306.0**	-	-	-	-	-	306.0	-	**306.0**	-	400.0	-	**400.0**	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	122.0	-	**122.0**	-	61.0	-	**61.0**	-	122.0	-	**122.0**	-	122.0	-	**122.0**	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	76.0	-	**76.0**	-	201.0	-	**201.0**	-	76.0	-	**76.0**	-	76.0	-	**76.0**	-
Conversion to DOHC with DCP	CDOHC	590.0	-	**590.0**	-	373.0	-	**373.0**	-	590.0	-	**590.0**	-	746.0	-	**746.0**	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	384.0	558.0	**471.0**	-	293.0	440.0	**366.5**	-	384.0	558.0	**471.0**	-	512.0	744.0	**628.0**	-
Turbocharging and Downsizing	TRBDS	822.0	-	**822.0**	-	1223.0	-	**1223.0**	-	822.0	-	**822.0**	-	1229.0	-	**1229.0**	-
Diesel Techs																	
Conversion to Diesel	DSL	4105.0	4490.0	**4297.5**	**5600.0**	2963.0	3254.0	**3108.5**	**4000.0**	4105.0	4490.0	**4297.5**	**5600.0**	5125.0	5617.0	**5371.0**	**7000.0**
Conversion to Diesel following TRBDS	DSL	3110.0	3495.0	**3302.5**	**5600.0**	1567.0	1858.0	**1712.5**	**4000.0**	3110.0	3495.0	**3302.5**	**5600.0**	3723.0	4215.0	**3969.0**	**7000.0**
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs																	
Electric Power Steering (EPS)	EPS	105.0	120.0	**112.5**	-	105.0	120.0	**112.5**	-	105.0	120.0	**112.5**	-	-	-	-	-
Improved Accessories	IACC	173.0	211.0	**192.0**	-	173.0	211.0	**192.0**	-	-	-	-	-	-	-	-	-
12V BAS Micro-Hybrid	MHEV	490.0	-	**490.0**	-	427.0	-	**427.0**	-	502.0	-	**502.0**	-	-	-	-	-
Higher Voltage/Improved Alternator	HVIA	84.0	-	**84.0**	-	84.0	-	**84.0**	-	84.0	-	**84.0**	-	-	-	-	-
Integrated Starter Generator	ISG	2386.0	-	**2386.0**	-	2029.0	-	**2029.0**	-	2457.0	-	**2457.0**	-	-	-	-	-
Transmission Techs																	
Continuously Variable Transmission (CVT)	CVT	300.0	-	**300.0**	-	300.0	-	**300.0**	-	-	-	-	-	-	-	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	323.0	-	**323.0**	-	323.0	638.0	**480.5**	-	323.0	638.0	**480.5**	-	323.0	638.0	**480.5**	-
Dual Clutch Transmission (DCT)	DCT	218.0	-	**218.0**	**600.0**	97.0	218.0	**157.5**	**600.0**	97.0	218.0	**157.5**	**600.0**	97.0	218.0	**157.5**	**600.0**
Hybrid Techs																	
Power Split Hybrid	PSHEV	2534.0	2587.0	**2560.5**	**6200.0**	1932.0	1985.0	**1958.5**	**5200.0**	3173.0	3188.0	**3180.5**	**6400.0**	-	-	-	-
2-Mode Hybrid	2MHEV	-	-	-	-	6376.0	6429.0	**6402.5**	**9800.0**	8313.0	8328.0	**8320.5**	**12100.0**	14106.0	15171.0	**14638.5**	**15300.0**
Plug-in hybrid	PHEV	-	-	-	-	24376.0	24329.0	**24352.5**	**27500.0**	-	-	-	-	-	-	-	-
Vehicle Techs																	
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	1.0	2.0	**1.5**	-	1.0	2.0	**1.5**	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	1.0	2.0	**1.5**	-	1.0	2.0	**1.5**	-
Mass Reduction - 5%	MR5	-	-	-	-	-	-	-	-	2.0	4.0	**3.0**	-	2.0	4	**3.0**	-
Mass Reduction - 10%	MR10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	6.0	9.0	**7.5**	-	6.0	9.0	**7.5**	-	6.0	9.0	**7.5**	-	-	-	-	-
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	89.0	-	**89.0**	-	89.0	-	**89.0**	-
Secondary Axle Disconnect	SAX	117.0	-	**117.0**	-	117.0	-	**117.0**	-	117.0	-	**117.0**	-	117.0	-	**117.0**	-
Aero Drag Reduction 10%	AERO	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-	60.0	116.0	**88.0**	-

TABLE I.6 Incremental Costs ($) from NRC (2002)

NRC 2002				
Technologies				
Spark Ignition Techs	Abbreviation	Low	High	AVG
Low Friction Lubricants	LUB	-		-
Engine Friction Reduction	EFR	35.0	140.0	**87.5**
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	35.0	140.0	**87.5**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	70.0	120.0	**95.0**
Cylinder Deactivation, SOHC	DEAC	112.0	252.0	**182.0**
VVT - In take Cam Phasing (ICP)	ICP	35.0	140.0	**87.5**
VVT - Dual Cam Phasing (DCP)	DCP	35.0	140.0	**87.5**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	70.0	120.0	**95.0**
Continuously Variable Valve Lift (CVVL)	CVVL	-	-	-
Cylinder Deactivation, OHV	DEAC	112.0	252.0	**182.0**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	35.0	140.0	**87.5**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	70.0	120.0	**95.0**
Conversion to DOHC with DCP	CDOHC	-	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	-	-	-
Turbocharging and Downsizinc	TRBDS	350.0	560.0	**455.0**
Diesel Techs				
Conversion to Diesel	DSL	-	-	-
Conversion to Diesel following TRBDS	DSL	-	-	-
Conversion to Advanced Diesel	ADSL	-	-	-
Electrification/Accessory Techs				
Electric Power Steering (EPS)	EPS	105.0	150.0	**127.5**
Improved Accessories	IACC	84.0	112.0	**98.0**
12V BAS Micro-Hybrid	MHEV	-	-	-
Higher Voltage/Improved Alternator	HVIA	-	-	-
Integrated Starter Generator	ISG	210.0	350.0	**280.0**
Transmission Techs				
Continuously Variable Transmission (CVT)	CVT	140.0	350.0	**245.0**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	140.0	280.0	**210.0**
Dual Clutch Transmission (DCT)	DCT	70.0	280.0	**175.0**
Hybrid Techs				
Power Split Hybrid	PSHEV	-	-	-
2-Mode Hybrid	2MHEV	-	-	-
Plug-in hybrid	PHEV	-	-	-
Vehicle Techs				
Mass Reduction - 1%	MR1	-	-	-
Mass Reduction - 2%	MR2	-	-	-
Mass Reduction - 5%	MR5	210.0	350.0	**280.0**
Mass Reduction - 10%	MR10	-	-	-
Mass Reduction - 20%	MR20	-	-	-
Low Rolling Resistance Tires	ROLL	14.0	56.0	**35.0**
Low Drag Brakes	LDB	-	-	-
Secondary Axle Disconnec	SAX	-	-	-
Aero Drag Reduction 10%	AERO	0.0	140.0	**70.0**

TABLE I.7 Incremental Costs ($) from EPA (2008)

EPA

Technologies		Small Car			Large Car			Minivan			Small Truck			Large Truck		
		I4			V6			V6			V6			V8		
Spark Ignition Techs	Abbreviation	Low	High	AVG	Low	High	AVG	Low	High	AVG	Low	High	AVG	Low	High	AVG
Low Friction Lubricants	LUB	3	-	**3**	3	-	**3**	3	-	**3**	3	-	**3**	3	-	**3**
Engine Friction Reduction	EFR	0	84	**42**	0	126	**63**	0	126	**63**	0	126	**63**	0	168	**84**
VVT - Coupled Cam Phasing (CCP), SOHC	CCP	59	-	**59**	119	-	**119**	119	-	**119**	119	-	**119**	119	-	**119**
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	169	-	**169**	246	-	**246**	246	-	**246**	246	-	**246**	322	-	**322**
Cylinder Deactivation, SOHC	DEAC	-	-	**-**	203	-	**203**	203	-	**203**	203	-	**203**	229	-	**229**
VVT - In take Cam Phasing (ICP)	ICP	59	-	**59**	119	-	**119**	119	-	**119**	119	-	**119**	119	-	**119**
VVT - Dual Cam Phasing (DCP)	DCP	89	-	**89**	209	-	**209**	209	-	**209**	209	-	**209**	209	-	**209**
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	169	-	**169**	246	-	**246**	246	-	**246**	246	-	**246**	322	-	**322**
Continuously Variable Valve Lift (CVVL)	CVVL	254	-	**254**	466	-	**466**	466	-	**466**	466	-	**466**	508	-	**508**
Cylinder Deactivation, OHV	DEAC	-	-	**-**	203	-	**203**	203	-	**203**	203	-	**203**	229	-	**229**
VVT - Coupled Cam Phasing (CCP), OHV	CCP	59	-	**59**	59	-	**59**	59	-	**59**	59	-	**59**	59	-	**59**
Discrete Variable Valve Lift (DVVL), OHV	DVVL	169	-	**169**	246	-	**246**	246	-	**246**	246	-	**246**	322	-	**322**
Conversion to DOHC with DCP	CDOHC	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	122	420	**271**	204	525	**364.5**	204	525	**364.5**	204	525	**364.5**	228	525	**376.5**
Turbocharging and Downsizing	TRBDS	690	-	**690**	120	-	**120**	120	-	**120**	120	-	**120**	810	-	**810**
Diesel Techs																
Conversion to Diesel	DSL	2790	-	**2790**	3045	-	**3045**	3120	-	**3120**	3405	-	**3405**	4065	-	**4065**
Conversion to Diesel following TRBDS	DSL	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Conversion to Advanced Diesel	ADSL	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Electrification/Accessory Techs																
Electric Power Steering (EPS)	EPS	118	197	**157.5**	118	197	**157.5**	118	197	**157.5**	118	197	**157.5**	118	197	**157.5**
Improved Accessories	IACC	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
12V BAS Micro-Hybrid	MHEV	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Higher Voltage/Improved Alternator	HVIA	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Integrated Starter Generator	ISG	2477	-	**2477**	3153	-	**3153**	-	-	**-**	-	-	**-**	-	-	**-**
Transmission Techs																
Continuously Variable Transmission (CVT)	CVT	231	-	**231**	270	-	**270**	270	-	**270**	-	-	**-**	-	-	**-**
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	76	167	**121.5**	76	167	**121.5**	76	167	**121.5**	76	167	**121.5**	76	167	**121.5**
Dual Clutch Transmission (DCT)	DCT	141	-	**141**	141	-	**141**	141	-	**141**	141	-	**141**	141	-	**141**
Hybrid Techs																
Power Split Hybrid	PSHEV	3754	-	**3754**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
2-Mode Hybrid	2MHEV	-	-	**-**	4655	-	**4655**	4655	-	**4655**	4655	-	**4655**	6006	-	**6006**
Plug-in hybrid	PHEV	4500	-	**4500**	6750	-	**6750**	6750	-	**6750**	6750	-	**6750**	10200	-	**10200**
Vehicle Techs																
Mass Reduction - 1%	MR1	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mass Reduction - 2%	MR2	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mass Reduction - 5%	MR5	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mass Reduction - 10%	MR10	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Mass Reduction - 20%	MR20	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Low Rolling Resistance Tires	ROLL	6	-	**6**	6	-	**6**	6	-	**6**	6	-	**6**	6	-	**6**
Low Drag Brakes	LDB	-	-	**-**	-	-	**-**	-	-	**-**	87	-	**87**	87	-	**87**
Secondary Axle Disconnect	SAX	676	-	**676**	676	-	**676**	676	-	**676**	676	-	**676**	-	-	**-**
Aero Drag Reduction 10%	AERO	-	-	**-**	-	-	**-**	0	75	**37.5**	0	75	**37.5**	0	75	**37.5**

TABLE I.8 Technology Effectiveness, Incremental (Percent) Fuel Consumption Benefit from EEA (2007), Sierra Research (2008), Martec (2008), and NESCCAF (2004)

EEA													
Technologies		I4			I-6			V6			V8		
Spark Ignition Techs	Abbreviation	Low	High	AVG	Low	High	AVG	Low	High	AVG	Low	High	AVG
Low Friction Lubricants	LUB	14	18	16	17	23	20	17	23	20	20	28	24
Engine Friction Reduction	EFR	18	60	39	23	85	54	23	85	54	27	88	58
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	50	54	52	50	54	52	100	108	104	100	108	104
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	-	-	-	-	-	-	-	-	-	-	-	-
Cylinder Deactivation, SOHC	DEAC	-	-	-	302	318	310	302	318	310	205	225	215
VVT - In take Cam Phasing (ICP)	ICP	50	54	52	50	54	52	100	108	104	100	108	104
VVT - Dual Cam Phasing (DCP)	DCP	76	84	80	76	84	80	178	190	184	178	190	184
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	142	158	150	188	212	200	198	222	210	255	285	270
Continuously Variable Valve Lift (CVVL)	CVVL	314	346	330	380	420	400	440	480	460	575	625	600
Cylinder Deactivation, OHV	DEAC	-	-	-	302	318	310	302	318	310	205	225	215
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-	-	-	-	-	-	-	-	-	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	82	94	88	120	140	130	120	140	130	144	170	157
Conversion to DOHC with DCP	CDOHC	-	-	-	-	-	-	-	-	-	-	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	145	155	150	193	207	200	193	207	200	240	260	250
Turbocharging and Downsizing	TRBDS	480	520	500	540	580	560	550	610	580	630	690	660
Diesel Techs													
Conversion to Diesel	DSL	-	-	2200.0	-	-	-	-	-	3200.0	-	-	-
Conversion to Diesel following TRBDS	DSL	-	-	-	-	-	-	-	-	-	-	-	-
Conversion to Advanced Diesel	ADSL	-	-	-	-	-	-	-	-	-	-	-	-
Electrification/Accessory Techs												-	
Electric Power Steering (EPS)	EPS	75	85	80	75	85	80	75	85	80	75	85	80
Improved Accessories	IACC	-	-	-	-	-	-	-	-	-	-	-	-
12V BAS Micro-Hybrid	MHEV	320	380	350	320	380	350	320	380	350	320	380	350
Higher Voltage/Improved Alternator	HVIA	16	18	17	16	18	17	16	18	17	16	18	17
Integrated Starter Generator	ISG	-	-	-	-	-	-	-	-	-	-	-	-
Transmission Techs													
Continuously Variable Transmission (CVT)	CVT	225	255	240	360	400	380	360	400	380	360	400	380
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	190	325	258	190	325	258	190	325	258	190	325	258
Dual Clutch Transmission (DCT)	DCT	195	225	210	195	225	210	195	225	210	195	225	210
Hybrid Techs													
Power Split Hybrid	PSHEV	-	-	-	-	-	-	-	-	-	-	-	-
2-Mode Hybrid	2MHEV	-	-	-	-	-	-	-	-	-	-	-	-
Plug-in hybrid	PHEV	-	-	-	-	-	-	-	-	-	-	-	-
Vehicle Techs													
Mass Reduction - 1%	MR1	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 2%	MR2	-	-	-	-	-	-	-	-	-	-	-	-
Mass Reduction - 5%	MR5	100	140	120	100	140	120	100	140	120	100	140	120
Mass Reduction - 10%	MR10	380	440	410	380	440	410	380	440	410	380	440	410
Mass Reduction - 20%	MR20	-	-	-	-	-	-	-	-	-	-	-	-
Low Rolling Resistance Tires	ROLL	18	22	20	18	22	20	18	22	20	18	22	20
Low Drag Brakes	LDB	-	-	-	-	-	-	-	-	-	-	-	-
Secondary Axle Disconnect	SAX	-	-	-	-	-	-	-	-	-	-	-	-
Aero Drag Reduction 10%	AERO	23	33	28	23	33	28	23	33	28	23	33	28

continued

TABLE I.8 Continued

Sierra Research			
Technologies		Midsize	Truck
Spark Ignition Techs	Abbreviation	Low	Low
Low Friction Lubricants	LUB	13	16
Engine Friction Reduction	EFR	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	-	-
Cylinder Deactivation, SOHC	DEAC	335	410
VVT - In take Cam Phasing (ICP)	ICP	-	-
VVT - Dual Cam Phasing (DCP)	DCP	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	-	-
Continuously Variable Valve Lift (CVVL)	CVVL	-	-
Cylinder Deactivation, OHV	DEAC	335	410
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	-	-
Conversion to DOHC with DCP	CDOHC	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	515	630
Turbocharging and Downsizinc	TRBDS	814	996
Diesel Techs			
Conversion to Diesel	DSL	-	-
Conversion to Diesel following TRBDS	DSL	5775	7063
Conversion to Advanced Diesel	ADSL	-	-
Electrification/Accessory Techs			
Electric Power Steering (EPS)	EPS	76	140
Improved Accessories	IACC	-	-
12V BAS Micro-Hybrid	MHEV	-	-
Higher Voltage/Improved Alternator	HVIA	68	83
Integrated Starter Generator	ISG	-	-
Transmission Techs			
Continuously Variable Transmission (CVT)	CVT	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	-	-
Dual Clutch Transmission (DCT)	DCT	450	551
Hybrid Techs			
Power Split Hybrid	PSHEV	-	-
2-Mode Hybrid	2MHEV	-	-
Plug-in hybrid	PHEV	-	-
Vehicle Techs			
Mass Reduction - 1%	MR1	-	-
Mass Reduction - 2%	MR2	-	-
Mass Reduction - 5%	MR5	-	-
Mass Reduction - 10%	MR10	-	-
Mass Reduction - 20%	MR20	-	-
Low Rolling Resistance Tires	ROLL	-	-
Low Drag Brakes	LDB	-	-
Secondary Axle Disconnec	SAX	-	-
Aero Drag Reduction 10%	AERO	-	-

continued

TABLE I.8 Continued

Martec Research				
Technologies		MPFI, DOHC, 4V L4	MPFI, DOHC, 4V V6	MPFI, DOHC, 4V V8
Spark Ignition Techs	Abbreviation			
Low Friction Lubricants	LUB	-	-	-
Engine Friction Reduction	EFR	-	-	-
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	-	-	-
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	-	-	-
Cylinder Deactivation, SOHC	DEAC	-	-	-
VVT - In take Cam Phasing (ICP)	ICP	-	-	-
VVT - Dual Cam Phasing (DCP)	DCP	-	-	-
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	-	480	-
Continuously Variable Valve Lift (CVVL)	CVVL	428	675	825
Cylinder Deactivation, OHV	DEAC	-	-	-
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-	-	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	-	-	-
Conversion to DOHC with DCP	CDOHC	-	-	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	440	558	746
Turbocharging and Downsizinç	TRBDS	-	855	1289
Diesel Techs				
Conversion to Diesel	DSL	-	-	-
Conversion to Diesel following TRBDS	DSL	-	3542	5198
Conversion to Advanced Diesel	ADSL	-	-	-
Electrification/Accessory Techs				
Electric Power Steering (EPS)	EPS	-	-	-
Improved Accessories	IACC	-	-	-
12V BAS Micro-Hybrid	MHEV	627	-	-
Higher Voltage/Improved Alternator	HVIA	-	-	-
Integrated Starter Generator	ISG	617	-	-
Transmission Techs				
Continuously Variable Transmission (CVT)	CVT	-	-	-
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	638	638	638
Dual Clutch Transmission (DCT)	DCT	450	450	450
Hybrid Techs				
Power Split Hybrid	PSHEV	5246	7871	9681
2-Mode Hybrid	2MHEV	-	-	-
Plug-in hybrid	PHEV	-	-	-
Vehicle Techs				
Mass Reduction - 1%	MR1	-	-	-
Mass Reduction - 2%	MR2	-	-	-
Mass Reduction - 5%	MR5	-	-	-
Mass Reduction - 10%	MR10	-	-	-
Mass Reduction - 20%	MR20	-	-	-
Low Rolling Resistance Tires	ROLL	-	-	-
Low Drag Brakes	LDB	-	-	-
Secondary Axle Disconnec	SAX	-	-	-
Aero Drag Reduction 10%	AERO	-	-	-

continued

TABLE I.8 Continued

NESCCAF		
Technologies		Large Car
		V6
Spark Ignition Techs	Abbreviation	
Low Friction Lubricants	LUB	16
Engine Friction Reduction	EFR	16
VVT- Coupled Cam Phasing (CCP), SOHC	CCP	173
Discrete Variable Valve Lift (DVVL), SOHC	DVVL	278
Cylinder Deactivation, SOHC	DEAC	173
VVT - In take Cam Phasing (ICP)	ICP	105
VVT - Dual Cam Phasing (DCP)	DCP	210
Discrete Variable Valve Lift (DVVL), DOHC	DVVL	383
Continuously Variable Valve Lift (CVVL)	CVVL	623
Cylinder Deactivation, OHV	DEAC	173
VVT - Coupled Cam Phasing (CCP), OHV	CCP	-
Discrete Variable Valve Lift (DVVL), OHV	DVVL	-
Conversion to DOHC with DCP	CDOHC	-
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	278
Turbocharging and Downsizing	TRBDS	-420
Diesel Techs		
Conversion to Diesel	DSL	-
Conversion to Diesel following TRBDS	DSL	-
Conversion to Advanced Diesel	ADSL	1125
Electrification/Accessory Techs		
Electric Power Steering (EPS)	EPS	60
Improved Accessories	IACC	75
12V BAS Micro-Hybrid	MHEV	-
Higher Voltage/Improved Alternator	HVIA	60
Integrated Starter Generator	ISG	-
Transmission Techs		
Continuously Variable Transmission (CVT)	CVT	263
6/7/8-Speed Auto. Trans. with Improved Internals	NAUTO	-
Dual Clutch Transmission (DCT)	DCT	-
Hybrid Techs		
Power Split Hybrid	PSHEV	5246
2-Mode Hybrid	2MHEV	-
Plug-in hybrid	PHEV	-
Vehicle Techs		
Mass Reduction - 1%	MR1	-
Mass Reduction - 2%	MR2	-
Mass Reduction - 5%	MR5	321
Mass Reduction - 10%	MR10	-
Mass Reduction - 20%	MR20	-
Low Rolling Resistance Tires	ROLL	96
Low Drag Brakes	LDB	-
Secondary Axle Disconnect	SAX	-
Aero Drag Reduction 10%	AERO	134

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Probabilities in Estimation of Fuel Consumption Benefits and Costs

The committee estimated cumulative fuel consumption by successively multiplying the base fuel consumption by one less the estimated fractional reductions associated with specific technologies. The estimates of cumulative cost impacts are obtained by successively adding individual retail price equivalent change estimates. The committee has provided rough confidence intervals for the individual fractional reductions. The confidence intervals are based on the committee's judgment and have not been derived in a rigorous, reproducible method. The committee's intent in providing the confidence intervals is to convey its opinion that all such estimates are subject to uncertainty. The committee believes it is important to communicate the degree of uncertainty in estimates of fuel consumption potential and cost even though it cannot make these estimates with precision or scientific rigor. Given the judgmental nature of our fuel consumption and cost estimates, the committee has attempted to aggregate them with an appropriate degree of mathematical rigor. The following describes the method used by the committee to aggregate its estimates of uncertainty for individual technologies to estimate the confidence intervals for the full technology pathways shown in Chapter 9.

Assuming the individual estimates of cost impacts are independent, the variance of the sum of n cost estimates is equal to the sum of the variances. Thus the standard deviation of the sum is the square root of the sum of the squared standard deviations. Let $\pm 1.64\omega$ be the committee's estimated confidence interval for the retail price impact of technology i. The confidence interval for the sum of i price impact estimates would be $\pm 1.64\omega$, where ω_n is defined as follows.

$$\omega_n = \sqrt{\sum_{i-1}^{n} \omega_i^2} \qquad \text{Equation 1}$$

Let f_i be the impact of technology i on fuel consumption, where $f_i = 1 - \Delta_I$ and Δ_I is the expected fractional reduction expected from technology I, and let p_i be the expected increase in retail price equivalent. Let $\pm 1.64\sigma_i$ be the committee's estimated confidence interval for technology i and assume that σ_i^2 is a reasonable estimate of the variance of the estimate, whose distribution is assumed to be symmetric. Furthermore, it is assumed that the individual technology estimates are independent. The exact formula for the variance of the product of n independent random variables was derived by Goodman (1962), who also pointed out that if the square of the coefficients of variation (σ_i^2/f^2) of the variables is small, then an approximation to the exact variance should be reasonably accurate. The committee's estimates of fuel consumption reduction are on the order of f = 1 – 0.05, in general, while its estimates of the confidence intervals 1.64σ are on the order of 0.02. Thus the square of the coefficients of variation are on the order of 0.00015/0.9025 = 0.00016. However, Goodman also notes that his approximate formula tends to underestimate the variance, in general. As a consequence, we use his exact formula, shown below in Equation 2.

$$Var\left(\prod_{i=1}^{n} f_i\right) = \prod_{i=1}^{n} f_i^2 \left[\prod_{i=1}^{n}\left(\frac{\sigma_i^2}{f_i^2}+1\right)-1\right] \qquad \text{Equation 2}$$

$$1.64 \times StdDev\left(f_n\right) = 1.64 \times \sqrt{Var\left(\prod_{i=1}^{n} f_i\right)}$$

Equation 1 can be used to calculate a confidence interval for either the cumulative fuel consumption or cumulative cost impacts by calculating the square root of the variance and multiplying by 1.64. The committee believes that its $1.64\sigma_i$ bounds represent, very approximately, a 90 percent confidence interval. Assuming that the cost and fuel consumption estimates are also independent, the probability that fuel consumption is within its 90 percent confidence bounds and cost is within its confidence bounds at the same time implies that the joint confidence interval is an 81 percent confidence interval.

$$\mathrm{Prob}\left(f_i - 1.64\sigma_i < f_i < f_i + 1.64\sigma_i\right) = 0.9$$
$$\mathrm{Prob}\left(p_i - 1.64\sigma_i < p_i < p_i + 1.64\sigma_i\right) = 0.9$$
$$\mathrm{Prob}\left(f_i - 1.64\sigma_i < f_i < f_i + 1.64\sigma_i\right)$$
$$\bigcap \mathrm{Prob}\left(p_i - 1.64\sigma_i < p_i < p_i + 1.64\sigma_i\right) = 0.9 \times 0.9 = 0.81$$

The committee did not address what specific probability distribution the uncertainty about fuel consumption and cost impacts might take. However, if one assumes they follow a normal distribution, then the ratio of a 90 percent confidence interval to an 81 percent confidence interval would be approximately 1.64/1.31 = 1.25. Thus, an appropriately rough adjustment factor to convert the individual confidence intervals to a joint confidence interval of 90 percent would widen them by about 25 percent.

REFERENCE

Goodman, L.A. 1962. The variance of a product of K random variables. Journal of the American Statistical Association 57(297):54-60.

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Model Description and Results for the EEA-ICF Model

METHODOLOGY OVERVIEW

The lumped parameter approach to fuel consumption modeling uses the same basic principles as all simulation models, but instead of calculating fuel consumption second by second, as is sometimes done, it uses an average cycle. Such an approach has been used widely by industry and regulatory agencies, most recently by the U.S. Environmental Protection Agency (EPA) to help assess the 2012-2016 proposed fuel economy standards (EPA, 2008). The method can be generally described as a first-principles-based energy balance, which accounts for all the different categories of energy loss, including the following:

- Losses based on the second law of thermodynamics,
- Heat loss from the combusted gases to the exhaust and coolant,
- Pumping loss,
- Mechanical friction loss,
- Transmission losses,
- Accessory loads,
- Vehicle road load tire and aerodynamic drag losses, and
- Vehicle inertial energy lost to the brakes.

Conceptually, each technology improvement is characterized by the percent change to each of the loss categories. If multiple technologies are employed to reduce the same category of loss, each successive technology has a smaller impact as the category of loss becomes closer to zero.

EEA-ICF Inc.[1] has developed a lumped parameter model that is broadly similar in scope and content to the EPA model (Duleep, 2007). In this model, all of the baseline vehicle energy losses are determined computationally, and many of the technology effects on each source of loss have been determined from data presented at technical conferences. However, the EPA does not document how the various losses were determined for the baseline vehicle: It says only that the vehicle has a fixed percentage of fuel lost to each category. The EPA also does not document how the technology-specific improvements in each category of loss were characterized. It appears that the losses for both the baseline vehicle and the effects of technology improvements were based not on computed values but on expert opinion.

[1] Energy and Environmental Analysis, Inc. (EEA) was acquired by ICF International during the course of this study. In this appendix, reference is made to EEA-ICF, although in the report as a whole reference is made simply to EEA.

MODEL COMPUTATIONS

Here the committee summarizes the EEA-ICF model. GM researchers Sovran and Bohn (1981) used numerical integration over the Federal Test Procedure city and highway driving cycles to determine the energy required at the wheel to move a vehicle over the driving cycle as a function of its weight, frontal area, drag coefficient, and tire rolling resistance coefficient. This procedure is used to compute the energy requirement at the wheel for the given baseline vehicle and translated to energy at the engine output shaft by using transmission and driveline efficiency factors (which differ by transmission type and number of gears) derived from the open literature. Accessory energy requirements are added as a fixed energy amount that is a function of engine size. This determines total engine output energy; average cycle power is then computed by distributing the energy over the cycle time when positive engine output is required—that is, the time spent at closed throttle braking and idle are accounted for separately. Average cycle RPM excluding idle was obtained for specific vehicles from simulation models on specific vehicles, and these data are scaled by the ratio of the N/V for the data vehicle and the baseline vehicle. The data are used to determine average brake mean effective pressure (BMEP) for the positive power portion of the cycle.

Fuel consumption is determined by the following relationship:

$$IMEP = BMEP + FMEP + PMEP$$

where I is for indicated, F is for friction, P is for pumping, and MEP is the mean effective pressure in each category. The fuel consumption model is derived from a methodology to estimate an engine map using a semiempirical model developed by researchers at Ford and the University of Nottingham (Shayler et al., 1999). In this formulation, fuel consumption is proportional to IMEP divided by indicated thermal efficiency (sometimes called the Willans line), friction is determined empirically from engine layout and is a function of RPM only, and PMEP is simply intake manifold pressure (atmospheric pressure). Intake manifold pressure is solved for any given BMEP, since IMEP is also proportional to intake pressure. This model explicitly derives thermal efficiency, friction loss, and pumping loss for the baseline vehicle. Fuel consumption at idle and closed throttle braking are modeled as functions of engine displacement only. The baseline engine is always modeled with fixed valve lift and timing, and the pumping loss is adjusted for the presence of variable valve timing if applicable. The model can be construed as a two-point approximation of a complete engine map and is a very reasonable representation of fuel consumption at light and moderate loads where there is no fuel enrichment.

The technologies are characterized by their effect on each of the losses explicitly accounted for in the model, and the representation is similar in concept to the representation in the EPA model. In the EEA-ICF analysis, the committee collected information on the effect of each engine technology on peak engine efficiency, pumping loss, and friction loss as a cycle average from technical papers that describe measured changes in these attributes from prototype or production systems. When these losses are not explicitly measured, they are computed from other published values such as the change in compression ratio, the change in torque, or the measured change in fuel consumption.

Comparison of Results to Detailed Simulation Model Outputs

Both EEA-ICF and EPA have compared the lumped parameter results with new full-scale simulation modeling results on several vehicle classes with different combinations of planned technological improvements. The simulations were done by the consulting firm Ricardo, Inc., and documented in a separate report (Ricardo, 2008). The Ricardo work modeled five baseline vehicles (standard car, large car, small MPV, large MPV, and large truck) and 26 technology combinations, covering gasoline and diesel power trains used in the EPA model, but there was no simulation of hybrids.

In a majority of the comparisons done by EPA, the lumped parameter model estimates were close to the Ricardo estimates, and the EPA concluded the results of their model were plausible, although a few technology packages required additional investigation. The EPA has indicated that it will continue to use the lumped parameter approach as an analytical tool, perhaps adjusting it to improve its fidelity as more simulation results become available.

EEA-ICF also performed analysis for the NRC Committee on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy (Duleep, 2008a, 2008b). Based on the committee's experience, when a number of engine, transmission, and other technology improvements are simultaneously added to a baseline vehicle, the net fuel economy benefit can be approximated by taking 90 percent of the additive sum of the individual technology benefits, as developed by EEA-ICF. The committee used this technique to develop a quick approximation of the level of agreement likely between the Ricardo simulations and the EEA-ICF lumped parameter model. It was able to perform a quick analysis of only 23 of 26 packages developed by Ricardo, since there were no data on HCCI engines, which were used in three of the Ricardo technology packages.

Ricardo included one technology for which the committee had no specific data. It called this "fast warm-up" technology because it involved the control of coolant flow to the engine immediately after cold start. Based on the data presented by Ricardo, the benefit of the technology was estimated at 1 percent, including the benefit of the electric water pump. All other technology benefits were based on the data from ICF-EEA previous reports to DOE on fuel economy technology. These benefit estimates were adjusted for the presence or absence of technologies on the baseline vehicle, since all benefits in the DOE reports have been typically defined relative to an engine with fixed valve timing and a four-speed automatic transmission. The results are illustrated in Figure K.1, and the plot shows the difference between the Ricardo results and the quick approximation method.

In 16 of the 23 cases, the Ricardo estimate is within +5 percent of the quick estimate. In two cases, the Ricardo estimates were more than 10 percent lower than the quick estimates, as shown in Figure K.1. In five cases, the Ricardo estimates were 10 percent (or more) higher than the quick estimate. The difference implies that the benefits are larger than the simple sum of individual technology benefits and that technology synergies are positive. The committee also examined the technology packages in the two "low" and five "high" outliers. Both low outliers had technology packages with a continuously variable transmission (CVT) as one of the technologies. The five high outliers had no major technology improvement in common.

More detailed analysis was also done with the EEA-ICF lumped parameter model. Constraints on resources and time allowed the committee to analyze only 9 of the 23 cases with the lumped parameter model, but the 9 cases included both high and low outliers from the previous analysis. Three technology packages were analyzed for a standard car, which used a Toyota Camry baseline; three for a compact

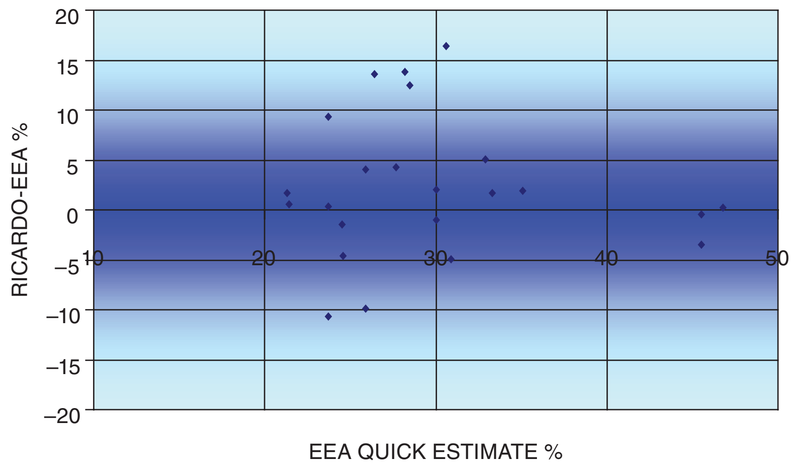


FIGURE K.1 Comparison of the difference between the Ricardo, Inc., results and the quick approximation method.

van, which used a Chrysler Voyager baseline; and three for a standard pickup, which used a Ford F-150 baseline. Table K.1 shows the results and compares them with those of the quick method. The more detailed modeling reduced the average difference between the Ricardo estimates and the committee estimates for the Toyota Camry and the Chrysler compact van but increased the difference for the Ford F-150 truck. The largest observed difference is for Package 10 on the Ford, where the baseline 5.4-L V8 is replaced by a 3.6-L V6 turbo GDI engine and the downsizing is consistent with the 33 percent reduction that was used.

Comparison of Model Results to NRC Estimates

The NRC study has developed a series of technology paths whose combined effect on fuel consumption was estimated from expert inputs on the marginal benefits of each successive technology given technologies already adopted. Paths were specified for five different vehicles: small cars, intermediate/large cars, high-performance sedans, body-on-frame small trucks, and large trucks. There were no substantial differences in the paths or the resulting fuel consumption estimates across the five vehicles: All estimated decreases in fuel consumption were between 27 and 29 percent for

TABLE K.1 Comparison of Fuel Economy Improvements (in Percent) from Ricardo, Inc., Modeling, EEA-ICF Quick Analysis, and the EEA-ICF Model

Vehicle	Technology Package	Ricardo Estimate	EEA Quick Result	EEA Model Result
Toyota Camry	Z	33.0	23.7	32.6
	1	13.0	23.7	23.1
	2	22.0	22.4	21.9
	RMS difference		8.15	5.85
Chrysler Voyager	4	26.0	30.9	29.9
	6b	35.5	33.3	35.5
	16	41.0	28.5	36.6
	RMS difference		7.85	3.39
Ford F-150	9	32.0	30.0	28.3
	10	42.0	28.2	26.4
	16	23.0	21.3	23.4
	RMS difference		8.12	9.25

NOTE: RMS, root mean square difference between the EEA-ICF estimate and the Ricardo estimate. The differences seem to be in the same range as the differences between the EPA estimates with their lumped parameter model and the Ricardo estimates. It is also important to note that the EPA model results are more consistent with the results of the EEA-ICF model. The “low” Ricardo result for Package 1 on the Camry is also significantly lower than the EPA estimate of 20.5 percent fuel economy benefit, which is closer to the EEA-ICF estimate of 23 percent than to the Ricardo 13 percent estimate. Similarly, the high Ricardo estimate for Package 10 on the Ford F-150 is also substantially higher than the EPA estimate of 30.5 percent fuel efficiency gain, which is, in turn, higher than the committee estimate of 26.4 percent but much lower than the Ricardo estimate of 42 percent.

spark-ignition engines and 36 and 40 percent for diesel engines. Since the "performance sedan" and intermediate sedan specifications were not very different, only the small car, one intermediate car, and two trucks were simulated. Simulation was done for the spark ignition engine and the diesel engine paths, but not for the hybrid path.

Table K.2 lists the model results versus the committee estimates for the eight cases (four for spark ignition and four for diesel). In general, the model forecasts are very close to but typically slightly lower than the forecasts of experts, although well within the range of uncertainty included in the committee estimate. Only one vehicle, the full-size truck, shows a larger difference on the diesel path. Historically, the committee's method of forecasting the marginal benefit of technology along a specified path has been criticized as potentially leading to an overestimation of benefits for spark ignition engines since it could lead to infeasible solutions if total pumping loss reduction estimated exceeded the actual pumping loss. The simulation model output's explicit tracking of the losses addresses this issue directly to ensure that no basic scientific relationships are violated.

Fuel consumption is decreased by reducing the tractive energy required to move the vehicle (by reducing weight, aerodynamic drag, or rolling resistance), reducing losses to the transmission and drive line, reducing accessory energy consumption, or reducing engine fuel consumption during idle and closed throttle braking. Fuel consumption can also be reduced by increasing engine efficiency over the cycle, which is accomplished by increasing peak efficiency or by reducing mechanical friction and pumping loss. Figures K.2 through K.5 show the technology path steps and track the reductions from both approaches separately, with the reduction in energy required to drive through the test cycle shown on top and the engine efficiency shown below. Peak engine efficiency actually decreases slightly due to turbocharging and downsizing, but the cycle efficiency increases from about 24 to 29 percent owing to reduction in pumping and friction loss (blue part of the bar). The general trends are very similar across all four vehicle types, but the key feature is that pumping and friction loss are not reduced to physically impossible levels for the solution.

TABLE K.2 Comparison of Fuel Consumption Reductions (in Percent) for NRC Estimates and the EEA-ICF Model

Spark Ignition Path	NAS	EEA-ICF
Small car	27	26.7
Intermediate/large car	29	27.3
BOF small truck	27	27.3
BOF large truck	29	26.2
Diesel path		
Small car	37	35.7
Intermediate/large car	37	36.2
BOF small truck	37	36.6
BOF large truck	40	36.5

NOTE: BOF, body on frame.

REFERENCES

Duleep, K.G. 2007. Overview of lumped parameter model. Presentation to the National Research Council Committee for the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy on October 26, Washington, D.C.

Duleep, K.G. 2008a. EEA-ICF Analysis of Ricardo simulation outputs. Presentation to the National Research Council Committee for the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy on February 26, Washington, D.C.

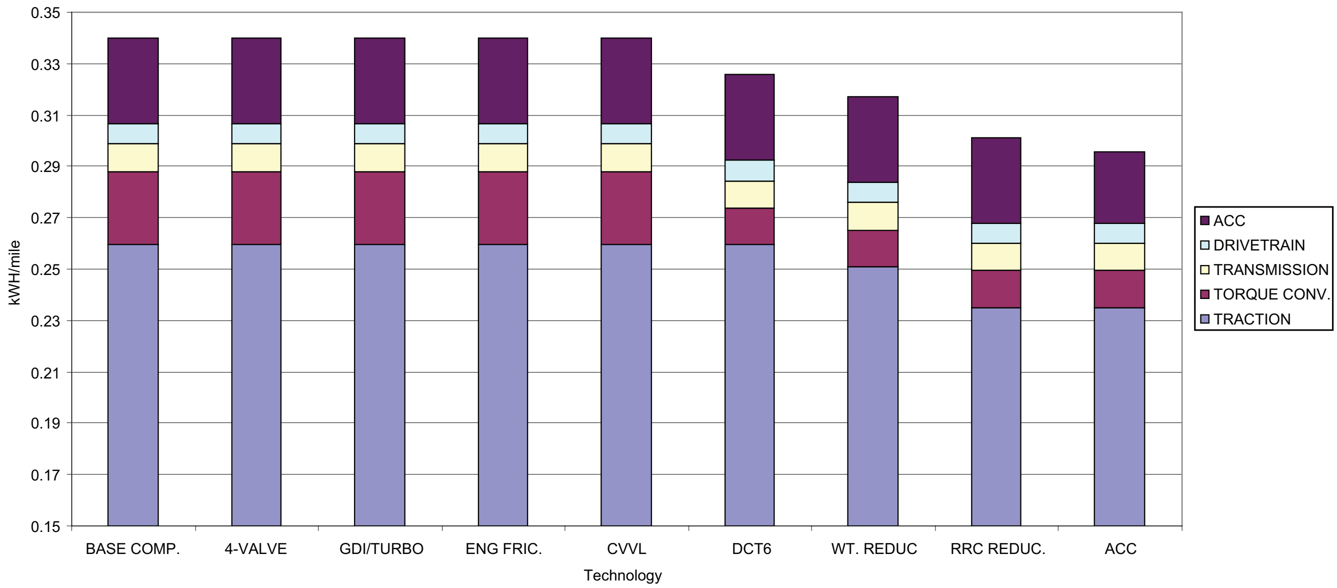
Duleep, K.G. 2008b. EEA-ICF analysis update. Presentation to the National Research Council Committee for the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy on April 1, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 2008a. EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions. EPA420-R-08-008. Ann Arbor, Mich.

Ricardo, Inc. 2008. A Study of the Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies. Report to the Environmental Protection Agency. June 26.

Sovran, G., and M. Bohn, 1981. Formulae for the tractive energy requirements of the vehicles driving the EPA schedules. SAE Paper 810184. SAE International, Warrendale, Pa.

Shayler, P., J. Chick, and D. Eade. 1999. A method of predicting brake specific fuel consumption maps. SAE Paper 1999-01-0556. SAE International, Warrendale, Pa.



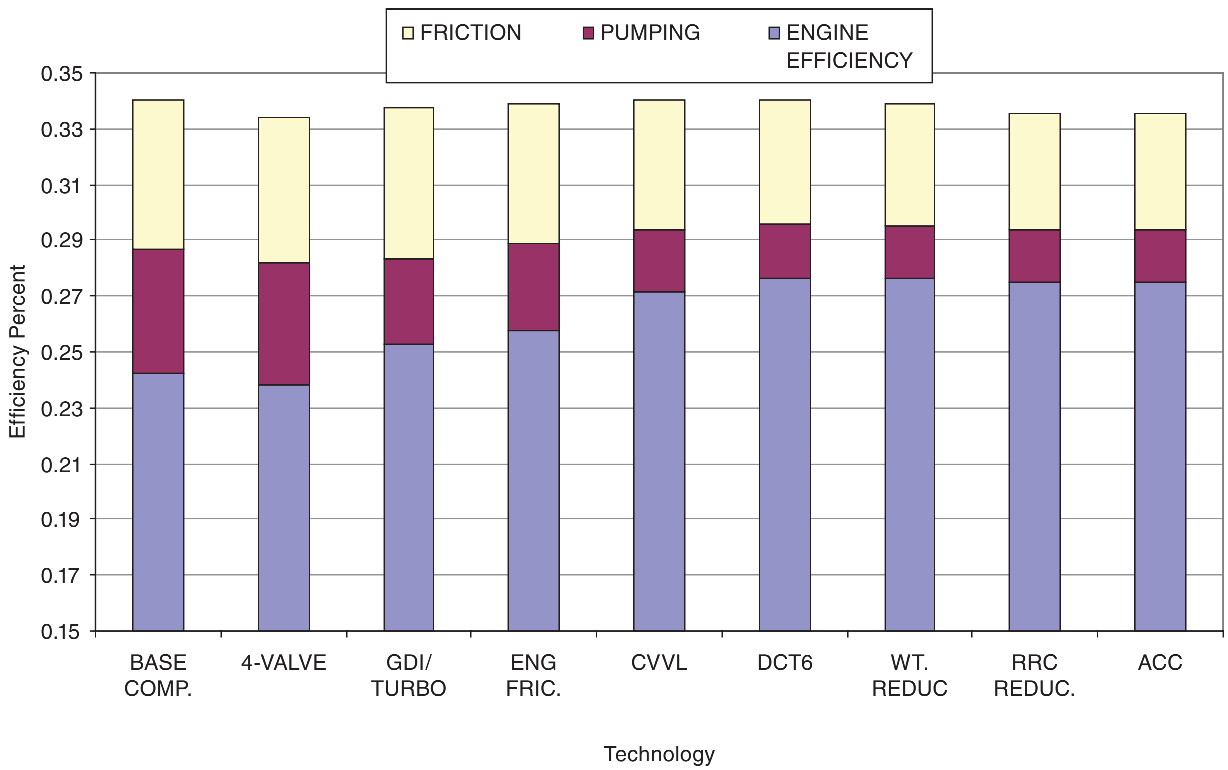


FIGURE K.2 Technology path steps and reduction in energy required to drive through the test cycle (top) and the engine efficiency (bottom), body-on-frame small truck.

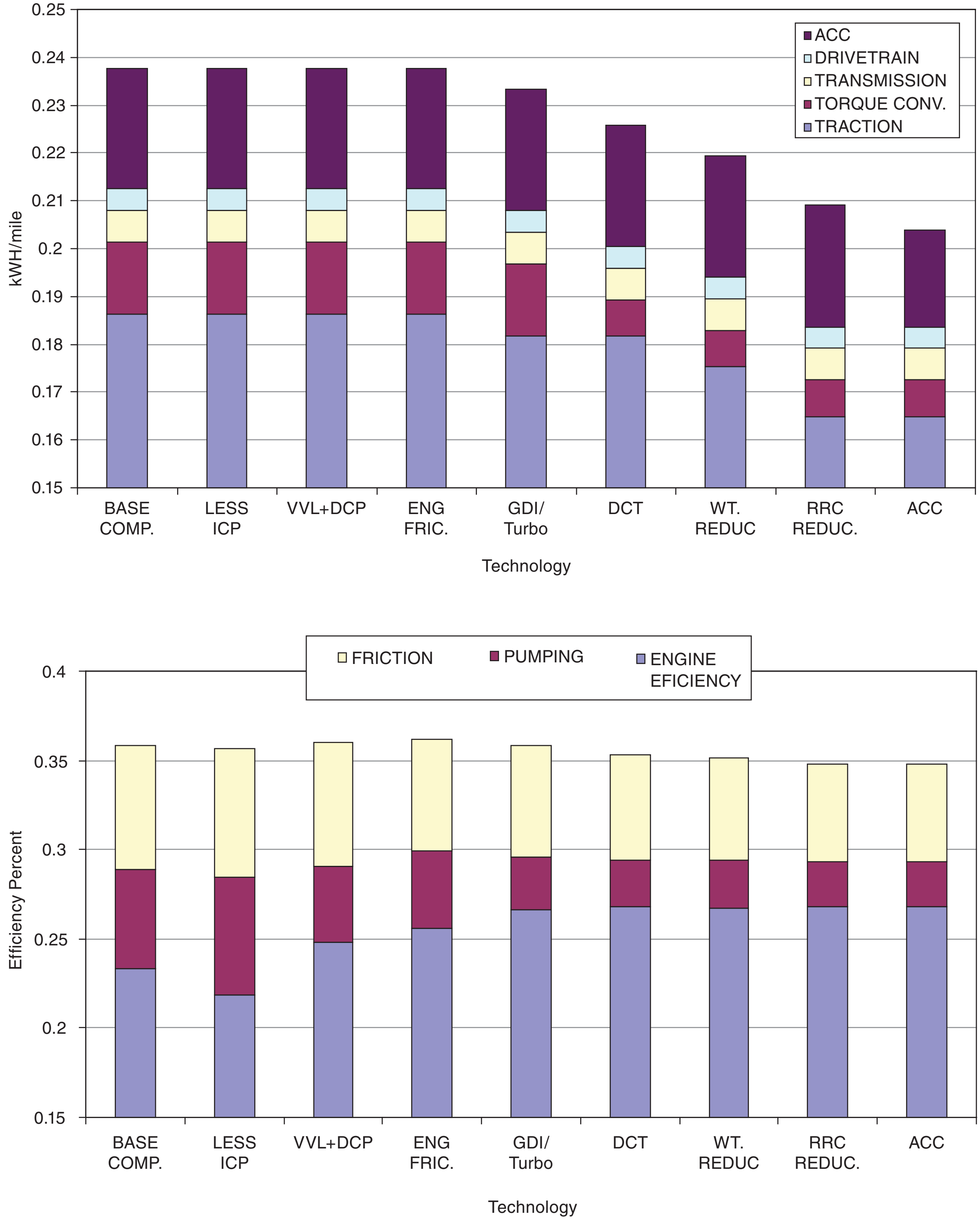
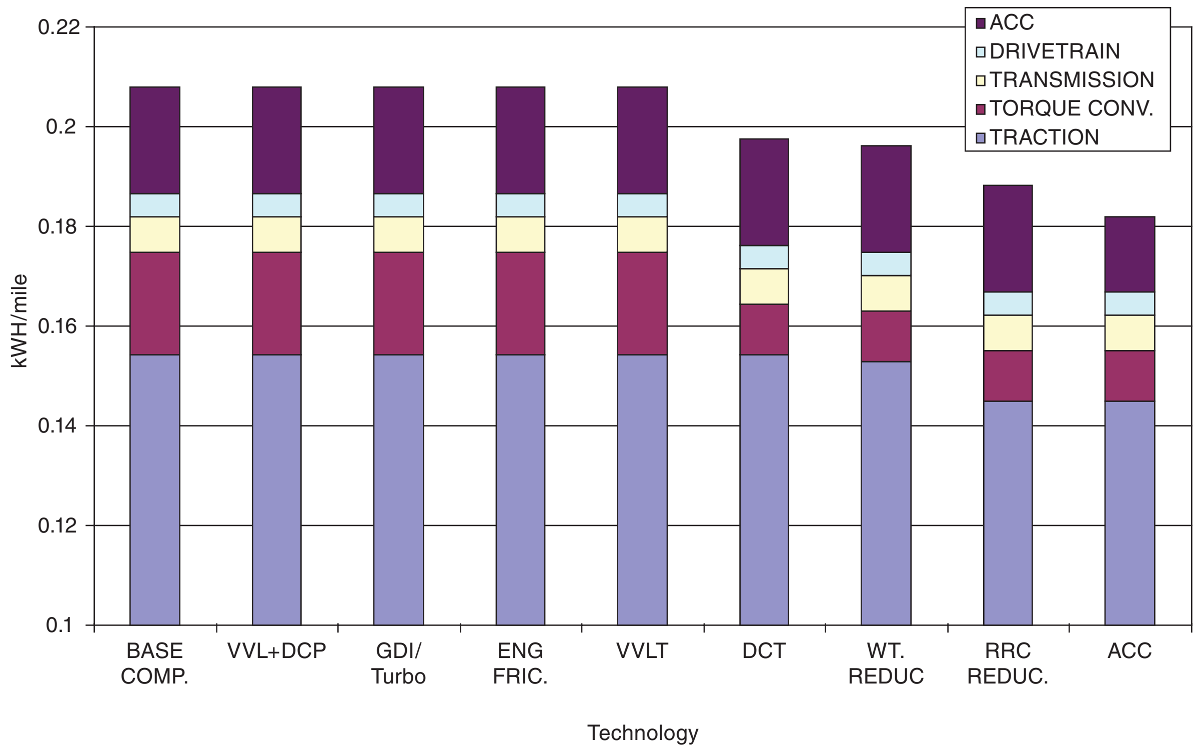


FIGURE K.3 Technology path steps and reduction in energy required to drive through the test cycle (top) and the engine efficiency (bottom), midsize sedan.



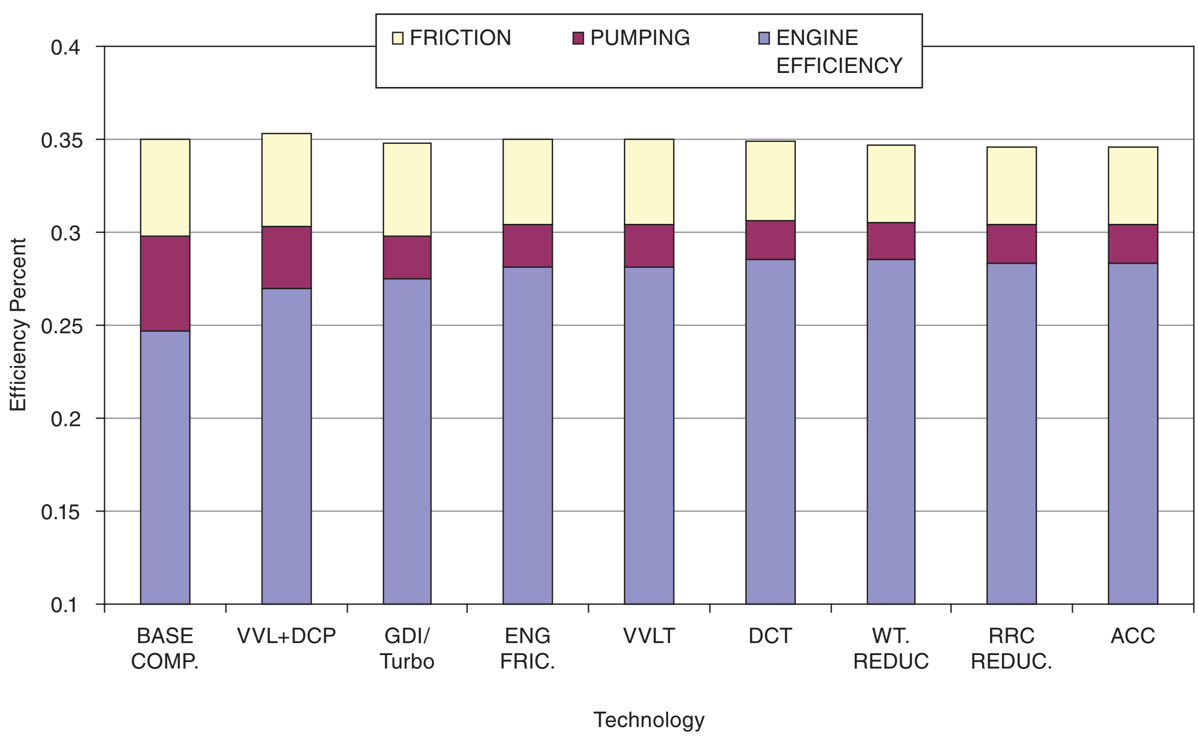


FIGURE K.4 Technology path steps and reduction in energy required to drive through the test cycle (top) and the engine efficiency (bottom), small car.

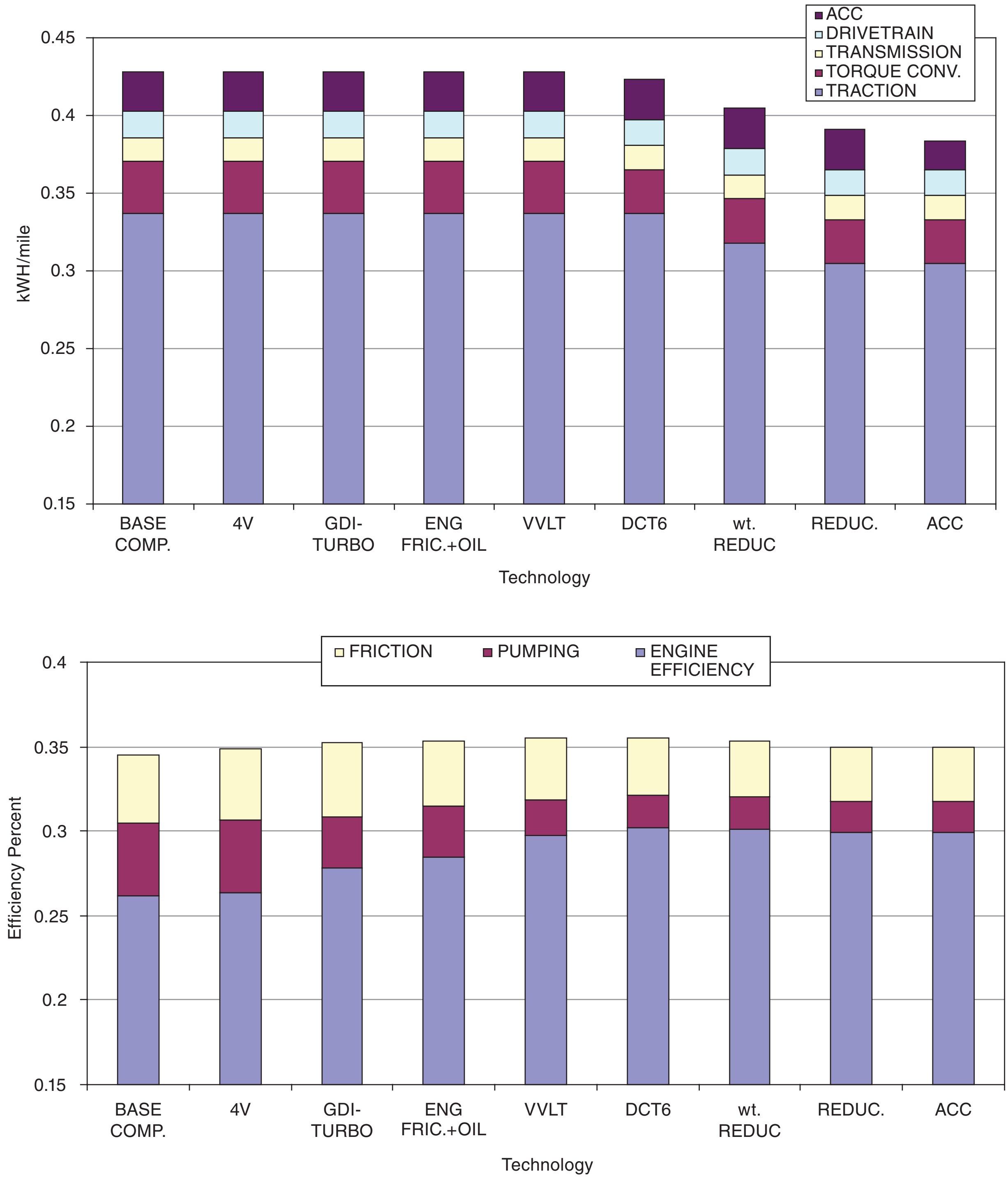


FIGURE K.5 Technology path steps and reduction in energy required to drive through the test cycle (top) and the engine efficiency (bottom), full-size truck.

Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis

United States
Environmental Protection
Agency

Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

United States
Environmental Protection
Agency

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Table of Contents

Statement of Need

The original Renewable Fuel Standard (RFS) program was adopted by EPA to implement the provisions of the Energy Policy Act of 2005 (EPAct), which added section 211(o) to the Clean Air Act (CAA). With the passage of the Energy Independence and Security Act of 2007 (EISA), Congress made several important revisions to the renewable fuel requirements. This rule revises the RFS program regulations to implement these EISA provisions.

Overview

The displacement of gasoline and diesel with renewable fuels has a wide range of environmental and economic impacts. This Regulatory Impact Analysis (RIA) utilizes case study approaches to assess the impacts of an increase in production, distribution, and use of the renewable fuels sufficient to meet the RFS2 volumes established by Congress in the Energy Independence and Security Act of 2007 (EISA). This reflects our updated assessment compared to the draft RIA conducted in support of the Notice of Proposed Rulemaking (NPRM). Because the standards were mandated by Congress in EISA, the impacts we are assessing are not being used to justify or support the decisions for the RFS2 volume standards, but rather to provide an assessment of the projected impacts of these standards when fully implemented. This information can then be used in future public policy decisions. As explained below, the estimates contained in this RIA should not be interpreted as the impact of the RFS2 standards themselves because market forces may lead to increased production of renewable fuels even in the absence of the RFS2 standards. Rather, the impacts estimated in this RIA must be understood to refer to the consequences of an expansion of renewable fuel use, whether caused by the RFS2 program or by market forces.

The analytical approach taken by EPA in this RIA is to predict what the world would be like, in terms of a range of economic and environmental factors, if renewable fuel use increases to the level required by the RFS2 standards. We then compare this to two reference cases without the RFS2 progam. The primary reference case is a projection made prior to EISA by the US Energy Information Administration (EIA) in their 2007 Annual Energy Outlook (AEO2007) of renewable fuel volumes that would have been expected in 2022 (13.56 billion gallons). We then combined this with AEO2009 energy consumption and cost estimates. While AEO2007 is not as up-to-date as AEO2009, we could not use later projections by EIA for renewable fuel use because they already include the impact of the RFS2 standards as required by EISA as well as fuel economy improvements under CAFE as required in EISA. Upon completion of our fuel cost analyses as described in Chapter 4, however, it became apparent that by 2022, we are projecting that renewable fuel production costs will decline and crude oil prices rise to the point that renewable fuels are less expensive than gasoline and diesel fuel, even in the absence of any tax subsidies. One of the primary drivers for this is the fact that AEO2009 projects \$116 per barrel of crude oil in 2022 (instead of the \$53 per barrel projection in AEO2007). This implies that market forces will lead to a greater increase in renewable fuel volumes than was projected in AEO2007, even in the absence of the RFS2 standards.

However, it is difficult to estimate the extent to which these market forces, in the absence of the RFS2 standards, would indeed spur investments to increase renewable fuel production and usage. Given the magnitude of the capital investment needed for the RFS2 renewable fuel volumes, the risk associated with these investments due to the fact that for the bulk of the volume we are relying on new cellulosic biofuel technology, and the uncertainty in future crude oil prices, market forces alone may result in a level of investment insufficient to achieve the renewable fuel volumes mandated by RFS2. EPA believes that cellulosic renewable fuels are least likely to achieve the RFS2 mandates due to market forces alone. While current DOE and USDA programs are helping to stimulate the market for cellulosic renewable fuels, investment in this segment of the fuels market is still very limited. The limitations of market forces are reflected in the projections of AEO2009, which despite projecting large increases in oil prices still projects that renewable fuel volumes will be less than those required by RFS2.

Given the difficulty in projecting renewable fuel volumes in the absence of the RFS2 standards, EPA chose to rely on the projections in AEO2007 as its primary reference case. EPA believes that the actual renewable fuel volumes achieved in the absence of the RFS2 standards would fall somewhere between its reference case projections and the volumes mandated by RFS2. The impacts estimated in this RIA therefore cannot be interpreted as the impact of the RFS2 program itself. Rather, they are an estimate of the impact of an increase in use of renewable fuels, whether caused by RFS2 or by market forces.

Another important limitation of this analysis is that it does not consider certain offsetting effects. In particular, for our emissions (GHG and non-GHG) and air quality analyses we have assumed that the production of renewable fuels to satisfy the RFS2 results in an energy equivalent decrease in production of petroleum-derived fuels. This is despite the fact that our other analyses predict that increased renewable fuel use will reduce worldwide crude oil prices, which in turn could lead to an increase in the quantity of crude oil demanded. Thus, there may be offsetting effects that are not completely captured by our analysis. For example, an increase in world demand for crude oil resulting from depressed prices caused by the increased use of renewable fuels in the U.S could partially offset some of the decrease in GHG emissions we have projected. At the same time, there may be other indirect impacts as well that might go in the opposite direction, since crude oil is used for more than just the gasoline and diesel fuel being displaced by renewable fuels.

The table below provides the results of many of the analyses contained throughout this RIA. Only shown are the results for the RFS2 volume control case relative to the AEO2007 reference case, and only the results for 2022 when the program is fully phased in.

Impact Summary of the Renewable Fuel Volumes Required by RFS2 in 2022 Relative to the AEO2007 Reference Case (2007 Dollars)

Category	**Impact in 2022**	**Chapter Discussed**
Emissions and Air Quality		
GHG Emissions	-138 million metric tons	2.7
Non-GHG Emissions (criteria and toxic pollutants)	-1 to +10% depending on the pollutant	3.2
Nationwide Ozone	+0.12 ppb population-weighted seasonal max 8hr average	5.4
Nationwide $PM_{2.5}$	+0.002 $\mu g/m^3$ population-weighted annual average $PM_{2.5}$	5.4
Nationwide Ethanol	+0.409 $\mu g/m^3$ population-weighted annual average	3.4
Other Nationwide Air Toxics	-0.0001 to -0.023 $\mu g/m^3$ population-weighted annual average depending on the pollutant	3.4
$PM_{2.5}$-related Premature Mortality	33 to 85 additional cases of adult mortality (estimates vary by study)	5.4
Ozone-related Premature Mortality	36 to 160 additional cases of adult mortality (estimates vary by study)	5.4
Other Environmental Impacts		
Loadings to the Mississippi River from the Upper Mississippi River Basin	Nitrogen: +1.43 billion lbs. (1.2%) Phosphorus: +132 million lbs. (0.7%)	6.4
Fuel Costs		
Gasoline Costs	-2.4¢/gal	4.4
Diesel Costs	-12.1 ¢/gal	4.4
Overall Fuel Cost	-$11.8 Billion	4.4
Gasoline and Diesel Consumption	- 13.6 Bgal	4.4
Capital Costs		
Total Capital Costs Thru 2022	$90.5 Billion	4.4
Food Costs		
Corn	+8.2%	5.1
Soybeans	+10.3%	5.1
Food	+$10 per capita	5.1
Economic Impacts		

Energy Security	+$2.6 Billion	5.2
Monetized Health Impacts	-$0.63 to -$2.2 Billion	5.4
Monetized GHG Impacts (SCC)[a]	+$0.6 to $12.2 Billion (estimates vary by SCC assumption)	5.3
Oil Imports	-$41.5 Billion	5.2
Farm Gate Food	+$3.6 Billion	5.1
Farm Income	+$13 Billion (+36%)	5.1
Corn Exports	-$57 Million (-8%)	5.1
Soybean Exports	-$453 Million (-14%)	5.1
Total Benefits in 2022[b]	+$13 to $26 Billion (estimates vary by SCC assumption)	5.5

[a] The models used to estimate SCC values have not been exercised in a systematic manner that would allow researchers to assess the probability of different values. Therefore, the interim SCC values should not be considered to form a range or distribution of possible or likely values. See Section 5.3 for a complete summary of the interim SCC values.
[b] Sum of Overall Fuel Costs, Energy Security, Monetized Health Impacts, and GHG Impacts (SCC) in 2022. This measure does not include the costs of the investments needed to increase renewable fuel production. Those capital costs through 2022 total to $90.5 billion.

The document is organized as follows:

Chapter 1: Renewable Fuel Production and Consumption
This chapter describes the various feedstocks and renewable fuel types that could potentially be used to meet the renewable fuel volumes required by EISA. The availability and challenges of harvesting, storing, and transporting these feedstocks are discussed, as well as the different renewable fuel production technologies, industry plans, and potential growth projections for future facilities. A discussion of renewable fuel distribution and consumption is included. Chapter 1.2 defines the reference and RFS2 control cases that were used throughout the rest of this Regulatory Impact Analysis to assess the impacts of the increased renewable fuel volumes needed to reach the RFS2 mandated volumes.

Chapter 2: Lifecycle GHG Analysis
This chapter describes the methodology used to determine the lifecycle greenhouse gas (GHG) emissions of the renewable fuels required by EISA, and to determine which fuels qualify for the four GHG reduction thresholds established in EISA. Future inclusion of other feedstocks and fuel is discussed, as well as the overall GHG benefits of the RFS program. It also contains our assessment of the GHG emission reductions projected to result from the increased use of renewable fuels.

Chapter 3: Impacts on Non-GHG Pollutants
This chapter discusses the expected impacts of increased renewable fuel volumes on emissions of hydrocarbons (HC), oxides of nitrogen (NOx), carbon monoxide (CO), particulate matter (PM10 and PM2.5), sulfur oxides (SOx), ammonia (NH3), ethanol, and air toxic emissions of benzene, 1,3-butadiene, acetaldehyde, formaldehyde, acrolein, and naphthalene. Emissions from

vehicles and off-road equipment, as well as emissions from the entire fuel production and distribution chain are considered. . This chapter also presents the projected impacts of increased renewable fuel volumes on ambient concentrations of $PM_{2.5}$, ozone and air toxic pollutants, and describes the health and environmental effects associated with these pollutants.

Chapter 4: Impacts on Cost of Renewable Fuels, Gasoline, and Diesel
The impact of increasing the use of renewable fuels on the production and distribution costs of transportation fuels are discussed. Renewable fuel production and distribution costs are presented along with their impact on gasoline and diesel fuel costs. Per-gallon and nationwide costs are presented.

Chapter 5: Economic Impacts
This chapter summarizes the impacts of increased renewable fuel use on the U.S. and international agricultural sector, U.S. petroleum imports, and the consequences of reduced oil imports on U.S. energy security. It also examines the greenhouse gas benefits and the co-pollutant health and environmental impacts from the wider use of renewable fuels in the U.S. needed to meet the RFS2 mandated volumes.

Chapter 6: Impacts on Water
This chapter discusses the impacts of increased renewable fuel volumes on water quality and quantity. Changes in the Upper Mississippi River Basin watershed were modeled.

Chapter 7: Final Regulatory Flexibility Analysis
The Final Regulatory Flexibility Analysis (FRFA) evaluates the impacts of the RFS2 standards on potential small entities. In developing the FRFA, we conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking. Small business recommendations and final rule provisions are discussed.

Appendix
EPA conducted a comprehensive analysis of the NOx, PM, HC, and CO emission impacts of biodiesel blends based on heavy-duty, in-use diesel chassis and engine exhaust emissions data.

List of Acronyms and Abbreviations

ACE	American Coalition for Ethanol
ACS	American Cancer Society
ADM	Archer Daniels Midland
AEO	Annual Energy Outlook (an EIA publication)
AHC	Aromatic hydrocarbons
ARMS	Agricultural Resource Management Survey
ASTM	American Society of Testing and Materials
B0, B5, B20, etc	Percent of biodiesel, e.g., B5= 5% biodiesel, 95% diesel
bbl	Barrel
BEA	Bureau of Economic Analysis
Bgal, bgal, bilgal, bg	Billions of gallons
BGY	Billions of gallons per year
BPCD	Barrels Per calendar day
BPSD	Barrels per stream day
bpd, bbls/day	Barrels Per Day
Brix	A measurement of the sugar content of a solution at a given temperature
BTL	Biomass-to-liquid
BTU	British Thermal Unit
BU	Bushel
Bu/acre	Bushels per acre
BZ	Benzene
C	Carbon
C&D	Construction and Demolition
CA	California
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CARB	California Air Resources Board
CaRFG3	California Phase 3 RFG
CBG	Cleaner Burning Gasoline
CBI	Caribbean Basin Initiative
CB05	Carbon Bond 05
CD	Census Division
CFEIS	EPA's Certification and Fuel Economy Information System
CFR	Code of Federal Regulations
c/gal	Cents per gallon
CG	Conventional Gasoline
CH_3CHO	Acetaldehyde
$CH_3C(O)OO\cdot$	Acetyl peroxy radical
$CH_3C(O)OONO_2$	Peroxyacetyl nitrate
CHF	Congestive heart failure
CHP	Combined Heat and Power Technology
CIMT	Carotid intima-media thickness
CMAQ	Community Multi-scale Air Quality model
CO	Carbon Monoxide
CO2	Carbon Dioxide
COHb	Carboxyhemoglobin
Co-op	Cooperative
CRC	Coordinating Research Council
CRGNSA	Columbia River Gorge National Scenic Area

CRP	Conservation Reserve Program
CTL	Coal-to-liquid
DDGS	Distillers' Dried Grains with Solubles
DGS	Distillers' Grains with Solubles
DHHS	Department of Health and Human Services
DOE	Department of Energy
DRIA	Draft Regulatory Impact Analysis
dt	Dry ton
E&C	Engineering and Construction
E0	Gasoline Blend which Does Not Contain Ethanol
E10	Gasoline Blend containing a nominal 10 percent ethanol by volume
E85	Gasoline Blend containing 85 percent ethanol by volume
E200	Percent of Fuel Evaporated at 200 Degrees F (ASTM D 86)
E300	Percent of Fuel Evaporated at 300 Degrees F (ASTM D 86)
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EISA	Energy Independence and Security Act
Energy Act	Energy Policy Act of 2005 (also the Act)
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005 (also 'the Energy Act' or 'the Act')
ETBE	Ethyl Tertiary Butyl Ether
ETOH	Ethanol
EU	European Union
ex CA	Excluding California
F, °F	Fahrenheit
F-T	Fischer-Tropsch
FAME	Fatty acid methyl ester
FAPRI	Farm and Agricultural Policy Research Institute
FASOM	Forestry and Agriculture Sector Optimization Model
FBP	Feed Boiling Point (also Final Boiling Point)
FCC	Fluidized Catalytic Cracker
FCCU	Fluidized Catalytic Cracking Unit
FHWA	Federal Highway Administration
FOEB	Fuel Oil Equivalent Barrel
FR	Federal Register
FRM	Final Rulemaking
FRTP	Fixed Reduction Trigger Point
FFV	Flexible Fuel Vehicle
FTP	Federal test procedure
g/Btu	Grams per Btu
g/day	Grams per day
Gal, gal	Gallon
GDP	Gross Domestic Product
GEOS	Goddard Earth Observing System
GHG	Greenhouse Gases
GPA	Geographic Phase-in Area
GREET	Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation model
GWP	Global warming potentials
ha	Hectare
H_2O	Water
HC	Hydrocarbon(s)
HCO	Heavy Cycle Oil (a refinery stream)
HCHO	Formaldehyde
HDN	Naphtha Hydrotreater (also Hydro-Denitrogenation Unit)

HEI	Health Effects Institute
HNO_3	Nitric acid
HSR	Heavy Straight Run (a refinery stream)
HVGO	Heavy Vacuum Gas Oil (a refinery stream)
IARC	International Agency for Research on Carcinogens
IBP	Initial Boiling Point
IRFA	Initial Regulatory Flexibility Analysis
k	Thousand
kbbl	Thousand barrels
kg	kilogram
kwh	Kilowatt Hour
L, l	Liter
Lb, lb	Pound
LCC	Land Capability Classification
LCO	Light Cycle Oil (a refinery stream)
LEV	Low emission vehicle
LLE	Liquid-Liquid Extraction
LNS	Light Naphtha Splitter
LP	Linear Programming (a type of refinery model)
LSR	Light Straight Run (a refinery stream)
m^2	Square meter
MCIP	Meteorology-Chemistry Interface Processor
mg/m^3	Milligrams per cubic meter
MGY, MMgy	Million Gallons per Year
mm	Millimeter
MM	Million
MMBTU	Million British Thermal Units
MMbbls/cd	Millions of barrels per calendar day
MMGal/yr	Millions of gallons per year
MOBILE (5, 6, 6.2)	EPA's Motor Vehicle Emission Inventory Model (versions)
MON	Motor Octane Number
MOVES	Motor Vehicle Emissions Simulator
MOVES2006	EPA's Next Generation Highway Vehicle Emission Model
MSAT	Mobile Source Air Toxics
MSAT1	2001 Mobile Source Air Toxics Rule
MSAT2	2006 Proposed Mobile Source Air Toxics Rule
MSW	Municipal Solid Waste
Mt	Metric ton
MTBE	Methyl Tertiary-Butyl Ether
N	Nitrogen
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistics Service
NATA	National Air Toxic Assessment
NBB	National Biodiesel Board
NCGA	National Corn Growers Association
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network
NCSU	North Carolina State University
NGL	Natural gas plant liquids
NH3	Ammonia
NIOSH	National Institute of Occupational Safety and Health
NMHC	Non-Methane Hydrocarbons

NMIM	National Mobile Inventory Model (EPA software tool)
NMOG	Non-methane organic gases
NONROAD	EPA's Non-road Engine Emission Model
NONROAD2005	EPA's Non-road Engine Emission Model Released in 2005
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NRCS	Natural Resource Conservation Service
NREL	National Renewable Energy Laboratory
O_3	Ozone
OA	Organic aerosol
OC	Organic carbon
·OH	Hydroxyl radical
OM	Organic mass
OMB	Office of Management and Budget
OMHCE	Organic Material Hydrocarbon Equivalent
ORD	Office of Research and Development
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation and Air Quality
Oxy-fuel, oxyfuel	Winter oxygenated fuel program
PADD	Petroleum Administration for Defense District
PAHs	Polycyclic aromatic hydrocarbons
PAN	Peroxyacetyl nitrate
PM	Particulate Matter
PM_{10}	Coarse Particle
$PM_{2.5}$	Fine Particle
PM AQCD	Particulate Matter Air Quality Criteria Document
PMA	Petroleum Marketing Annual (an EIA publication)
POM	Polycyclic Organic Matter
PONA	Paraffin, Olefin, Naphthene, Aromatic
ppb	Parts per billion
ppm	Parts Per million
PPN	Peroxypropionyl nitrate
PRTP	Percentage Reduction Trigger Point
PSI	Pounds per Square Inch
QBtu	Quadrillion btu
Quadrillion	10^{15}
(R+M)/2	Octane calculation (RON+MON)/2
R&D	Research and Development
RBOB	Reformulated Blendstock for Oxygenate Blending
rd	Renewable diesel
RFA	Regulatory Flexibility Act
RFG	Reformulated Gasoline
RFS	Renewable Fuels Standard
RFS1	Renewable Fuels Standard Program promulgated in 2007.
RFS2	Renewable Fuels Standard Changes
RIA	Regulatory Impact Analysis
RIMS	Regional Input-Output Modeling System
RIN	Renewable Identification Number
RON	Research octane number
RPMG	Renewable Products Marketing Group

RSM	Response Surface Model
RVP	Reid Vapor Pressure
S	Sulfur
SBA	Small Business Administration
SBAR Panel, or 'the Panel'	Small Business Advocacy Review Panel
SBREFA	Small Business Regulatory Enforcement Fairness Act (of 1996)
scf	Standard cubic feet
SER	Small Entity Representative
SI	Spark Ignition
SOA	Secondary Organic Aerosol
SOC	Secondary organic carbon
SOC	Soil organic carbon
SOx	Oxides of Sulfur
SULEV	Super ultra low emission vehicle
SVOC	Semi-volatile organic compound
T50	Temperature at which 50% (by volume) of fuel evaporates (ASTM D 86)
T90	Temperature at which 90% (by volume) of fuel evaporates (ASTM D 86)
TAME	Tertiary Amyl Methyl Ether
Ton	2000 lbs
Tonne	Metric tonne (equivalent to 1.1 tons); also metric ton
TRQ	Tariff rate quotas
ULEV	Ultra low emission vehicle
U.S.C.	United States Code
USDA	U.S. Department of Agriculture
VGO	Vacuum Gas Oil (a refinery stream)
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
vol%	Percent by volume, volume percent
WDGS	Wet Distillers Grain w/ Solubles
wt%	Percent by weight, weight percent
yr, y	Year

Chapter 1: Renewable Fuel Production and Consumption

1.1 Biofuel Feedstock Availability

Currently, the main feedstocks used for renewable fuel production in the U.S. are corn for ethanol and soy for biodiesel. As technologies improve, we expect more emphasis on using cellulosic feedstocks such as agricultural residues, forestry residues, etc. However, limitations may occur due to concerns over sustainable removal rates for initial cellulosic feedstocks. Thus, dedicated energy crops which are touted as requiring low fertilizer and energy inputs as well as having the ability of being grown on marginal lands may also enter the market. The following sections discuss the current and potential availability of biofuel feedstocks and the potential challenges that must be overcome in order for enough feedstock to be collected and converted to biofuel to meet the EISA requirement of 36 billion gallons of renewable fuel by 2022.

1.1.1 Starch/Sugar Feedstocks

The following sections describe starch and sugar feedstocks that can be used to produce ethanol. Currently, the majority of ethanol that is produced in the U.S. is from corn. Recently, there have been plans to convert sugarcane grown in the U.S. into ethanol as well as the introduction of relatively new crop varieties for biofuel conversion. We also describe feedstocks used in the production of ethanol outside the U.S.

1.1.1.1 Domestic Corn and Other Grain Ethanol

Today's ethanol is primarily corn-based ethanol, which accounts for the majority of the over 10 billion gallons of domestic fuel ethanol estimated to be produced by the end of 2009. According to multiple sources, as much as 18 billion gallons of corn ethanol could be produced by the 2016-18 timeframe, see Table 1.1-1.[1] For the final rule, we modeled 15 billion gallons of corn ethanol to meet the EISA standards. We used the Forestry and Agriculture Sector Optimization Model (FASOM) and the Farm and Agricultural Policy Research Institute (FAPRI-CARD) model to assess the impact of increased renewable fuel volume from business-as-usual on crop acreage, crop allocation to fuel vs. other uses, costs, etc. See Section 1.2 for more discussion on the renewable fuel volumes assumed for our analyses and Chapter 5 of the RIA for more details on the agricultural modeling. Important modeling parameters considered include crop yields and ethanol yield per bushel of feedstock as these factors impact the amount of feedstock necessary per gallon of biofuel produced. Table 1.1-1 also shows a summary of the parameters used and the results from our analyses.

Table 1.1-1. Corn Ethanol Production Forecast Parameters and Corresponding Years

Source (cited in text above)	Fuel Volumes/Year (billion gallons)	Acres Planted (millions)	Yield (bu/acre)	Corn Allocation to Ethanol	Ethanol Conversion (gal/bu)[b]
USDA Baseline	14/2018	90	175	35%	2.76
USDA Study	15/2016	92	170	37%	2.8
NCGA Analysis[c]	12.8-17.8/2016	76-78[a]	178-193	33-40%	2.9-3.0
EPA FRM Analysis (Base Yield Case)	15/2022	92/81[a]	185	41%	2.85
EPA FRM Analysis (Higher Yield Case)	15/2022	77/71[a]	233	36%	2.85

[a]Acres harvested
[b]We assume all figures above include denaturant, but most references do not specify; Differences also occur depending on whether dry or wet mills are assumed, wet mills have slightly lower yields
[c]National Corn Growers Association

Corn is mainly grown in 12 states within the United States: Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin.[2] See Table 1.1-2.

Table 1.1-2.
U.S. Corn for Grain Area Harvested by State in 2008 and Forecasted November 1, 2009

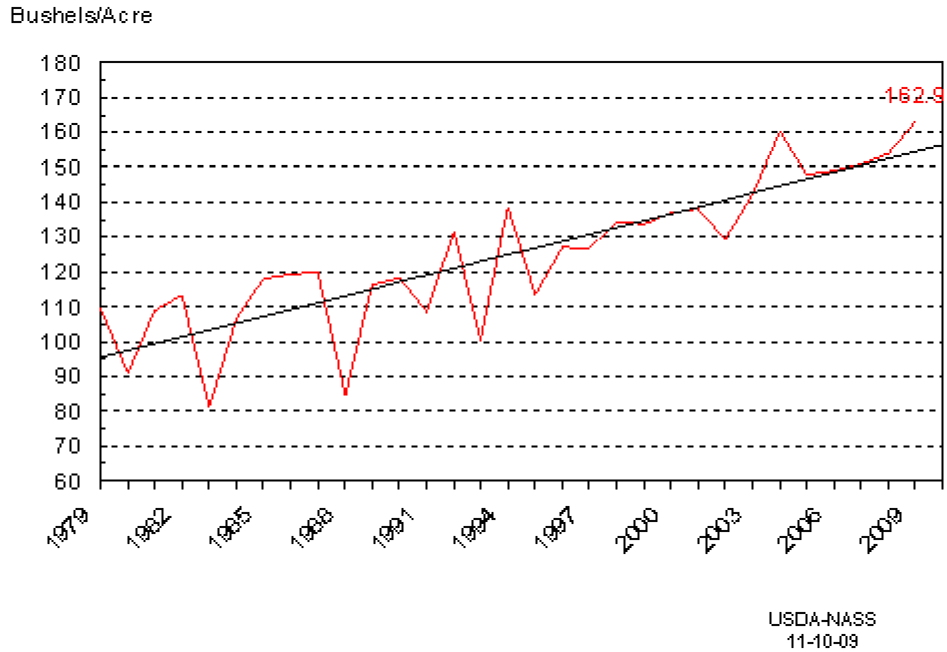
State	Total Harvested 2008 (1000 Acres)	2009 Forecast (1000 Acres)
Illinois	11,900	11,800
Indiana	5,460	5,440
Iowa	12,800	13,350
Kansas	3,630	3,870
Kentucky	1,120	1,130
Michigan	2,140	1,990
Minnesota	7,200	7,100
Missouri	2,650	2,900
Nebraska	8,550	8,900
Ohio	3,120	3,120
South Dakota	4,400	4,600
Wisconsin	2,880	2,900
Other States	12,790	12,194
Total	**78,640**	**79,294**

Corn yield per acre has been increasing over the past three decades.[1,3] See Figure 1.1-1**.** In our economic modeling assessment under the base yield case, the national average corn yield is approximately 185 bu/acre in 2022, with specific yields calculated at the regional level. The national average depends on crop production in each region in a given year (see Chapter 5 of this RIA). These yield increases over time are consistent with the United States Department of Agriculture (USDA) projections.[4] As further described in Chapter 5, we also investigated a

[1] Calculated from 1977-2007.

higher corn yield scenario of 233 bu/acre in 2022, developed in consultation with our colleagues at USDA as well as industry groups e.g. Monsanto and Pioneer.

Figure 1.1-1. U.S. Corn Yields (1978-2009)



The percent of U.S. corn produced allocated to ethanol has increased in recent years. In 2007, the percent of U.S. corn used for ethanol was around 23 percent and in 2008 the percent had increased to 30 percent. As of December 2009, the majority of corn is still being used as animal feed (42 percent), with smaller portions going to ethanol (33 percent), exports (16 percent), and human food and seed (9 percent).[5] For the final rule, the FASOM projects that approximately 41 percent of corn would need to be allocated to the ethanol industry by 2022 under the base corn yield assumption and 36 percent of corn under the higher corn yield assumptions to produce 15 billion gallons of corn ethanol.

The amount of corn allocated to fuel vs. other uses has caused much controversy over the production and use of corn-based ethanol in the past few years. There is concern that the use of corn for fuel could potentially divert corn needed to feed people. On the other hand, it is entirely possible that other countries (e.g. Argentina or Brazil) could increase their production of corn to match the increase in demand for food *and* fuel, thus meeting both needs. In addition, higher crop yields in all countries could decrease the amount of land necessary for a fixed amount of renewable fuel produced. We rely on our modeling results to help inform us of the potential impacts of an increased growth in renewable fuels (see Chapter 5 for more detail).

Over the last 15 years, ethanol industry optimization of cooking, mashing, and fermentation conditions has increased the amount of ethanol produced from a bushel of corn. According to USDA reports, by about 2010 we can expect all plants on-line to yield an average of 2.76 gallons per bushel.[6,7] In addition, based on discussions with USDA, we believe it is reasonable to expect an increase in corn kernel starch content of 2-4 percent over the next decade through advances in plant breeding and new corn varieties. Combining these figures, we project industry average denatured ethanol yields to reach 2.85 gallons per bushel by 2022 for dry mills and 2.63 gallons per bushel for wet mills. See Section 1.4 of this RIA for more information on corn ethanol biofuel production technologies, e.g. dry mill vs. wet mill.

Other grains that can be processed into ethanol include grain sorghum (milo), wheat, and barley. The production of ethanol from these grains generally involves the same processes as the production from corn, and can be used together in the same plant.

1.1.1.2 Imported Sugar Ethanol

After corn, sugar crops (i.e. sugar beets and sugarcane) are the world's next largest feedstock sources for ethanol.[8,9] Sugar beets are mainly grown in France, Germany, and in the U.S., with the majority of the feedstock typically used to produce sugar for food and feed. Compared to sugar beets, sugarcane is produced in much higher volume and has been able to support a growing sugar and ethanol market. Due to a higher availability of sugarcane feedstock for ethanol production, we expect that imported ethanol to the U.S. will likely come from sugarcane.

World production of sugarcane is approximately 1.4 billion metric tons (MT) and is concentrated mainly in tropical regions, particularly in Latin America, Africa, and South and Southeast Asia. Roughly 100 countries produce sugarcane today.[10] Brazil is currently the world's largest producer of sugarcane (569 million MT in the 2008/9 harvest season) and offers the greatest potential for growth, due primarily to the availability of suitable lands for expanding sugarcane cultivation.[11] In Brazil, just 20% of the arable land is cultivated, totaling 156 million acres. The following Table 1.1-3., describes the land available/used in 2007. As there are 494 million acres of pastureland and a considerable area of unused arable land (190 million acres), it is believed that there could be a large expansion in sugarcane.[12]

Table 1.1-3. Brazil Land Areas in 2007.[13]

	Million Acres
Brazil (Total Area)	2100
Total Preserved Areas and Other Uses*	1260
Total Arable Area	840
Cultivated Land (All Crops)	156
Soybeans	51
Corn	35
Oranges	2
Sugar Cane	19
Sugar Area	11
Ethanol Area	8
Pastureland	494
Available land (ag, livestock)	190

***Areas include Amazon Rain Forest, protected areas, conservation and reforestation areas, cities and towns, roads, lakes, and rivers.**

The statistics above, however, do not indicate whether the land available requires any additional usage of water or has the proper soil and climate conditions for sugarcane. According to one study, there is at least 148 million acres of additional land available with proper soil and climate conditions for sugarcane without utilizing environmentally protected land (i.e. Amazon and native reserves) and without the use of irrigation.[14] This translates to approximately 90 billion gallons of ethanol potential (using a yield of approximately 600 gal/acre which is a conservative estimate based on existing technology). Although it is not probable that all this land will be converted to sugarcane ethanol, the estimate puts into prospective the large potential for sugarcane ethanol to be produced in Brazil.

Another study commissioned by the Brazilian Government produced an analysis in which Brazil's arable land was evaluated for its suitability for cane. The benefit of this study is that it provides more detail on the land quality and yield assumptions used in its estimates than the study and statistics shown above.[15] The study eliminated areas protected by environmental regulations and those with a slope greater than 12% (those not suitable for mechanized farming). The following Table 1.1-4 shows an estimate of the available land that could be used for sugarcane expansion. The potential fuel volume from these acres is dependent on whether or not irrigation takes place. Overall, with greater irrigation, more acres are available that fall in the higher potential yield categories than without irrigation. As can be seen, there are potentially large areas of land available for sugarcane expansion in Brazil.

Table 1.1-4.
Potential Volumes Utilizing Available Land for Sugarcane Expansion[2,16,17]

Potential	Ethanol Yield (gal/acre)	Potential Area (million acres)		Potential Ethanol Volume (billion gallons)	
		w/o irrigation	w/ irrigation	w/o irrigation	w/ irrigation
High	659	20	94	13	62
Good	592	281	242	166	143
Average	524	369	414	193	217
Inadequate	0	224	143	0	0
Total		894	894	373	422

The actual potential for ethanol from sugarcane will, however, be further limited by the amount of sugarcane diverted towards food and other uses. Taking into account demands for food and feed, the Oak Ridge National Laboratory (ORNL) *Biofuel Feedstock Assessment for Selected Countries* report suggests that perhaps more than 30 billion gallons of ethanol-equivalent fuel could be produced from available sugarcane supply by 2017. Brazil is estimated to produce approximately 2/3 of the potential supply. The majority of this supply would likely be consumed within the country, with the leftover potentially available for export to the U.S. and other countries. Recent government and industry estimates indicate that approximately 3.8-4.2 bgal of ethanol could be available for export from Brazil by 2022 (with close to 17 billion gallons being produced and 13 billion gallons consumed domestically). See Section 1.5.2.1 of

[2] Adapted from CGEE, ABDI, Unicamp, and NIPE, Scaling Up the Ethanol Program in Brazil. Assumed a conversion factor of 20 gallons of ethanol per tonne of sugarcane feedstock to compute gal/acre. A "high" potential refers to ethanol yields that are higher than current industry averages, while "good" refers to good quality land and productivity that is about equal to the current average. Explanations for "Average" and "Inadequate" were not provided.

this RIA for further details on Brazilian ethanol production and consumption. Thus, there appears to be a large enough potential for Brazil to increase production of sugarcane to meet its internal demands as well as export to the United States and other countries.

Countries other than Brazil generally lack the land resources, appropriate soils, and climate for large expansion of sugarcane production.[18] India and China are the second and third largest producers, however, most of the cultivatable land area is already in use and government policies discourage reallocation of arable land for biofuel production. Although Argentina and Columbia have significant underutilized lands available, these resources generally do not have suitable soil and climate characteristics for sugarcane production. Due to these factors, Brazil is the most likely country able to produce substantial volumes of sugarcane for biofuel production in the future.

1.1.1.3 Domestic Sugar Ethanol

Currently, there are no U.S. plants producing ethanol from sugar feedstocks.[19] Brazil and several other countries are producing ethanol from sugarcane, sugarbeets, and molasses, showing that it is economically feasible to convert these feedstocks into ethanol (see Section 1.1.1.2). However, the economics of producing ethanol from sugar feedstocks in these countries is not directly comparable to the economics of producing ethanol from sugar feedstocks in the U.S. Over the longer term, the profitability of producing ethanol from sugarcane, sugarbeets, and molasses depends on the prices of these crops, the costs of conversion, and the price of gasoline.

Sugarcane in the U.S. is grown mainly in Florida and Louisiana, with smaller amounts from Hawaii and Texas. See Table 1.1-5. Sugarbeets, on the other hand, are grown in more northern states, with the majority of production in Minnesota, Michigan, and Idaho as shown in Table 1.1-6. As noted, these feedstocks are not currently used for commercial production of ethanol, however, this may change in the near future.

Table 1.1-5.
Sugarcane Area Harvested (for sugar only, not seed) by State in 2008 and 2009

State	Total Harvested 2008 (1000 Acres)	Total Harvested 2009 (1000 Acres)
Florida	384	372
Hawaii	20	20
Louisiana	380	375
Texas	37	39
Total	**821**	**806**

Table 1.1-6.
Sugarbeet Area Harvested by State in 2008 and 2009

State	Total Harvested 2008 (1000 Acres)	Total Harvested 2009 (1000 Acres)
Idaho	116	163
Michigan	136	136
Minnesota	399	455
Other States	354	397
Total	**1005**	**1151**

Recent news indicates that there are plans in the U.S. to produce ethanol from sugar feedstocks. For instance, sugarcane has been grown in California's Imperial Valley specifically for the purpose of making ethanol and using the cane's biomass to generate electricity to power the ethanol distillery as well as export excess electricity to the electric grid.[20] There are at least two projects being developed at this time that could result in several hundred million gallons of ethanol produced. One company is California Ethanol and Power which is currently in the development stage and plans to build a facility that produces 60 million gallon per year of sugarcane ethanol and 50 megawatts of electricity.[21] The company plans to break ground by early 2010 and be operational by 2011. The sugarcane is being grown on marginal and existing cropland that is unsuitable for food crops and will replace forage crops like alfalfa, Bermuda grass, Klein grass, etc. Harvesting is expected to be fully mechanized. Another company is Pacific West Energy LLC which plans to produce 12-15 million gallons per year of ethanol on the island of Kauai in Hawaii, perhaps as early as 2010. Hawaii is well suited for sugarcane ethanol production due to several factors, including lower costs for feedstock compared to those in the continental U.S., high prices for electricity and liquid fuels, and state production incentives.[22] Thus, there is potential for these projects and perhaps others to help contribute to the EISA biofuels mandate.

There is also potential for the use of new crops with certain traits similar to traditional sugar and corn feedstocks. For example, a new crop referred to as Sugarcorn is a hybrid cross between sugarcane and corn.[23] The plant contains genes from Midwestern corn, tropical maize and sugarcane, resulting in a variety that doesn't flower to produce grain but instead produces sugar in its stalks. Researchers are currently working to increase sugar yields, increase the plant's hardiness and develop ways to prevent the plant from being pollinated by nearby crops of traditional corn. Potential benefits include reduced water and fertilizer consumption during the growth of the plant.

Another crop receiving greater attention is sweet sorghum. Sweet sorghum refers to varieties of sorghum with high concentration of soluble sugars in the sap.[24] They are used for the production of syrup, alcoholic beverages, crystal sugar, etc. The interest in bioenergy production from sweet sorghum comes from the easy accessibility of readily fermentable sugars combined with very high yields for biomass. Yield varies with location and variety and ranges from 8-49 tons/acre. After extraction of the juice, the bagasse can also be used as cellulosic feedstock or other purposes. Groups interested in building facilities in the U.S. that can process sorghum juice include the Tampa Bay Area Ethanol Consortium in Florida and the Texas BioEnergy Marketing Associates in Texas.

1.1.2 Cellulosic Biofuel Feedstocks

Various cellulosic feedstocks can potentially be used to produce cellulosic biofuel. These include agricultural residues, forest residues, urban waste, and dedicated energy crops. We describe each type in the following sections.

1.1.2.1 Agricultural Residues

The harvesting of agricultural residues could provide a large source of readily available feedstock for cellulosic biofuels. We estimated the amount of crop residue could potentially be produced, and of that, how much could be removed or harvested to determine the total amount that could be available to produce biofuel in 2022. The amount of residue that can be harvested is limited by how much residue must be left on the field to maintain soil health and by the mechanical efficiency of the harvesting operation. We discuss harvesting limitations due to maintaining soil health below, while mechanical efficiencies, storage, and transport issues are discussed in Section 1.3 of this RIA. Feedstock costs are discussed in Section 4.1.1.2 of the RIA.

Sustainable Removal

In terms of soil health, residues perform many positive functions for agricultural soils. Recent studies and reviews have attempted to address these issues. Existing research can be used to some extent to guide practices or make estimates, especially for corn stover harvest in the Corn Belt, which has been studied more extensively than other residues except, perhaps, wheat.

In a review by five USDA Agricultural Research Service (ARS) scientists, Wilhelm et al. acknowledged the complexity of interactions between soil type, climate, and management when considering crop residue effects on soil. They recommended that removal rates be based on regional yield, climatic conditions and cultural practices, with no specific rates given.[25] Using the Revised Universal Soil Loss Equation (RUSLE) technology and the Wind Erosion Equation (WEQ), Nelson predicted safe residue removal rates for minimizing soil loss in the Eastern and Midwestern U.S. These predictions varied widely over time and location as a result of the complex interactions discussed by Wilhelm et al.[26,27] In another recent review, sponsored by the U.S. Department of Energy (DOE), Mann et al. concluded that before specific recommendations could be made, more information was needed on the long term effects of residue harvest, including: 1) water quality; 2) soil biota; 3) transformations of different forms of soil organic carbon (SOC); and 4) subsoil SOC dynamics.[28] Current USDA Natural Resource Conservation Service (NRCS) practice standards for residue management do not recommend specific residue quantities and point to the use of the RUSLE2 model for guidance.[29] Despite broad recognition of the need for specific guidelines for residue removal, none yet exist.

With the upsurge in biofuels and the obvious prospects of removing significant quantities of residue, many questions remain regarding the long-term effects on soils from residue removal.

Residues have not yet been removed at the contemplated rates over a period sufficiently long for the effects to be clearly determined. Another difficulty is that while the effects of removing a residue may appear to one observer to have affected the soil in a certain manner, it may not be completely clear that the observed effects were fully related to the residue removal or, were in fact related to a change or to combinations of changes in other variables that were simply missed. A second observer may view the same results in an honest, but different manner. There are many variables and many different interactions among them that assigning effects is very difficult at best. There simply are no real-world data available for determining long-term effects. Nevertheless, we can describe some of the interactions that take place and how they can potentially affect soil health.

Soil erosion is an extremely important national issue. Most, if not all, agricultural cropland in the United States experiences some degree of soil erosion each year due to rainfall (water) and/or wind forces. Rainfall erosion (sheet and rill) occurs when rain directly strikes the soil, dislodging particles in the top layer.[3] When soil becomes saturated, particles are transported down the slope of the field. Soil erosion due to wind occurs in much the same manner as rainfall with wind forces dislodging soil particles and carrying them along and above the field surface (creep and saltation) or suspending them above the field.[4] While eroded soil does not disappear, the erosion process moves soil particles to other locations in the field (either downslope or downwind) where they can be transferred into waterways or onto non-croplands.

The amount of soil erosion that agricultural cropland experiences is a function of many factors: field operations (field preparation, tillage, etc.) in preparation for the next crop, timing of field operations, present throughout the year, soil type, field characteristics such as field slope, and the amount of residue (cover) left on the field from harvest until the next crop planting. Crop rotation cover provided by agricultural crop residues, both fallen and standing, helps to minimize rainfall and wind energy as it strikes or blows across the ground as well as helping to keep soil particles from being transported after they have been dislodged. Climatic conditions such as rainfall, wind, temperature, etc. must be accounted for. Studies predict that up to 30% of surface residue can be removed from some no-till systems without increased erosion or runoff.

The NRCS has established tolerable soil loss limits (T values) for all soil types in all counties throughout the United States. The tolerable soil loss values denote the maximum rate of soil erosion that can occur for a particular soil type that does not lead to prolonged soil deterioration and/or loss of productivity. Tolerable soil loss limits take into account the rate of topsoil formation, role of topsoil formation, loss of nutrients, erosion rate at which gully erosion would commence, and potential erosion-control factors that farmers would be able to implement. However, T values are not a function of the type of crop grown.

Another important aspect associated with soil conservation involves soil tilth. Soil tilth is defined as the physical condition of the soil as related to its ease of tillage, fitness as a seed bed, impedance to seedling emergence and root penetration, and all other physical conditions that

[3] rill: A small intermittent watercourse with steep sides, usually only a few inches deep; www.hancockcoingov.org/surveyor/drainage_glossary_of_terms.asp.

[4] saltation: the movement of sand-sized particles by a skipping and bouncing action in the direction the wind is blowing

influence crop development. Tilth depends upon soil granulation and its stability (soil workability) as well as organic matter content, moisture content, porosity, water retention, degree of aeration, rate of water infiltration, drainage, and capillary-water capacity, all of which are affected by crop residue removal. Preliminary values of required tilth have been estimated by the NRCS.

Various tillage operations are associated with management of agricultural crop residues and planting preparation throughout the year. Type and number of tillage operations employed for any particular crop from the time of harvest until the next planting have a tremendous effect on the amount of soil lost to erosion during the year, and hence, the amount of residue that can possibly be removed for energy purposes. It must be noted that even though crop residues may be used for energy purposes, the farmer is, first and foremost, in the business of producing grain. Therefore, he will be concerned with using those tillage operations that will provide him with the highest possible yield at the next harvest, and not necessarily those that tend to maximize erosion control on his lands.[30]

All agricultural cropland upon which nearly any crop is grown within a particular county can exhibit a wide variation in soil erodibility, field slope and length, climate conditions, and management practices. Within any one particular county there can be many different soil types (50 or more) used to grow agricultural crops. In addition, and possibly more importantly, not all soil types within a county may be suitable for agricultural crop production. Some soils possess characteristics that make them highly susceptible to erosion that may not be able to sustain certain cropping practices. Production of conventional agricultural crops on these lands may severely and/or permanently reduce the soil's ability to provide sustained, economical production. For this reason, the NRCS implemented a land capability classification (LCC) that ranges from I (one) to VIII (eight) that is applied to all soils within a county.

With added nitrogen fertilizers, residues can increase soil organic matter (SOM). However, roots appear to be the largest contributor to new SOM, making residues less important for carbon accrual. Residue removal leading to higher erosion and runoff rates would greatly decrease SOM and nutrients. Residue harvest may also require increased fertilizer inputs to make up for nutrients removed in the plant material. When returned to the land, crop residue also replenishes soil organic carbon (SOC) that typically has already been reduced 30 to 50% of precultivation levels through crop production activities. Soil organic carbon retains and recycles nutrients, improves soil structure, enhances water exchange characteristics and aeration, and sustains microbial life within the soil. It's been reported that crop yield and the value of environmental services (C and N sequestration) were greater for soils with greater SOC. Limited research has shown that removing stover reduces grain and stover yield of subsequent crops and further lowers soil organic matter levels.[31]

Residue removal can result in detrimental changes in many biological soil quality indicators including soil carbon, microbial activity, fungal biomass and earthworm populations, indicating reduced soil function. Some disease-producing organisms are enhanced by residue removal, others by residue retention, depending on crop and region. Residue cover can also reduce evaporation from the soil surface, thereby conserving moisture and increasing the number of days a crop can survive in drought conditions. Improved soil physical properties related to crop residues, such as reduced bulk density, e.g., the soil is looser and lighter, and greater aggregate stability, also lead to better water infiltration and retention.

In colder climates, residues are linked to reduced yields due to lower soil temperatures resulting in poor germination. Stubble mulching, as opposed to residue chopping, can help overcome this problem. Even though residue-associated yield reductions have been found on poorly drained, fine-textured soils, these soils often have low erosion risk and residues might safely be removed.

Despite the many important benefits of crop residues, research shows their effects can vary. For instance, some reports showed lower yields in systems with high crop residues due to increased disease or poor germination; others reported higher yields when soil moisture is limiting. Other studies suggest that residues do not contribute significantly to soil carbon. Many studies found that additional N fertilizer is needed when residues are left on soils to avoid N uptake (immobilization) from soil or allow for soil carbon accrual. For appropriate residue removal recommendations, the conditions leading to these varied effects of residues must be elucidated.

Soil health as related to residue removal is an extremely complex issue for which, as yet, there are no specific guidelines for residue removal. Wrong decisions, carried out over extended periods could have far reaching deleterious effects. Sustainable residue removal rates for biofuel production vary by system, according to such factors as management and cropping practice, crop yield, climate, topography, soil type and existing soil quality. Keeping in mind that gravimetric rates are not the same as percent soil cover (% mass is not the same as % coverage), appropriate conversion is necessary and varies by crop and region. While areas with low slopes and high yields may support residue harvest, in many areas the residue amounts required to maintain soil quality could be even higher than current practices. What is meant by ‘high’ and ‘low’ slopes has yet to be absolutely determined, which determination also depends on soil type and other cropping practices. Removal rates will need to be reduced as climates become warmer or more humid, for lower C:N residue or lower yielding crops, as soil disturbance (e.g. tillage) increases, or as soils become coarser textured, compared to the conditions in which most studies occurred (in the U.S. Midwest Corn Belt for no-till corn).[32] The most important aspect of this is that any or all of the interacting variables that determine how much residue can be removed, can, and usually do, change from year-to-year, across both wide regions of the country as well as across single counties and farms. A change in one variable nearly always changes how all the variables interact.

Given all the issues we’ve discussed regarding residue removal and soil health, rather than try to predict, county-by-county how much residue will be available, we assumed in our FASOM modeling that the available amount will be somewhere between 0% and 50%, at least until the issues we have discussed are settled. We based the amount removable based on the tillage practice: 0% removed for conventional tillage, 35% removed for conservational tillage, and 50% removed for no-till for corn stover.[33] Removal rates for wheat straw were based on the Billion Ton study.[34] We believe that given the uncertainties in removal rates, our assumptions are reasonable.

Agricultural Residue Summary

Corn and wheat are currently receiving the most attention across the industry due to their concentrated production areas and because they generate the majority of total residue produced. This also means they will more likely be able to support commercial scale production. In aggregate, the other residues provide fairly significant quantities of material, but because they are spread out, e.g., less densely planted both in the field and in a county or state, they are less likely able to support commercial operations.

We analyzed various reports on the availability of agricultural residues. These are summarized in Table 1.1-7. The agricultural residue estimates in Table 1.1-7 are based on historical/recent data, and thus, could be considered conservative in comparison to the future (2022) which would typically have higher crop yields or increases in acres harvested.

Table 1.1-7. Estimated Agricultural Residue Feedstock Availability (per year)[35,36,37,38,39]

Source	Total Available	Total Removable Sustainably	Crops Analyzed
USDA	>500 million tons	not specified	Eight leading U.S. Crops, e.g. corn, wheat, soy, oats, barley, rice (did not specify other two)
NREL	495 million tons	173 million tons	Corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, beans, peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed
Gallagher	not specified	156 million tons	Corn, wheat, sorghum, barley, oats, rice
Walsh	not specified	144 million tons at $40/dry ton, ~150 million tons at >$40/dry ton for corn; 7 million tons at $40/dry ton, ~10-11 million tons at >$40/dry ton for wheat	Corn and wheat
Graham	216 million tons	65 million tons at 30% removal rate and current conditions; 112 million tons at 50% removal rate using no-till conditions	Corn

Based on our FASOM modeling for the final rule, corn stover was the most economical agricultural residue projected to be used to produce ethanol in order to meet the 16 Bgal EISA cellulosic biofuel requirement. We estimate that by 2022 about 400 million wet tons of corn stover could be produced, see Table 1.1-8. Approximately 53 million dry tons of corn stover would be needed to produce the 4.9 billion gallons of cellulosic biofuel estimated to be used by our agricultural modeling in 2022.[5] Smaller amounts will be required from sugarcane bagasse, wheat residue, as well as sweet sorghum pulp (bagasse) to produce another 0.8 billion gallons of cellulosic biofuel.[6] Thus, the residue collected to meet EISA would be a small fraction of the total residue produced nationwide – though potentially higher fractions in some local areas. See Section 1.8.1.3 for more details on the use of agricultural residues for our cellulosic plant siting analysis developed for the air quality modeling.

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[5] Assuming conversion yield of 92.3 gal/dry ton as updated by NREL yields. Adjusted for moisture content, see FASOM documentation (Beach, 2010) for more details.

[6] Bagasse is technically a by-product of the sugarcane process and not an agricultural residue, we include it here for simplification. Sweet sorghum pulp is also a by-product of sweet sorghum processing.

Table 1.1-8.
FASOM Estimated Total Agricultural Residue Feedstock Possible in 2022 (million wet tons)[7]

State/Region	Barley	Corn	Oats	Rice	Sorghum	Wheat	Total
Alabama	*0.0*	*1.2*	*0.0*	*0.0*	*0.1*	*0.6*	***1.9***
Arizona	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.4*	***0.6***
Arkansas	*0.0*	*1.3*	*0.0*	*8.1*	*0.4*	*0.9*	***10.8***
California	*0.5*	*0.9*	*0.0*	*2.0*	*0.1*	*2.9*	***6.6***
Colorado	*0.5*	*6.3*	*0.1*	*0.0*	*0.7*	*9.9*	***17.4***
Connecticut	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
Delaware	*0.1*	*0.6*	*0.0*	*0.0*	*0.0*	*0.2*	***0.9***
Florida	*0.0*	*0.2*	*0.0*	*0.0*	*0.0*	*0.1*	***0.3***
Georgia	*0.0*	*5.5*	*0.1*	*0.0*	*0.2*	*1.5*	***7.2***
Idaho	*2.9*	*0.4*	*0.0*	*0.0*	*0.0*	*4.4*	***7.7***
Illinois	*0.0*	*65.3*	*0.1*	*0.0*	*0.3*	*3.6*	***69.2***
Indiana	*0.0*	*33.0*	*0.0*	*0.0*	*0.0*	*1.7*	***34.8***
Iowa	*0.0*	*79.1*	*0.3*	*0.0*	*0.2*	*0.1*	***79.7***
Kansas	*0.0*	*12.4*	*0.2*	*0.0*	*9.9*	*29.3*	***51.8***
Kentucky	*0.1*	*7.8*	*0.0*	*0.0*	*0.1*	*2.8*	***10.9***
Louisiana	*0.0*	*0.3*	*0.0*	*2.2*	*0.1*	*0.5*	***3.1***
Maine	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.1***
Maryland	*0.2*	*1.7*	*0.0*	*0.0*	*0.0*	*1.0*	***2.9***
Massachusetts	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
Michigan	*0.0*	*9.2*	*0.1*	*0.0*	*0.0*	*3.7*	***13.1***
Minnesota	*0.3*	*39.7*	*0.3*	*0.0*	*0.0*	*4.2*	***44.6***
Mississippi	*0.0*	*1.2*	*0.0*	*1.1*	*0.3*	*1.1*	***3.8***
Missouri	*0.0*	*14.7*	*0.0*	*0.4*	*0.7*	*3.7*	***19.5***
Montana	*3.0*	*0.0*	*0.8*	*0.0*	*0.0*	*6.6*	***10.4***
Nebraska	*0.0*	*53.2*	*0.0*	*0.0*	*1.1*	*6.4*	***60.7***
Nevada	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	***0.3***
New Hampshire	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
New Jersey	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	***0.1***
New Mexico	*0.0*	*0.6*	*0.0*	*0.0*	*0.7*	*1.6*	***2.9***
New York	*0.0*	*0.3*	*0.1*	*0.0*	*0.0*	*0.3*	***0.7***
North Carolina	*0.2*	*9.0*	*0.2*	*0.0*	*0.6*	*1.3*	***11.3***
North Dakota	*6.5*	*3.0*	*1.1*	*0.0*	*0.0*	*16.1*	***26.7***
Ohio	*0.0*	*15.1*	*1.1*	*0.0*	*0.0*	*3.9*	***20.0***
Oklahoma	*0.2*	*0.7*	*0.1*	*0.0*	*1.4*	*17.1*	***19.5***
Oregon	*1.3*	*0.1*	*0.4*	*0.0*	*0.0*	*0.3*	***2.1***
Pennsylvania	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.9*	***1.1***
Rhode Island	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
South Carolina	*0.0*	*1.2*	*0.0*	*0.0*	*0.0*	*0.4*	***1.7***
South Dakota	*0.8*	*15.2*	*1.3*	*0.0*	*0.9*	*9.9*	***28.1***
Tennessee	*0.0*	*2.7*	*0.0*	*0.0*	*0.1*	*1.4*	***4.2***
Texas	*0.1*	*7.5*	*0.8*	*1.2*	*9.6*	*13.6*	***32.7***
Utah	*0.4*	*0.1*	*0.0*	*0.0*	*0.0*	*1.7*	***2.2***
Vermont	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
Virginia	*0.3*	*2.5*	*0.0*	*0.0*	*0.0*	*2.0*	***4.8***
Washington	*1.5*	*0.6*	*0.1*	*0.0*	*0.0*	*7.5*	***9.8***
West Virginia	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	***0.0***
Wisconsin	*0.1*	*12.9*	*0.4*	*0.0*	*0.0*	*1.2*	***14.7***
Wyoming	*0.5*	*0.2*	*0.1*	*0.0*	*0.0*	*0.6*	***1.4***
Total	***20***	***406***	***8***	***15***	***27***	***166***	***642***

[7] Assumes straw to grain ratio for barley and wheat (1.5:1) and for corn, oats, rice, and sorghum (1:1); Also assumes 0.024 ton/bu for barley and oats, 0.028 ton/bu for corn, 0.05 ton/cwt for rice and sorghum, and 0.03 ton/bu for wheat. For more details on assumptions please refer to the following: Beach, Robert; McCarl, Bruce, *U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description*, RTI International, January, 2010.

1.1.2.2 Dedicated Energy Crops

Crops developed and grown specifically as a renewable source of cellulosic material for biofuel production are not yet commercial, but have significant potential. Currently, crops such as corn that are grown and harvested for energy uses in the United States are also used for agricultural purposes and serve many important uses other than biofuel production. This competition could be reduced by the use of non-agricultural feedstocks for cellulosic biofuel production. Urban wastes and forest and agriculture residues could likely be the first feedstocks used in cellulosic biofuel production due to lower feedstock costs and availability; However, there are many uncertainties over land availability and sustainable removal rates for residues.

Many of the energy crops investigated are perennial species grown from roots or rhizomes that remain in the ground after harvesting the above-ground biomass. While most agricultural crops are annual species, perennials are considered beneficial in many ways. Dedicated perennial energy crops have the potential to grow on marginal lands, produce high yields, and may have low input needs. Once a perennial crop is established costs are reduced, as the need for tillage is lowered. The root system that remains in the soil can also facilitate the acquisition of nutrients thus decreasing the need for large fertilizer inputs. In southern climates, perennials have the potential for higher yield per acre of land than annual crops. This is due to the fact that perennial plants develop more quickly in the spring and the canopy of foliage can sustain for longer in the fall. This makes it possible for the plants to be more photosynthetically active and have a more efficient energy conversion system. Perennial energy crops also increase soil productivity, sequester carbon, and provide refuge for wildlife.

The following sections describe several of the most commonly discussed dedicated energy crops (switchgrass, miscanthus, and hybrid poplars) as well as some less familiarly known crops and the potential marginal lands on which they can be grown. While not all of these energy crops were specifically modeled in our agricultural models, switchgrass (which is often used as the main "model" energy crop), was projected to be a likely and significant feedstock for the production of renewable fuel to meet EISA.[8,40] For the final rule, FASOM projected that 7.9 ethanol-equivalent billion gallons out of the 16 billion gallon cellulosic biofuel required would come from switchgrass. See Chapter 5 for more details on the agricultural modeling.

Switchgrass

The energy crop that has received the most attention is switchgrass. Switchgrass is a perennial warm season grass that is native to the United States. It typically reaches heights of 3-5 feet, but can grow to more than 10 feet in some southern regions. It has a deep root system that extends many feet below the earth. It may be the ideal energy crop mainly because it can tolerate many soil types and climates from drought conditions to floods. It is also resistant to many pests and diseases. The photosynthetic pathway of switchgrass (and other perennials) allows it to produce high biomass yields with low amounts of chemical input. In the spring, switchgrass develops a photosynthetic canopy of biomass more quickly, and it also persists

[8] Assuming 16 Bgal cellulosic biofuel total, 2.3 Bgal from Urban Waste; 13.7 Bgal of cellulosic biofuel for ag residues, forestry biomass, and/or energy crops would be needed.

longer in the fall than annual plants, allowing for a high net conversion of solar energy per year.[41]

Highly variable yields have been estimated at 1-12 dry tons/acre per year depending on soil, location, and variety. A yield of 4-5.5 dry tons/acre is a reasonable average today.[42] In a long term study sponsored by the DOE, average yield after 10 years of growth was 4.8-7.6 tons/acre for switchgrass when harvested annually.[9,43] Biannual harvests were also done experimentally to try and achieve the maximum yields possible but the harvests showed little difference in total yield. Biannual harvests resulted in approximately 70% of the yield for the first cut and 30% for the second.[44]

Water and nitrogen availability are the main resources that limit production of warm-weather grasses such as switchgrass. Nitrogen accessibility for these plants depends on many factors. Harvesting frequency, soil content, and removal rates all affect the nitrogen available to the plant. In a study by S.B. McLaughlin, initial nitrogen fertilization rates were 40-120 kg/ha (36-107 lbs/acre); however they discovered that a reduction to only 20 kg/ha (17.8 lbs/acre) of nitrogen was sufficient to produce similar yields in single cut systems in the mid-Atlantic region.[45] Reduced nitrogen amounts were similar in other regions of the country.

Miscanthus

Miscanthus is a tall perennial grass that has been evaluated as a potential energy crop most extensively in Europe where it is already being grown for biofuel purposes. The genus is primarily tropic or sub-tropic in origin but there is a wide climactic range at the species level.[46] This characteristic makes it more suitable for establishment over the ranging climates of North America. Giant miscanthus (*Miscanthus x gigantus*) is a hybrid variety that can grow 12-14 feet tall. It is a cold-tolerant warm season grass and has similar characteristics to switchgrass with high yields and low amounts of input.[47] In the Midwest, the growing season of Miscanthus is April to October. The plant grows large green foliage that maximizes in approximately late August. As the temperature falls the foliage fades and drops off leaving the stem. The stem is the commercially important part of the plant and resembles bamboo. Stems can reach nine feet in length, ½ to ¾ in diameter, and are harvested in the winter after drying occurs.[48]

Establishment of a crop takes approximately 2 years, with maximum yields reached in the third year depending on soil fertility. In established crops 5-10 shoots per square foot can be developed. Yields in various studies from the University of Illinois were 9-16 tons/acre in various regions in Illinois. The southern regions of the state with poor soil quality also saw high yields illustrating that miscanthus is suitable for growth and high achievable yields on marginal land.[49] Yields in Europe ranged widely, with irrigated crops reaching 12 tons/acre and un-irrigated yields of 4-10 tons/acre in the fall. According to trials conducted in Europe, the quality of miscanthus biomass for conversion to biofuel improves by delaying harvesting until after the winter months and the plant has time to dry sufficiently. However, this reduced yields by 30 percent.[50] In comparison to switchgrass, research out of Illinois also concluded that miscanthus can yield more biomass for conversion to biofuel because of its even higher photosynthetic efficiency and longer growing season.[51] In terms of input, miscanthus uses nitrogen extremely

[9] Switchgrass variety used in this study was Alamo. Other varieties could result in different yields.

efficiently and therefore does not need to be fertilized for high yields to be achieved. There is also no need for pesticides; however, herbicides have been used to control weed populations.[52]

Challenges in growing and producing miscanthus crop include high establishment costs, problems in winter survival during the first year, and potentially high water needs. European cost estimates are similar to other perennial plants at approximately $64 per dry ton; however they estimate that a growing cycle of 10-12 years is required to recover the start-up costs of $267 per planted acre.[53] The bulk of the high initial cost comes from planting and harvesting machinery. Establishment of a stronger market for growing these energy crops, as well as increased knowledge of propagation of the species, will inevitably lower overhead costs.[54]

Hybrid Poplar

The poplar tree is another option being investigated for use as a dedicated energy crop. Woody perennial plants have some of the same characteristics of the perennial grasses that make them suitable for possible use as an energy crop. They retain significant amounts of root biomass below ground, require little tillage, grow fast large canopies, and require less fertilization than their agricultural counterparts.

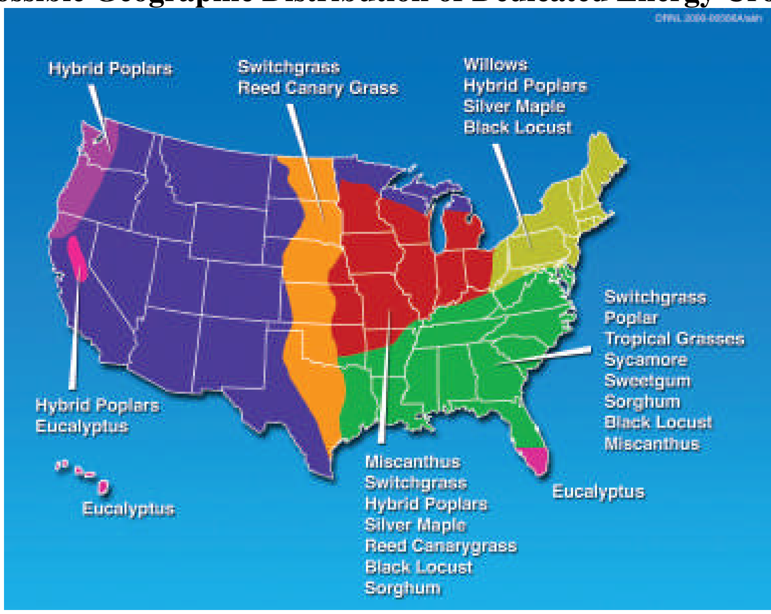
Technological advances in harvesting and genetics may help produce species that will be more suitable for use as an energy crop. Genetic information has helped to understand the characteristics the poplar tree. The complex genetic information obtained from the genome of this plant will make possible the engineering of faster growing trees with more biomass available for harvest.[55]

Other Potential Feedstocks

Several other perennial plants have the possibility to be used as dedicated energy crops. As previously described, the characteristics of perennial species make some optimal for use in this capacity. Because these plants have not been grown in agricultural sectors, they have not been extensively researched and fully optimized. Corn is a crop that has been scientifically studied for decades because of its continued importance in the market. Dedicated energy crops must see this type of investment to bring about further knowledge of basic biology which will lead to advances in breeding and eventual domestication of the species that have promise. The DOE along with university researchers have identified several other plants as potential energy crops. These include additional types of grasses such as reed canary grass, high biomass forage sorghum, and energy cane. Yields for forage sorghum are high and vary from 10-20 dry tons per acre depending on the genotype used.[56] High tonnage energy cane perhaps offers the greatest potential for much of East Texas and the U.S. Gulf Coast, as commercially grown varieties can produce up to 40 dry tons per acre under optimal conditions.[57] Hybrid willow, silver maple, black locust, sweetgum, and eucalyptus are other perennial woody plants that are possibilities.[58]

Significantly accelerated testing and selection for populations will be necessary in establishing these plants. Breeding for desired traits and adaptability across a wide array of environments in multiple physiologic and geographic regions will be necessary. No single species of dedicated energy plant will be optimal for all areas of the country, especially considering the amount of biofuels needed. Temperature, rainfall, and soil composition are highly variable across the continental United States; therefore, using a diverse group of plant species optimal for each growing region is a likely strategy. With current information and characteristics of each plant, the DOE has estimated where the possible growing areas could occur (see Figure 1.1-2).[59]

Figure 1.1-2.
Possible Geographic Distribution of Dedicated Energy Crops



Marginal Land Assessment

One of the benefits of perennial species is their suitability for growth on marginal lands. A study by Elliot Campbell of Stanford University assessed abandoned land availability and the potential for this land to be used for energy crops.[60] Because of the increased demand for biomass energy, using abandoned crop or pasture lands to grow some of these crops could be a better alternative than converting forested areas or using agriculture lands. This study estimated the amount of global abandoned land available, the amount of biomass that could be grown on these lands, and the corresponding use of that biomass for energy purposes.

Historical land use data, satellite imagery, and a global ecosystem model were used for the estimates. The study considered "abandoned land" as land that was previously used for pasture or crops but has since been abandoned and not converted to urban or forested areas. Historical land use data was obtained from the History Database of the Global Environment 3.0 (HYDE) which consisted of gridded maps which show the fraction of crop and pasture land within each grid cell for decades between 1700 and 2000. The Center for Sustainability and the Global Environment (SAGE) land use database was used to check and supplement the HYDE database. They used a MODIS satellite map to exclude areas that have transitioned into forest or urban areas. Two different mathematical approaches were then used to estimate a conservative and a high estimate of total land available. Biomass production was estimated using the Carnegie-Ames-Stanford Approach ecosystem model which takes into account climate data, soil texture, land cover and the normalized difference vegetation index (NDVI), but does not take into account fertilizer use or irrigation, which could increase yields.

The low and high estimates for global abandoned land, excluding forested and urban areas are 951 and 1166 million acres. The authors found that these lands could produce between 1.6 and 2.1 billion tons of biomass respectively. In the United States an average of approximately 146 million acres of abandoned land was estimated. Assuming natural growth on these lands, approximately 321 million tons/year of biomass could be produced. At just 80 gallons of ethanol per ton of biomass, there could be the potential to produce approximately 26 billion gallons from a grass crop such as switchgrass. It is pointed out that there will be significant differences between crop types and management styles which will effect growth and yields. Although perennial grasses can be grown on these lands, yields may be lower than they would be on more suitable agricultural lands.

On a state-by-state basis, the areas with the highest amount of available abandoned lands are in the West. Texas has the largest amount of abandoned land estimated at 10.37 million acres. Wyoming, Utah, Oregon, New Mexico, Nevada, Colorado and California each contribute over 5 million abandoned acres to the total. Midwestern states including Iowa, Wisconsin, Illinois, and Ohio have approximately 3-4 million acres of abandoned land each (see Table 1.1-9). These lands may be more conducive to crop production than the more arid parts of the West. However, the condition and quality of these lands is unknown at this time. It would be difficult to estimate the specific types of energy crops that could be grown on these lands. Also, in the DOE assessment previously referenced, most of the Western states are not implicated as areas of possible biomass growth (above Figure 1.1-2).

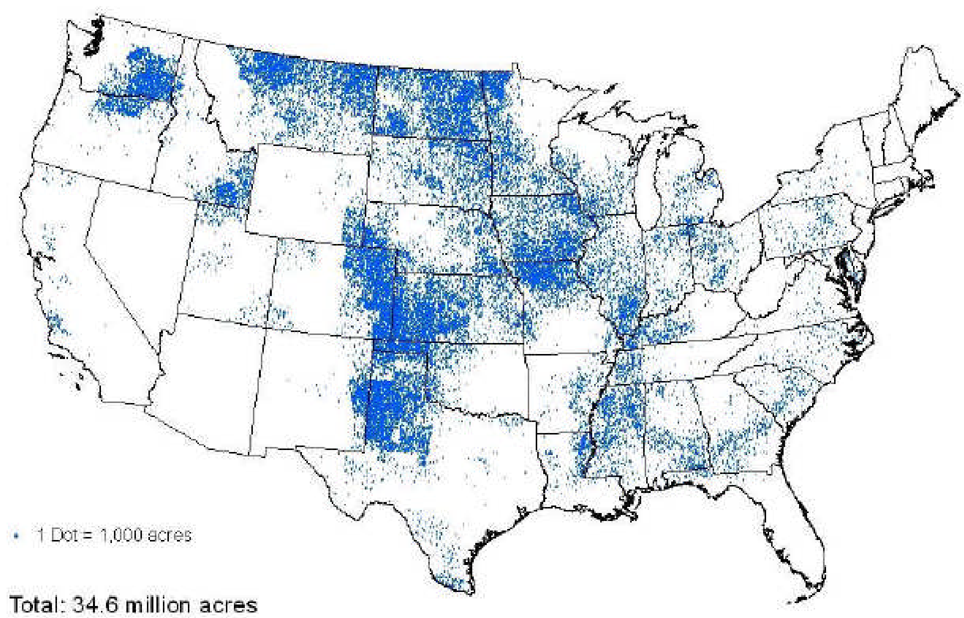
Table 1.1-9. Abandoned Agriculture Land and Potential Production by State[61]

State	Area (Million ha)	Area (Million acres)	Production (MM tons biomass/yr)	Ethanol Production Rate (gallons/tons)
Alabama	1.4	3.46	13.2	3.82
Alaska	0.3	0.74	0.4	0.54
Arizona	1.9	4.69	2.4	0.51
Arkansas	1.1	2.72	11.1	4.09
California	3.6	8.89	13.2	1.48
Colorado	2.7	6.67	8.1	1.21
Connecticut	0.1	0.25	0.6	2.43
Delaware	0.1	0.25	0.5	2.02
District of Columbia	0	0	0	0
Florida	0.5	1.24	2.7	2.19
Georgia	1.6	3.95	15.2	3.85
Idaho	1.4	3.46	4.7	1.36
Illinois	1.6	3.95	11.4	2.88
Indiana	1.2	2.96	8.5	2.87
Iowa	1.6	3.95	12.7	3.21
Kansas	0.3	0.74	1.8	2.43
Kentucky	0.8	1.98	6.7	3.39
Louisiana	0.9	2.22	7.8	3.51
Maine	0.1	0.25	0.8	3.24
Maryland	0.4	0.99	2.7	2.73
Massachusetts	0.2	0.49	1.1	2.23
Michigan	1.5	3.71	9	2.43
Minnesota	1.6	3.95	10.7	2.71
Mississippi	1	2.47	9.1	3.68
Missouri	1.5	3.71	14.1	3.81
Montana	1.7	4.2	6.8	1.62
Nebraska	0.4	0.99	2.2	2.23
Nevada	2.1	5.19	3	0.58
New Hampshire	0	0	0.3	0
New Jersey	0.2	0.49	1.9	3.85
New Mexico	3	7.41	5.4	0.73
New York	1.7	4.2	10.2	2.43
North Carolina	0.7	1.73	6.2	3.59
North Dakota	1	2.47	4.4	1.78
Ohio	1.4	3.46	8.9	2.57
Oklahoma	1.1	2.72	8.8	3.24
Oregon	2.2	5.43	8.2	1.51
Pennsylvania	1	2.47	8.2	3.32
Rhode Island	0	0	0.2	0
South Carolina	0.8	1.98	7.3	3.69
South Dakota	0.3	0.74	2	2.7
Tennessee	1.1	2.72	10.3	3.79
Texas	4.2	10.37	25.3	2.44
Utah	2.6	6.42	4.7	0.73
Vermont	0.1	0.25	1	4.05
Virginia	0.7	1.73	6.7	3.88
Washington	0.9	2.22	4	1.8
West Virginia	0.1	0.25	0.5	2.02
Wisconsin	1.4	3.46	9.9	2.86
Wyoming	2.8	6.92	6.1	0.88
Totals	58.9	145.5	321	
Total Ethanol Volume[a]				**25.68 Bgal Ethanol/yr**

a. Assuming a conservative 80 gal/ton conversion rate

The estimates of abandoned agricultural land do not include land enrolled in the Conservation Reserve Program (CRP), which could be an additional source of land available for energy crops. Land in this program is farmland that is converted to trees, grass, and areas for wildlife cover, but is considered crop land by the models in the abandoned land study. Environmental benefits of this land include the creation of wildlife habitat, increasing soil productivity, reducing soil erosion and improving ground and surface water quality.[62] As of November 2009, there were 31.2 million acres under the CRP contract which is down 2.6 million acres from the prior year.[63] Approximately 28 million CRP acres are growing with native or introduced grasses, suggesting that there is a significant amount of switchgrass already in the environment. Figure 1.1-3 shows the land allocation in the United States in 2008.[64] Recently, the 2008 Farm Bill capped the number of acres in the CRP at 32 million acres for 2010-2012. Following historical trends, it is possible that some of these acres will go into crop production. While some of this land may go for biofuel production, the benefits of producing energy crops will have to be weighed against the benefits of having the land in the CRP.

Figure 1.1-3. 2008 CRP Enrollment



1.1.2.3 Wood Residues

There is a substantial amount of forestland here in the U.S. It is estimated that 749 million acres, or one-third, of the U.S. land area is forested. Of this forested land, two-thirds (504 million acres) is considered timberland which contains more than 20 ft^3 of woody material per acre – the other one-third of the forest land contains less than 20 ft^3 of woody material per acre. Most of this forested land, 58 percent, is privately owned, another 29 percent of the forest land is publicly owned, and 13 percent is owned by the forest industry. A higher percentage of the land is privately owned in the East, and a higher percentage of the land is publicly owned in the West.

Of the 749 million acres of forestland, 77 are reserved as parks or wilderness and would likely be considered off limits for harvesting for biomass. Also, 168 million acres of timberland is considered not suitable for harvesting for biomass because of poor soil, lack of moisture, high elevation, or rockiness.[65]

The U.S. forestry industry harvests a portion of this forest land to produce its products, and in the process of doing so, it generates woody residues that can be recovered for the purpose of producing cellulosic biofuels. Major sources of solid waste wood generated in the U.S. include forestry residues, primary and secondary mill residues, and urban wood residues. All this material is being produced through the everyday practices of the forestry industry providing its primary wood products to the various industries it supplies. In addition, forests which are not currently harvested for wood could be thinned. This thinning of the forests would not just be to provide biomass, but as part of a strategy which may be beneficial for the forests, or to avoid external costs such as forest fires. Each of these categories is further described below:

Forestry residues

In-forest operations generally include four major sources of materials: logging residues, other removals, fuelwood, and fuel treatment wood.[66] In the process of removing, or logging, the larger woody portion of the trees (5 inch diameter and greater), the logging industry creates logging residues. Logging residues typically include tops of harvested trees and unwanted trees cut or knocked down and left on site, including dead and cull trees. Other removals are growing stock and other sources cut and burned or otherwise destroyed in the process of converting forest land to non-forest uses, such as for making way for new housing or industrial developments. They also include growing stock removed in forestry cultural operations. Forest residues are also available from fuelwood, which is harvested wood used in the residential and industrial sectors for energy. Thus, forest residues are already being created or harvested today.

Primary and secondary mill residues

Harvested wood from forests is converted into consumer products at wood processing mills. Primary mills convert roundwood products (i.e., tree trunks and logs) into other wood products, including sawmills that produce lumber, pulp mills, veneer mills, etc. Secondary mills use the products from primary mills to produce other products such as millwork, containers and pallets, buildings and mobile homes, furniture, flooring and paper and paper products. While primary and secondary mills are typically separate facilities, both primary wood processing and secondary conversion to finished consumer products can occur in the same facility.[67] Both primary and secondary mills produce residue and woody waste material. For example, the residue generated by primary mills includes bark, slabs and edgings, sawdust and peeler cares. This waste material could be used as feedstock to produce biofuels.

Urban wood residues

The two principal sources of urban wood residues are municipal solid waste (MSW) and construction and demolition (C&D) debris. Municipal solid waste contains solid wood from both wastewood and yard trimmings. Yard trimmings include herbaceous material and woody trimmings. Construction waste is made of contemporary building materials with little contamination. Sources include new residential construction, new nonresidential building construction and repair and remodeling of existing buildings. Demolition waste, on the other hand, is a heterogeneous mixture of material from demolishing buildings and structures and is difficult to remove uncontaminated portions. The potential contribution of urban wood residues to the production of biofuels is discussed in the Section 1.1.2.4 of this RIA.

The Thinning of Forests

While the above categories are associated with existing forest harvesting or other removal activities, the thinning of forests would largely be a new activity. Many U.S. forests have become overgrown and very dense with forest material, and a portion of this overgrown forest will die, dry out and decay. This decaying forest material can provide a source of fuel for forest fires that are expensive to fight or contain. Over the previous 10 years forest fires have consumed 49 million acres and cost the U.S. taxpayer $8.2 billion.[68] This cost does not include the additional cost due to the loss of human life, the loss of personal property and the impact on the environment. Thinning forests involves the removal of excess forest material from the forests that could help to prevent some of these forest fires, or at least help to reduce their impact. Also, thinning these forests to prevent them from becoming overly dense could potentially help them to remain healthier. There are many thinning operations today, but the material is burned or left to decompose instead. The removed excess woody material from overgrown forests could provide a source of biomass for producing biofuels.

Accessibility of Wood Residues

Despite the availability of woody residues for producing cellulosic biofuels, there are several obstacles for woody residues that are not present when utilizing feedstocks such as agricultural residues. For instance, forestlands will likely be managed less intensively than agricultural lands because forests provide multiple-use benefits (e.g., wildlife habitat, recreation, and ecological and environmental services).[69] This in effect makes it more difficult to take steps to increase the productivity of forest areas. Also, there are factors or site conditions that can affect tree growth, including poor soils, lack of moisture, high elevation, and rockiness. The limits caused by some of these factors would likely not be overcome, resulting in lower productivity than what could be theoretically possible. Also, a couple of these factors, the high elevation and rockiness, results in areas of forestland which is inaccessible by forestry equipment. Forestry residues are also demanded for other purposes other than for production of a transportation fuel (e.g. for process fuel). These reasons would make it more challenging to collect and use woody residues in large quantities compared to agricultural residues.

On the other hand, there may be some benefits to the use of woody residues. One example is the removal of excess forestry biomass to reduce the risk of fires and/or to improve forest health. In addition, resources such as primary and secondary mill residues and urban wood residues are already collected at the processing facility and it seems probable that some cellulosic facilities could be co-located to mills and/or landfills to increase the likelihood of having close and steady feedstocks readily available. Some states may also be endowed with larger wood resources than agricultural residues.

In making estimates of potential forest residue availability, certain assumptions about accessibility and recoverability are typically made. For example, some studies assume that residue collection is completed at the same time as harvesting, meaning that all residues are regarded as one hundred percent accessible.[70] This might become possible due to integrated harvesting systems which could harvest forest biomass in a single pass operation such that residual forest residue for producing biofuels could be produced along with conventional forest products.[71] Other estimates for accessibility have been lower, with about sixty percent of North American temperate forest considered accessible (not reserved or high-elevation and within 15 miles of major transportation infrastructure).[72] In terms of recoverability, some studies have assumed sixty-five percent of logging residues and fifty percent of other removal residues as being recoverable while others report an average potential recovery of sixty percent and as much as sixty-five percent when utilizing newer technology.[73] Refer to Section 1.3 for more discussion on the harvesting and transport of wood residues.

Sustainable Removal

While there has been some discussion of sustainable removal practices for crop residues, there has been less review on the topic for woody residues. As forest residues have been traditionally left in the forest to decompose, there remains much to be learned about the harvesting of forest residues in a sustainable way that still leaves sufficient nutrients to maintain the forest and to replenish the soil. This is reiterated in reports on woody residue removal which emphasize the need for more detailed studies on the range of ecological effects, from wildlife to soils.

Currently, practices for how much forest residue should be maintained in the forest to maintain forest health vary substantially. For example, a district for one study on the removal of forestry residues required about 5 tons per acre be left whereas other districts had no such requirements.[74] In a different source, a summary of national forest land management plans from 1995 indicated about 60 percent of western national forest timberland base to be suitable for timber production operations.[75] This issue is not only applicable in the United States, but also in Europe, where the use of forest biomass for energy is also being considered. A Swedish study showed that the main incentive for forest owners not to sell forestry residues was concerns for soil fertility.[76] Therefore, although there have been suggested limitations to the amount of residue suitable for removal there has yet to be consensus over the optimal amount.

Some recent long-term soil productivity studies are beginning to provide some useful data post-harvesting. One study, which assessed the soil condition 5 years after harvest of the woody biomass, showed that for most of the sites there was not a significant impact on soil carbon and nitrogen and compaction, while at one site there was a significant reduction of soil carbon and nitrogen. Another study which tracked the soil quality 10 years after harvesting the forest biomass came to some interesting conclusions.[77] Complete removal of the surface organic matter did lead to declines in the concentration of soil carbon, however, this effect was attributed to the loss of the forest floor. Soil compaction did reduce productivity in clay soils, but increased the productivity in sandy soils, and was not a factor if an understory was present.[78] Thus, these two studies suggest that forestry operations, if they are designed for the soil type and the area that the operations are taking place, may be designable to protect the sustainability of forests. However, additional studies and data review is likely necessary to fully understand these impacts.

Yet another issue regarding sustainable removal is the affect of forest residue extraction on biodiversity. The removal of forest residue may affect biodiversity because lower amounts of wood in the forest imply fewer habitats for species using wood for breeding. Species may also be threatened because certain insects colonize in wood that may be burned for energy purposes. Several forestry management methods, such as lower planting densities, aggressive thinnings, prescribed burning, and longer rotations have been suggested as ways to maintain biodiversity in actively managed forests.[79] Quantitative predictions about how much habitat loss various species can tolerate are almost impossible to make. Instead, one study recommended making qualitative predictions on which types of habitats or wood types are most threatened. For instance, this study examined Sweden's forest fuel extractions and concluded that coniferous wood can be harvested to a rather large extent, whereas deciduous tree species should be retained to a larger degree.[80] Another study in the southern Appalachians suggests that selective harvesting to maintain a forest with regions of many different ages and structural classes is key to maintaining biodiversity.[81] As different regions will certainly have species specific to their own regions, more research is necessary to determine appropriate recommendations on maintaining biodiversity.

Another issue that has been considered is the occurrence of soil disturbance due to the use of forest residue collection equipment. Studies have shown that the growth of woody plants and yields of harvestable plant products are decreased by soil compaction from residue collection equipment, because of the combined effects of high soil strength, decreased infiltration of water and poor soil aeration.[82] In another study, the use of a residue bundling machine caused some measurable amounts of soil disturbance and an increase in "soil exposed" area at some locations.[83] Thus, it is important to limit the severity of soil disturbances with minimal passes and relatively low ground pressure.

Energy Content of Forest Residue and Biofuel

Woody material obtained by the harvesting or thinning of forest is somewhat more energy dense compared to other forms of biomass. On its Biomass Program webpage, the Department of Energy lists the higher heating values (lower heating values were not available) for many different types of biomass for dry samples.[84] These values for woody biomass are summarized in Table 1.1-10.

Table 1.1-10. Energy Content of Forest Material

Tree name	Higher Heating Value (BTU/lb dry wood)
Hybrid Popular	8,384 - 8,491
Black Locust	8,409 - 8,582
Eucalyptus	8,384 - 8,432
American Sycamore	8,354 - 8,481
Eastern Cottonwood	8,431
Monterey Pine	8,422

Because woody material is energy dense, it can produce a large amount of renewable fuel per ton of feedstock. Based on recommendations from our cellulosic modeling efforts with the National Renewable Laboratory (NREL), we assumed 101.5 gallons of ethanol could be produced per ton for hardwood feedstocks in 2022. This is 10 percent more than the yield of 92.3 gallons of ethanol per ton used for agricultural residues and switchgrass. The reasoning for the higher yields for hardwoods is their potential for higher carbohydrate compositions and thus more sugars available for conversion to ethanol. These yields were used in our forest and agricultural modeling as described in Chapter 5. NREL also completed a more recent feedstock analysis indicating that yield differences may be smaller, i.e. closer to 95 gal/dry ton for hardwoods. This work will be beneficial as we continue to make improvements to our analyses in the future. For more information on feedstock considerations and their impacts on biorefining refer to the NREL report in the docket.[85]

Availability of Forest Residue

The quantity of forest residue available to produce biofuels was estimated by two different studies. We summarize those two studies, and then summarize data which we received directly from the U.S. Forest Service. In addition, we were able to incorporate the forestry sector component in the FASOM model, as further described in Chapter 5. As these feedstocks are now allowed to compete with the various agricultural feedstocks and energy crops in the market, we believe it is a more robust analysis than our prior proposal method of analyzing the agriculture and forestry sectors separately. Therefore, our final rule is based on results taken from our forest and agricultural modeling in FASOM.

Billion Ton Study

A landmark assessment of the potential biomass available from existing forest land in the U.S. was recently conducted by the USDA and the Department of Energy (DOE).[86] This landmark assessment was titled "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Supply," which is also known as the Billion Ton Study. We reviewed this study and are summarizing much of the information contained in that report here because it is very useful background about U.S. forest land and its potential contribution to biofuels production.

The total forest inventory is estimated to be about 20.2 billion dry tons. The report authors estimated that about 2.2 percent of the total forest inventory is harvested each year, which corresponds to 444 million dry tons. This removal rate is estimated to be less than the annual average forest growth, which suggests, at least on an aggregate basis, that this removal rate is sustainable. It is estimated that 78 percent of this removal was for roundwood products (sawlogs, pulpwood, veneer logs and fuel wood), 16 percent was logging residue and about 6 percent was classified as other removals. Thus, the Billion Ton study authors estimate that 67 million dry tons of logging residue could potentially be available for biofuel production, which is comprised of 49 million dry tons of primary logging residue, and 18 million dry tons of other removals. The Billion Ton study estimates that 65 percent of the total logging and other residue would be recovered for use. The two reasons cited for not collecting the other 35 percent is that some of the logging residue is comprised of small pieces, such as small branches and leaves, which would not be economically recoverable, and that it would be necessary to leave behind a portion of the logging residue to protect the sustainability of the forest as well as the wildlife which thrives in the forest. For these reasons, the Billion Ton Study authors estimated that 41 million dry tons of forest residue could be sustainably removed from the U.S. forests as byproduct from existing logging operations. Virtually all this removal is from privately owned land where the logging operations occur today.

Additional forest residue is available downstream of the logging operations at mills. In the process of making their products, primary wood processing mills create some wood residue. However, almost all of this waste wood is recovered or burned for process heat. For example, the bark from the logged wood is burned as fuel or converted into mulch. The Billion Ton authors estimated that just under 2 million dry tons per year of residue would be available from the primary wood processing mills as feedstock for producing biofuels.

The Billion Ton study estimated that additional wood waste could also be available from secondary wood processing mills, which refine crude wood into more refined products. The report authors could not find any data on how much residue is produced by these secondary wood processing mills, however, a study of these facilities did provide an estimate. Approximately 15.6 million dry tons per year were estimated to be available from the smaller of these secondary wood processing mills, however, the report estimated that only 40 percent, or 6 million dry tons per year, would be available for biofuels production.

Another industry which processes harvested wood is the pulp and paper mill industry. These companies process wood into fiber to make paper and cardboard. Most of the pulp and paper mills use the Kraft process or sulfate pulping process which converts half of the woody material into fiber, while the other half is a byproduct termed black liquor. The black liquor contains a substantial amount of biomass. The pulp and paper industry is already using all of this black liquor, plus purchasing and using some fossil fuels, to generate the electricity and heat that it needs for its plants. Therefore, the authors of the Billion Ton Study estimated that there would not be any residue available from the pulp and paper industry to produce biofuels.

The Billion Ton study estimated that another potential source of biomass from forests would be the selective thinning of forests to help reduce the risk of fire, or to facilitate the fighting of fires in the case that fires break out. Using a forest evaluation tool called the Fuel

Treatment Evaluator, the Forest Service estimated tree densities for forests all across the U.S. and identified forests which contain excess woody material. The forests which contain excess woody material are candidates for providing additional biomass for producing biofuels. The Forest Service estimated the total amount of excess woody material to be 8.4 billion dry tons.

The Forest Service next estimated the portion of this excess woody material that could be harvested for biofuels production. Despite the fact that this inventory exists today, the Billion Ton Study authors assumed that this excess woody inventory would be used over a 30 year period to reflect a sustainable removal rate. This assumption reduces the total yearly available amount of excess woody biomass to 280 million dry tons per year. Another limiting factor is that much of our nations forest is remote, thus, only 60 percent of this excess woody material was estimated to be removable for use. The next assumption made is that the best of this woody material, which is the woody material more than 5 inches in diameter and which comprises 70 percent of this material, would be used for feedstock for the logging industry. Thus, the remaining 30 percent would be residue that would serve as feedstock for the biofuels industry. Finally, the last assumption made is that of the excess woody material harvested, 15 percent would be lost between harvesting and use, thus the total amount of woody biomass was adjusted to be 15 percent lower. These assumptions result in 18 million dry tons of additional woody biomass that could be used to supply the biofuels industry annually, and 42 million dry tons that would supply the logging industry.

As shown below in Table 1.1-11, the Billion Ton Study estimates that a total of 67 million dry tons per year would be available from non-urban forests. It is important to note that not all of the forest biomass in the Billion Ton Study, specifically wood from national forests and perhaps much of the fuel wood, would be eligible to be used as a qualifying biofuel feedstock under the RFS2 program. Despite this limitation, the Billion Ton Study is an important source of information, especially when considering the maximum amount of sustainably removable forest biomass.

Table 1.1-11.
Quantity of Forest Biomass Available for Producing Biofuels

	Quantity (million dry tons)
Logging Residue	41
Primary Mill Residue	2
Secondary Mill Residue	6
Forest Thinnings	18
Total	67

The Billion Ton Study authors projected that forest harvesting and mill activity will increase in the future, thus increasing the amount of forest residues that would be available for producing biofuels. The authors estimated the future forest residue supply in the year 2050 and concluded that the logging residue is expected to increase from 41 million dry tons to 64 million dry tons. Also in 2050, the primary and secondary mill residue quantity is projected to increase from a total of 8 million dry tons per year to a total of 24 million dry tons per year. No estimate was provided for any increase, or decrease, in the amount of forest woody material that would be available from thinning forests. If the projected 39 million dry ton increases in forest residue comes to fruition, then the total amount of forest residue that would be available for producing biofuels in 2050 would be 106 million dry tons per year. We are primarily interested in compliance with the RFS2 biofuels standard in 2022, which is just over 1/3rd of the way between today and 2050. Thus, by interpolating the projected future forest residue in 2022 relative to current levels and those in 2050, the report supports the conclusion that 79 million dry tons of forest residue would be available in 2022.

U.S. Cellulosic Biomass Study

Another estimate for the amount of forest residue that could be used to produce biofuels was made by Marie Walsh in a report titled "US Cellulosic Biomass Supplies and Distribution".[87] This report also uses the Forest Service data base for its estimates, so its conclusions resemble those of the Billion Ton study. However, an important difference between this Cellulosic Biomass Study and the Billion Ton Study is that Marie Walsh estimated a cost curve for the amount of biomass available for her Cellulosic Biomass study for multiple future years.

In this report, Marie Walsh estimates that 63 million dry tons of logging residue is created in the lower 48 states. Of this total amount of logging residue, 65 percent is estimated to be accessible by roads, and not all the accessible logging residue is considered recoverable because some of it is too small to recover. This study also estimates the cost for recovering this available logging residue for future years for five year intervals through 2030. The amount of logging residue available at different price points and for different years is summarized in Table 1.1-12.

Table 1.1-12.
Quantity of Logging Residue Available at Varying Prices
(million dry tons)

	$20/dt	$25/dt	$30/dt	$35/dt	$40/dt	$45/dt	$50/dt	$75/dt	$100/dt
2007	0.06	1.84	6.22	10.89	24.02	31.29	31.29	36.19	38.50
2010	0.065	1.81	6.41	13.23	29.37	38.70	38.70	45.02	47.89
2015	0.065	1.95	6.80	13.62	29.99	39.35	39.35	45.71	48.60
2020	0.067	2.10	7.22	14.41	31.51	41.20	41.20	47.79	50.77
2025	0.067	2.17	7.46	14.81	32.32	42.19	42.19	48.90	51.95
2030	0.068	2.25	7.70	15.22	33.12	43.17	43.17	50.01	53.13

To qualify under RFS2, the biofuel producer would need to show that the forest residue is from a qualifying planted forest as specified under RFS2. This could limit the quantity of biomass available under RFS2 to lower levels that those shown in the table.

Marie Walsh also identified the quantity of woody material that would be available at specific prices from other removal supplies – trees removed to make way for the construction of buildings. Marie Walsh estimates that a total of approximately 24 million dry tons of forest residue falls within this category. She estimated that perhaps 50 percent of this material would be available for biofuel production. Marie Walsh added the other removal supplies to the logging residue and estimated their availability at different price points, increasing the available biomass by 25 percent. The combined total is summarized in Table 1.1-13.

Table 1.1-13.
Quantity of Forest Residue and Other Removals Available at Varying Prices
(million dry tons)

	$20/dt	$25/dt	$30/dt	$35/dt	$40/dt	$45/dt	$50/dt	$75/dt	$100/dt
2007	0.09	2.63	10.49	15.16	32.16	41.62	41.62	47.71	50.49
2010	0.09	2.63	10.76	17.59	38.08	49.17	49.17	56.68	60.03
2015	0.09	2.79	11.26	18.08	38.87	50.00	50.00	57.56	60.93
2020	0.09	2.96	11.80	19.00	40.58	52.04	52.04	59.84	63.31
2025	0.10	3.07	12.15	19.50	41.56	53.21	53.21	61.15	64.68
2030	0.10	3.17	12.51	30.02	42.55	54.39	54.39	62.47	66.07

To qualify under RFS2, the biofuel producer would need to show that the "other removal supplies" that it is interested in purchasing would qualify under RFS2. Some of this category could quality as MSW while another portion of it may qualify if the trees are being removed to prevent a wildfire from damaging the nearby buildings. However, the RFS2 definitions could limit the quantity of this category of biomass that could qualify under RFS2.

This report also estimates the amount of primary and secondary mill residues available for biofuels production. Like the Billion Ton study, Marie Walsh also concludes that only a very small amount of primary mill residue is estimated to be currently unused and available for producing biofuels. She concludes that out of the 88.7 million dry tons of primary mill residue which are generated, that only 1.3 million dry tons is not used for fuel, fiber or other sources as discussed above. However, she provides an additional assessment that, at the right price, the primary mill residue could be drawn away from these other users of the primary mill residue. The assumption is that for fiber uses, the primary mill residue could be drawn away from the current users at 35% of the product price. For other uses, including for fuel, it is assumed that at 65% of the market price of the raw wood value, the primary mill residue could be purchased away from the current users. Table 1.1-14 below estimates the price that specific estimated primary mill residue volumes could be available for producing biofuels.

Table 1.1-14.
Quantity of Primary Mill Residue is Available at Varying Prices
(million dry tons)

	$20/dt	$25/dt	$30/dt	$35/dt	$40/dt	$45/dt	$50/dt	$75/dt	$100/dt
2007	0.43	4.93	6.03	19.34	20.14	41.46	42.38	50.31	51.04
2010	0.55	5.70	7.29	21.91	22.80	46.03	47.37	56.29	57.33
2015	0.56	5.93	7.51	22.88	23.77	48.00	49.34	58.55	59.61
2020	0.58	6.16	7.74	23.85	24.73	49.97	51.31	60.82	61.88
2025	0.59	6.34	7.93	24.58	25.47	51.46	52.82	62.55	63.61
2030	0.60	6.52	8.12	25.31	26.20	52.96	54.31	64.28	65.35

The author also attempted to estimate the amount of secondary mill residue that could be available for producing biofuels. She observed that data is scant on the amount of secondary mill residue. She referenced a study (Rooney, 1998) that estimated that only a very small volume of secondary mill residue would be available for producing biofuels. Of 12.5 million dry tons of secondary mill residue which is generated, only 1.2 million dry tons is available for producing biofuels. Unlike the analysis conducted for primary mill residue, the author did not attempt to estimate the extent that biofuels producers could bid the secondary mill residue away from the current users.

Marie Walsh also assumes that three very difficult-to-quantify sources of forest material could be available as biomass for producing biofuels. One of these potential sources is the forest material that could be available through the thinning of overgrown forests to help reduce the fire risk within these forests. Marie Walsh referenced one study which estimated that 100 to 200 million acres of overgrown forest could be harvested. No estimate, however, was provided for the amount of this forest material that could be available from forest thinning.

Another potential source of forest material for biofuel production that the study discussed is a portion of the estimated 35.4 million tons of fuel wood used to heat homes and to provide heat for industries. The author cited a report which estimated that fuel wood use decreased from 1986 to 2000, but began to increase again and is expected to increase through 2050. This presumably means that if the demand for fuel wood is lower than previously, that some of that fuel wood could be available for producing biofuels. However, in this report, Marie Walsh did not make any firm estimate for this.

The Marie Walsh report also discussed that forest pulpwood supply is exceeding demand in the Southeast. The demand of forest pulpwood decreased from 131 to 121 million tons per year from 1993 to 2003, and this demand is expected to further decrease through 2020, and some have projected that this decrease in demand will continue beyond 2020. During the period between 1993 and 2003, pulpwood acreage and management intensity have increased, which suggests that the Southeast is and will continue to be over supplied. This oversupply of forest pulpwood could potentially provide additional biomass to the biofuels industry, although she did not provide any firm estimate for this nor an estimate of how much might qualify under RFS2.

It is important to note that not all of the forest biomass in the US Cellulosic Biomass Study would be eligible to be used as a biofuel feedstock under the RFS2 program. Despite this limitation, like the Billion Ton Study, this study is an important source of information, especially when considering the maximum amount of sustainably removable forest biomass.

While both of these studies provide quality assessments for the total amount of forest residue available for producing biomass, they both have an important limitation as well. The limitation is that these reports did not assess whether the forest residue in any particular area, along with other potential biomass, is of sufficient density to adequately supply a potential cellulosic biofuel plant. This feedstock density assessment must also consider the feedstock availability requirements made by cellulosic plant investors or banks, which may choose to require that a certain excess amount of feedstock be available to justify the use of that biomass in a cellulosic ethanol plant. Without considering these limitations, these studies may overestimate the quantity of biomass that would be truly usable and also the ultimate amount of biofuel that could be produced. Some of these issues were addressed in our cellulosic plant siting analysis in Section 1.8. Also, a study by the Western Governor's Association, which was designed to account for local biomass density, assessed the quantity of forest and other biomass that could be used for producing biofuels.[88] Because this study was only conducted for the Western United States instead of the entire country, we did not summarize it here. However, the study is being expanded nationwide and once completed it will provide nationwide results based on this very robust, bottom-up approach.

U.S. Forest Service Data

To assess forest residue supply within the feedstock density and supply constraints, we obtained county-by-county forest residue data from the U.S. Forest Service.[89] The information was provided by the subcategories of logging residue, primary mill residue, timberland thinnings, and other removals. The information also included urban forest residue, however, because that material is included with the other MSW, we did not consider it here (discussed later in Section 1.1.2.4). Like the studies discussed above, the national forest lands are omitted from consideration, and the urban forest residue is not considered here, but in the section discussing MSW. Most, if not all, of this material, therefore, would be eligible to be used as a feedstock for the production of biofuels under the RFS2 program, with the possible exception of some of the unused mill residues. The information was also provided at different price points. The quantities of forest residues are summarized by source type in Tables 1.1-15, 1.1-16 and 1.1-17. To avoid presenting a large amount of data, we aggregated the county data by state, and we are presenting the data at specific price points: $30/dry ton, $45/dry ton and $70/dry ton.

Table 1.1-15.
Volume of Forest Residue Available for Producing Biofuel
Biomass Available at $30/ton

	Logging Residue	Other Removals	Timerland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	433,519	7,117	1,896,798
Arizona	8,849	22,436	33,085	1,351	65,721
Arkansas	851,772	385,492	369,083	12,889	1,619,236
California	334,870	0	871,351	65,088	1,271,309
Colorado	9,203	7	0	2,302	11,511
Connecticut	4,195	15,339	10,465	3,949	33,949
Delaware	15,051	12,109	4,918	0	32,077
Florida	535,215	257,704	240,947	2,202	1,036,067
Georgia	1,556,954	496,631	553,627	45,138	2,652,350
Idaho	126,573	0	41,548	6,006	174,126
Illinois	139,101	117,589	115,431	18,523	390,644
Indiana	281,242	52,087	198,112	10,627	542,068
Iowa	56,049	27,580	48,991	159	132,780
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	344,948	55,196	1,246,311
Louisiana	1,317,139	440,293	300,924	30,075	2,088,431
Maine	1,206,438	470	80,314	42,483	1,329,705
Maryland	90,722	415	40,994	17,067	149,197
Massachusetts	35,461	31,043	13,801	0	80,305
Michigan	379,463	122,476	327,640	13,763	843,343
Minnesota	348,807	331,492	132,712	26,878	839,889
Mississippi	1,548,534	355,071	425,344	95,138	2,424,088
Missouri	387,434	265,146	342,077	79,787	1,074,443
Montana	131,335	0	66,592	9,136	207,063
Nebraska	10,572	9,386	11,707	4,971	36,637
Nevada	15	53	0	0	67
New Hampshire	157,321	174	47,802	7,019	212,316
New Jersey	2,959	39	2,288	1,437	6,723
New Mexico	11,929	1,279	25,898	4,902	44,008
New York	367,003	54,671	163,336	27,390	612,400
North Carolina	1,013,165	629,632	560,814	12,811	2,216,422
North Dakota	1,453	7,601	3,822	265	13,141
Ohio	185,398	9,053	83,676	22,600	300,726
Oklahoma	173,869	98,794	53,043	495	326,200
Oregon	760,276	31	527,702	16,316	1,304,326
Pennsylvania	543,663	699	224,978	170,972	940,312
Rhode Island	884	22,860	2,800	389	26,934
South Carolina	714,551	348,289	301,850	1,051	1,365,741
South Dakota	6,972	14,436	2,993	2,294	26,695
Tennessee	316,706	244,920	423,906	187,583	1,173,115
Texas	616,777	218,464	185,718	3,021	1,023,979
Utah	2,973	7	9,909	4,437	17,325
Vermont	104,876	18,652	48,395	0	171,923
Virginia	741,673	406,800	436,870	39,366	1,624,709
Washington	641,144	22	925,479	21,446	1,588,091
West Virginia	488,356	24,714	161,653	118,779	793,502
Wisconsin	568,800	491,132	260,293	60,410	1,380,636
Wyoming	11,343	0	14,050	34,014	59,407
Total	18,530,943	6,165,088	9,485,083	1,295,560	35,476,674

Table 1.1-16.
Tons of Forest Residue Available for Producing Biofuel
Biomass Available at $45/ton

	Logging Residue	Other Removals	Timerland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	506,045	7,117	1,969,324
Arizona	13,566	21,210	34,967	1,351	71,094
Arkansas	851,772	385,492	429,414	12,889	1,679,567
California	583,478	0	949,468	65,088	1,598,034
Colorado	10,056	11	30,619	2,302	42,988
Connecticut	4,301	16,095	10,465	3,949	34,810
Delaware	17,932	14,145	6,700	0	38,777
Florida	535,215	257,704	266,597	2,202	1,061,718
Georgia	1,556,954	496,631	644,295	45,138	2,743,018
Idaho	216,303	0	52,594	6,006	274,902
Illinois	139,153	117,589	115,431	18,523	390,696
Indiana	281,464	52,087	221,845	10,627	566,023
Iowa	56,050	27,607	49,551	159	133,367
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	407,371	55,196	1,308,735
Louisiana	1,317,139	440,293	330,512	30,075	2,118,019
Maine	1,280,511	495	102,442	42,483	1,425,931
Maryland	94,579	421	40,994	17,067	153,060
Massachusetts	39,127	33,191	13,801	0	86,119
Michigan	391,732	128,600	410,302	13,763	944,398
Minnesota	358,518	341,894	159,990	26,878	887,280
Mississippi	1,548,534	355,071	467,935	95,138	2,466,679
Missouri	387,434	265,146	466,082	79,787	1,198,448
Montana	215,597	0	70,775	9,136	295,507
Nebraska	10,710	9,434	11,707	4,971	36,822
Nevada	22	71	0	0	93
New Hampshire	165,519	197	57,566	7,019	230,301
New Jersey	3,184	40	2,423	1,437	7,084
New Mexico	17,239	1,287	26,862	4,902	50,291
New York	384,457	56,552	189,696	27,390	658,094
North Carolina	1,013,165	629,632	668,420	12,811	2,324,028
North Dakota	1,454	7,601	3,822	265	13,142
Ohio	186,022	9,069	88,572	22,600	306,263
Oklahoma	173,869	98,794	62,700	495	335,858
Oregon	1,341,835	34	574,948	16,316	1,933,133
Pennsylvania	1,341,835	34	574,948	170,972	2,087,789
Rhode Island	957	25,039	2,800	389	29,185
South Carolina	714,551	348,289	352,018	1,051	1,415,909
South Dakota	11,872	15,581	3,253	2,294	32,999
Tennessee	316,706	244,920	507,698	187,583	1,256,906
Texas	616,777	218,464	219,187	3,021	1,057,448
Utah	3,758	0	10,786	4,437	18,980
Vermont	108,542	19,182	53,836	0	181,560
Virginia	741,673	406,800	524,372	39,366	1,712,212
Washington	1,067,587	23	981,839	21,446	2,070,895
West Virginia	488,356	24,714	241,184	118,779	873,033
Wisconsin	576,938	499,302	327,027	60,410	1,463,677
Wyoming	18,163	0	18,202	34,014	70,380
Total	20,928,463	6,198,742	11,301,737	1,295,560	39,724,502

Table 1.1-17.
Tons of Forest Residue Available for Producing Biofuels
Biomass available at $70/ton

	Logging Residue	Other Removals	Timerland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	581,654	7,117	2,044,933
Arizona	13,566	24,510	38,678	1,351	78,105
Arkansas	851,772	385,492	492,094	12,889	1,742,247
California	583,478	0	1,000,615	65,088	1,649,181
Colorado	10,056	11	30,619	2,302	42,988
Connecticut	4,301	16,095	10,465	3,949	34,810
Delaware	17,932	14,145	6,700	0	38,777
Florida	535,215	257,704	332,353	2,202	1,127,474
Georgia	1,556,954	496,631	776,911	45,138	2,875,634
Idaho	216,303	0	61,926	6,006	284,235
Illinois	139,153	117,589	115,431	18,523	390,696
Indiana	281,464	52,087	221,845	10,627	566,023
Iowa	56,050	27,607	49,551	159	133,367
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	463,904	55,196	1,365,268
Louisiana	1,317,139	440,293	375,052	30,075	2,162,559
Maine	1,280,511	495	166,117	42,483	1,489,605
Maryland	94,579	421	40,994	17,067	153,060
Massachusetts	39,127	33,191	13,801	0	86,119
Michigan	391,732	128,600	533,107	13,763	1,067,203
Minnesota	358,518	341,894	200,599	26,878	927,889
Mississippi	1,548,534	355,071	516,598	95,138	2,515,342
Missouri	387,434	265,146	643,929	79,787	1,376,295
Montana	215,597	0	83,023	9,136	307,755
Nebraska	10,710	9,434	11,707	4,971	36,822
Nevada	22	71	0	0	93
New Hampshire	165,519	197	58,098	7,019	230,833
New Jersey	3,184	40	2,423	1,437	7,084
New Mexico	17,239	1,287	32,187	4,902	55,616
New York	384,457	56,552	192,851	27,390	661,249
North Carolina	1,013,165	629,632	800,455	12,811	2,456,063
North Dakota	1,454	7,601	3,822	265	13,142
Ohio	186,022	9,069	88,572	22,600	306,263
Oklahoma	173,869	98,794	81,634	495	354,792
Oregon	1,251,094	34	566,594	16,316	1,834,037
Pennsylvania	546,418	707	340,497	170,972	1,058,594
Rhode Island	957	25,039	2,800	389	29,185
South Carolina	714,551	348,289	395,555	1,051	1,459,446
South Dakota	11,872	15,581	4,129	2,294	33,875
Tennessee	316,706	244,920	516,550	187,583	1,265,759
Texas	616,777	218,464	253,670	3,021	1,091,931
Utah	3,758	7	14,717	4,437	22,918
Vermont	108,542	19,182	71,105	0	198,829
Virginia	741,673	406,800	630,366	39,366	1,818,206
Washington	1,067,587	23	1,029,985	21,446	2,119,041
West Virginia	488,356	24,714	287,639	118,779	919,489
Wisconsin	576,938	499,302	420,775	60,410	1,557,425
Wyoming	18,163	0	21,598	34,014	73,775
Total	20,042,304	6,202,722	12,593,373	1,295,560	40,133,959

The U.S. Forest Service data reveals that there are large amounts of forest material in the Southeast, the far Northeast and the Northwest portions of the U.S. The data also shows that the price curve for this forest material is fairly flat over the range summarized here. This suggests that the forests which are already accessible by roads provide access to low cost forest material from the thinning of timberland. However, to access more and more of the timberland, the costs ramp up quickly. These numbers are also significantly different than those presented in the proposed rule. This is due to a misunderstanding in how the number should be interpreted. According to our contacts at the U.S. Forest Service whether logging residue or timberland thinnings would be available would depend on the type of logging operation being used. We cannot, therefore, assume that 100% of the logging residue and timberland thinnings would be available, as this would be double counting the potential for wood residues. Instead, we must assume that a certain percentage of logging operations would produce logging residue and that the rest would produce timberland thinnings. Based on suggestions from the U.S. Forest Service we have assumed that 50% of logging operations would produce logging residue and 50% would produce forestry thinnings. Additionally, the U.S. Forest Service data includes unused mill residue, which may not be qualifying biofuel feedstock under RFS2 depending on the source of the wood. While these changes result in a significant decrease in the amount of wood residue available from current forestry operations they have no impact on our analyses. This is due to the fact that the amount of wood residues used in cellulosic biofuel production, as projected by the FASOM model, is still far less than the total available wood residue.

It is also important to note that this data is based solely on current forestry operations. It represents the amount of wood residue that would be available today if these residues were recovered. The United States contains much forest land that is not currently in active production due to insufficient demand and low prices for forestry products. If demand for cellulosic feedstock sufficiently increased the demand for forestry products it is very possible that logging operations would expand to meet this need. In this sense, the data from the U.S. Forest service is not an evaluation of the maximum amount of forestry residue that could be sustainable removed, but rather a measure of how much residue could be recovered based on current logging operations. Logging operations are financed based on their higher value products (i.e., lumber), not based on demand for lower value products (i.e., residues), so it is unlikely investments would be made to harvest forest residues absent demand for lumber operations. Nevertheless, this data is valuable, as the value for cellulosic biomass would likely have to be significantly higher than we are projecting in order to drive logging operation expansion.

Forestry Sector Modeling in FASOM

In addition to the agriculture sector, the FASOM model also contains a forestry component, which details forest acres across the U.S. as well as production of forestry products. Running the forestry and agriculture components of the model simultaneously shows the interaction between these two sectors as they compete for land, as well as the effect on products and prices in each respective sector. In total, FASOM includes a representation of seven major land use categories, including cropland, cropland pasture, forestland, forest pasture, rangeland, developed land, and acres enrolled in the Conservation Reserve Program (CRP). More information on these land categories can be found in Chapter 5.1.2.

Various products from the forestry sector in the FASOM model can be used to produce cellulosic renewable fuel. These products include hardwood and softwood milling, and logging residues. The FASOM model projected that 110 million gallons from forestry logging would be used to meet the cellulosic biofuel standard under EISA.

Wood Summary

We compared the quantity of potential biomass supplies projected to be available in 2022 by the two studies and the data that the Forest Service provided us in Table 1.1-18.

Table 1.1-18.
Forest Biomass Availability in 2022 at Different Prices (million dry tons)

	Price ($/ton)		
	30	**45**	**70**
Billion Ton Study		79	
U.S. Cellulosic Biomass Study	20	103	118
Forest Service Data	35	40	40

For the rule we were able to incorporate the forestry sector model in FASOM which projected 110 million gallons of forestry biomass would be used to meet the cellulosic biofuel standard. This would require close to 1 million dry tons per year of forestry biomass. As noted by the studies and data from the U.S. Forest Service, this amount is a small fraction of the large amount of forestry biomass potentially available. Although there is additional forestry biomass available for cellulosic renewable fuel production, other sources of cellulosic renewable fuel (switchgrass and corn residue, in particular) are relatively more profitable for producers of cellulosic renewable fuel feedstocks. For details on the economic impacts of the RFS2 program, including prices of cellulosic feedstocks as modeled in FASOM, see Chapter 5.

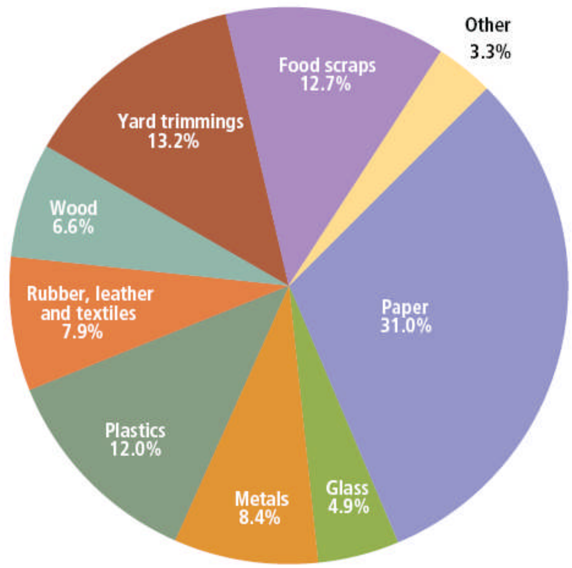
1.1.2.4 Urban wastes

Cellulosic feedstocks available at the lowest cost to the ethanol producer will likely be chosen first. This suggests that urban waste which is already being gathered today and typically incurs a fee for its disposal may be among the first to be used. Urban wastes are used today in a variety of ways. Most commonly, wastes are ground into mulch, dumped into land-fills, or incinerated. Estimating the amount of urban waste available for biofuel production involves understanding the types of materials that can be found in urban waste, potential competing uses of urban waste, and the challenges with separating a mixed feedstock.

Municipal Solid Waste

MSW consists of paper, glass, metals, plastics, wood, yard trimmings, food scraps, rubber, leather, textiles, etc. See Figure 1.1-4 for the percent composition of MSW generated (before recycling) in 2008.[90] Construction and demolition debris is not included in the estimate and is discussed separately below.

Figure 1.1-4.
Total MSW Generation (by Material), 2008
250 Million Tons (Before Recycling).



The portion of MSW that can qualify as renewable biomass under the program is already discussed in the preamble, Section II.B.4.d. The bulk of the biogenic portion of MSW that can be converted into biofuel is cellulosic material such as wood, yard trimmings, paper, and much of food wastes. Paper made up the majority of the total MSW generated in 2008, approximately 31 percent.

Although recycling/recovery rates are increasing over time, there appears to still be a large fraction of biogenic material that ends up unused and in land-fills. In order to project the portion of material that can potentially be used for biofuel purposes, we must understand how the composition of landfilled material changes over time. To do this, we first analyzed the trends from 2000-2007 for the percent composition of total MSW generated from paper/paperboard, wood, and yard trimmings over time as shown in Table 1.1-19 in order to project the percent composition of total MSW generated for the year 2022 for those categories (i.e. calculated to be 24.5% paper, 5.6% wood, and 12.8% yard trimmings and 15.1% food scraps).[91] In general, there appears to be a decrease in the percentage of total MSW generated from paper, slight increase for food scraps, and a relatively stable percent composition of wood and yard trimmings.

Table 1.1-19. Percent Composition of Total MSW Generated (including recyclable material): Paper, Wood, and Yard Trimmings

	2000	2004	2005	2006	2007	…	2022
Material							
Paper/paperboard	36.7	34.6	33.9	33.6	32.7	…	24.5
Wood	5.5	5.6	5.6	5.5	5.6	…	5.6
Yard Trimmings	12.8	12.7	12.8	12.7	12.8	…	12.8
Food Scraps	11.2	11.8	12.1	12.2	12.5	…	15.1

We also analyzed the trends from 2000-2007 for the percent composition of total MSW discarded (i.e. after recycling has occurred) to project the percent compositions for the year 2022 (i.e. calculated to be 8% paper, 8% wood, 3% yard trimmings, and 21.5% food scraps), see Table 1.1-20 and Table 1.1-21. Comparing Table 1.1-19 and Table 1.1-20, we note that historically there is a lower percent of paper and yard trimmings that is discarded than generated for MSW. This makes sense because a large percentage of these materials are recycled. Other than recycling, some MSW material is also combusted for energy use. This material we assume would be unavailable for biofuel use, and therefore report in Table 1.1-21 the percent composition of total MSW discarded after accounting for both recycling and combustion for energy use.

Table 1.1-20. Percent Composition of Total MSW Discarded (not including recycled material): Paper, Wood, and Yard Trimmings

	2000	2004	2005	2006	2007
Material					
Paper/paperboard	29.6	26.6	25.1	24.1	22.3
Wood	7.0	7.3	7.5	7.4	7.6
Yard Trimmings	8.7	7.0	7.1	7.2	6.9
Food Scraps	15.4	16.7	17.3	17.6	18.2

Table 1.1-21. Percent Composition of Total MSW Discarded (not including recycled or combusted material): Paper, Wood, and Yard Trimmings

	2000	2004	2005	2006	2007	…	2022
Material							
Paper/paperboard	25.4	23.2	21.9	21.1	19.5	…	8.0
Wood	6.0	6.4	6.6	6.5	6.6	…	8.0
Yard Trimmings	7.5	6.1	6.2	6.3	6.0	…	3.0
Food Scraps	13.2	14.6	15.1	15.4	15.9		21.5

The total amount of MSW generated (prior to recycling) is assumed to increase over time due to population growth. Biocycle magazine (2008) reports MSW estimates for each state in the U.S. based off of 2006 population data.[92] We used U.S. Census Bureau population projections by state to scale up or down the MSW estimates depending on whether the state populations increase or decrease by 2022. The total amount of MSW generated (prior to recycling) was estimated to be 415 million tons in 2022. As we are interested in the volume of MSW available for biofuel use, we focused only on waste estimated to be landfilled, which is a portion of the total MSW generated. We used estimates on the percentage of MSW landfilled by state from Biocycle in order to estimate the amount of MSW potentially available to biofuels (after recycling).

Knowing the total amount of MSW landfilled is only part of the picture. We also need to understand the types of cellulosic material likely to make up the MSW landfilled. For this, we were able to gather state composition data (i.e. percent wood vs. paper vs. other materials) of landfills for MSW *generated*, however, we were in fact interested in acquiring state composition data for the MSW *landfilled*.[93,94,95,96,97,98,99,100,101,102,103] Using the state composition data, we estimated the percent composition of MSW landfilled by state using a ratio of percent composition of national material generated (estimated in Table 1.1-19) and landfilled (estimated in Table 1.1-21) and state percent composition data for MSW generated (gathered from the multiple state reports). We then multiplied the volume of MSW (in tons) generated for each state in the year 2022 by the percent of MSW estimated to be landfilled (provided in Biocycle) and by the percent composition of MSW landfilled by state. Some states did not provide composition data, therefore, we estimated average percentages based on the states within a similar location in the U.S. where data was provided (e.g. if Utah data was unavailable, we assumed compositions would be similar to other rocky mountain states).

Furthermore, the amount of MSW potentially available is limited by assumptions on percent moisture and percent contamination. We assumed that paper, wood, yard trimmings, and food scraps have a 10%, 20%, 40%, and 70% moisture content, respectively.[104,105] We also assumed that wood is approximately 50% contaminated, due to objects such as nails, paint, chemicals, etc. typically associated with such feedstocks.[106] Paper and food wastes are assumed to be mostly uncontaminated, assuming 95% uncontaminated.[107] Yard trimmings are also assumed to be largely uncontaminated, assuming 75% uncontaminated. We account for contamination because it is likely to affect the quality of the wood waste and could potentially cause problems in the processing steps of cellulosic material to biofuel depending on the process utilized. Thus, for this analysis we conservatively assumed that the estimated contaminated portions would not be used for biofuel production. In addition, not all yard trimming can be assumed to be wood, 90% is assumed to be from wood.[108] We also estimated the amount of food waste that is cellulosic material to be 45%.[109] We estimate that 23.8 million dry tons could be available after accounting for these factors from paper, 0.9 million dry tons from yard trimmings, 5.3 million dry tons from wood, and 6.5 million dry tons from food waste.

Construction and Demolition (C&D) Debris

C&D debris mostly comes from building demolition and renovation, and the rest comes from new construction. Roughly equal percentages of building-related waste are estimated to come from the residential and commercial building sectors. The composition of C&D materials varies significantly, depending on the type of project from which it is being generated. For example, materials from older buildings is likely to contain plaster and lead piping, while new construction materials may contain significant amounts of drywall, laminates, and plastics. For building materials, EPA estimates the overall percentage of debris in C&D materials falls within the following ranges:

Table 1.1-22.[110]
Percentage Composition of C&D Debris (by volume)

Concrete and mixed rubble	40-50%
Wood	20-30%
Drywall	5-15%
Asphalt roofing	1-10%
Metals	1-5%
Bricks	1-5%
Plastics	1-5%

In 1996, total C&D debris generated was estimated to be approximately 124 million metric tons.[111] As seen in Table 1.1-22 above, only a portion of this, however, would be made of woody material. We based our estimate of C&D wood in 2022 on the equation adopted from Wiltsee's analysis.[112] The equation estimated C&D wood based on population size. We estimated approximately 31 million tons could be available from this resource by 2022; however, we assumed that 50% of that could potentially be contaminated and a portion of the feedstock would likely already be recovered. Thus, we estimate that only 8 million dry tons would be available for biofuels.

Urban waste summary

After estimating the total amount of urban waste available as described in the sections above, we further estimated the potential locations that could utilize this material. This is described in more detail in Section 1.8.1.3, the cellulosic ethanol plant siting analysis. From this analysis we determined that of the 44.5 million dry tons of MSW and C&D wood waste available, approximately 26 million dry tons would be used to produce 2.3 ethanol-equivalent billion gallons of fuel.[10] We estimated urban wastes outside our agricultural modeling as the models do not focus on such feedstocks. The other portion of the 16 billion gallons of cellulosic biofuel standard (13.7 billion gallons) was split among the other feedstock types, namely agricultural residues, forestry biomass, and energy crops, depending on the economic competitiveness. Refer to Chapter 5 more details on the FASOM and FAPRI-CARD modeling.

1.1.2.5 Imported Cellulosic Feedstocks or Biofuels

Cellulosic biofuel could also be produced internationally. One example of internationally produced cellulosic biofuel is ethanol produced from bagasse from sugarcane processing in Brazil. Currently, Brazil burns bagasse to produce steam and generate bioelectricity. However, improving efficiencies over the coming decade as well as mechanization of sugarcane harvesting (no burning of biomass in fields) may allow an increasing portion of bagasse to be allocated to other uses, including cellulosic biofuel, as additional straw could potentially be collected and used to produce bioelectricity.

[10] Assuming 90 gal/dry ton ethanol conversion yield for urban waste in 2022

In fact, a recent study was performed under the Memorandum of Understanding to advance collaboration in biofuels, signed by Brazil and the United States on March 2007.[113] The key objective of the work was to compare the techno-economic performance for thermochemical and biochemical conversion of sugarcane residues to ethanol. Studies such as this one help identify the anticipated costs and challenges with utilizing cellulosic feedstocks for biofuels.

Another study assessed the biomass feedstock potential for selected countries outside the United States and projected supply available for export or for biofuel production.[11,114] For the study's baseline projection in 2017, it was estimated that approximately 21 billion ethanol-equivalent gallons could be produced from cellulosic feedstocks at $36/dry tonne or less. The majority (~80%) projected is from bagasse, with the rest from forest products. Brazil was projected to have the most potential for cellulosic feedstock production from both bagasse and forest products. Other countries including India, China, and those belonging to the Caribbean Basin Initiative (CBI) also have some potential although much smaller feedstock supplies are projected as compared to Brazil.

1.1.2.6 Cellulosic Feedstock Summary

Table 1.1-23 summarizes our internal estimate of the types of cellulosic feedstocks projected to be used and their corresponding volume contribution to 16 billion gallons cellulosic biofuel by 2022 for the purposes of our impacts assessment. Refer to previous sections for more details on how the values in this summary table were derived. The majority of feedstock is projected to come from dedicated energy crops, with smaller volumes from agricultural residues, forestry biomass, and urban waste.

Table 1.1-23.
Cellulosic Feedstocks Assumed To Meet EISA In 2022[12]

Feedstock	**Volume (Ethanol-equivalent Bgal)**
Agricultural Residues	5.7
Corn Stover	4.9
Sugarcane Bagasse	0.6
Wheat Residue	0.1
Sweet Sorghum Pulp	0.1
Forestry Biomass	0.1
Urban Waste	2.3
Dedicated Energy Crops (Switchgrass)	7.9
Total	16.0

11 Countries evaluated include Argentina, Brazil, Canada, China, Colombia, India, Mexico, and CBI
12 Volumes are represented here as ethanol-equivalent volumes, a mix of diesel and ethanol volumes.

1.1.3 Biodiesel & Renewable Diesel Feedstocks

In general, plant and animal oils are valuable commodities with many uses other than transportation fuel. Therefore we expect the primary limiting factor in the supply of both biodiesel and renewable diesel to be feedstock availability and price. Primary drivers for this are increasing worldwide demand for use as food as incomes rise in developing countries, as well as increased recognition that these materials have value based on their energy or hydrocarbon content as substitutes for petroleum. Expansion of biodiesel market volumes beyond the mandates is dependent on it being able to compete on a price basis with the petroleum diesel being displaced.

The primary feedstock for domestic biodiesel production in the U.S. has historically been soybean oil, with other plant and animal fats and recycled greases making up a varying portion of the biodiesel pool as commodity prices rise and fall. For example, following a rise in soy oil prices and then a decline in diesel prices, the share of biodiesel being produced from rendered or reclaimed fats or other cheap feedstocks increased steeply in 2008 and 2009.[115] Another feedstock we project to become a significant and economical alternative over the next decade is corn oil produced during ethanol production (see 1.1.3.2 below).

1.1.3.1 Virgin Plant Oils

Agricultural commodity modeling we have done for this proposal (see Chapter 5 of this document) suggests that soybean oil production will stay relatively flat in the future, meaning supplies will be tight and prices supported at a high level as biofuel and food-related demand increases. Modeling scenarios conducted for the year 2022 with the EISA mandates indicates that domestic soy oil production would support about 660 million gallons of biodiesel production. This material is most likely to be processed by biodiesel plants (as opposed to renewable diesel hydrotreating processes) due to the large available capacity of these facilities and their proximity to soybean production. Compared to other feedstocks, virgin plant oils are most easily processed into biofuel via simple transesterification due to their homogeneity of composition and lack of contaminates.

1.1.3.2 Corn Oil Extracted During Ethanol Production

A source of feedstock which could provide significant volume is oil extracted from corn or its fermentation co-products in the dry mill ethanol production process. Often called corn fractionation, dry separation, or corn oil extraction, these are a collection of processes used to get additional product streams of value from the corn. This idea is not new, as existing wet mill plants create several streams of product from their corn input, including oil. In a dry mill setting, the kernel can be separated into the bran, starch, and germ components ahead of fermentation, or alternatively, oil can be extracted from the distillers' grains after fermentation. Both have advantages and disadvantages related to plant capital cost and energy consumption, as well as yield of ethanol and the other coproducts. For more information on these technologies, see Section 1.4.1.3.

Extraction of oil from the thin stillage or distillers' grains with solubles (DGS) streams is a proven technology that can be retrofitted into existing plants relatively cheaply. Front-end separation (fractionation) requires more intensive capital investment than is required to extract oil from the DGS, and therefore is best designed into the plant at the time of construction. However, it yields a larger array of co-products, and generally also results in ethanol process energy savings since less unfermentable material is going through the process train. The corn oil produced from the fractionation process is food grade corn oil and therefore has a significantly higher market value than the inedible corn oil produced by the oil extraction process. For our analyses for the final rule we have chosen to focus only on the oil produced by extraction, as we believe the higher value of the food grade corn oil makes it highly unlikely it will be used in biodiesel production.

Information on the expected oil extraction rates, capital costs, and energy use of corn oil extraction systems is based on conversations with several technology providers. Depending on the configuration, this system can extract 25-75 percent of the oil from the fermentation co-products, producing an oil stream which can be used as feedstock by biodiesel facilities. Since it offers another stream of revenue from the corn flowing into ethanol plants, we assumed approximately 70 percent of projected total ethanol production will implement some type of corn oil extraction system by 2022, generating approximately 680 million gallons per year of corn oil biofuel feedstock.[116,13] We expect this material to be processed in biodiesel plants with pretreatment capabilities for handling feedstocks with significant free fatty acid (FFA) content. At this time it is uncertain whether there will be third party aggregators of this extracted oil, or whether individual ethanol plants will contract directly with nearby biodiesel facilities, which may ultimately impact where and how this feedstock is processed.

1.1.3.3 Yellow Grease and Other Rendered Fats

Rendered animal fats and reclaimed cooking oils and greases are another potentially significant source of biodiesel feedstock. The National Renderer's Association gives a quantity of approximately 11 billion lbs of fats and greases available annually for all uses, and suggests this will grow by 1% per year.[117] This figure is broken down into several categories, and includes "yellow grease" and "other grease" collected and processed by rendering companies each year. The NRA defines yellow grease as material primarily derived from restaurant grease or cooking oil (they do not define "other grease" but we can assume this is trap grease or other reclaimed material). Adding together the NRA's "yellow grease" and "other grease" categories, we arrive at 2.7 billion lbs per year (all figures there are for 2005).

Similarly, a 2004 report prepared for New York State Energy Research and Development Authority by LECG, LLC describes yellow grease as material produced by restaurants and food service.[118] (This report describes grease recovered from sewer traps as brown grease, and suggests it is too low in quality to be used for biodiesel production.) Based on USDA and US Census data, LECG shows production of yellow grease by restaurants to be on the order of 9 lbs per capita per year, equivalent to about 2.7 billion lbs/yr. Unfortunately, it's not clear whether this quantity would include or be in addition to the NRA figures, but given the similarity of

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[13] The projected fraction of plants doing corn oil extraction was based on a conversation with several technology providers and various people working in the ethanol industry.

numbers, it seems reasonable to suspect that the NRA total includes the same sources of grease as assessed by LECG.

Thus, the figures we use here assume that the NRA figures already include collection of a large portion of restaurant and trap grease by rendering companies; we have not included additional waste greases that other studies have suggested might be available based on per-capita use of cooking oils, wastewater treatment disposal, etc. Perhaps there is some additional waste grease not being collected or counted by the NRA that is, or could be, aggregated and direct to biofuel production, but there is unfortunately no good way for us to determine this.

Our projections would use approximately 22% of this material for biofuel use in 2022 (= 380 million gallons x 7.5 lb/gal / 13 million lbs). In a written statement by David Meeker of the NRA, he asserts that it could be feasible for as much as 30% of the 11 billion lbs to be directed to biofuel production on a long-term basis.[119] The feasibility of consumption of this volume of rendered material was also supported by comments from a large rendering company (Darling International).

Much of biodiesel production seems to rely on niches of feedstock availability and market outlets. We project that approximately 230 MMgal/yr of rendered or reclaimed fats will be processed by biodiesel plants possessing acid pretreatment capabilities to handle these high-free fatty acid feedstocks. We project another 150 MMgal/yr of this material will be used by renewable diesel facilities. It is possible that renewable diesel manufacturers will arrange direct contract or joint venture with animal processing or rendering operations, taking advantage of volumes or prices of feedstock that may not typically be available on the open market to smaller, unaffiliated biodiesel plants.

Some comments submitted to the docket by Endicott Biofuels, LLC, suggest there are additional sources of waste greases and oils sufficient to produce an additional 2 or more billion gallons' worth of biofuel (beyond what we account for above) if they could be collected and processed. We have chosen to ignore these volumes in this analysis, as their use will likely require further pre-treatment and additional processing steps beyond the capabilities most of the installed biodiesel production capacity. However, it is conceivable that these materials may begin to be used in significant quantities as dictated by regulatory or economic conditions.

1.1.3.4 Algae

Algae are single-celled algae species that grow quickly and can be cultivated to produce biomass for the downstream production of fuel based on the oil and residuals found in the biomass. Many of these algae species are targeted for their high lipid content, and thus are a promising feedstock for biofuel production. While some algae companies are focusing on the use of algae for biodiesel production, it is important to note that algae can alternatively be used for producing ethanol or crude oil for gasoline or diesel which could also help contribute to the advanced biofuel mandate.[14] Some of the potential benefits of using algae as a biofuel feedstock are that algae can be grown on marginal land, can require low water inputs, can recycle waste streams from other processes, does not compete with food production, and has high oil yield.

[14]Algenol and Sapphire Energy, see http://www.algenolbiofuels.com/ and http://www.sapphireenergy.com/

Mass cultivation of microalgae has been ongoing since the 1950s for medical and pharmaceutical purposes. Since the 1980s, algae-to-biofuel research has been heavily funded by governments such as Japan, France, Germany and the United States. The research program in the US was especially large. The Aquatic Species Program, backed by the National Renewable Energy Laboratory, ran from 1978-1996 to look at the use of aquatic plants, specifically algae, as sources of energy. From about 1982 through the termination of the program, research concentrated on algae for biofuel production, specifically in open ponds.[120] Two branches to research large scale algaculture systems were funded: the "High Rate Pond" and the "Algae Raceway Production System" from 1980 to 1987. By 1988 several large (1,000 m^2) systems were designed and built at the "Outdoor Test Facility."[121] However, overall productivity of the ponds was lower than expected at around 10 grams algae / m^2 / day, due to cold temperatures and native species of algae taking over the ponds. After the program ended the total amount of algae research was relatively small because of lack of funding and growing interest in cellulosic ethanol.[122] In the 1990s Japan's NEDO-RITE Optical Fiber Bioreactor project obtained support from several private companies, laboratories, and academic institutions. However, the program was unsuccessful due to high costs for producing algae. Most recently, universities and start-up companies have been conducting pilot studies on the cultivation and processing of algae. With the high price of oil in 2008 and increased interest from airline providers to cut costs, fuel companies and start-ups have begun collaboration efforts to develop alternative biofuels from algae.

For analyses purposes, we assumed that 100 million gallons of algae-based biodiesel would be available by 2022 to help meet the biomass-based diesel standard. We believe this is reasonable given several announcements from the algae industry about their production plans which is further described in Section 1.5.4.3.[15]

A recent report released in October 2009 entitled "Cultivating Clean Energy: The Promise of Algae Biofuels" is a good resource for understanding the basic pathways for algae-based biofuels and summarizes some of the areas that can be improved to further commercialization of algae-based biofuels.[123] We discuss some of the information contained in the report, below.

In addition, we have consulted with the National Renewable Energy Laboratory (NREL) on developing several reasonable pathway scenarios for algae producing oils for biodiesel.[124] While there are many different technologies and fuel combinations being considered for algae-based biofuels, we believe the analyses completed by NREL for the FRM are representative of what is possible for the algae industry by 2022. As time permits, we hope to evaluate different configurations and their impact on production parameters. To provide further understanding, the modeling completed by NREL also included sensitivity analyses which evaluated various parameters and their affect on the costs of production (e.g. nutrients required, CO_2 delivered,

[15] Sapphire Energy plans for 135 MMgal by 2018 and 1 Bgal by 2025; Petrosun plans for 30 MMgal/yr facility in Arizona; Solazyme plans for 100 MMgal by 2012/13; US Biofuels plans for 4 MMgal by 2010, 50 MMgal by full scale. Only several companies have thus far revealed production plans, and more are announced each day. It is important to realize that future projections are highly uncertain, and we have taken into account the best information we could acquire at the time.

etc.). The following sections also summarize some of the assumptions and results from the NREL modeling for algae; see the technical document for more details. Also, refer to Chapter 2 for a discussion of how we used the modeling of algae pathways from NREL for our lifecycle analyses. For more information on the costs of production for algae from biodiesel, refer to Chapter 4.

Cultivation

Algae require several inputs, including water, land, nutrients, and in most cases, light to sustain growth. The configuration of the algal system impacts the amount of these inputs needed. Microalgae, which can have a high mass percentage of triacylglycerols, or natural oils, can be cultivated typically using either of two methods.

One method that is currently in use, and was studied widely by the Aquatic Species Program, involves using large, open ponds to grow algae; generally considered the most efficient and low-cost option is the so- called "raceway" ponds, as their shape is similar to an oval racetrack. A paddle wheel is used to keep the water in motion around the pond. Other open pond systems include unstirred and circular ponds; however, these may have more limited use for large scale fuel production.

The other method of algae cultivation utilizes closed "photobioreactors" which can fall in two groups, flat plate and tubular. Flat plate PBRs are made up of a clear plastic containment system and tubular PBR's are clear tubes that carry a circulation of culture between degassing and harvesting. Tube PBRs are generally considered more feasible for large scale use since they are modular and can accommodate higher flows.[125] PBRs can also be placed indoor or outdoor. Indoor closed PBRs usually require artificial illumination. Outdoor closed PBRs use natural daylight and in some cases also artificial light. There are also variations on cultivation systems such as hybrid (combined open and closed) cultivation, heterotrophic cultivation (without light), and integrated biofixation systems.[16]

Due to higher cell densities, the use of photobioreactors typically has lower land use in comparison to open pond systems producing the same volume of fuel. While other oil crops may need large amounts of agricultural land in order to meet a sizable portion of US liquid fuel demand, algae may limit the amount of land needed due to its high productivity and do not require the displacement of agricultural crops.[126,127,128]

When cultivated in enclosed photobioreactors, evaporation of water is limited, and water extracted during the drying process can be mostly reclaimed.[129] Even in open raceway-style ponds where evaporation is not negligible, water requirements are still considerably lower than with conventional agricultural crops. It is estimated that, in order to produce enough algal biomass for 60 billion gallon biodiesel/year, 20-120 trillion gallons of water/year are needed. This is several orders of magnitude lower than the 4,000 trillion gallon/year used to irrigate the entire US corn crop.[130]

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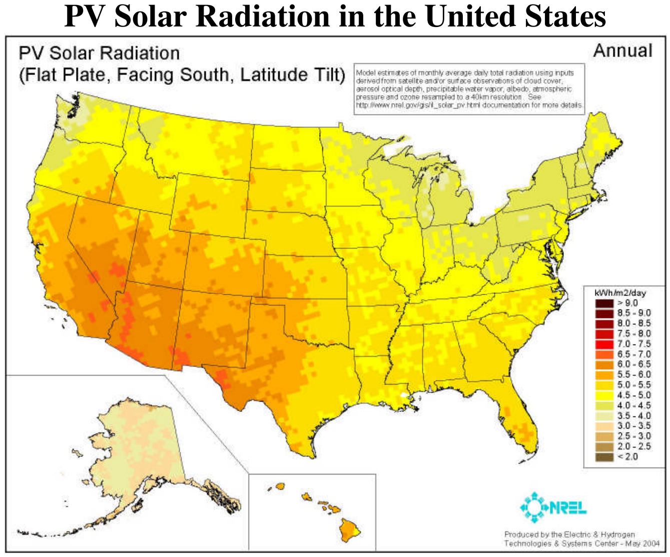
[16] For more information on these variations, refer to the recent report "Cultivating Clean Energy: The Promise of Algae Biofuels".

Algae can also thrive in brackish water, with salt concentrations up to twice that of seawater, which is often available in saline groundwater aquifers in the southwest.[131, 132] However, the salt, other minerals, and contaminants may pose a problem to the dewatering and extraction process, depending on the method used.

Aside from sunlight, land, and water, algae require two main physical inputs for growth: CO_2 and nutrients.[133] Nutrients can be obtained from conventional fertilizers, or from domestic or industrial waste sources, such as farm refuse and manure.[134] Co-locating algae farms with animal husbandry, in order to directly use the manure as a nutrient, would reduce transportation costs.[135] In addition, both of these inputs can be obtained from waste streams from other energy processes. They can be coupled with coal-burning power plants or even ethanol plants, and can effectively recycle between 50% and 90% of flue gasses, depending on the size of the algae farm.[136,137,138] The highly controlled environment of algae photobioreactors make them especially suitable to process and recycle CO_2 in flue gasses, as the gas can be bubbled or channeled into the water.[139]

The US southwest is perhaps one of the most promising locations for economic algae-for-biofuel cultivation, due to its high solar insolation (see Figure 1.1-5), availability of saltwater aquifers, and relatively low current land use.[140,141] Ideally, algae farms could be co-located with coal-burning power plants in order to recycle the carbon emissions. One study states that 1,700 power plants throughout the United States have enough surrounding land to support a commercial-scale algae system, however, only a limited number of these are in the southwest, due to lower population densities.[142]

Figure 1.1-5.
PV Solar Radiation in the United States



In terms of yields, certain species of algae can produce 80 percent of their body weight as oils, however, oil levels of 20-50 percent are more common.[143,144] Raceway systems are typically lower cost but have lower productivity compared to photobioreactors. The following Table 1.1-24 is based on the modeling of algae production from NREL and gives an idea of the yields that are reasonable under a base case (assumptions reasonable but still challenging in near future), aggressive case (assumes identification of a strain with near optimal growth rates and lipid content) and a max case (represents near theoretical maximum based on photosynthetic efficiencies).

Table 1.1-24. Potential Algae Yield[17] (gal/acre per year)

Base Case		Aggressive Case		Max Case	
op	PBR	op	PBR	op	PBR
2108	5271	6748	16863	12151	30395

Harvesting

Harvesting is necessary to recover biomass from the cultivation system. Commonly used techniques include flocculation, dissolved air flotation (DAF), centrifugation, microfiltration, and decantation. Additional techniques include discrete sedimentation, membrane filtration, phototactic autoconcentration, tilapia-enhanced sedimentation, tube settling, and ultrasonic separation. Wet biomass may also be dewatered or dried. Dewatering decreases the moisture content by draining or mechanical means. Additional drying can follow using e.g. drum dryer, freeze dryer, spray dryer, rotary dryer, or by solar drying.

Oil Extraction and Recovery

Oil from algae can be extracted through chemical, mechanical, or electrical processes to separate the algal oil from the cell membrane. The TAGs (Triacylglycerides) are typically the main product which goes to biodiesel production. The remainder consists of carbohydrates, proteins, nutrients, and ash), usually referred to as algal residue.

The extraction step is commonly regarded as the most speculative in terms of large-scale feasibility.[145] Thus extraction is a critical area of research going forward to achieve practical algal lipid production. Some of the methods discussed are solvent extraction, supercritical fluid extraction, mechanical extraction, osmotic shock, and sonication.

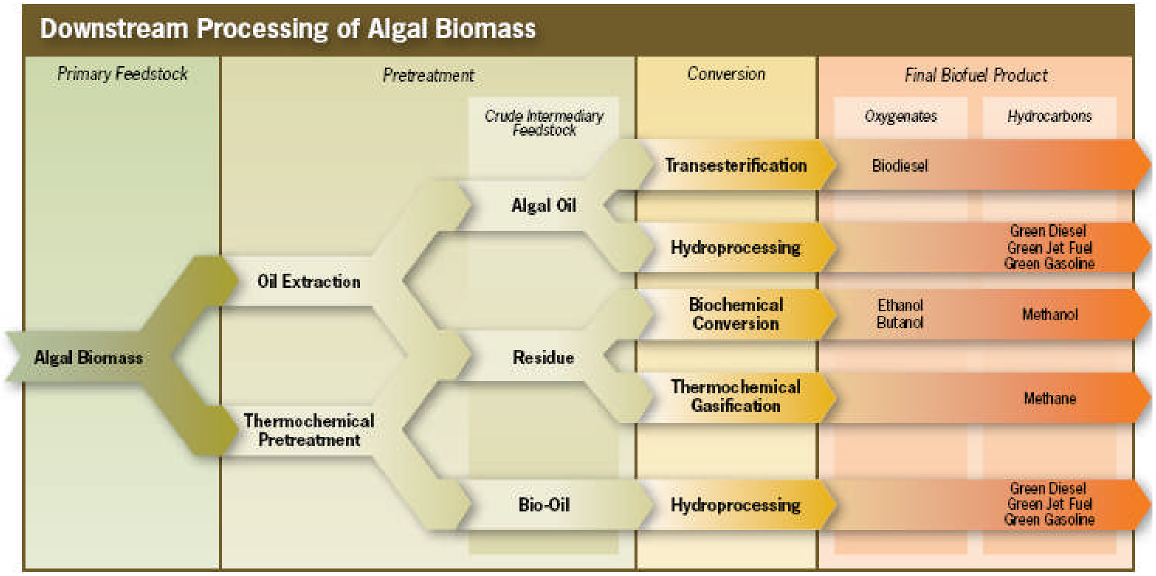
The spent biomass (i.e. algal residue) can be used in anaerobic digestion and power generation via gas turbine which provides power to run the plant. The other method commonly discussed is its use as animal feed.

Oil Conversion to Biofuel

Algal oil can undergo transesterification to produce biodiesel or be hydroprocessed to renewable products (e.g. renewable diesel) depending on the slate of products desired. In some cases, the entire algae biomass is converted using thermochemical and biochemical methods such as pyrolysis, gasification, liquefaction, and fermentation to produce biofuels. See Figure 1.1-6 for the various pathways for the processing of algal biomass.

[17] Only land required for pond/PBR, not including land necessary for processing equipment

Figure 1.1-6. Pathways for Processing Algal Biomass[146]



1.1.3.5 Other Potential Feedstocks

The following sections describe several oil crops that have also been discussed as potential biofuel feedstocks. While we have not projected the use of these crops in our current impact analyses, these may still be used to help meet the biomass-based diesel and total renewable fuel standards under EISA.

Jatropha

Jatropha is a genus of plants, consisting of both shrubs and trees, some of which hold promise as a feedstock for the production of biofuels. One species in particular, *Jatropha curcas*, yields seeds that contain between 25-45 percent lipids, which can be processed to produce biodiesel. The production potential of *J. curcas* has led to the popularity of the crop as a biofuel feedstock. In particular, some potential advantages include growth on marginal lands, tolerance to drought, low nutrient and labor inputs, and high oil yield.

J. curcas has been traditionally cultivated for living fences, to conserve soil moisture, reclaim soil, control erosion, and used locally in soap production, insecticide, and medicinal application.[147,148] Most recently, *J. curcas* has been investigated as an energy crop. *J. curcas* originated in Central America, mainly growing in arid and semi-arid conditions; now it is also found in the tropical regions of Africa, Asia, and North and South America.[149] Because of *J. curcas'* deep root system, it can grow in lands that have been previously heavily cultivated or otherwise have low levels of essential minerals and nutrients in the top levels of soil; this results in the recycling of nutrients from deeper soil levels.[150,151] In addition, because the plant is a perennial (living up to 50 years) the root system stays in place, which can significantly reduce erosion and even reverse desertification.[152,153]

As a wild plant which has not yet been domesticated, *J. curcas* has a large potential for improving many qualities, such as minimizing inputs, maximizing yields, and developing tolerance for various climates. For example, there is still little known on water use efficiency of *J. curcas* as a crop.[154] Even though *J. curcas* can survive moderate droughts by dropping its leaves, the effect of water starvation on seed yield and oil content in the seeds is mostly unknown. Water use efficiency of sister species *Jatropha pandurifolia* and *Jatropha gossypifolia* are reported as 3.68 and 2.52 mol CO_2/mol H_2O, respectively.[155] This is similar to that of other oil seed species like soybean, with a water use efficiency of 3.90 mol CO_2 /mol H_2O.[156] Thus, it is conceivable that water requirements of *J. curcas* will be similar to that of other oil seed species; although the plant may survive droughts, it may not produce efficiently or economically when it is water-deprived.[157] Obviously, further studies relating water use to crop production must be performed.

Because *J. curcas* has been observed growing on low quality soils with low nutrient amounts, it is often assumed that the plant would be able to grow as a commercial crop in these conditions. However, research indicates that *J. curcas* growth and production of seed is severely limited by soil fertility.[158,159] The long-term impact of monocultures of jatropha on soil health has also not been studied thoroughly. Some studies indicate that *J. curcas* may not be sustainable, unless specific steps are taken to ensure the plantations' long term health.[160,161]

The seed of *J. curcas*, as previously mentioned, has a lipid content of roughly 25-45 percent by weight.[162,163] Thus, assuming a seed oil content of 35 percent and an extraction efficiency of 75 percent, this would yield 404-2040 kg oil/ha or 439-2217 liter oil/ha.[164] This is somewhat higher than other oil producing crops like soybean, sesame, sunflower, rapeseed, and castor with a range of 375-1200 liter oil/ha.

Currently, *J. curcas* is present in 2 states (Florida and Hawaii) in the U.S.[165] Because of *J. curcas'* intolerance to frost, only small portions of the United States are typically considered for cultivation with current crop varieties. Areas with the most suitable climate conditions for cultivation can extend as far as 30° N in latitude; this would include the southern parts of Texas and Louisiana, and most of Florida.[166] Assuming no irrigation (as *J. curcas* is assumed to be a low-input crop), an absolute minimum of 500 mm of rainfall is required for substantial production, this occurs in the easternmost portions of Texas, and all of Louisiana and Florida.[167] The University of Florida has done some breeding and genetic manipulation of *J. curcas*, with the goal of increasing hardiness and tolerance to colder climates.[168] As research progresses and new varieties are identified, future locations for growth of *J. curcas* may be possible than currently suggested.

Canola

Canola is a type of rapeseed that has been bred to produce edible oil with low levels of erucic acid and meal with low levels of toxins, allowing it to be used for livestock feed. It was developed in Canada, but is now grown in many places around the world including the United States. Currently about 1.2 million acres of canola is grown in the United States. Canola can be grown as either a spring or winter crop, with yields for winter canola being significantly higher than those for spring canola (1,500 pounds per acre vs. 3,500 pounds per acre).[169] The oil content of the canola seeds is approximately 40%. The oil produced from the canola seeds is low in saturated fat and high in omega-3 fatty acids, making it desirable for use as edible oil. These traits, combined with the higher price of canola oil result in very little canola oil being used in biodiesel production today. The high oil yields and potential for canola to be grown as a winter crop may result in an increase in canola oil production in the United States and a greater availability for its use as a biodiesel feedstock.

Camelina

Camelina is an oilseed crop native to Northern Europe and Central Asia that has been grown in Europe for thousands of years for use as an edible oil as well as industrial purposes. It is primarily considered a weed in North America and is most common in the northern Midwest. Recently there has been interest in the potential use of the oil extracted from camelina seeds as a biodiesel feedstock. Camelina's suitability to northern climates, low moisture, and marginal soils allow it to be grown in areas that are unsuitable for other major oilseed crops such as soy beans, sunflower, and canola. Camelina also requires the use of few, if any, herbicides, as well as little to no tillage.[170] Camelina can also be used to break the continuous planting cycle of small grains, effectively reducing the disease, insect, and weed pressure in fields planted with wheat the following year.[171] Camelina seeds contain approximately 40% oil and have averaged yields of over 1100 kg/ha (~1000 pounds per acre) in long term trials in Rosemount, Minnesota, though future yields improvements through selective breeding are likely.[172] Camelina is currently being grown on approximately 50,000 acres of land the U.S., primarily in Montana, eastern Washington, and the Dakotas.[173]

Pennycress

Pennycress is a winter annual weed currently established in every state except Hawaii, but especially prevalent in the Midwest and northwest. It has several qualities that make it a potential feedstock source for biodiesel production. Pennycress germinates in the fall and grows as a winter cover crop. Pennycress flowers and produces seeds in late April and May. These seeds can be harvested in early June, allowing the fields to be planted with soy beans. Pennycress seed yields have been as high as 2000 pounds per acre in wild stands and yield 36% oil when crushed.[174] In addition to the oil, the seeds of pennycress also contain the chemical sinigrin, which has potential uses as a bio-fumigant. The crushed pennycress seeds could be used as a weed killer for high value crops that would also provide value as a fertilizer. There are concerns, however, about the invasive nature of pennycress. Even though it does not compete directly with summer annual crops due to its growing season, there is some concern that, once established, pennycress would be very difficult to remove. It has also not been grown as a commercial crop, and little is yet known about planting and cultivation requirements.

Pennycress is currently being grown on several five to ten acre plots by BioFuels Manufacturers of Illinois. They plan to construct a 45 million gallon per year biodiesel plant in Peoria County that would use soy oil, animal fats, and vegetable oils as feedstock when it begins operation and plans to use pennycress oil as a significant feedstock source in the future.[175] While the initial attempts to grow pennycress were unsuccessful, more recent on farm trials have resulted in the successful establishment of pennycress.[176] Pennycress has a large potential as a secondary crop if its cultivation proves to be profitable.

1.1.3.6 Imported Biodiesel

The European Union is expected to continue as the largest consumer of biodiesel, with use projected to be almost 3 billion gallons per year by 2018.[177,178,179] Given the E.U.'s limited land suitable for oilseed crops, it is likely that a significant portion of this fuel will be either imported or made from imported feedstock.[180] During this timeframe, other significant producers of biodiesel or its feedstocks, such as Argentina, Brazil, Indonesia, and Malaysia, are expected to increase domestic use of biofuels due to mandates or simple economic advantage.[181]

Our primary control scenario projects U.S. use of biodiesel to rise to approximately 1.5 billion gallons by 2022. Given competition for imports by the E.U. and Asian markets where retail fuel prices are among the highest in the world, as well as the feasibility to produce this biofuel from domestically-sourced feedstocks (see discussion above), we do not expect imports to contribute to U.S. biodiesel for the foreseeable future. Thus, we are not assuming any imports of biodiesel for our analyses.

1.1.3.7 Biodiesel Feedstock Summary

Table 1.1-25 shows the volumes and uses of biodiesel and renewable diesel feedstocks as projected for the analyses in this rulemaking. Total volume here (1.67 billion gallons) fulfills the Biomass Based Diesel category requirements (1.0 billion gallons) and contributes to the Other Advanced Biofuel (0.67 billion gallons), as projected for our primary control case (see Section 1.2.2).

Table 1.1-25.
Estimated 2022 Biodiesel & Renewable Diesel Volumes
Based on Feedstock Availability (million gallons of fuel)

Feedstock type	Base catalyzed biodiesel	Acid pretreatment biodiesel	Renewable diesel
Virgin vegetable oil	660	-	-
Corn oil from ethanol production	-	680	-
Rendered animal fats and greases	-	230	150
Algae oil or other advanced source	100	-	-

1.2 RFS2 Biofuel Volumes

Our assessment of the renewable fuel volumes required to meet the Energy Independence and Security Act (EISA) necessitates establishing a primary set of fuel types and volumes on which to base our assessment of the impacts of the new standards. EISA contains four broad categories: cellulosic biofuel, biomass-based diesel, total advanced biofuel, and total renewable fuel. As these categories could be met with a wide variety of fuel choices, in order to assess the impacts of the rule, we projected a set of reasonable renewable fuel volumes based on our best estimate of likely fuels that could come to market.

The following subsections detail our rationale for projecting the amount and type of fuels needed to meet EISA. To assess the impacts of the increase in renewable fuel volume from business-as-usual (what is likely to have occurred without EISA), we have established reference and control cases. The reference cases are projections of renewable fuel volumes without the enactment of EISA and are described in further detail in Section 1.2.1. It is difficult to ascertain how much of the impact from the displacement of gasoline and diesel with renewable fuels might be due to the natural growth in renewable fuel use due to market forces as crude oil prices rise versus what might be forced by the RFS2 standards. Regardless, these assessments provide important information on the wider public policy considerations related to renewable fuel production and use, climate change, and national energy security. The control cases are projections of the volumes and types of renewable fuel that might be used to comply with the EISA volume mandates. For the NPRM we had focused on one primary control case whereas for the final rule we have expanded the analysis to include two additional sensitivity cases. We assume in each of the cases the same ethanol-equivalence basis as was used in the RFS1 rulemaking to meet the standard. Volumes listed in the tables for this section are in straight-gallons and allow for the reader to calculate ethanol-equivalent gallons if necessary (i.e. times 1.5 for biodiesel or 1.7 for cellulosic diesel and renewable diesel). Sections 1.2.2 and 1.2.3 aim to describe the control cases in greater detail as well as provide fuel volumes and types for years prior to 2022.

The main difference between the volumes used for the NPRM and the volumes used for the FRM is the inclusion of cellulosic diesel for the FRM. The NPRM made the simplifying assumption that the cellulosic biofuel standard would be met entirely with cellulosic ethanol. However, due to growing interest and recent developments in hydrocarbon-based or so-called "drop-in" renewable fuels as well as butanol, and marketplace challenges for consuming high volumes of ethanol, we have included projections of more non-ethanol renewables in our primary control case for the final rule.[18] In the future, this could include various forms of "green hydrocarbons" (i.e., cellulosic gasoline, diesel and jet) and higher alcohols, but for simplicity our analyses have modeled it all as cellulosic diesel fuel. We have also included some algae-derived biofuels in our FRM analyses given the large interest and potential for such fuels. We have continued to assume zero volume for renewable fuels or blendstocks such as biogas, jatropha, palm, imported cellulosic biofuel, and other alcohols or ethers in our control cases. Although we have not included these renewable fuels and blendstocks in our impact analyses, it is important to note that they can still be counted under our program if they meet the lifecycle thresholds and definitions for renewable biomass, and recent information suggests that some of them may be likely.

[18] Comments received from Advanced Biofuels Association, Testimony on June 9, 2009 suggesting a number of advanced biofuel technologies will be able to produce renewable diesel, jet fuels, gasoline, and gasoline component fuels (e.g. butanol, iso-octane). Similar comments were received from the New York State Department of Environmental Conservation (Docket EPA-HQ-OAR-2005-0161-2143), OPEI and AllSAFE (Docket EPA-HQ-OAR-2005-0161-2241), and the Low Carbon Synthetic Fuels Association (Docket EPA-HQ-OAR-2005-0161-2310).

1.2.1 Reference Cases

Our primary reference case renewable fuel volumes are based on the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2007 reference case projections.[19] While AEO 2007 is not as up-to-date as AEO 2008 or AEO 2009, we chose to use AEO 2007 because later versions of AEO already include the impact of increased renewable fuel volumes under EISA as well as fuel economy improvements under CAFE as required in EISA, whereas AEO 2007 did not.

For the final rule we also assessed a number of the impacts relative to the reference case assuming the mandated renewable fuel volumes under RFS1 from the Energy Policy Act of 2005 (EPAct). This allows for a more complete assessment of the impacts of the EISA volume mandates, especially when combined with the impacts assessment conducted for the RFS1 rulemaking (though many factors have changed since then). Table 1.2-1 and Table 1.2-2 summarize the renewable fuel volumes for years 2022 and prior, for the AEO 2007 and the RFS1 reference cases, respectively.

[19] AEO 2007 was only used to derive renewable fuel volume projections for the primary reference case. AEO 2009 was used for future crude oil cost estimates and for estimating total transportation fuel energy use.

Table 1.2-1. AEO 2007 Reference Case Renewable Fuel Volumes (billion gallons)

	Advanced Biofuel			Non-Advanced Biofuel	Total Renewable Fuel
	Cellulosic Biofuel	Biomass-Based Diesel[a]	Other Advanced Biofuel		
Year	Cellulosic Ethanol[c]	FAME Biodiesel[b]	Imported Ethanol	Corn Ethanol	
2010	0.12	0.32	0.29	10.49	11.22
2011	0.19	0.33	0.16	10.69	11.37
2012	0.25	0.33	0.18	10.81	11.57
2013	0.25	0.33	0.19	10.93	11.70
2014	0.25	0.23	0.20	11.01	11.69
2015	0.25	0.25	0.39	11.10	11.99
2016	0.25	0.35	0.51	11.16	12.27
2017	0.25	0.36	0.53	11.30	12.44
2018	0.25	0.36	0.54	11.49	12.64
2019	0.25	0.37	0.58	11.69	12.89
2020	0.25	0.37	0.60	11.83	13.05
2021	0.25	0.38	0.63	12.07	13.33
2022	0.25	0.38	0.64	12.29	13.56

[a] Biomass-Based Diesel could include FAME biodiesel, cellulosic diesel, and non-co-processed renewable diesel.

[b] Only fatty acid methyl ester (FAME) biodiesel volumes were considered

[c] AEO 2007 reference case assumes actual production of cellulosic biofuel (i.e. not corn ethanol plants utilizing 90% biomass for energy) and therefore was assumed to be 0.25 billion gallons.

Table 1.2-2. RFS1 Reference Case Renewable Fuel Volumes (billion gallons)

	Advanced Biofuel			Non-Advanced Biofuel	Total Renewable Fuel
	Cellulosic Biofuel	Biomass-Based Diesel[a]	Other Advanced Biofuel		
Year	Cellulosic Ethanol[c]	FAME Biodiesel[b]	Imported Ethanol	Corn Ethanol	
2010	n/a	n/a	n/a	n/a	n/a
2011	n/a	n/a	n/a	n/a	n/a
2012	0.00	0.303	0.00	7.046	7.35
2013	0.00	0.303	0.00	7.046	7.35
2014	0.00	0.303	0.00	7.046	7.35
2015	0.00	0.303	0.00	7.046	7.35
2016	0.00	0.303	0.00	7.046	7.35
2017	0.00	0.303	0.00	7.046	7.35
2018	0.00	0.303	0.00	7.046	7.35
2019	0.00	0.303	0.00	7.046	7.35
2020	0.00	0.303	0.00	7.046	7.35
2021	0.00	0.303	0.00	7.046	7.35
2022	0.00	0.303	0.00	7.046	7.35

[a] Biomass-Based Diesel could include FAME biodiesel, cellulosic diesel, and non-co-processed renewable diesel.
[b] Only fatty acid methyl ester (FAME) biodiesel volumes were considered
[c] Under the RFS 1 reference case, we assumed the 250-million gallon cellulosic standard set by EPAct would be met primarily by corn ethanol plants utilizing 90% biomass for energy, thus actual production of cellulosic biofuel is zero.

1.2.2 Primary Control Case

Table 1.2-3 summarizes the fuel types and volumes for the primary control case for the years 2010-2022. Although actual volumes and feedstocks will likely be different, we believe the projections made here are within the range of expected outcomes when the standards are met and allow for an assessment of the potential impacts of the RFS2 rule. More details on contributions of different feedstock types within the renewable fuel categories here can be found in Section 1.1.

Table 1.2-3.
Primary Control Case Projected Renewable Fuel Volumes (billion gallons)

Year	Advanced Biofuel						Non-Advanced Biofuel	Total Renewable Fuel[f]
	Cellulosic Biofuel		Biomass-Based Diesel[a]		Other Advanced Biofuel			
	Cellulosic Ethanol	Cellulosic Diesel[b]	FAME[c] Biodiesel	NCRD[d]	Other Biodiesel[e]	Imported Ethanol	Corn Ethanol	
2010	0.03	0.04	0.61	0.04	0.22	0.29	11.24	12.48
2011	0.08	0.10	0.72	0.08	0.17	0.16	12.07	13.38
2012	0.15	0.20	0.92	0.08	0.12	0.18	12.83	14.48
2013	0.31	0.41	0.92	0.08	0.28	0.19	13.42	15.61
2014	0.54	0.71	0.85	0.15	0.39	0.20	14.09	16.93
2015	0.92	1.22	0.85	0.15	0.53	0.39	14.79	18.85
2016	1.31	1.73	0.85	0.15	0.56	0.63	15.00	20.23
2017	1.69	2.24	0.85	0.15	0.60	1.07	15.00	21.60
2018	2.15	2.85	0.85	0.15	0.64	1.51	15.00	23.15
2019	2.61	3.46	0.85	0.15	0.68	1.96	15.00	24.71
2020	3.23	4.28	0.85	0.15	0.72	1.88	15.00	26.11
2021	4.15	5.50	0.85	0.15	0.77	1.81	15.00	28.23
2022	4.92	6.52	0.85	0.15	0.82	2.24	15.00	30.50

[a] Biomass-Based Diesel could include FAME biodiesel, cellulosic diesel, and non-co-processed renewable diesel.
[b] Cellulosic Diesel includes 1.96 billion gallons from Fischer-Tropsch Biomass-to-Liquids (BTL) processes and 4.56 billion gallons from this or other types of cellulosic diesel processes in year 2022. In order to calculate the split of cellulosic ethanol vs. cellulosic diesel in years prior to 2022, we assumed the same percentage of the total cellulosic biofuel standard as in year 2022, i.e. 31% cellulosic ethanol and 69% cellulosic diesel.
[c] Fatty acid methyl ester (FAME) biodiesel
[d] Non-Co-processed Renewable Diesel (NCRD)
[e] Other Biodiesel is biodiesel that could be produced in addition to the amount needed to meet the biomass-based diesel standard.
[f] May not total due to rounding.

1.2.2.1 Cellulosic Biofuel

As defined in EISA, cellulosic biofuel means renewable fuel produced from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions, as determined by the Administrator, that are at least 60% less than the baseline lifecycle greenhouse gas emissions.

When many people think of cellulosic biofuel, they immediately think of cellulosic ethanol. However, cellulosic biofuel could be comprised of other alcohols, synthetic gasoline, synthetic diesel fuel or heating oil, and synthetic jet fuel, propane, and biogas. Whether cellulosic biofuel is ethanol will depend on a number of factors, including production costs, the form of tax subsidies, credit programs, and issues associated with blending the biofuel into the fuel pool. For instance, under the Farm Bill of 2008, both cellulosic ethanol and cellulosic diesel receive the same tax subsidies ($1.01 per gallon each). The tax subsidy, however, gives ethanol producers a considerable advantage over those producing cellulosic diesel due to the feedstock quantity needed per gallon produced (i.e. typically the higher the energy content of the product, the more feedstock that is required). On an energy basis, cellulosic ethanol would receive approximately $13/mmBtu while cellulosic diesel would receive approximately $8/mmBtu. It will also depend on the relative demand for gasoline and diesel fuel. For example, European refineries have been undersupplying the European market with diesel fuel supply and oversupplying it with gasoline, and based on the recent diesel fuel price margins over gasoline, it seems that the U.S. is falling in line with Europe. Therefore, if the U.S. trend is toward being relatively oversupplied with gasoline, there could be a price advantage towards producing renewable fuels that displace diesel fuel rather than a gasoline fuel replacement like ethanol.

One large advantage that cellulosic diesel has over ethanol is the ability for the fuel to be blended easily into the current distribution infrastructure at sizeable volumes. There are currently factors tending to limit the amount of ethanol that can be blended into the fuel pool (see Section 1.7. of the RIA for more discussion). Thus, the production of cellulosic diesel instead of cellulosic ethanol could help increase consumption of renewable fuels.

Cellulosic biofuel could also be produced internationally. One example of internationally produced cellulosic biofuel is ethanol produced from bagasse from sugarcane processing in Brazil. Currently, Brazil burns bagasse to produce steam and generate bioelectricity. However, improving efficiencies over the coming decade as well as mechanization of sugarcane harvesting (no burning of biomass in fields) may allow an increasing portion of bagasse to be allocated to other uses, including cellulosic biofuel, as additional straw could potentially be collected and used to produce bioelectricity. Although international production of cellulosic biofuel is possible, it is uncertain whether this supply would be available primarily to the U.S. or whether other nations would consume the fuel domestically. Therefore, our analyses for cellulosic biofuel primarily focus on North America, and for our impact analyses just on domestic supplies.

As discussed, there is uncertainty as to which mix of cellulosic biofuels will be produced to fulfill the 16 Bgal mandate by 2022. For assessing the impacts of the RFS2 standards, we used AEO 2009 (April release) cellulosic ethanol volumes (4.92 billion gallons), as well as the cellulosic biomass-to-liquids (BTL) diesel volumes (1.96 billion gallons) using Fischer-Tropsch

(FT) processes. We consider BTL diesel from FT processes as a subset of cellulosic diesel. In order to reach a total of 16 billion ethanol-equivalent gallons, we assumed that an additional 4.56 billion gallons of cellulosic diesel could be produced from BTL or other cellulosic diesel processes.

1.2.2.2 Biomass-Based Diesel

Biomass-based diesel as defined in EISA means renewable fuel that is biodiesel as defined in section 312(f) of the Energy Policy Act of 1992 with lifecycle greenhouse gas emissions, as determined by the Administrator, that are at least 50% less than the baseline lifecycle greenhouse gas emissions. Biomass-based diesel can include fatty acid methyl ester (FAME) biodiesel, renewable diesel (RD) that has not been co-processed with a petroleum feedstock, as well as cellulosic diesel. Although cellulosic diesel produced through the Fischer-Tropsch (F-T) process or other processes could potentially contribute to the biomass-based diesel category, we have assumed for our analyses that the fuel and its corresponding feedstocks (cellulosic biomass) are already accounted for in the cellulosic biofuel category as discussed in the previous Section 1.2.2.1.

FAME and RD processes can make acceptable quality fuel from vegetable oils, fats, and greases, and thus will generally compete for the same feedstock pool. For our analyses, we have assumed that the volume contribution from FAME biodiesel and RD will be a function of the available feedstock types. For our analysis we assumed that virgin plant oils would be preferentially processed by biodiesel plants. Other feedstocks assumed to be used by biodiesel plants are fuel-grade corn oil from corn oil extraction, fats, waste oils, and waste greases. For the FRM we have also included a small volume of oil feedstock from algae for biodiesel production. We note that there are a wide range of new feedstocks being researched and developed for the production of biodiesel, e.g. camelina and pennycress. While these new feedstocks may prove to be commercially available in the future, we have not assumed that they are used for analyses purposes.

For RD, we assumed that the feedstocks used are from fats, waste oils, and waste greases. This is because the RD process involves hydrotreating (or thermal depolymerization), which is more severe and uses multiple chemical mechanisms to reform the fat molecules into diesel range material. The FAME process, by contrast, relies on more specific chemical mechanisms and requires pre-treatment if the feedstocks contain more than trace amounts of free fatty acids or other contaminates which are typical of recycled fats and greases. In terms of volume availability of feedstocks, supplies of fats, waste oils, and waste greases are more limited than virgin vegetable oils. As a result, our control case assumes the majority of biomass-based diesel volume is met using biodiesel facilities processing vegetable oils, with RD making up a smaller portion and using solely fats, waste oils, and waste greases.

The RD production volume must be further classified as co-processed or non-co-processed, depending on whether the renewable material was mixed with petroleum during the hydrotreating operation. EISA specifically forbids co-processed RD from being counted as biomass-based diesel, but it can still count toward the total advanced biofuel requirement. What fraction of RD will ultimately be co-processed is uncertain at this time, since little or no commercial production of RD is currently underway, and little public information is available about the comparative economics and feasibility of the two methods. Current industry plans indicate, however, that co-processing renewable diesel may not be as favorable as non-co-processed RD, and therefore, we have chosen to assume zero volumes of co-processed RD.[20] Non-co-processed RD volumes are based on production plans from Syntroleum.

1.2.2.3 Other Advanced Biofuel

As defined in EISA, advanced biofuel means renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions, as determined by the Administrator, that are at least 50% less than baseline lifecycle greenhouse gas emissions. As defined in EISA, advanced biofuel includes the cellulosic biofuel, biomass-based diesel, and co-processed renewable diesel categories that were mentioned in Section 1.2.2.1 and Section 1.2.2.2 above. However, EISA requires greater volumes of advanced biofuel than just the volumes required of these fuels. It is entirely possible that greater volumes of cellulosic biofuel, biomass-based diesel, and co-processed renewable diesel than required by the Act could be produced in the future. Our control case assumes that the cellulosic biofuel volumes will not exceed those required under EISA. We do assume, however, that additional biodiesel than that needed to meet the biomass-based diesel volume will be used to meet the total advanced biofuel volume. Despite additional volumes assumed from biodiesel, to fully meet the total advanced biofuel volume required under EISA, other types of advanced biofuel are necessary through 2022.

We have assumed for the analyses conducted that for our control case the most likely source of advanced fuel other than cellulosic biofuel and biomass-based diesel would be from imported sugarcane ethanol and perhaps limited amounts of co-processed renewable diesel. Our assessment of international fuel ethanol production and demand indicate that anywhere from 3.8-4.2 Bgal of sugarcane ethanol from Brazil could be available for export by 2020/2022. If this volume were to be made available to the U.S., then there would be sufficient volume to meet the advanced biofuel standard. To calculate the amount of imported ethanol needed to meet the EISA advanced biofuel standards, we assumed it would make up the difference not met by cellulosic biofuel, biomass-based diesel and additional biodiesel categories. The amount of imported ethanol required by 2022 is approximately 2.2 Bgal.[21] Refer to Section 1.5.2 for a more detailed discussion on imported ethanol.

Recent news indicates that there are also plans for sugarcane ethanol to be produced in the U.S in places where the sugar subsidy does not apply. For instance, sugarcane has been grown in California's Imperial Valley specifically for the purpose of making ethanol and using the cane's biomass to generate electricity to power the ethanol distillery as well as export excess electricity to the electric grid.[22] There are at least two projects being developed at this time that

[20] On May 13, 2009 ConocoPhillips and Tyson suspended plans for building RD co-processing facilities. The tax credit for RD co-processing that helped fund the project was cut from $1 a gallon to 50 cents a gallon as part of the credit bill approved by Congress and signed by President Bush in late 2008. The non-co-processing tax credit remains at $1 a gallon.

[21] The exceptions were for the years from 2010-2015 in the control case, where we assumed AEO 2007 imported ethanol volumes; otherwise, imported ethanol volumes would be zero and lower than the reference case volumes.

[22] Personal communication with Nathalie Hoffman, Managing Member of California Renewable Energies, LLC, August 27, 2008

could result in several hundred million gallons of ethanol produced. The sugarcane is being grown on marginal and existing cropland that is unsuitable for food crops and will replace forage crops like alfalfa, Bermuda grass, Klein grass, etc. Harvesting is expected to be fully mechanized. Thus, there is potential for these projects and perhaps others to help contribute to the EISA biofuels mandate. This could lower the volume needed to be imported from Brazil.

Butanol is another potential motor vehicle fuel which could be produced from biomass and used in lieu of ethanol to comply with the RFS2 standard. Production of butanol is being pursued by a number of companies including a partnership between BP and Dupont. Other companies which have expressed the intent to produce biobutanol are Baer Biofuels and Gevo. The near term technology being pursued for producing butanol involves fermentation of starch compounds, although it can also be produced from cellulose. Butanol has several inherent advantages compared to ethanol. First, it has higher energy density than ethanol which would improve fuel economy (mpg). Second, butanol is much less water soluble which may allow the butanol to be blended in at the refinery and the resulting butanol-gasoline blend then more easily shipped through pipelines. This would reduce distribution costs associated with ethanol's need to be shipped separately from its gasoline blendstock and also save on the blending costs incurred at the terminal. Third, butanol contains less oxygen, allowing it to be blended in higher concentrations than 10% which would likely allow butanol to be blended with gasoline at high enough concentrations to avoid the need for most or all of high concentration ethanol-gasoline blends, such as E85, that require the use of fuel flexible vehicles. Thus, butanol would enable achieving most of the RFS2 standard by blending a lower concentration of renewable fuel than having to resort to a sizable volume of E85 as in the case of ethanol. The need to blend ethanol as E85 provides some difficult challenges. The use of butanol may be one means of avoiding these blending difficulties.

At the same time, butanol has a couple of less desirable aspects relative to ethanol. First, butanol is lower in octane compared to ethanol – ethanol has a very high blending octane of around 115, while butanol's octane ranges from 87 octane numbers for normal butanol and 94 octane numbers for isobutanol. Potential butanol producers are likely to pursue producing isobutanol over normal butanol because of isobutanol's higher octane content. Higher octane is a valuable attribute of any gasoline blendstock because it helps to reduce refining costs. A second negative property of butanol is that it has a much higher viscosity compared to either gasoline or ethanol. High viscosity makes a fuel harder to pump, and more difficult to atomize in the combustion chamber in an internal combustion engine. The third downside to butanol is that it is more expensive to produce than ethanol, although the higher production cost is partially offset by its higher energy density.

Another potential source of renewable transportation fuel is biomethane refined from biogas. Biogas is a term meaning a combustible mixture of methane and other light gases derived from biogenic sources. It can be combusted directly in some applications, but for use in highway vehicles it is typically purified to closely resemble fossil natural gas for which the vehicles are typically designed. The definition of biogas as given in EISA is sufficiently broad to cover combustible gases produced by biological decomposition of organic matter, as in a landfill or wastewater treatment facility, as well as those produced via thermochemical processing of biomass.

Currently, the largest source of biogas is landfill gas collection, where the majority of fuel is combusted to generate electricity, with a small portion being upgraded to methane suitable for use in heavy duty vehicle fleets. Current literature suggests approximately 24 billion ethanol-equivalent gallons of biogas (referring to energy content) could potentially be produced in the long term, with about two thirds coming from biomass gasification and about one third coming from waste streams such as landfills and human and animal sewage digestion.[182, 183] Because the majority of the biogas volume estimates assume biomass as a feedstock, we have chosen not to include this fuel in our analyses since we are projecting most available biomass will be used for cellulosic liquid biofuel production in the long term. The remaining biogas potentially available from waste-related sources would come from a large number of small streams requiring purification and connection to storage and/or distribution facilities, which would involve significant economic hurdles. An additional and important source of uncertainty is whether there would be a sufficient number of vehicles configured to consume these volumes of biogas. Thus, we expect future biogas fuel streams to continue to find mostly non-transportation uses such as electrical power generation or facility heating.

1.2.2.4 Other Renewable Fuel

The remaining portion of total renewable fuel not met with advanced biofuel is assumed to come from corn-based ethanol (including small amounts from other starch grains and waste sugars). EISA effectively sets a limit for participation in the RFS program of 15 Bgal of corn ethanol, and we are assuming for our analysis that sufficient corn ethanol will be produced to meet the 15-Bgal limit that either meets the 20% GHG threshold or is grandfathered. It should be noted, however, that there is no specific "corn-ethanol" mandated volume, and that any advanced biofuel produced above and beyond what is required for the advanced biofuel requirements could reduce the amount of corn ethanol needed to meet the total renewable fuel standard. This occurs in our projections during the earlier years (2010-2015) in which we project that some fuels could compete favorably with corn ethanol (e.g. biodiesel and imported ethanol). Beginning around 2016, fuels qualifying as advanced biofuels likely will be devoted to meeting the increasingly stringent volume mandates for advanced biofuel. It is also important to note that more than 15 Bgal of corn ethanol could be produced and RINs generated for that volume under the RFS2 regulations. However, obligated parties would not be required to purchase more than 15 Bgal worth of non-advanced biofuel RINs, e.g. corn ethanol RINs.

We are assuming for our analysis that sufficient corn ethanol will be produced to meet the 15 Bgal limit. This assumes that corn ethanol plants are constructed or modified to meet the 20% GHG threshold, or that sufficient corn ethanol production exists that is grandfathered and not required to meet the 20% threshold. Our current projection is that up to 15 Bgal could be grandfathered, but actual volumes will be determined at the time of facility registration. Refer to Section 1.5.1.4 for more information.

1.2.3 Additional Control Cases Considered

Since there is significant uncertainty for what fuels will be produced to meet the 16 billion gallon cellulosic biofuel standard, we have decided to investigate two other sensitivity cases for our cost and emission impact analyses conducted for the rule. The first case, we refer to as the "low-ethanol" control case and assume only 250 million gallons of cellulosic ethanol (from AEO 2007 reference case). The rest of the 16 billion gallon cellulosic biofuel standard is made up of cellulosic diesel (9.26 billion gallons), as shown in Table 1.2-4. The second case, we refer to as the "high-ethanol" control case and assume the entire 16 billion gallon cellulosic biofuel standard is met with cellulosic ethanol, see Table 1.2-5.

Table 1.2-4.
Low-Ethanol Control Case Projected Renewable Fuel Volumes (billion gallons)

Year	Advanced Biofuel						Non-Advanced Biofuel	Total Renewable Fuel[f]
	Cellulosic Biofuel		Biomass-Based Diesel[a]		Other Advanced Biofuel			
	Cellulosic Ethanol	Cellulosic Diesel[b]	FAME[c] Biodiesel	NCRD[d]	Other Biodiesel[e]	Imported Ethanol	Corn Ethanol	
2010	0.00	0.06	0.61	0.04	0.22	0.29	11.24	12.47
2011	0.00	0.14	0.72	0.08	0.17	0.16	12.07	13.35
2012	0.01	0.29	0.92	0.08	0.12	0.18	12.83	14.42
2013	0.02	0.58	0.92	0.08	0.28	0.19	13.42	15.49
2014	0.03	1.01	0.85	0.15	0.39	0.20	14.09	16.72
2015	0.05	1.74	0.85	0.15	0.53	0.39	14.79	18.49
2016	0.07	2.46	0.85	0.15	0.56	0.63	15.00	19.72
2017	0.09	3.18	0.85	0.15	0.60	1.07	15.00	20.94
2018	0.11	4.05	0.85	0.15	0.64	1.51	15.00	22.31
2019	0.13	4.92	0.85	0.15	0.68	1.96	15.00	23.69
2020	0.16	6.08	0.85	0.15	0.72	1.88	15.00	24.85
2021	0.21	7.82	0.85	0.15	0.77	1.81	15.00	26.61
2022	0.25	9.26	0.85	0.15	0.82	2.24	15.00	28.57

[a] Biomass-Based Diesel could include FAME biodiesel, cellulosic diesel, and non-co-processed renewable diesel.
[b] Cellulosic Diesel includes 1.96 billion gallons from Fischer-Tropsch Biomass-to-Liquids (BTL) processes and 4.56 billion gallons from this and other types of cellulosic diesel processes in year 2022. In order to calculate the split of cellulosic ethanol vs. cellulosic diesel in years prior to 2022, we assumed the same percentage of the total cellulosic biofuel standard as in year 2022, i.e. 2% cellulosic ethanol and 98% cellulosic diesel.
[c] Fatty acid methyl ester (FAME) biodiesel
[d] Non-Co-processed Renewable Diesel (NCRD)
[e] Other Biodiesel is biodiesel that could be produced in addition to the amount needed to meet the biomass-based diesel standard.
[f] May not total due to rounding.

Table 1.2-5.
High-Ethanol Control Case Projected Renewable Fuel Volumes (billion gallons)

	Advanced Biofuel						Non-Advanced Biofuel	Total Renewable Fuel[f]
	Cellulosic Biofuel		Biomass-Based Diesel[a]		Other Advanced Biofuel			
Year	Cellulosic Ethanol	Cellulosic Diesel[b]	FAME[c] Biodiesel	NCRD[d]	Other Biodiesel[e]	Imported Ethanol	Corn Ethanol	
2010	0.10	0.00	0.61	0.04	0.22	0.29	11.24	12.51
2011	0.25	0.00	0.72	0.08	0.17	0.16	12.07	13.45
2012	0.50	0.00	0.92	0.08	0.12	0.18	12.83	14.62
2013	1.00	0.00	0.92	0.08	0.28	0.19	13.42	15.89
2014	1.75	0.00	0.85	0.15	0.39	0.20	14.09	17.43
2015	3.00	0.00	0.85	0.15	0.53	0.39	14.79	19.70
2016	4.25	0.00	0.85	0.15	0.56	0.63	15.00	21.44
2017	5.50	0.00	0.85	0.15	0.60	1.07	15.00	23.17
2018	7.00	0.00	0.85	0.15	0.64	1.51	15.00	25.15
2019	8.50	0.00	0.85	0.15	0.68	1.96	15.00	27.13
2020	10.50	0.00	0.85	0.15	0.72	1.88	15.00	29.11
2021	13.50	0.00	0.85	0.15	0.77	1.81	15.00	32.08
2022	16.00	0.00	0.85	0.15	0.82	2.24	15.00	35.06

[a] Biomass-Based Diesel could include FAME biodiesel, cellulosic diesel, and non-co-processed renewable diesel.
[b] Cellulosic Diesel is assumed to be zero, while cellulosic ethanol is assumed to be 100% of the cellulosic biofuel standard.
[c] Fatty acid methyl ester (FAME) biodiesel
[d] Non-Co-processed Renewable Diesel (NCRD)
[e] Other Biodiesel is biodiesel that could be produced in addition to the amount needed to meet the biomass-based diesel standard.
[f] May not total due to rounding.

1.3 Feedstock Harvesting, Transportation, & Storage

A reliable and affordable source of cellulosic feedstocks will be vital for the development of a large scale cellulosic biofuel industry. While Section 1.1 of the RIA examined the availability of cellulosic feedstocks for conversion to biofuels, this section focuses instead on the process of harvesting, storing, and transporting these feedstocks to the biofuel production facilities. For biofuels that use traditional crops such as corn, soy bean oil, or sugar cane, these feedstock storage and delivery systems are already well established. For other feedstocks, however, such as herbaceous energy crops or wood residue, new feedstock supply systems will have to be put into place. Each of these potential feedstocks presents unique challenges that must be overcome in order for them to be used for large scale biofuel production. For more information on the costs associated with the harvest, storage, and transportation processes see Chapter 4 of the RIA.

1.3.1 Feedstock Harvesting

Feedstock harvesting refers to all the steps necessary to make the feedstock available at the roadside for transportation and storage. For MSW, this is a relatively simple process. MSW is already collected on a large scale and in order to enable it to be used as a feedstock all that is required is that it be sorted to remove the portion that is undesirable for biofuel production. Agricultural residues and herbaceous energy crops, on the other hand, are not currently being harvested on a large scale and therefore new processes must be developed to make them available to be used in the production of biofuels.

1.3.1.1 Municipal Solid Waste (MSW) Collection

As discussed above, MSW is one of the potential sources of renewable fuel feedstock that already has a well developed collection system already in place. In many cases cities and municipalities are already recovering recyclable materials, such as metals, plastics, and paper, from the collected waste streams. After these valuable materials have been removed from the waste stream the remainder of the waste material can, in many cases, be used for the production of renewable with little or no additional separation required. Alternatively, a waste stream of similar quality may be able to be obtained without the potentially expensive separation process if the waste material is separated by the waste producer at the curbside. One potential producer of biofuels from MSW indicated in a confidential conversation that this was the method they planned to use to obtain their feedstock.

In parts of the country where these recyclable materials are not currently recovered it will be necessary for the biofuel producer who wishes to use this material to first remove the metals, plastics, and other contaminated materials before this material may be used. This sorting can be done either by hand or with an automated process. Cleaner streams are produced when the waste stream is sorted by hand, however this is a slower and more expensive process. Potential biofuel producers indicated to us that the automated separation systems that currently exist produce waste streams of acceptable quality and are thus more likely to be used due to their lower costs. If the biofuel producer was responsible for waste separation it is likely that the separation facility and the biofuel production facility would be located at the same site, and thus no transportation would be necessary between these two facilities.

1.3.1.2 Wood Residue Collection and Harvest

Another potential source of feedstock that may be converted to cellulosic biofuels are wood residues. This category of feedstock refers to a large range of currently unused wood wastes from forestry and wood processing industries. Significant sources of wood residue are either currently available or expected to be available in the near future in the form of mill residues, forest residue, and forestry thinnings.

Mill Residue

One source of currently available wood residue is mill residue. Mill residue is a waste product of both primary mills, mills that convert roundwood into other wood products, and secondary mills, those that produce finished consumer products. Because this residue is currently being produced at the primary and secondary mills all that would be required for its use as a cellulosic biofuel feedstock is it's collection and transportation to the biofuel production facility or for the co-located construction of a biofuel facility.

Forest Residue

The largest portion of wood residue available as cellulosic feedstock is forest residues. However, unlike residues such as primary or secondary mill residues that could be available on-site at a processing facility, forestry residues would need to be collected and transported similarly to conventional forest products. The amount of residues potentially available is a function of harvest amount, logging method, and type and location of timberlands.[184] In addition, residue availability is limited by economic factors. According to one study, "the actual operations of harvesting, collecting, processing and transporting loose forest residues are costly and present an economic barrier to recovery and utilization of wood for energy".[185] Thus, there are still challenges that need to be addressed before large-scale use of forestry residues is possible.

Currently, the most cost-effective method of recovering forest residue for biomass is in-woods chipping.[186] This method is suitable for operations where there is whole-tree skidding to roadside, good road access to chip vans and chippers, and sufficient biomass volume per acre. However, in-woods chipping systems are not as effective when ground-based skidding is restricted or when there are no merchantable products other than biomass. In addition, the chip vans designed to haul wood chips were built for highway use and often do not have sufficient suspension systems for remote forest roads. There are also high costs for wood grinders with low production rates.[187] Fortunately, there have been developments in alternative methods to reduce the costs of biomass collection systems.

There has been much focus recently on developing methods of densifying residues in order to increase productivity of handling operations (i.e. hauling, skidding, and loading). New approaches to removing forestry residues are currently being evaluated (e.g. slash bundling machines, horizontal grinders, and roll on/off container transport). One of the advantages of using slash bundling machines is the ability to store biomass longer than in chip form. Storing biomass at roadside in the form of biomass bundles could provide a more secure and stable biomass supply than with chips which are smaller and have greater surface area for potential weathering. Utilizing roll on/off containers allows for recovery of residue from difficult-to-access locations and in such situations could be competitive with regular highway chip vans.

While these are just some of the ways to improve recovery operations for forestry residues, these methods still have challenges. For example, there are some difficulties with bundling of brittle residues or short, large diameter pieces. In addition, some residues may include rocks or trash that can result in additional saw maintenance and reduced utilization. With millions of acres of forest, there is no single residue treatment option that will meet the needs of all situations. Forest land managers will need to weigh the different options for dealing with forest residues to determine the most cost-effective means for residue removal in their specific locations.

Forest Thinnings

A third source of wood residue is forestry thinnings. Forest thinnings refer to woody material removed from forests that have become overgrown, either to reduce the risk of forest fires or to increase productivity of the forest. The material removed is too small or damaged in some other way and is unsuitable to be sold as roundwood. Because of its low value, much of the wood residue removed from forests today as forest thinnings is either burned or left to decompose. Currently the cost to fell the thinnings is paid for by the land owner. Therefore, in order to use this material as a cellulosic feedstock the forest thinnings would only have to be collected from the forest and moved to the roadside. Once at the roadside they would likely be either chipped or bundled using the process previously discussed to increase the density of the thinnings, and thus reduce the transportation costs.

1.3.1.3 Agricultural Residue Harvest

Agricultural residue is a very large and potentially readily available cellulosic feedstock source for biofuels producers. While the residues of some crops have been harvested for many years, much crop residue is left on the fields in order in increase soil quality and protect against erosion from wind and rain as discussed in Section 1.1. Despite the many benefits of leaving agricultural residue on the fields we believe that it is possible to remove some portion of the agricultural residues without significant negative impacts to the soil quality in many parts of the country. We also believe that agricultural residues will make up a large portion of the cellulosic feedstocks used for biofuel production by 2022. The following section discusses the likely process for agricultural residue harvest and the associated challenges we anticipate. We have chosen to focus our discussion on corn stover as it is expected that it will be used more extensively than any other agricultural residue, and because there is more uncertainty surrounding its harvest than other small grains, such as wheat, oats, barley, and rice, that are regularly harvested currently.

Corn stover harvest, at present, requires multiple machines: combines, shredders, rakes, balers, bale wagons, and stackers just to get the stover bales to the side of the field; dry matter is lost during each operation. Currently, there are no harvesting machines designed specifically for residue harvest, other than perhaps, for small grain straws that use common hay equipment. One proposal for corn stover harvest is to shut the spreader off on the grain combine in order to form a windrow, of sorts, following which the windrow is baled.[188] However, modern combines leave most of the stalk standing. In order to harvest as much of the stover as possible, it is necessary to shred the standing stalks and then rake all of it together prior to baling.[189] The baler pickup must be set high enough to avoid picking up dirt and dirt clods, the dirt-particles from which are very hard on harvesting equipment and that would demand a cleanup stage in downstream processing, which of itself would translate into overall dry matter losses. As such, it is likely that the baler will leave some amount of stover. After baling, the bales, whether round or square, would be picked up from the field and moved to the roadside, where they would await transportation to a storage facility.

We anticipate that by 2022, the corn stover harvest will be reduced to a single-pass operation during which the amount of residue left on the field will be less a function of harvest efficiency and more a function of the farmer/grower and the harvesting company being able to determine how much residue must be left to maintain soil health. A combine designed specifically for the job must still be constructed, but we expect that it will cut the whole stalk a few inches above the soil, leaving some stalk anchored to the ground. A single-pass harvester could cut the entire plant a few inches above the ground and pull all of it, e.g., stalks, leaves, cobs, and grain into the combine, where they become a single, mixed grain and stover stream. The harvester blows the entire stream into tractor-pulled grain-carts that run along-side the harvester. When a cart is filled, it is replaced by an empty cart, and the full cart is hauled to the field side, where it's unloaded into bulk 'walking-floor' semi trailers, and hauled to a co-op or depot type elevator/facility for further processing and storage. At the elevator, the stover/grain mix is unloaded into equipment for further processing before it's sent to storage. Although a facility (equipment, buildings, etc.) at an elevator for separating the corn grain from the stover has not been constructed, we anticipate that it could operate very much like a modern grain harvester/combine, except it will obviously be stationary. The entire stream could be fed, by chain or belt, where it drops between a cylinder covered with rough steel bars and a piece of equipment called a concave. As the cobs are rubbed between the steel bars and concave, the corn grain rubs off and drops onto a perforated belt; most of the stover remains are larger than corn grain pieces, and is moved rearward toward the spreader. The corn grain and small stover particle fall through and are carried to a chaffer.

Small grain straws, such as those from wheat, oats, barley, and rice have been harvested for many years. A significant difference between the harvesting equipment used for corn stover and these grains, is that the small grain plant is cut off near the ground and passes through the combine at the time of harvest. It falls to the ground from the harvester into somewhat of a windrow; in some cases, the windrow many need to be raked together before baling to gain maximum removal efficiency. Since the whole grain plant had dried prior to harvest, it's not necessary to wait for the straw to dry before it's baled. Small grain straws can be baled, hauled, and stacked in standard small bales or in larger 3' x 4' x 8' square bales with current hay equipment.

Sugarcane bagasse is not harvested, in the sense we've discussed 'a harvest.' It is a byproduct of sugar production from sugarcane, delivered by truck and trailer from the sugar processing facility to the ethanol plant. If sugarcane bagasse were to be used as a cellulosic feedstock the only additional step that would be required would be to transport the bagasse from the sugar fermentation facility to the cellulosic biofuel production facility if they are not co-located.

1.3.1.4 Energy Crop Harvest

Energy crops are another very large potential, yet currently unutilized, source of cellulosic feedstock. As with corn stover, no harvesting process for energy crops currently exists. Additionally, the harvesting process used for energy crops will vary greatly depending on whether the energy crop is herbaceous, such as switchgrass or miscanthus, or woody, such as hybrid poplar. Nevertheless, we believe that the harvesting practices for energy crops will resemble those currently used for small grains and tree plantations respectively.

Herbaceous Energy Crops

The harvesting process for herbaceous energy crops, such as switchgrass and miscanthus, is expected to closely resemble that described for corn stover in the preceding section. When the herbaceous energy crops are sufficiently dry they will be cut with a mower or swather, similar to those used to harvest hay, and left on the field in windrows. The energy crops will then be baled and moved to the roadside where they will await transportation to a storage location.

While it is possible to harvest herbaceous energy crops using currently available equipment designed for hay and other agricultural residues, the high yields of these crops present several challenges. The higher production rates per acre of energy crops, when compared to hay or corn stover, will require unique equipment designs. There is also likely to be a small harvest window where the crop is ready to be harvested, but before the onset of winter weather, especially in northern parts of the country. As more energy crops are grown and harvested as feedstocks for biofuels and energy sources in other sectors, it is likely that harvesting equipment will be developed that is optimized for energy crops.

There may also be significant regional variation in the harvesting process for energy crops. Energy crops grown in the south will have a longer harvest window, as winter weather arrives at a later date, and in many cases is not severe enough to halt harvesting operations. Longer growing seasons in the south may also enable multiple harvests in the same year to further increase yields. Finally, in parts of the country where year round harvest is possible energy crops may be able to be harvested on an as needed basis, negating the need for secondary storage and significantly reducing the delivered cost of the energy crops to the biofuel producers. For more information on cellulosic feedstock storage and it's impact on feedstock price see sections 1.3.2 and 4.1.1.2.

Woody Energy Crops

As with herbaceous energy crops, it is possible to harvest woody energy crops with equipment currently in use by logging operations and the pulp and paper industry. Trees can be cut and gathered using a feller buncher and then transported to the roadside. Once at the roadside they can either be chipped and blown into chip vans for transportation to the biofuel production facility, or bundled using the process described above in the forest residue section. It is more likely, however, that woody energy crops will be harvested using equipment specifically designed for that purpose and able to take advantage of the regular spacing of the trees found on tree plantations. In Europe self propelled harvesters that cut and chip the woody energy crops are being used. The wood chips are then stored in large stacks until they are transported to the facility where they will be used[190]. Work is also being done in Canada to design a harvester capable of cutting, shredding, and baling woody energy crops. These bales would then be transported to a storage area and allowed to dry before being chipped and used for biofuel production. We anticipate that woody energy crops will be harvested using a process optimized to fit the individual woody energy crop plantation, likely resembling one of the processes just described.

1.3.2 Feedstock Transportation and Storage

Once cellulosic feedstocks have been made available at the roadside, either through collection or harvesting, they must then be transported to the biofuel production facility. For some feedstocks, such as sorted MSW, this may be as simple as delivering the feedstock to a biofuel production facility rather than a landfill. For other feedstocks, such as agricultural residue or energy crops, it will require a much more complicated process involving multiple relocations, loadings, and unloadings, as well as storage in a secondary storage facility. The complexity of the transportation of the feedstock from the location where it is produced to the biofuel production facility is most dependent on whether the feedstock is available year round and harvested on an as needed basis or collected or harvested on an annual or semi-annual basis.

1.3.2.1 Secondary Storage

One potential challenge for cellulosic biofuel producers is where the cellulosic material will be stored before it is converted into fuel. Some feedstocks, such as MSW or wood residues, can be collected or harvested year round. It will therefore only be necessary for the biofuel production facility to store a small amount of feedstock on site, we estimate 3-4 days worth, and additional feedstock can be received regularly directly from the producers. Agricultural residues and herbaceous energy crops, however, are harvested annually or semi-annually, and therefore the biofuel producer must be able to store a years worth of feedstock. Because of the low energy density of cellulosic feedstocks it would not be feasible to store a years worth of feedstock at the biofuel production site, as this would require an area of several hundred acres for feedstock storage alone at larger facilities.

One method that has been suggested is storing baled feedstock at the roadside on the farms where it is produced. It would then be loaded onto trucks and transported to the biofuel production facility as needed. This method of cellulosic storage at the farms where it is produced would be problematic. Storing significant quantities of feedstock at the farm sites could force land that would otherwise be used for feedstock production to be instead used for feedstock storage. Heavy traffic by the bale loaders and trucks used for transportation could cause significant damage to the farmers' fields. Finally, because access to these feedstocks would often be over unimproved private roads on the farmers land there is a real risk that feedstock supply could be interrupted by extended periods of inclement weather. We believe that the combination of these factors makes feedstock storage at the site where it is produced unlikely.

Another storage option would be to use secondary storage sites. In this method of feedstock storage baled cellulosic feedstock would be moved from the site of production to a secondary storage facility at the time of harvest. It would then be transported from the secondary storage site to the biofuel production facility as needed. Feedstock from many farms would be collected at a single secondary storage site. The number of secondary storage sites would depend on the size of the biofuel production plant and the density of the feedstock production. Storing cellulosic feedstock in secondary storage sites increases the delivered cost of the feedstock, but could be necessary due to the limitations of on farm storage mentioned above.

In addition to where the cellulosic feedstock is stored, there is also the question of how the feedstock will be stored. Many different ways of storing the feedstock have been suggested, ranging from stacked bales exposed to the weather, to bales wrapped in plastic, to storage in covered buildings or pole barns. The issue of whether the feedstock should be baled as round or square bales also effects how the feedstock should be stored. Round bales store better in the open than square bales since rain, and particularly snow, collect on flat surfaces more readily than on round. When stacked, however, round bales usually cannot be stacked more than three bales high without the risk of deformation, instability of the stack, and dry matter loss. Square bales, however, can be stacked as many as five high without the risk of instability.

In making the decision whether to store the bales in an indoor facility the cost of the storage facility must be weighed against the dry matter loss that will result from storing the bales in the open. Dry stover bales stored indoors or outdoors had average dry matter losses of 5% and 15%, respectively. Wrapping dry bales in net or plastic wrap and storing on a well drained surface significantly reduced dry matter loss compared to storing twine wrapped dry bales on the ground.[191] Wrapping bales in net of plastic, however, is usually done at the time of bailing at the farm site, and it is not clear whether it is feasible to transport and stack wrapped bales at a secondary storage site. Indoor storage is, in most cases, a concrete slab with a roof, supported by poles, with open sides (pole-barn). Depending on the number of bales to be stored, the slab must be sized to include aprons around all four edges with aisles between stacks to accommodate stacking and hauling equipment and for fire safety. Considering these many factors, we believe that indoor storage is the storage method that will be most widely utilized. This is the storage method which was used in our cost analysis, which can been seen in more detail in Section 4.1.1.

1.3.2.2 Municipal Solid Waste (MSW) Transportation

Transportation and storage of MSW as a feedstock is relatively simple. If the biofuel producer is using MSW that has already been separated, all that would be required would be to transport the feedstock from the facility where it is separated, most likely a recycling center, to the biofuel production facility. This would be done in large over-the-road trucks. The biofuel producer would have to store several days worth of feedstock at the fuel production site to ensure that fuel production is not interrupted, but because MSW is produced and collected year round no secondary storage would be necessary.

If the biofuel producer is receiving unsorted MSW it is probable that the sorting facility would be co-located with the biofuel production facility. If the biofuel production facility is near the source of MSW it may be possible for the local refuse collection trucks to deliver the MSW to the plant directly. If the biofuel production facility is located some distance from the MSW source it will be more cost effective to transfer the MSW from local refuse collection trucks to large over-the-road trucks for transportation to the biofuel production facility. Once again, no secondary storage would be required due to the consistent availability of MSW. In this case, however, the biofuel producer would have to arrange for the transportation of recovered recyclable materials, as well as contaminated waste that cannot be used to produce biofuels.

1.3.2.3 Wood Residue Transportation

Wood residues are expected to be collected from the places they are produced, the primary or secondary mill for mill residues and the roadside of the forestry operation for forest residue and forest thinnings, and transported directly to the biofuel production facility in large over-the-road trucks. For each of the three types of wood residues we expect that the wood will be chipped or processed in some other way to increase the density of the residue before transportation. This will reduce transportation costs by allowing a greater mass of wood residue to be transported by each truck. As with MSW, secondary storage is unlikely to be necessary for wood residues as they are available to be harvested throughout the year.

1.3.2.4 Agricultural Residue and Energy Crop Transportation and Storage

Unlike MSW and wood residues, which are available to be harvested and collected throughout the course of the year, agricultural residues and herbaceous energy crops are harvested on an annual or semi-annual basis. As a result, a large amount of feedstock, enough to supply the biofuel production facility for a whole year, must be stored and delivered throughout the year. We expect secondary storage sites, as described above, will be the best option. Following the baling operation, the bales of agricultural residue or energy crops will be picked up from the field in 10-bale loads, by vehicles designed for that purpose. Such vehicles are currently used to gather hay bales today. The bales are subsequently unloaded or dropped at the field-edge. Later, the bales are loaded onto wagons pulled by high-speed tractors that haul as many as 20-bales per load to satellite storage (the pole-barns described in Section 1.3.2.1). The bales are unloaded and stacked for storage until they are needed at the ethanol plant. Transport to the plant is by over-the-road trucks and trailers that can haul net-loads of up to about 45- to 50-tons. However, because the bale density is low (on average, about half the weight of a similarly sized hay bale), the maximum number of bales a truck can haul usually weighs much less than the maximum allowable weight. Grinding the baled feedstock before transportation to the biofuel production facility would increase the density of the feedstock, and therefore increase the mass that each truck could transport and lower the overall transportation costs.

As discussed in Section 1.3.1.2, we anticipate that the corn stover harvest could become a single-pass operation by 2022. In this case corn stover would be transported from the farm to a specialized cellulosic feedstock depot to be processed. Equipment at the cellulosic feedstock depot would chop and dry the corn stover. This distributed preprocessing facility can provide significant cost benefits by producing a higher value cellulosic feedstock with improved handling, transporting, and merchandising potential. In addition, data supporting the preferential deconstruction of feedstock materials due to their bio-composite structure identifies the potential for significant improvements in equipment efficiencies and compositional quality upgrades.[192] The stover, now with flowability characteristics similar to small cereal grains, is moved by standard grain loading and unloading systems into large corrugated steel bins for intermediate storage. In this harvest format, the stover is handled by only two machines before it reaches the roadside and never hits the ground, significantly reducing dry matter losses. The biofuel producer would then pick up its feedstock from the elevator/depot in trucks and trailers for transport to the facility. We believe stover feedstock in the ground format could have a significantly higher bulk-density than baled stover, which should translate into lower transportation costs.

1.3.3 Cellulosic Feedstock Transportation and Storage Tool

In order to better estimate the impacts of transport and secondary storage on the overall price of cellulosic ethanol, we have developed a tool that estimates the location of future cellulosic ethanol plants. Using these locations, we can estimate the average cost for transport of feedstock material both locally (within the plant-containing county) as well as imported from other areas in the country. The tool also provides us an estimate of the type of feedstock material used by each plant, allowing us to determine the average cost of secondary storage for these materials.

1.3.3.1 Basis and Assumptions for Transport Tool

Feedstock densities and locations have been compiled on a county basis for use within the tool. This information has been provided by a variety of sources, including the National Forestry Service for forestry residue, the National Agricultural Statistical Service (NASS, 2007) for agricultural residues and Elliot Campbell from Stanford University for energy crops. Municipal solid waste is also considered for this tool. For more information regarding the sources of data used for the tool, see Section 1.1.2 of this RIA. Data for agricultural residues provided by NASS reported harvested grain values, and needed to be modified to reflect agricultural residue values, using grain to residue ratios[193]. Data provided from FASOM modeling was used in this tool for total feedstock usage as well as farmside cost.

In order to simplify the location of plants within the tool, we have assumed that plants will be constructed at a county centroid. Therefore, transport within a county to a plant is based on the transport of feedstock material from farmside to the county centroid, with consideration for feedstock density within the county as well as the total county area. Furthermore, transport of feedstock between counties (for plants importing feedstock outside the county they are located in) is based on the distance between county centroid locations, with an additional factor to account for the added distance of using on-road transportation. Information regarding the costs of this transportation can be found in Section 4.1.1.2 of this RIA.

Assumptions for secondary storage used in the tool closely follow the determinations made in Section 1.3.2 above. Secondary storage costs in the tool are based on the amount of feedstock to be stored, the density of the feedstock being stored, as well as the type of feedstock itself. As discussed in Section 1.3.2, the tool assumes that no secondary storage is necessary for either municipal solid waste, which would be transported to the plant directly by waste removal services; or for forest residue, which can be harvested year-round and transported on as-needed to the plant. Capital costs used in the tool for plant selection are based on current refinery modeling, broken down by PADD location. These capital costs are based on the total production volume of the plant and the PADD that it is located within. For more information on transport, secondary storage, and capital costs, please refer to Section 4.1.1.2 in this RIA.

1.3.3.2 Transport Tool Operation

The tool begins operation by compiling feedstock availability (by county) based on the data sources discussed in Section 1.3.3.1. Using county locations, it builds a list for each county that contains the locations of other counties within a set maximum range (these other counties will be referred to as neighbors for the remainder of this section). This list will serve as the basis for county to county feedstock transport further on in the tool operation. The tool then adds feedstock information such as feedstock densities, total amount of feedstock available, and feedstock type specific to each county. Using this feedstock information, the tool generates a list of all feedstocks available for each county; both within the county itself as well as feedstock available for import from other neighboring counties. At the end of this step in the tool operation, each county has a datapoint in the tool which contains a complete list of all feedstock available to that location.

Using the list of feedstocks available to each county generated in the last step, as well as the transportation and secondary storage cost assumptions discussed in Section 1.3.3.1, the tool calculates and adds complete cost information for each feedstock available to a county. These costs include the farmside cost of the feedstock, the transportation required to move the feedstock to the centroid of its own county and the secondary storage of that feedstock. If the feedstock is available by import from a neighboring county, the transportation cost of moving that feedstock from the neighboring county is also added to the complete feedstock cost for that source. At the end of this step in the tool operation, each county datapoint contains a list detailing the total cost of each feedstock available as they would be delivered to that county.

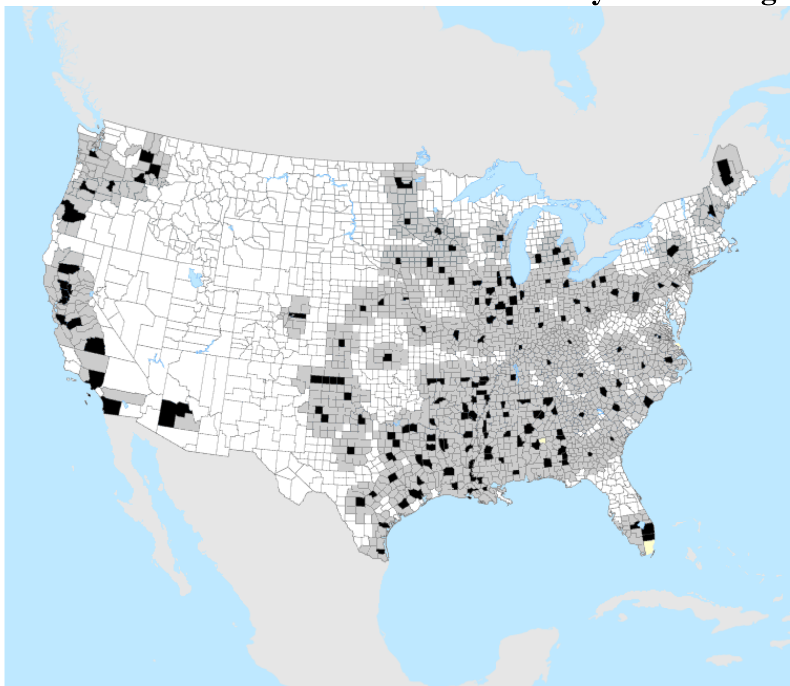
In the next step of the tool operation, the list of feedstock availability cost is used to choose feedstocks that a plant located at each county centroid would processes. For each county, the cheapest feedstock from the list is selected for the plant. The volume of feedstock available at this price is then converted to gallons (based on feedstock conversion modeled by FASOM) and added to a running count of the total volume of feedstock processed by that county. Capital costs associated with the increased volume are also added to the total cost of the feedstock processing for that county. The tool continues adding feedstock sources to a county by selecting the next cheapest feedstock on the list. Selection proceeds until either the county either reaches a set maximum processing volume, or when adding another feedstock would produce a result more expensive on a price per gallon basis. At the end of this step, each county datapoint contains information regarding the cheapest total cost to produce cellulosic ethanol at that location.

The tool proceeds by scanning the entire list of county locations for the cheapest processing location that could be constructed. This location is added as an estimated cellulosic ethanol plant location for the final output of the tool. The feedstock used in by location is removed as a source from any feedstock availability list used by other counties. The tool then repeats using this modified feedstock data, starting from the step involving the selection of feedstocks used in a county. In this way, a list of estimated plant locations is chosen by always selecting the next cheapest location in which a plant can be built; this provides the final output of the tool. The tool stops operation when the total processed volume of all locations selected reaches the sixteen billion gallon maximum discussed in Section 1.3.3.1.

1.3.3.3 Final Tool Output and Interpretation

Not only does the tool provide estimated plant locations, it also provides supplementary information we have used to estimate average transportation and storage costs for feedstocks used by each plant, and subsequently all plants estimated by the tool. Since both the farmside feedstock cost as well as the contribution of capital cost is known for each of the estimated plants (as these are inputs to the tool), the transportation and storage costs can be calculated for each ton of feedstock processed by that plant, including county to county transport. The cost of transportation for each plant can then be averaged with the other plants selected by the tool to arrive at a total transportation and storage cost average across all plants selected by the tool. For more information about how these transportation and storage costs are used, see Section 4.1.2 in this RIA.

Figure 1.3-1
Illustration of Estimated Plant Sites Selected by Plant Siting Tool



Counties in black show active plant locations, counties in grey show active feedstock use

In Figure 1.3-1 above, an illustration of the plant locations selected by the tool can be seen. It is important to note that the above average number of plants selected for the southern region of the United States is most likely due to the lower capital costs associated within the this region. The tool takes into account regional variations of plant construction and operation costs. The lower capital cost in the southern region (most likely due to existing construction infrastructure for conventional oil refineries) reduces the overall price of plants selected in these locations, and we feel explains why the tool has a preference for this region of the country. More specific information on these capital cost regions can be found in Section 4.1.1.2 of this RIA.

The tool was run multiple times using differing values for total feedstock availabilities as well as the percentage of feedstock associated with each type. We have selected the tool output that most closely matches the output for feedstock usage provided by the FASOM model, as we feel that it is important to keep the feedstock usage quantities consistent across our analyses. However, as improved input factors and estimates are developed over time, the tool can be easily adjusted and updated to take into account this new information.

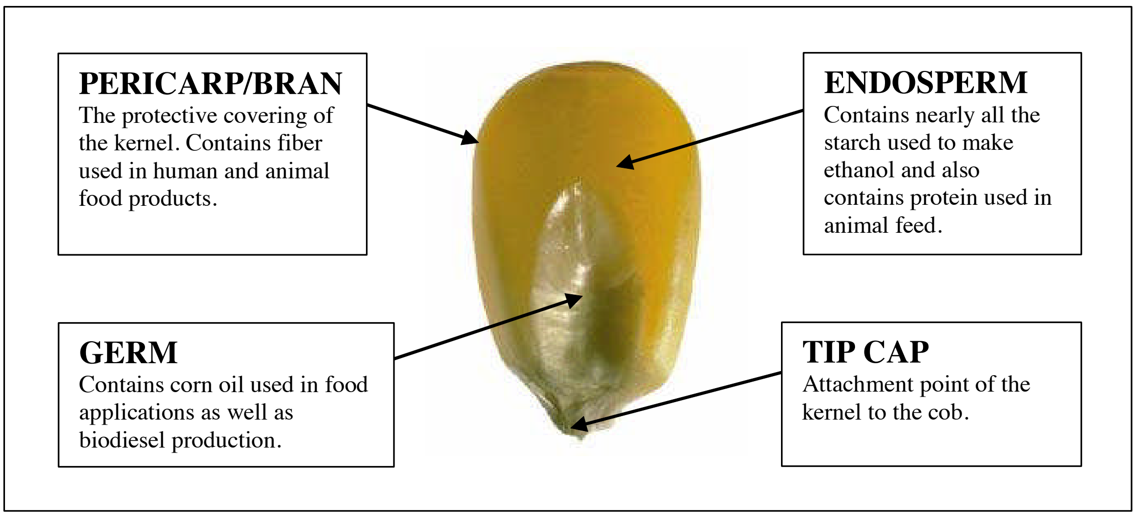
1.4 Biofuel Production Technologies

Biofuel production technologies continue to evolve with research and development efforts focused on reducing costs and increasing efficiencies. Improvements include increasing conversion yields for various feedstocks, reducing energy and materials usage, eliminating or reducing wastes, finding alternative uses for by-products, etc. For those technologies not yet commercial, researchers are combining their innovative ideas to develop cost-effective processes to produce biofuel at low enough costs to compete with their petroleum counterparts. The following sections describe both proven and new technologies which may be used to produce renewable fuels to meet the EISA 36 billion gallon standard by 2022.

1.4.1 Corn Ethanol

There are two primary processes for converting corn (and other similarly processed grains) into ethanol: wet milling and dry milling. The main difference between the two is in the treatment of the grain. Dry mill plants grind the entire kernel (shown below in Figure 1.4-1) and generally produce only one primary co-product: distillers grains with solubles (DGS). The co-product is sold wet (WDGS) or dried (DDGS) to the agricultural market as animal feed. Wet mill ethanol plants separate the grain kernel prior to processing into its component parts and produce other co-products (usually gluten feed, gluten meal, and food-grade corn oil) in addition to DGS. Each process is described in greater detail in the subsections that follow.

Figure 1.4-1. Components of the Corn Kernel



1.4.1.1 Dry Milling Technology[194]

In traditional dry mill plants, first the corn is screened to remove any unwanted debris. Then, it goes through a hammer mill where it is ground into course flour also know as "meal." Next the meal is cooked to physically and chemically prepare the starch for fermentation.

The first step of the cooking process is to form a hot slurry. The meal is mixed with water, the pH is adjusted, and an alpha-amylase enzyme is added. The slurry is heated to 180–190°F for about 30–45 minutes to reduce viscosity.

The second step in the cooking process is liquefaction, which occurs in two steps. First the hot slurry is pumped through a pressurized jet cooker at approximately 220°F and held for about 5 minutes. The mixture is then cooled by an atmospheric or vacuum flash condenser. After cooling, the mixture is held for 1–2 hours at 180–190°F to give the alpha-amylase enzyme time to break down the starch into short-chain carbohydrates also know as "dextrins." Once cooking is complete, a pH and temperature adjustment is made, a second enzyme (glucoamylase) is added, and the resulting mixture (also know as "mash") is pumped into the fermentation tanks.

During the fermentation process, the glucoamylase enzyme breaks down the dextrins to form simple sugars. Yeast is added to convert the sugar into ethanol and carbon dioxide. The mash is then allowed to ferment for 50–60 hours. The result is a mixture that contains 10-15% ethanol by volume (20 to 30-proof) as well as solids from the grain and added yeast.

From here, the fermented mash is pumped into a multi-column distillation system where additional heat is added. The columns utilize the differences in the boiling points of ethanol and water to boil off and separate the ethanol. By the time the product stream leaves the distillation columns, it contains about 95% ethanol by volume (190-proof). The residue from this process, called stillage, contains non-fermentable solids and water and is pumped out from the bottom of the columns into the centrifuges.

The final step in the ethanol production process is dehydration to remove the remaining 5% water. The ethanol is passed through a molecular sieve to physically separate the water from the ethanol based on the different sizes of the molecules. The result is 200-proof anhydrous (waterless) ethanol. At this point, a denaturant, which typically is natural gas liquids, is added (making it unfit for human consumption) and the ethanol is placed into storage.

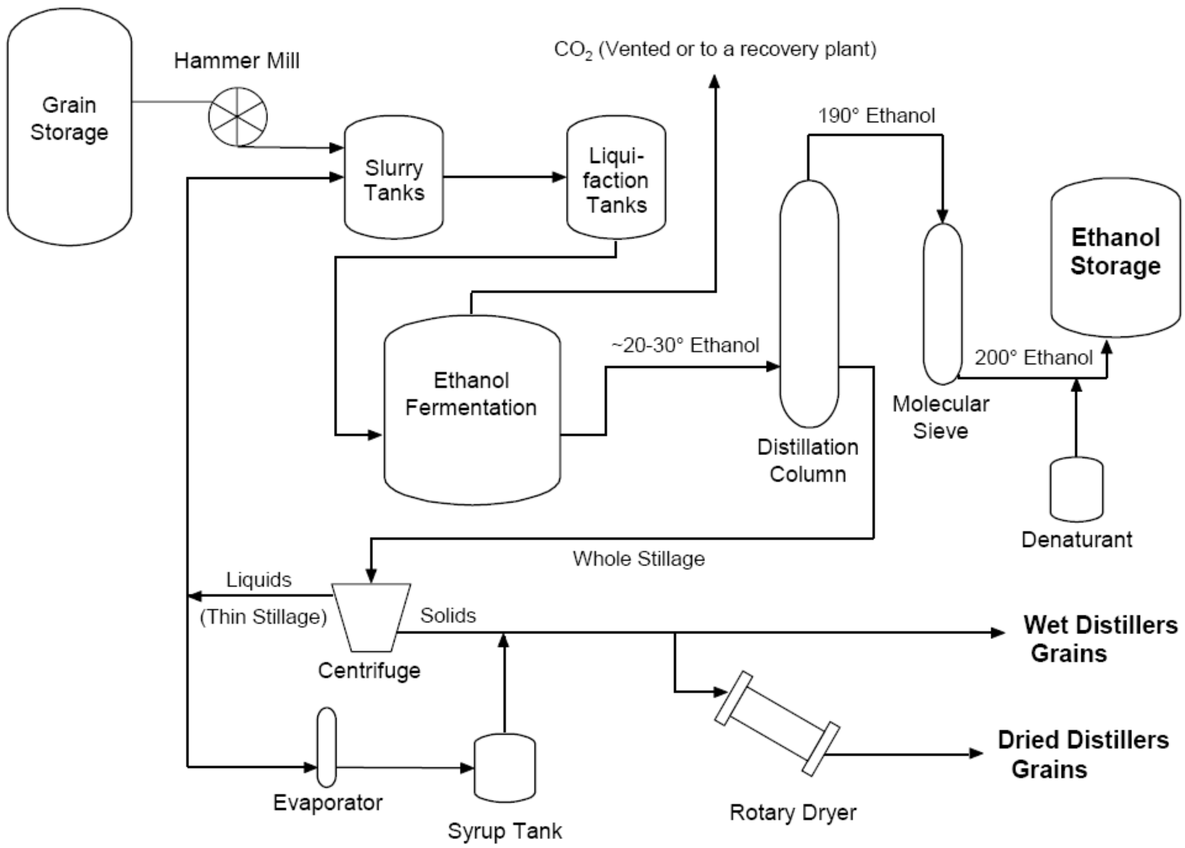
During the ethanol production process, two primary co-products are created: carbon dioxide and distillers grains. As yeast ferment the sugar, they release large amounts of carbon dioxide gas. In some plants it's released into the atmosphere, but where local markets exist, it's captured and purified with a scrubber and sold to the food processing industry for use in carbonated beverages and flash-freezing applications.

The stillage from the bottom of the distillation columns contains solids from the grain and added yeast as well as liquid from the water added during the process. It is separated via centrifuge into thin stillage (a liquid with 5–10% solids) and wet distillers grain.

Some of the thin stillage is routed back to the cooking tanks as makeup or "backset" water, reducing the amount of fresh water required by the cooking process. The rest is sent through a multiple-effect evaporation system where it is concentrated into a condensed distillers solubles or "syrup" containing 25–50% solids. This syrup, which is high in protein and fat content, is then mixed back in with the distillers grain to make wet distillers grains with solubles.

Wet distillers grains with solubles (WDGS) contain most of the nutritive value of the original feedstock (plus added yeast) and can be easily conveyed as a wet cake for transport. As such, WDGS makes an excellent cattle ration for local feedlots and dairies. However, WDGS must be used soon after it's produced because the wet grains spoil easily. Since many ethanol plants are located in areas where there are not enough nearby cattle to utilize all the feed, a portion or all of the WDGS is sent through a drying system to remove moisture and extend the shelf life. The resulting dried distillers grains with solubles (DDGS) are commonly used as a high-protein ingredient in cattle, swine, poultry, and fish diets. Distillers grains are also being researched for human consumption. A schematic of a typical dry-mill ethanol plant is shown below in Figure 1.4-2.

Figure 1.4-2. Dry Milling Process



1.4.1.2 Wet Milling Technology[195]

In wet mill plants, first the corn is soaked or "steeped" in a dilute sulfurous acid solution for 24-48 hours. The steeping process facilitates the separation of the corn kernel into germ, fiber, gluten, and starch.

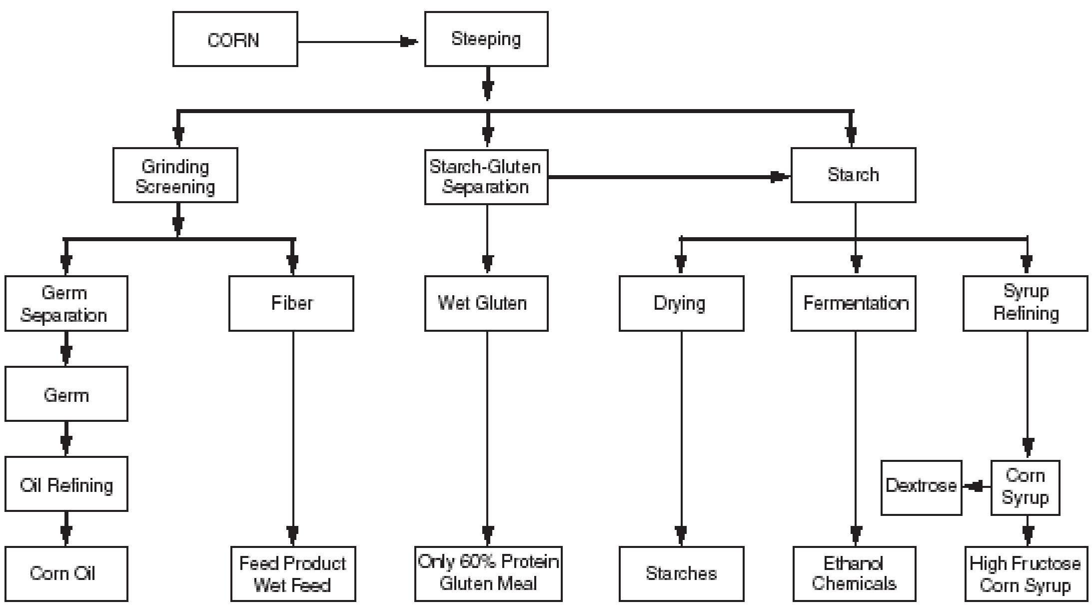
After steeping, the corn slurry is processed through a series of grinders to separate out the germ. The germ is either extracted on-site or sold to crushers who extract the corn oil. The corn oil in its crude state can be sold to the biodiesel or renewable diesel industry. However, most wet mill plants refine the product into food-grade corn oil for use in cooking applications. The remaining fiber, gluten and starch components are further segregated using centrifugal, screen, and hydroclonic separators.

The steeping liquor is concentrated in an evaporator. This concentrated product, heavy steep water, is co-dried with the fiber component and is then sold as corn gluten feed to the livestock industry. Heavy steep water is also sold by itself as a feed ingredient and is used as a component in Ice Ban, an environmentally-friendly alternative to salt for removing ice from roads.

The gluten component (protein) is filtered and dried to produce the corn gluten meal co-product. This product is highly sought after as a feed ingredient in poultry broiler operations.

The starch and any remaining water from the mash is generally processed in one of three ways: fermented into ethanol, dried and sold as dried or modified corn starch, or processed into corn syrup. If made into ethanol, the fermentation process is very similar to the dry mill ethanol production process described above. A schematic of the wet milling process is shown below in Figure 1.4-3.

Figure 1.4-3. Wet Milling Process



1.4.1.3 Advanced Technologies

A number of corn ethanol plants are exploring new technologies with the potential to increase their profits by producing higher value co-products and reducing the ethanol plants energy requirements. Dry fractionation and corn oil extraction seek to recover the oil in the corn kernel for sale in the food, feed, or biodiesel markets. Cold starch fermentation and membranes that reduce ethanol distillation energy requirements are two of several new technologies focusing on reducing the energy usage of ethanol production facilities. Finally a growing number of companies are utilizing alternative boiler fuels and/or incorporating combined heat and power (CHP) technology into their facilities to reduce to plant energy requirements, and in some cases, produce excess power for the grid. The advanced technologies currently being pursed by the corn ethanol industry are described in more detail below.

Dry Fractionation

Dry fractionation is a mechanical separation of the corn kernel into its three component pieces, the germ, bran, and endosperm before fermentation. This separation decreases the amount of non-fermentable material sent through the process and allows each of the components to be processed separately to produce new, higher-value co-products. As shown in Figure 1.4-1, the germ is the small, non-fermentable part of the kernel consisting primarily of protein and oil. Food grade corn oil can be extracted from the germ. After the oil has been extracted, the remainder of the germ can then be blended into the DGS to increase its protein content. The bran, or pericarp, is the protective outer covering of the kernel. The bran can be sold as cattle feed, human fiber additive, or corn fiber. It can also be burned to reduce the amount of coal or natural gas required for ethanol production. The endosperm, which contains approximately 98% of the starch, and is the only fermentable portion of the kernel, is sent to the fermentation vessels. Decreasing the amount of non-fermentable materials (germ and bran) in the process has many beneficial effects, including increasing the production capacity of the plant, decreasing the energy required to dry the DGS, and potentially decreasing the enzyme requirement of the plant by up to 30%.

While the production capacity of the plant increases with the addition of dry fractionation, the amount of corn used to produce a gallon of ethanol increases by approximately 2-3% due to starch loss in the fractionation process. Dry fractionation is also a capital intensive process, costing an estimated $35 million to add to an existing 100 million gallon per year ethanol plant. Dry fractionation is currently able to recover 50% or more of the corn oil contained in the corn kernel. For our economic analyses we have assumed an oil recovery rate of 50% for ethanol plants that use dry fractionation. Several companies, including ICM, Delta-T, and POET currently offer dry fractionation options for new or existing plants.

Corn Oil Extraction[196]

An alternative method to recovering the oil contained in the corn kernel is corn oil extraction. Corn oil extraction is a method of mechanical separation, often by centrifuge, used to extract the crude corn oil from the thin stillage (the non-ethanol liquid left after fermentation), the DGS before it has been dried, or a combination of both. While the corn oil is of a lower quality and value than that produced from corn fractionation, the equipment can be easily added to existing ethanol production facilities and is relatively inexpensive. We estimate that adding corn oil extraction equipment to an existing 100 million gallon per year corn ethanol plant would cost between $5 million and $12 million, depending on the type of equipment used and the percentage of oil recovered. The starch losses associated with dry fractionation do not occur with corn oil extraction as the whole kernel still goes through the fermentation process. The gains in plant capacity and reduced enzyme usage of the dry fractionation process are similarly not realized.

The oil recovered using the corn oil extraction process is distressed oil and cannot be sold as a food grade product. Markets for this product do exist, however, as an additive to cattle feed or as a biodiesel feedstock. In addition to generating an additional revenue stream, extracting the corn oil has several other benefits for the ethanol producer. Because the oil is an insulator, removing it improves the heating efficiency of the DGS dryers and reduces the energy demand of the ethanol plant. Reducing the oil content of the DGS also improves its flowability and concentrates its protein content. The de-fatted DGS is potentially more marketable than DGS containing corn oil, as higher quantities may be able to be included in the diets of poultry and swine. Several ethanol producers are currently using corn oil extraction technology and have reported oil recovery rates of greater than 33%. Technology providers have indicated that in the near future they expect to be able to extract up to 75% of the oil contained in the kernel. For our economic analyses we have assumed that by 2022 ethanol production plants using oil extraction technology will be able to extract 66% of the oil in the corn.

Cold Starch Fermentation[197198]

POET Biorefining, the United States' largest corn ethanol producer[23], has developed a cold starch fermentation process that uses raw-starch hydrolysis to convert starch to sugar, which then ferments to ethanol without heat. The patent-pending POET technology eliminates the cooking process that has been part of ethanol production for years. According to POET, the BPX™ process not only reduces energy costs, but also releases additional starch for conversion to ethanol, increases protein content and quality of co-products, increases co-product flowability, potentially increases plant throughput, and significantly decreases plant emissions. The benefits of the process include reduced energy costs, increased ethanol yields, increased nutrient quality in the distillers grains and decreased plant emissions. At least 20 POET plants currently utilize the BPX™ cold starch fermentation technology. According to POET, the BPX™ process, which yields 20% ethanol in fermentation, increases theoretical ethanol yields from the industry standard of 2.7 gallons of ethanol per bushel of corn up to 3 gallons per bushel. POET also recently announced that it was funding a research collaboration with Iowa State University to help improve the efficiency of the BPX™ process.

As with any new process there are several potential drawbacks to cold starch fermentation. Because heat is not used to aid in the hydrolysis of starch, more enzymes may be required. These additional enzymes may cost the ethanol producer more than $500,000 per year for a 100 million gallon per year plant. An additional benefit of the cooking process is that it sterilizes the starch slurry before fermentation, killing microorganisms and neutralizing toxins that are often contained in the corn. Without this step, the microorganisms may compete with the yeast, lowering ethanol yields. Toxins may pass through the process to the DGS and cause problems with the animals that eat it. One way to minimize these problems is to treat the starch slurry with antibiotics, however recently this practice has been criticized for contributing to antibiotic tolerant or resistant bacteria. Any ethanol producer considering using cold starch fermentation must first determine whether the potential gains in ethanol yields and energy savings outweigh these risks.

[23] At the time of our November 2009 plant assessment. For more information, refer to Section 1.5.1.1.

Membrane Replacement

Several companies are currently working to produce commercially viable polymeric membranes that could potentially reduce the energy used in distillation and eliminate the need for molecular sieve units currently used in most ethanol plants. One such company, Vaperma, has partnered with GreenField Ethanol to prove the viability of its Siftek™ technology. Siftek™ membranes have been successfully installed in GreenField's Tiverton, Ontario demonstration plant and are scheduled to be installed in their Chatham, Ontario plant, which produces 187 million liters of ethanol per year, by the end of 2008. Vaperma claims its Siftek™ membranes are capable of producing a fuel grade ethanol product from an ethanol/water mixture that contains as much as 60% water. These membranes would replace the rectifier unit as well as the molecular sieves used in a conventional ethanol plant, potentially reducing the energy consumption of the ethanol dehydration process by up to 50%. Another way for these membranes to be used is to treat the ethanol/water vapor collected when the molecular sieve units are regenerated. This stream is usually recycled to the rectifier and makes up approximately one third of the feed to the rectifying column. Using Siftek™ technology to treat this stream reduces the feed to the rectifier, reducing energy consumption and increasing production rate by 20% or more. While membrane replacement technology has the potential to significantly reduce the energy demands of an ethanol plant, they are likely at least a couple of years from being commercially available. It is not expected that membrane replacement units would be retrofitted into existing plants due to the significant capital costs. These two factors will effectively limit the use of membrane separation units to new ethanol plants built in 2010 or later.

An alternative method of membrane replacement is to use ethanol-permeating membranes to eliminate the need for the beer column, followed by a water-selective membrane for final dehydration. Eliminating the need for the beer column as well as the rectifier and molecular sieve units would significantly reduce the capital costs of an ethanol plant, as well as lowering the energy requirements of ethanol separation. While this technology has the potential to significantly lower the cost and energy demands of an ethanol plant, it is highly unlikely that it will be available for near term commercialization. It has therefore not been considered section 1.5.1.3 on the forecasted growth of advanced ethanol technologies.

Combined Heat and Power[199]

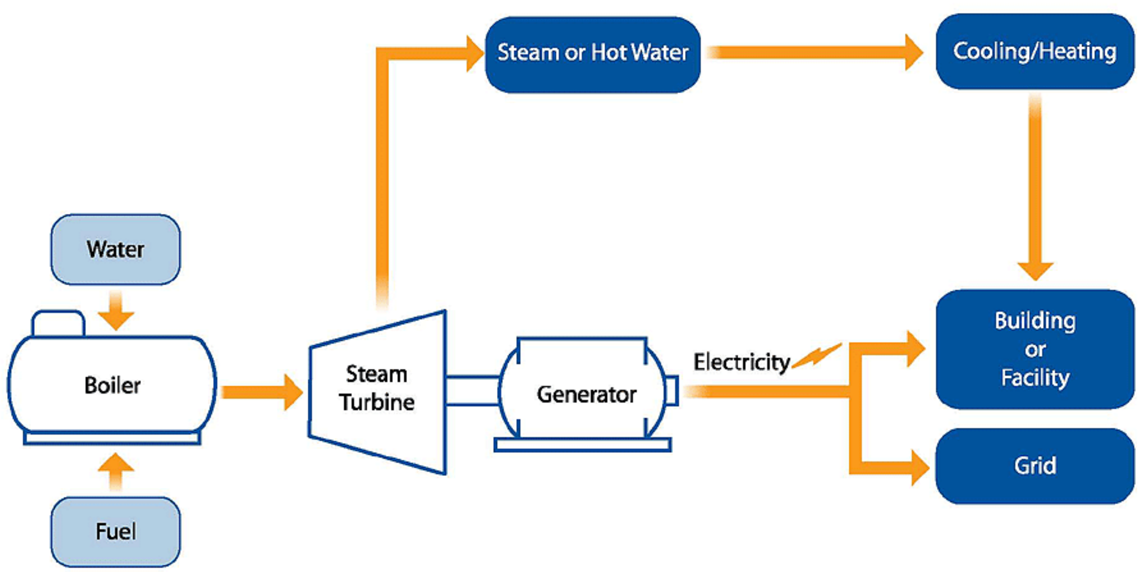
Ethanol production is a relatively resource-intensive process that requires the use of water, electricity, and steam. In most cases, water and electricity are purchased from the municipality and steam is produced on-site using boilers fired by natural gas, coal, or in some cases, alternative fuels (described in more detail below).[24] However a growing number of ethanol producers are pursuing combined heat and power (CHP) technology. CHP, also known as cogeneration, is a mechanism for improving overall plant efficiency by using a single fuel to generate both power and thermal energy. The most common configuration in ethanol plants involves using the boiler to power a turbine generator unit that produces electricity, and using waste heat to make process steam. In some cases, the generator produces excess electricity that can be sold to the grid. While the thermal energy demand for an ethanol plant using CHP

[24] Some plants pull steam directly from a nearby utility.

technology is slightly higher than that of a conventional plant, the additional energy used is far less than what would be required to produce the same amount of electricity in a central power plant. The increased efficiency is due to the ability of the ethanol plant to effectively utilize the waste heat from the electricity generation process.

The CHP system can be owned and operated solely by the ethanol plant, or jointly operated with the local utility company. In these cases it is common for the utility company to purchase the generator and to split the cost of the generator fuel with the ethanol plant. The utility company receives the electricity produced, while the ethanol plant uses the waste heat. These arrangements reduce the energy costs for both parties, as well as reducing the green house gas emissions that would be produced by operating the generator and boiler separately. An illustration of the more common CHP configuration typically seen in ethanol plants is shown below in Figure 1.4-4. Grants are available for industries looking to use CHP at both the state and national level. These grant programs will likely encourage a greater adoption of CHP among ethanol producers than would have otherwise been expected. We project that 26% of ethanol plants will use CHP in the future under the RFS2 program. For more information, refer to Section 1.5.1.3.

Figure 1.4-4. Steam Boiler with Steam Turbine



Alternative Boiler Fuels

In addition to CHP (or sometimes in combination), a growing number of ethanol producers are turning to alternative fuel sources to replace traditional boiler fuels (i.e., natural gas and coal), improve their carbon footprint, and/or become more self-sustainable. Alternative boiler fuels currently used or being pursued by the ethanol industry include biomass (wood and other organic feedstocks), co-products from the ethanol production process (bran, thin stillage or syrup), manure biogas (methane from nearby animal feedlots), and landfill gas (generated from the digestion of municipal solid waste). One potential alternative boiler fuel is biogas produced by the anaerobic digestion of the stillage in the ethanol production process. Sending the stillage to an anaerobic digester rather than drying it and selling it as DGS would produce sufficient biogas to exceed the energy requirements of the ethanol production facility. Excess methane could be sold to provide an additional revenue stream, however all revenue from DGS sales would be lost. Whether or not these systems are adopted in the future is likely to be dependent on the relative prices of electricity, natural gas, and DGS, as well as the capital costs of these systems.

For a breakdown of current and near-term[25] utilization of CHP technology and alternative boiler fuels, refer to Sections 1.5.1.1 and 1.5.1.2. For our 2022 projections of the potential utilization of these and other advanced technologies, refer to Section 1.5.1.3.

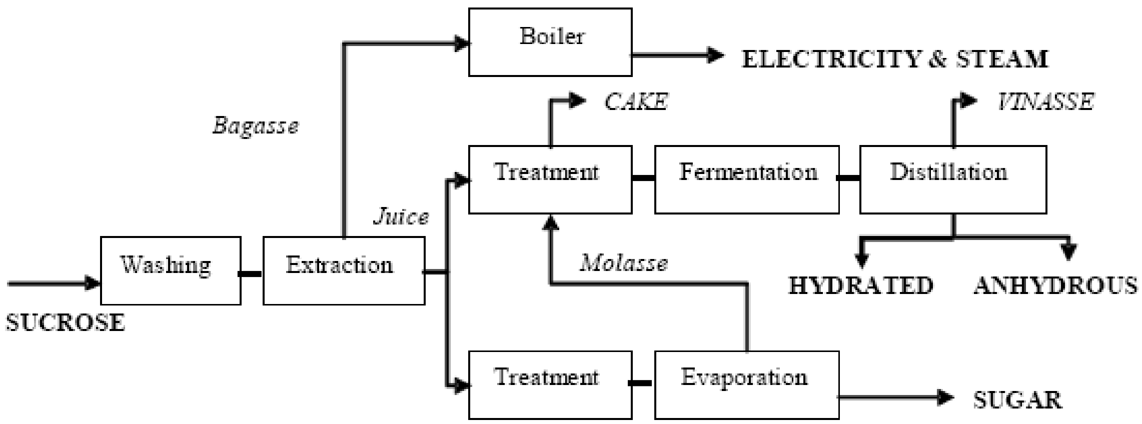
1.4.2 Ethanol from Sugarcane Juice and Molasses

The production of ethanol from sugarcane juice or molasses is the least complicated method to use biomass to produce ethanol since sugarcane contains six-carbon sugars that can be directly fermented. This is currently the method used to produce ethanol in Brazil. In contrast, starch or cellulosic feedstocks require additional steps before sugars are released for use in the fermentation step.

In the production of sugarcane ethanol and sugar from sugarcane juice or molasses, the cane stalks are shredded and the juice is extracted across tandem mills or a diffuser. The juice contains most of the soluble sugars and the leftover sugarcane fiber is bagasse. Next, the cane juice is filtered then heated and limed to precipitate impurities during the clarification process. The resultant clarified juice is then concentrated across an evaporation station (14-16°Brix up to 65°Brix). The syrup produced is then further evaporated in vacuum pans and seed crystallized, leading to a mixture of sucrose crystals surrounded by molasses with a concentration of 91-93°Brix. The sugar crystals and molasses are subsequently separated by centrifugation. In ethanol production in Brazil, the sugars in the juice are fermented into ethanol by the addition of yeast. Fermentation varies from 4-12 hours, with ethanol yields ranging from 80-90%. The fermented mixture is then distilled to produce hydrous (96 % ethanol) or anhydrous ethanol (99.7 % ethanol). The production of anhydrous ethanol is done by addition of cyclohexane or by the use molecular sieves. See Figure 1.4.5 for a diagram of the sugarcane ethanol and sugar production process.[200] The production of sugar (for food and export) or ethanol depends on the supply and demand changes for both products.

[25] Based on current company plants.

Figure 1.4-5. Simplified Overview of Sugarcane Ethanol and Sugar Production Process



In addition to ethanol, sugarcane also yields trash, bagasse, filter cake mud, and vinasse. These by-products are described below:

Trash (Leaves and Tops)

The tops, brown and green leaves of sugarcane are commonly referred to as trash. Sugarcane trash in Brazil is not currently harvested (it is typically burned in the field); however, it is anticipated to be collected for use in the future (i.e. 2020 and beyond) since the burning of sugarcane in Brazil is being phased-out and there is an increased mechanization of harvesting sugarcane. In the U.S., sugarcane trash is currently mechanically harvested and delivered to the factory with stalks. The collection and use of trash at the sugarcane ethanol facility is beneficial as greater electricity can be produced and potentially sold to the grid.

Bagasse

Bagasse is the fibrous material left over after juice is extracted from the crushed stalk of the sugarcane plant. It mainly consists of hemicellulose, cellulose and lignin valued mainly for its use to produce steam for electricity. U.S. factories and other industrial units have used bagasse mainly for steam production, but a few are producing electricity (co-generation) as well. In Brazil, most facilities are able to produce more energy than needed and have exported excess electricity to the grid. This is further discussed in Chapter 2 in the lifecycle section, as surplus electricity production displaces primarily fossil-based electricity production.

Filter Cake Mud

Filter cake is the dried, leftover solid material from precipitated mud after sugarcane juice clarification (via lime addition) at the facility. It is sometimes reapplied to sugarcane fields as a fertilizer.

Vinasse

Vinasse is the liquid waste product from the ethanol distillation process. It is rich in minerals, organic material, and water. Some countries are allowed to spray vinasse on sugarcane crops as fertilizer. For instance, it is produced and used throughout the harvest in Brazil but is not allowed in the U.S. Environmental legislation prohibits inappropriate disposal of vinasse into rivers, lakes, the ocean, and soils.

1.4.3 Cellulosic Biofuel

The following sections contain descriptions of cellulosic ethanol and cellulosic diesel production technologies. Section 1.4.3.1 introduces the two primary pathways for the production of cellulosic ethanol, through biochemical and thermochemical processes while Section 1.4.3.2 discusses cellulosic diesel which is produced through thermochemical processes. We end the section with specific company descriptions of cellulosic biofuel technologies and briefly describe how they differ from generic process discussions.

1.4.3.1 Cellulosic Ethanol

Cellulosic biomass has long been recognized as a potential source of mixed sugars for fermentation to fuel ethanol. The Germans may have been one of the earliest to try commercializing a process to produce ethanol from a cellulosic feedstock, probably from wood in the late 1890s. They used dilute acid to hydrolyze the cellulose to glucose and xylose, but were able to only produce a little less than 20 gallons per ton of feedstock; they soon improved the process enough to generate yields of around 50 gallons per ton. Eventually, two commercial-sized plants that used dilute sulfuric acid hydrolysis were constructed in the U.S. Lumber production decreased following World War I, which resulted in the closing down of cellulosic plants.[201, 202] Although corn-grain ethanol was used in the early 20th Century, especially by high-performance race cars and as an additive to raise gasoline octane, petroleum-derived gasoline eventually replaced it as the primary fuel for automobiles and light-duty trucks. From the early 1970's and up through the present, ethanol from corn, has been increasingly used as a fuel; however, recently, ethanol from cellulose is being viewed with increasing interest.

Several processing options are currently available to convert cellulosic biomass into ethanol. These conversion technologies generally fall into two main categories: biochemical and thermochemical. Biochemical conversion refers to the fermentation of sugars liberated from the breakdown of biomass feedstock. Thermochemical conversion includes the gasification and pyrolysis of biomass material into a synthesis gas or liquid oil for subsequent fermentation or catalysis. The main benefit of gasification/pyrolysis over the biochemical route is that thermochemical processes can more easily convert low-carbohydrate or "non-fermentable" biomass materials such as forest and wood residues to alcohol fuels and can more readily accept a wider variety of feedstocks.[203] However, the thermochemical process does have some drawbacks, such as tar production and clean-up gas procedures that require additional capital investment.

Since commercial production of cellulosic ethanol has not yet begun, it is unclear which process options will prove most viable or whether additional variations will emerge. At least in the near future, there have been plans to build both stand-alone biochemical and thermochemical ethanol processing plants. In addition, some investors are currently supporting research and development in both cellulosic processing procedures, neither choosing one conversion over the other.[204] The following subsections describe the process steps, current challenges, and targeted areas for improvement for each conversion method.

1.4.3.1.1 Biochemical Conversion

Unlike grain feedstocks where the major carbohydrate is starch, lignocellulosic biomass is composed mainly of cellulose (40-60 %) and hemicellulose (20-40 %). The remainder consists of lignin, a complex polymer which serves as a stiffening and hydrophobic (water-repelling) agent in cell walls.[205] Cellulose and hemicellulose are made up of sugars linked together in long chains called polysaccharides. Once hydrolyzed, they can be fermented into ethanol. Currently, lignin cannot be fermented into ethanol, but could be burned as a by-product to generate electricity.

Both starch (corn grain) and cellulosic feedstocks must be hydrolyzed prior to fermentation. Structural differences at the molecular level make it far more difficult, and therefore more costly, to hydrolyze cellulosic biomass than it is to hydrolyze starch. Glucose, $C_6H_{12}O_6$, the repeating monomer in both starch and cellulose, is a six-sided ring, similar in conformation to the classic 'chair' conformation of cyclohexane or benzene, except one carbon atom in the ring is replaced by an oxygen atom. For uniformity (and ease) of discussion, it is generally assumed that the first carbon atom next to the oxygen, is carbon #1; the numbering, 2-5, continues around the ring with oxygen in the 6th position; one of the four bonds of the fifth carbon atom is attached to the oxygen atom to complete the ring, one is attached to hydrogen atom and the fourth to a -CH_2OH group. Thus, a glucose molecule/monomer is a six-sided molecule, but not a six-carbon ring (although there are six-carbon molecules present, one of which is in the –methylhydroxy group).

The main difference between starch and cellulosic plant matter is that starch polysaccharides are made up of α-glucose monomers, uniformly strung together by α-linked 1,4-glucosidic bonds whereas cellulosic polysaccharides are made up of β-glucose monomers, strung together through β-linked 1,4-glucosidic bonds. In starch with the α-conformation, the hydroxyl group on carbon #1 is in the axial or α-position, which causes the -OH's on each successive glucose monomer to end up on the same side of the polymer. There are also 1,6-linked glucose branches that occur irregularly on approximately one in twenty-five glucose units.[206] The -OH groups on the same side of the polymer, along with the randomly attached 1,6-glucose branches, leaves starch polymers relatively weak, flexible, and able to easily wrap and twist together to form tiny granules (e.g., common, everyday corn starch),

Cellulosic polysaccharides are in the β-conformation with the hydroxyl group on carbon #1 is positioned away from the ring, in the equatorial or β-position, which causes the -OH's on each successive glucose monomer, added to the chain, to end up on opposite sides of the polymer. The hydroxyl groups lined up evenly and uniformly along opposite sides of each polymer strand allow intra-molecular hydrogen bonds to develop within each monomer. They also allow inter-molecular hydrogen bonds to develop between adjacent polymers to form tight, rigid, strong, mostly straight polymer bundles called microfibrils that act as the core constituent in the formation of plant cell walls that are also insoluble in water and resistant to chemical attack. The β-conformation and the resulting hydrogen bonds stabilize the glucose chair structure to help minimize the polymer's flexibility (which hinders hydrolysis) and to add to its strength.

The second cellulosic component is called hemicellulose. It consists mainly of a random mixture of highly branched and heavily substituted five- and six-carbon rings. The five-carbon residues are usually D-xylose and L-arabinose; the six-carbon residues are usually D-galactose, D-glucose, and D-mannose, and uronic and acetic acid. Hemicellulose is not as rigid or strong as cellulose, but does contribute additional strength and helps protect the plant cell wall against attack by microbes or water. Hemicellulose is relatively easy to hydrolyze, due to its highly branched, somewhat random or non-uniform structure.

Lignin, the third principle component, is a complex, cross-linked polymeric, high molecular weight substance derived principally from coniferyl alcohol by extensive condensation polymerization. Covalently bonded to the hemicellulose, it is essentially a glue-like polymer that covers the cellulose and hemicellulose polymer cell walls and helps hold them together, provides additional strength, helps resist microbial decay, and perhaps most importantly, for this discussion, inhibits hydrolysis. Its molecular weight is around 10,000.[207] While both cellulose and hemicellulose contribute to the amount of fermentable sugars for ethanol production, lignin does not, but can be combusted to provide process energy in a biochemical plant or used as feedstock to a thermochemical process.[208]

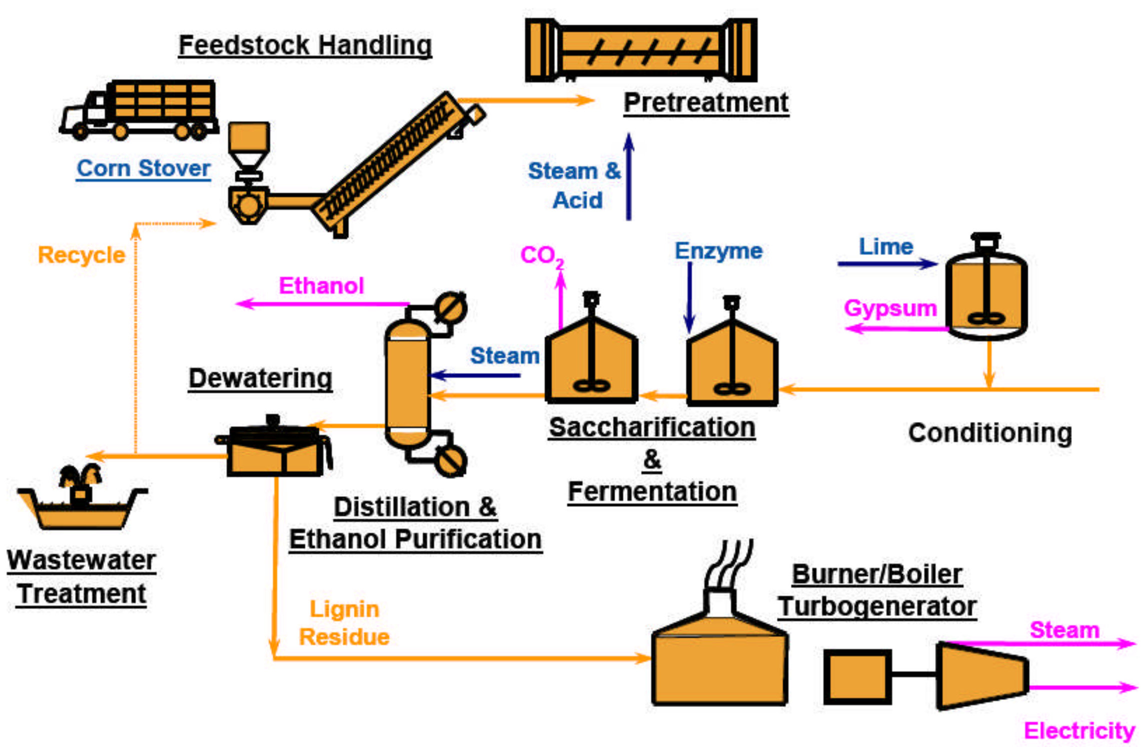
To review, a significant part of the reason it is more difficult and more costly to produce ethanol from cellulosic feedstocks, has to do with the differences in the molecular structures of simple starch and those of cellulosic plant matter. That is, as a plant grows, glucose monomers are added to the polysaccharide chains of the plant cell walls through condensation reactions. In general, condensation is a chemical process by which two molecules are joined together to make a larger, more complex molecule, and a molecule of water is a byproduct of the reaction. In the formation of polysaccharides, and enzyme catalyzes the reaction wherein the -OH group on carbon #1 of one monomer, or glucose residue, reacts with the -OH on carbon #4 or #6 of another residue. An H-OH (H_2O or water) molecule is removed leaving an -O- that links the monomers together to form the polysaccharide chain. Again, depending on the direction of the –OH group at carbon 1, it may be called an alpha (as in starch) or a beta (as in cellulose) linkage.[209]

Hydrolysis is the reverse reaction. The -H from an H-OH (water) molecule is added to one monomer and the remaining -OH is added to its pair, e.g., to the next monomer on the chain, to regenerate separate glucose monomers. During starch hydrolysis, water and water borne hydrolyzing enzymes can easily penetrate the randomly formed polymers (the tiny granular particles or bundles) in order to break the bonds to release glucose monomers. However, the cellulosic or glucan polymers formed in tightly packed, dense, rigid microfibrils are especially resistant to water and hydrolyzing enzymes. Xylan, the main constituent of hemicellulose, is more easily hydrolyzed than cellulose, but not easily fermented. Cellulose is not easily hydrolyzed, but readily ferments into alcohol. These are two of the major problems that must be satisfactorily resolved for biochemical conversion of cellulosic feedstocks.

Biochemical conversion processes typically use dilute acid with enzymes or concentrated acid to convert cellulosic biomass to sugar for fermentation to ethanol. Concentrated acid hydrolysis is fairly well developed and is being pursued to commercialization in certain niche situations. For example, concentrated acid hydrolysis is suitable for feedstocks such as municipal solid wastes which have largely heterogeneous mixtures.[210] Concentrated acid hydrolysis is typically much faster than enzymatic approaches, albeit at the cost of reduced sugar yields due to undesirable side reactions.[211] Enzymatic hydrolysis is mostly suitable for homogeneous mixtures because specific enzymes are needed to convert a given type of feedstock. The cost to enzymatically hydrolyze cellulose is expected to decline significantly as these technologies continue to improve.[212]

In general, steps of the biochemical process include: feedstock pretreatment, hydrolysis, saccharification and fermentation, ethanol dehydration, and lignin recovery. Refer to Figure 1.4-6 for an illustration of the enzymatic biochemical production process. We used NREL's study as a guide to describe, somewhat generically, how such a process might work. Refer to the NREL technical documents for greater detail.[213,214]

Figure 1.4-6.
Cellulosic Ethanol Biochemical Production Process (Enzymatic)



Stage 1 – Feedstock Pretreatment

Lignocellulosic biomass must undergo at least some pretreatment prior to hydrolysis. During the early years of cellulosic ethanol production (e.g., 2010 to 2015), we anticipate that this stage will likely occur within the facility. In the out years covered by this rule (2022) we believe that this stage may be moved outside the plant gate (e.g., upstream of the ethanol plant) to reduce transportation costs that are typically high due to the low density of this type of biomass. The biomass is pretreated with either a physical or chemical pretreatment method to help the polysacharides become more accessible to hydrolysis. Studies have shown a direct correlation between the removal of lignin and hemicellulose and the digestibility of cellulose.[215]

Physical pretreatment nearly always includes size reduction by some type of grinding, shredding, or chopping. For example, in order to biochemically process wood chips, e.g., poplar trees or willows, the chips must be reduced in size to 1-mm or less in order to increase the surface area for contact with acid, enzymes, etc. Breaking up a 5-in tree stem into 1-mm pieces would consume a large amount of energy. On the other hand, corn stover chips for a biochemical process can range up to a maximum size of 1.5 inches.[216]

Chemicals are also used for pretreatment. The most common chemical pretreatment methods for cellulosic feedstocks are dilute acid, hot water, alkaline, organic solvent, ammonia, sulfur dioxide, carbon dioxide, or other chemicals to make the biomass more digestible by the enzymes.[217,218] These chemicals cause the biomass to react quite differently.[219] For example, instead of hydrolyzing the hemicellulose (as in acidic pretreatments), an alkaline approach tends to leave the hemicellulose and cellulose intact. Enzymes are therefore required to digest both hemicellulose and cellulose at the same time when a basic pretreatment is used.

Different pretreatment approaches also affect the amounts of degradation products (e.g. furfurals, acetates) that occur from the decomposition of hemicellulose and lignin. This is important since these degradation products can inhibit microorganisms in the fermentation step. A well known pretreatment method that does not degrade biomass sugars or produce fermentation inhibitors is ammonia fiber expansion (AFEX). During AFEX, liquid ammonia is added to the cellulosic material followed by a rapid pressure release.

Each type of feedstock, whether softwoods, corn stover or bagasse, requires a particular combination of pretreatment methods to optimize the yields of that feedstock, minimize the degradation of the substrate, and maximize the sugar yield. Pretreatment of cellulosic biomass in a cost-effective manner is a major challenge of cellulose-ethanol technology research and development.[220] For more information on feedstock considerations and their impacts on biorefining refer to the NREL report completed for the final rule.[221]

Stage 2 – Pretreatment and Hydrolyzate Conditioning

NREL refers to this stage as a combination of pretreatment and hydrolysis. In their process flow diagram, the washed and sized-reduced feed is directly heated with steam and mixed with dilute sulfuric acid. The process converts, primarily, the hemicellulose polysaccharides xylan, mannan, arabinan and galactan, to produce the mixed sugars and further helps prepare the cellulose for hydrolysis. A small amount of glucan in the hemicellulose and in the cellulose is converted into glucose. The rundown from the acid hydrolysis reactor is fed to a blowdown tank that subsequently feeds a filter press. The filter press produces two main streams, a filter cake and a liquid filtrate, also called hydrolyzate. The filter cake carries the unhydrolyzed portions of the feed (e.g., glucans) among other insolubles, while the liquid carries that part of the feed that was hydrolyzed, mainly the xyloses.

The liquid portion is neutralized to remove gypsum and other contaminants that would be toxic to downstream enzymes. The cake is washed, mixed back with the detoxified liquid hydrolyzate, and fed to the saccharification reactors to hydrolyze the glucan polysaccharides.

Stage 3 – Saccharification and Co-Fermentation

We should point out that this is not 'Simultaneous Saccharification and Fermentation' (SSF). Saccharification, in the process we're discussing, takes place primarily in several reactors along with other intermediate treatments such as filtering and detoxifying. Using a cellulase enzyme cocktail, saccharification of the cellulose to glucose occurs first at an elevated temperature to take advantage of increased enzyme activity, which reduces the quantity of required enzyme as well as the reaction time.

The cellulase enzymes used to convert cellulose to sugars can be obtained in two ways. The first option is for a plant to produce it on-site. The second option requires the plant to purchase the enzymes from off-site enzyme manufacturers. Due to a joint research effort by DOE, Genencor International, and Novozymes Biotech, the cost for production of cellulase enzymes has been drastically reduced. Such research and development in areas of enzyme production have reduced the cost of cellulolytic enzymes by a factor of 10 to 30, down to 20 to 30 cents per gallon of ethanol produced.[222,223,224] It is estimated, however, that enzyme costs will have to be further reduced to a level comparable to those used to produce ethanol from corn grain at a cost of 3 to 4 cents per gallon of ethanol. The current challenge is to develop the correct enzyme "cocktails" to reflect differences in the physical and chemical characteristics of all the various types of cellulosic materials. It may be easier, therefore, to process single feedstocks (more homogeneous) rather than multiple feedstocks, in which variations are more likely.

Following cellulose saccharification, both the glucose and xylose sugars are co-fermented. Although xylan, the hemicellulose polysaccharide, is more easily hydrolyzed than glucan (cellulose polysaccharides), the xylose sugar is more difficult to ferment than is the glucose sugar. Different microbes as well as different residence times and process conditions may be required for each.

Because xylan can make up as much as 25% of plant matter it is imperative that as much of it as possible be fermented; the economic viability of biochemically produced ethanol depends heavily on it. This continues to be high on the list of challenges researchers are working on, but good progress has been made toward fermenting a higher percentage of xylose during the past few years.[225]

Stage 3A – Consolidated Bioprocessing e.g., Simultaneous Saccharification and Fermentation (SSF)

During the past few years, researchers have been looking for ways to combine saccharification and fermentation into a single step through the use of enzyme/microbe cocktails. If successful, we expect there could be significant capital cost savings in that fewer reactors and other support equipment and piping would be necessary. Also, it may be possible to reduce processing times if hydrolysis reactions can take place simultaneously, rather than sequentially. Such strategies are known as consolidated bioprocessing (CBP). CBP, however, is currently hampered by the relative inability of yeast to process recombinant cellulases (enzymes that help convert cellulose to sugars), and the relative lag in the development of molecular biological methods to manipulate organisms that secrete cellulases naturally.[226]

Stage 4 – Ethanol Dehydration

NREL's process model indicates that the fermentation reactor rundown stream, now called 'beer,' runs down the beer column feed surge tank. The beer column feed consists of about 83% water and only 5.5% ethanol; the balance of the mixture is very complex, but consists mostly of lignin. The beer column removes the dissolved CO_2 overhead and produces a water/ethanol bottom stream that is fed to a rectification column. According to NREL's model, the rectification column bottoms would be mostly water with about 0.05% ethanol that's recycled back to the process. The rectification column overhead that consists of about 92.5% ethanol and 7.5% water, is fed to a molecular sieve that produces a 99.5 wt.% ethanol product stream with about 0.5 wt.% water. Gasoline, a denaturant, is added to produce ethanol fuel.

Stage 5 – Lignin Recovery

Following the saccharification and fermentation of the xylan and glucan to ethanol, the lignin is gradually concentrated with other solids into a moist cake-like product that is about 48% insoluble solids. About 80% of the 48% insoluble solids is essentially lignin microbial cells, and other unconverted biomass remnants, (e.g., cellulose, xylose, glucan, xylan, other oligomers, etc.,) from the process. This material can be either combusted to provide process heat for the biochemical operation for a co-located starch ethanol plant, or as we discuss in the following section, could be used as feedstock for a thermochemical unit.

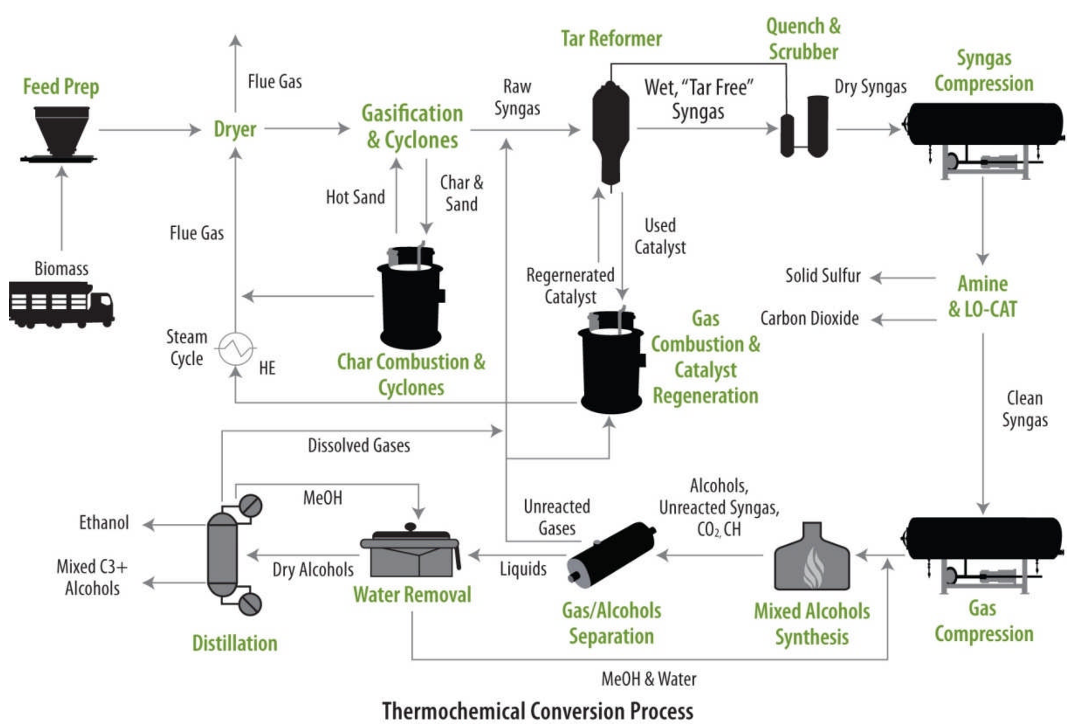
1.4.3.1.2 Thermochemical Conversion

Thermochemical conversion involves biomass being broken down into intermediates using heat and upgraded to fuels using a combination of heat and pressure in the presence of catalysts.[227] Thermochemical processes include pyrolysis (absence of oxygen), gasification (partial oxidation in the presence of a gasifying agent, usually air, oxygen, and/or steam), and combustion (complete oxidation). The former two conversion processes, pyrolysis and gasification, can be used to convert biomass into energy carriers for transportation use. It is important to note that these processing steps are also applicable to other feedstocks (e.g., coal or natural gas); the only difference is that a renewable feedstock is used (i.e. biomass) to produce cellulosic biofuel. A thermochemical unit can also complement a biochemical processing plant to enhance the economics of an integrated biorefinery by converting lignin-rich, non-fermentable material left over from high-starch or cellulosic feedstocks conversion.[228] We discuss the gasification and pyrolysis processes below.

Gasification

Compared to corn ethanol or biochemical cellulosic ethanol plants, the use of biomass gasification may allow for greater flexibility to utilize different biomass feedstocks at a specific plant. Mixed biomass feedstocks may be used, based on availability of long-term suppliers, seasonal availability, harvest cycle, and costs. Agricultural residue, energy crops, wood residues, and municipal solid waste are all being considered as potential feedstocks. Geographic location, availability of biomass, the existence of biomass suppliers, and costs would all likely influence the mix of biomass feedstocks utilized. The general steps of the gasification thermochemical process include: feedstock handling, gasification, gas cleanup and conditioning, fuel synthesis, and separation. Refer to Figure 1.4-7 for a schematic of the thermochemical cellulosic ethanol production process through gasification. For greater detail on the thermochemical mixed-alcohols route refer to NREL technical documentation.[229]

Figure 1.4-7.
Cellulosic Ethanol Thermochemical Gasification Process



Stage 1 – Feedstock Handling

The particle size requirement for a thermochemical process is around 10-mm to 100-mm in diameter.[230] Once the feed is ground to the proper size, flue gases from the char combustor and tar reformer catalyst regenerator dry the feed from the as received moisture level of around 30% to 50% moisture to the level required by the gasifier.

Stage 2 – Gasification

There are two general classes of gasifiers. First, partial oxidation (POx) gasifiers (directly-heated gasifiers) use the exothermic reaction between oxygen and organics to provide the heat necessary to devolatilize biomass and to convert residual carbon-rich chars. In POx gasifiers, the heat to drive the process is generated internally within the gasifier. A disadvantage of POx gasifiers is that oxygen production is expensive and typically requires large plant sizes to improve economics.

The second general class, called indirect gasification, uses steam gasifiers to accomplish gasification through heat transfer from a hot solid or through a heat transfer surface. Either the byproduct char and/or a portion of the product gas can be combusted with air (external to the gasifier itself) to provide the energy required for gasification. Although steam gasifiers have the advantage of not requiring oxygen, most operate at low pressure and therefore require product gas compression for downstream purification and synthesis unit operations.[231,232]

There are different subcategories of gasifiers which are either directly or indirectly heated. One subcategory is termed a bubbling fluidized bed gasifier and it employes a bubbling fluidized bed of inert material and the reactant (biomass) is also bubbled through the fluidized bed. A second variant is the circulating fluidized bed gasifier which is similar to the bubbling fluidized bed reactor except that a high feedstock and air flow rate circulates the fluidized bed out of and back into the reactor. For the fluidized bed, the bed material may either be inert alumina or sand which helps the heat transfer. There are also fixed bed reactors which either feed the reacting gas (oxygen or air) upward or downward through a fixed bed of the reactant (biomass). Because of the tar formed when using biomass as a feedstock, a second reactor is sometimes added which solely targets converting the tar to syn-gas. If the biomas feedstock is ground to a sufficiently small particle size, or liquefied, the biomass is considered to be "entrained" in the reactor, and the reactor is defined as an entrained flow reactor.

Indirect gasification using an entrained flow gasifier is described for this example. The gasification process begins as the biomass is fed to the reactor containing a heat transfer media, such as sand, and is partially reacted with air (or oxygen) which is introduced to the bottom of the reactor. The air serves as the carrier-gas and as the oxidant for partially oxidizing the biomass to syn-gas, carbon monoxide and hydrogen. In addition to the syngas produced, char and coke are also formed. The heat for the endothermic gasification reactions is supplied by circulating heat transfer media (e.g. sythetic sand) between the gasifier and the char combustor. The heat generated by the combustion of the char and coke heats the heat transfer media to over 1800°F. The syngas is separated from the sand and ash and sent to gas cleanup.

Stage 3 – Gas Cleanup & Conditioning

Once the biomass is gasified and converted to syngas, the syngas must be cleaned and conditioned. This raw syngas has a low to medium energy content depending on the gasifying agent and consists mainly of CO, H_2, CO_2, H_2O, N_2, and hydrocarbons. The minor components, tars, sulfur, nitrogen oxides, alkali metals, and particulates have the potential to negatively affect the syngas conversion steps. Therefore, unwanted impurities are removed in a gas cleanup step and the gas composition is further modified during gas conditioning. Gas conditioning steps include sulfur polishing to remove trace levels of H_2S and water-gas shift to adjust the final H_2/CO ratio for optimized fuel synthesis.

Stage 4 – Fuel Synthesis

After cleanup and conditioning, the "clean" syngas is comprised of essentially CO and H_2. The syngas is then converted into a liquid fuel by either a catalytic process or through the use of a microorganism. The fuel producer has the choice of producing diesel fuel or alcohols from syngas by optimizing the type of catalyst used and the H_2/CO ratio. Diesel fuel has historically been the primary focus of such processes, as it produces a high quality distillate product, however, with the 45 cent tax subsidy currently available for ethanol production, it may be economically advantageous for fuel producers to convert syngas to ethanol instead of to diesel fuel. Production of cellulosic diesel is discussed in further detail in the following Section 1.4.3.2.

Conceptual designs and techno-economic models have been developed for ethanol production via mixed alcohol synthesis using catalytic processes. The proposed mixed alcohol process produces a mixture of ethanol along with higher normal alcohols (e.g., n-propanol, n-butanol, and n-pentanol). The by-product higher normal alcohols have value as commodity chemicals and fuel additives. Typically the mixed alcohol products are high in methanol, but contain a wide distribution of several different alcohols. One concept proposed in literature is to completely recycle this methanol in order to increase the production of ethanol and higher alcohols which are generally more valuable. This concept was modeled by NREL for the thermochemical production of ethanol for the year 2012. Total mixed alcohol yield was 94.1 gallons per dry ton, in which 85% of the total alcohol product was ethanol. This was made possible through the addition of an almost complete recycle of methanol within the process.[233] For the final rule, we worked with NREL to develop the thermochemical mixed-alcohols model for the 2015 and 2022 timeframe, as discussed in greater detail in the technical document.[234] The analyses were used to inform us of the materials and energy use for these technologies for our lifecycle analyses discussed in Chapter 2.

In contrast to the catalytic processing of syngas to produce fuels there is also a fermentation process being pursued that utilizes a special microorganism (Clostridium ljungdahlii) to convert the syngas to ethanol.[235] This combined syngas and fermentation process has the benefit of having a significantly faster processing time, on the order of minutes, as compared to the typical biochemical process on the order of days.[236]

Stage 5 – Alcohol Separation

The liquid rundown from the low-pressure separator is dehydrated in vapor-phase molecular sieves, producing the dehydrated mixed alcohol feed into a methanol/ethanol overhead stream and a mixed, higher molecular weight alcohol bottom stream. The overhead stream is further separated into a methanol stream and an ethanol stream.

Heat & Power

A carefully integrated conventional steam cycle produces process heat and electricity (excess electricity is exported). Pre-heaters, steam generators, and super-heaters generate steam that drives turbines on compressors and electrical generators. The heat balance around a thermochemical unit or thermochemical/biochemical combined unit must be carefully designed and tuned in order to avoid unnecessary heat losses.[237]

1.4.3.2 Cellulosic Diesel

Cellulosic diesel fuel tecnologies convert cellulosic feedstocks to diesel fuel. There could be a whole set of technologies which fall in this category including thermochemical and other chemical processes and biochemical processes.

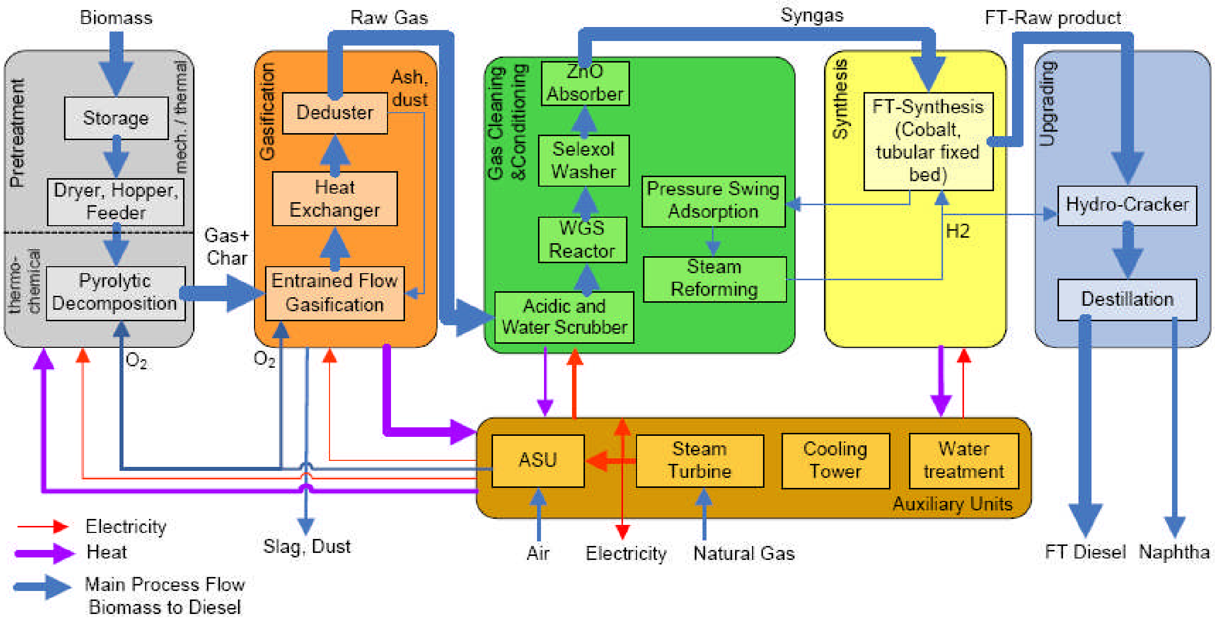
BTL Technology

One important cellulosic diesel fuel technology is a thermochemical process which is also termed biomass-to-liquids (BTL). Like the thermochemical ethanol process described previously, the BTL process produces a syngas from biomass. However, instead of reacting the syngas to alcohol, the syngas is fed to a Fischer-Tropsch (FT) reactor to primarily produce diesel fuel and some naphtha.[238]

The BTL method removes contaminants from the gasification stream prior to the reactions that form the liquid compounds. The resulting liquid fuel is essentially contaminant-free and is very similar to petroleum-based diesel fuel – in fact, its cetane number is higher than petroleum-based diesel fuel making it somewhat better in quality. Thus it can be easily blended with or used interchangeably with petroleum-based diesel fuel.

Figure 1.4-8 is a block diagram of a BTL process.

Figure 1.4-8.
Biomass to Liquids (BTL) Thermochemical Gasification Process



BTL plants, like thermochemical ethanol plants, are capital intensive plants with many subunits associated with them. The first couple of steps of BTL plants, including biomass processing and gasification, are similar to the thermochemical cellulosic ethanol plants described above. However, once the syngas is produced, it is then cooled producing high pressure steam, and is scrubbed to remove particulate matter. Impurities such as mercury, arsenic and trace metals are removed by a sulfur impregnated carbon reactor. The syngas is further treated in either a Selexol or Rectisol unit to remove hydrogen sulfide and concentrated carbon dioxide (CO2). The syngas is sent to a water gas shift reactor (WGS) to which causes a shift to more hydrogen and less carbon monoxide, which is necessary to establish an optimal mix of hydrogen and carbon for the downstream Fischer-Tropsch (FT) reactor.

The cleaned and water-shifted syngas is sent to the FT reactor where the carbon monoxide and hydrogen are reacted over a FT catalyst. The FT catalyst is either iron-based or cobalt-based. The cobalt catalyst is more expensive, although it does not require a recycle, while the less expensive iron catalyst does require a recycle. The FT reactor creates a syncrude, which is a variety of hydrocarbons that boil over a wide distillation range (a mix of heavy and light hydrocarbons). The syncrude from the FT reactor is sent to a distillation column where it is separated into various components based on their vapor pressure, mainly liquid petroleum gas (LPG), naphtha, distillate and wax fractions. The heavier compounds are hydrocracked to maximize the production of diesel fuel. The distillate boiling compounds have high cetane and thus are of high quality for blending into diesel fuel. Conversely, the naphtha material is very low in octane thus, it would either have to be upgraded, or blended down with high octane blendstocks (i.e., ethanol), or be upgraded to a higher octane blendstock to have much value for use in gasoline. The naphtha could also be sold as feedstock for the petrochemical market for manufacturing chemical products such as ethylene and benzene.

The unreacted carbon monoxide and hydrogen and any gaseous hydrocarbon material are burned to produce electricity in a turbine. The waste heat from the gas turbine along with the steam created to cool the syn-gas, may be sent to steam turbines to produce additional electricity. Most of the electricity would be used within the BTL plant, however, some could be sold to raise additional revenues.

Pyrolysis Diesel Fuel and Gasoline

Pyrolysis oils, or bio-oils, are produced by decomposing cellulosic biomass at lower temperatures than the gasification process, thus producing a liquid oil instead of a synthesis gas.[239] The reaction can occur either with or without the use of catalysts, but it occurs without any additional oxygen being present. The oil produced varies in oxygen content or viscosity according to the feedstock used. The oil must have particulates and ash removed in filtration to create a homogenous product and is further upgraded to hydrocarbon fuels via hydrotreating and hydrocracking processing, which reduces its total oxygen content. Some believe that pyrolysis could have a significant economic advantage over other cellulosic ethanol approaches, however, very little has been done in terms of optimizing the process, and as such, there are still many possibilities yet to be explored.[240] One of the finished fuels produced by the pyrolysis process is diesel fuel, however, a significant amount of gasoline would likely be produced as well.

1.4.3.3 Developing Technologies

When evaluating the array of biofuel technologies which could produce one or more fuels that could qualify under RFS2, we found that it is helpful to organize them into fuel technology categories. Organizing them into categories eases the task of understanding the costs and life cycle impacts of these technologies because like technologies likely have similar cost and life cycle impacts. The simplest organization is by the fuel produced. However, we frequently found that additional subdivisions were also helpful. Table 1.4-1 provides a list of technologies, the cellulosic fuels produced and a list of many of the companies which we learned are pursuing the technology (or something very similar to the technology listed in the category).

Table 1.4-1.
List of Biofuel Categories, the Fuels Produced and the Companies Pursuing the Technologies

Technology Category	**Fuels Produced**	**Companies**
Biochemical from Corn Grain	Ethanol	ICM, Delta T, Broin
Biochemical Cellulosic Ethanol	Ethanol	Abengoa, AE Fuels, Cornell Univ., Citrus Energy, DuPont/Danisco, Florida Crystals, Novenzymes, Poet, Western Biomass, ICM, Alltech/Ecofin, IOGEN, Qteros, and Raven Biofuels, BPI, New Age Energy, Universal, Fiberight, KL Energy.
Thermochemical/Catalytic conversion of Cellulose	Ethanol	Range Fuels, Pearson Technologies, Fulcrum Bioenergy, Enerkem, and Gulf Coast Energy.
Thermochemical/Biochemical conversion of Cellulose	Ethanol	Coskata and INEOS Bio.
Strong Acid Hydrolysis of Cellulose/Biochemical	Ethanol	Blue Fire, Arkenol, Pencor, Pangen, Auburn Univ., Agresti.
Dilute Acid, Steam Explosion of Cellulose/Biochemical	Ethanol	Verenium, BP, Central Minnesota Ethanol Coop.
Consolidated Bioprocessing (one step hydrolysis and fermentation) of Cellulose/Biochemical	Ethanol	Mascoma
Biochemical conversion of Cellulose via carboxylic acid	Ethanol, Gasoline, Jet Fuel, Diesel Fuel	Terrabon, Swift Fuels, Zeachem
Thermochemical/Fischer Tropsch	Diesel Fuel and Naphtha	Choren, Flambeau River Biofuels, Baard, Clearfuels, Gulf Coast Energy, Rentech, TRI.
Thermochemical/Fischer Tropsch	DME	Chemrec, New Page.
Catalytic Depolymerization of Cellulose	Diesel, Jet Fuel or Naphtha	Cello Energy
Biochemical conversion of Cellulose	Diesel, Jet Fuel or Naphtha	Bell Bioenergy
Catalytic Reforming of Sugars	Gasoline	Virent
Biochemical conversion of Sugars	Diesel, Jet Fuel or Gasoline	Amyris, Gevo, LS9.
Biochemial of Sugars – converted corn ethanol plants	Isobutanol	Gevo/ICM.
Pyrolysis of Cellulose	Diesel, Jet Fuel, or Gasoline,	Envergent (UOP/Ensyn), Dynamotive, Petrobras, Univ. of Mass, KIOR.
Hydrotreating of Plant Oils	Renewable Diesel Fuel	UOP, Neste, Eni,Conoco-Phillips, Dynamic Fuels (Syntroleum/Tyson).
Fatty Acid Methyl Ester (FAME)	Biodiesel	Many
Free Fatty Acid to Biodiesel	Biodiesel	Endicott
Production of Algae Oils via Photobioreactor or open pond	Algae Oil (Biodiesel or Renewable Diesel Fuel)	Solazyme, Algenol, Aurora Biofuels, Petrosun, Sapphire Energy, Livefuels, Solix, HR Biopetroleum (Cellana), XL Renewables, Petroalgae, Synthetic Genomics, GreenFuel.

Of the technologies listed above, many of them are considered to be "second generation" biofuels or new biofuel technologies capable of meeting either the advanced biofuel or cellulosic biofuel RFS standard. The following sections describe specific companies and the new biofuel technologies which the companies have developed or are developing. This summary is not meant to be an unabridged list of new biofuel technologies, but rather a description of some of the more prominent or interesting of the new biofuel technologies that serve to provide a sense of the technology categories listed above. The process technology summaries are based on information provided by the respective companies. EPA has not been able to confirm all of the information, statements, process conditions, and the process flow steps necessary for any of these processes and companies.

Sugar to Diesel Fuel - Amyris Biotechnologies

The Amyris technology produces hydrocarbon fuels from sugars through biochemical reactions. The technology uses custom designed yeast cells and is modular in design and can be collocated with existing ethanol plants to produce diesel fuel and gasoline.

Amyris's yeast cells are the key drivers of their conversion process. The process uses the same feedstocks that are currently used to make corn starch ethanol, which could be sugar cane or corn grain. Amyris has a 100 gallon per week pilot plant operating in Emeryville, CA, and in mid-2009 has completed construction of a pilot plant as well as a commercial demonstration plant in Brazil to showcase their technology. Amyris intends to convert its own sugar cane mills over with this technology starting in 2011. In 2012, Amyris expects to begin converting sugar cane mills owned by others with its sugar to hydrocarbon technology.

The diesel fuel capable of being produced from the process is compatible with the existing petroleum distribution system and provides better storage and cold flow properties than biodiesel.

Biochemical to Diesel Fuel - Bell Bio-Energy

Bell Bio-Energy has developed a biochemical technology which uses genetically engineered bacteria to convert cellulosic feedstocks directly to synthetic hydrocarbon fuels and compost. Depending on the types of bacteria used, this process can produce specific hydrocarbon types which can either be methane or other light hydrocarbons, gasoline, diesel or jet fuel type hydrocarbon compounds. For example, if a bacterium is chosen to produce gasoline, the bacteria may only produce octane, an eight carbon hydrocarbon molecule that boils within the distillation temperature range of gasoline.

After the inventors of this process completed their development work, they discussed their technology with the Department of Defense which became interested in this technology for providing fuels to their land and air based vehicles. The military agreed to partially fund the establishment of pilot plants at different military bases, however, of the original 7 conceived pilot plants, only one pilot plant was built at Fort Stewart in Georgia. The Fort Stewart pilot plant began operating in late 2008. Bell Bioenergy intends on starting up two demonstration plants – one associated with the University of California in Fresno, the other with the City of Atlanta. The primary output of these plants will be compost, however, these two plants are also expected to produce 1 to 2 million gallons of diesel fuel on an annual basis.

The technology works by first grinding the cellulosic feedstock into a smaller size and then immersing the ground cellulose with bacteria into water. The bacteria begin to digest the cellulose after only several hours, but require 30 to 60 days to fully digest the cellulose. The produced fuel is constantly removed from the reaction vessel, and a significant amount of organic material is also produced which will be marketed as potting soil. The process is expected to produce 30 to 40 gallons of renewable product per ton of feedstock and the simplicity of the process results in low capital costs per volume produced.

Strong Acid Hydrolysis/Biochemical - BlueFire Ethanol

BlueFire Ethanol has a commercial strong acid hydrolysis technology process that converts cellulosic materials into ethanol. The technology can make ethanol from urban trash, rice and wheat straws, wood waste and other agricultural residues. Acid hydrolysis is the main reaction mechanism to convert cellulosic and hemicellulosic material into simple sugars such as hexose and pentose or "C6 and C5" sugars. Fermentation of these sugars with microbes converts these sugars into ethanol. This process for converting cellulosic and hemicellulosic material into ethanol via acid hydrolysis and fermentation has been around for many decades; though it has not been economically competitive as the cost was not competitive with transport fuel made from petroleum. BlueFire's process is claimed to offer several improvements to existing acid hydrolysis technology, giving higher ethanol yields and lower production costs.

BlueFire uses a proprietary concentrated acid hydrolysis system and several other process improvements to make ethanol production more economically attractive than older acid hydrolysis methods. Some of BlueFire's stated improvements include a more efficient acid recovery system; higher sugar purities and concentrations; use of more efficient microbes to ferment C6 and C5 sugars into ethanol; the processes ability to use biomass feedstock's containing silica. The BlueFire process consists of the following main components; feedstock preparation; decrystallization/hydrolysis reaction; filtration of solids and liquids; separation of the acid and sugars; fermentation of the sugars and product separation. For product separation, ethanol effluent is separated using distillation and then dehydrated with molecular sieve technology.

BlueFire has successfully operated a pilot plant for six years near their headquarters in Southern California. BlueFire is in the process of building its first commercial facility which will be located in Lancaster California. As of the third quarter of 2009, BlueFire had obtained the permits to build this facility and was seeking additional funding and bids for the construction of the plant. The plant is expected to start up in 2011 or 2012 and will produce up to 3.9 million gallons of cellulosic ethanol per year from municipal solid waste (MSW). BlueFire is planning to start up another cellulosic ethanol plant which they call their Mecca or El Sobrante plant also using MSW as feedstock. Although this plant was initially envisioned to be located in California, it is likely that this plant will be built elsewhere in the U.S. No start up date has been announced for their Mecca plant.

Chemical Depolymerization - Cello-Energy

The Cello-Energy process is a catalytic depolymerization technology. At moderate pressure and temperature, the Cello-Energy process catalytically removes the oxygen and minerals from the hydrocarbons that comprise cellulose. This results in a mixture of short chain (3, 6 and 9 carbon) hydrocarbon compounds. These short chain hydrocarbon compounds are polymerized to form compounds that boil in the diesel boiling range, though the process can also be adjusted to produce gasoline or jet fuel. The resulting diesel fuel meets the ASTM standards, is in the range of 50 to 55 cetane and typically contains 3 ppm of sulfur. The resulting diesel fuel has been tested in Caterpiller engines to demonstrate the viability of the fuel.

The Cello-Energy process is reported to convert 94% of the hydrocarbon material to diesel fuel, although a very small amount of heavier hydrocarbons is also produced. The Cello Energy Process could be totally self-sufficient by routing 12% of the product to run generators to produce the electricity that the process needs. The only energy input is electricity - no natural gas or water is used in the process. The Cello process is on the order of 82 % efficient at converting the feedstock energy content into the energy content of the product, which is very high compared to most of today's biochemical and thermochemical processes which are on the order of 50 % efficient, or less.

Because of the simplicity of the process, the capital costs are very low. A 50 million gallon per year plant is claimed to only incur a total cost of $45 million. This is typical of the capital costs incurred when refiners expand their refineries, a very low cost for a grassroots plant. Because of its high efficiency in converting feedstocks into liquid fuel, the production and operating costs are estimated to be very low. By using some waste feedstocks today, production costs are reported to be less than $0.50 per gallon. However, even with feedstock costs in the $70 per ton range, which is the cost we used in our cost analysis, total costs would remain less than $1.00 per gallon of diesel fuel.

Cello-Energy was founded 16 years ago and after the chemistry was worked out, they built their first pilot plant in 1998. They next converted their pilot plant in 2004 to a larger continuously-operating demonstration plant that produced 4 million gallons per year of diesel fuel. In December 2008, Cello started up a 20 million gallon per year commercial demonstration plant. As of late 2009, the plant is operational, however, the production volumes are still very low. Cello is working to increase the production volume of its plant. According to the company, they are currently working to resolve materials handling and processing issues that surfaced when they attempted to scale up production to 20 MGY from a previously operated demonstration plant. As of November 2009, they had ordered new equipment and are waiting for it to arrive and be installed which they hoped would allow for operations to be restarted as early as February or March, 2010. Cello energy already has chosen locations to construct and start up two 50 million gallons per year plants by early 2011, though these are on hold until the Bay Minette facility is operational. This includes a facility in conjunction with the State of Georgia Energy Innovation Center, and one additional plant in Alabama. Cello explained that they will use prefabrication techniques so that these plants can readily be constructed, shipped and installed anywhere in the U.S.

Thermochemial/Fischer Tropsch - Choren

Choren has a technology called Carbo-V, which is a Fischer-Tropsch process that can be used to make diesel fuel. The process can process a wide variety biomass and recycled material materials as feedstocks. The process converts agriculture biomass, forestry biomass, biogenic waste and recycling substances into a synthesis gas which can be further converted to a diesel fuel using a Fischer-Tropsch reactor. The Carbo-V process can also be configured without the

Fischer-Tropsch hydrocracking technology, so as to produce electricity, heat and power, methanol, and other chemical feedstocks.

The principal aspect of the Carbo-V Process is a three-stage gasification process consisting of low temperature gasification, high temperature gasification and endothermic entrained bed gasification. In the first stage, biomass is partially oxidized with air or oxygen at temperatures between 400 and 500 °C. This breaks down the feedstock into a gas containing tar and solid carbon. In the second stage, the tar is oxidized at temperatures higher than the ash's melting point, converting the tar into a synthesis gas. In the third stage, solid carbon is mechanically pulverized and blown into the hot gasification stream. The fluidized carbon endothermicly reacts with the gasification stream and is converted into a synthesis gas. In the next Fischer-Tropsch stage of the process, the synthesis gas (CO and H2) reacts with the aid of a catalyst to form hydrocarbons. The resulting hydrocarbons produced from the three stages can then be sent to a hydrocracking process to produce primarily diesel fuel.

Choren will be building a commercial Plant in Freiberg/ Saxony Germany that is expected to be operational in 2011 or 2012. Initially, the plant will use biomass from nearby forests, the wood-processing industry and straw from farmland.

Thermochemical/Biochemical - Coskata

The Coskata process is a gasification-based technology which produces ethanol from biomass and other forms of carbon through a biofermentation route. A wide variety of feedstocks can be used, municipal waste, agriculture waste and other carbonaceous containing material. Since this process uses combustion and biofermentation, it is not easily classifiable as either a biochemical or thermochemical production method. This process requires that the biomass or carbonaceous material be processed to a small particle size and then it is injected into a gasifier.

The gasifier combusts any dry carboneous feed stocks into syngas, comprised primarily of carbon monoxide and hydrogen. The syngas produced is fermented in a reactor by micro-organisms, which convert the carbon monoxide and hydrogen directly into ethanol. The micro-organisms are low cost and can process a wide range of carbon monoxide and hydrogen molar ratios in the syngas, providing feedstock processing flexibility. No other enzymes are required by this process for producing ethanol, providing significant cost savings over current cellulosic and corn based fermentation production methods. The Coskata process is conducted at low pressures, which offers savings on capital and energy costs. Additional energy savings can be realized by employing membrane technology to separate ethanol from the reactor decant liquid. This technology uses gravity and filtration to recover ethanol, resulting in significant savings on distillation capital and energy costs used in other cellulosic and corn based production methods. Initial ethanol production cost estimates are lower than the biochemical and thermochemical cellulosic technologies described in previously in Subsections 1.4.3.1 and 1.4.3.2.

For woody biomass, Coskata estimates that each ton of this feedstock would generate about 100 gallons of ethanol and small amounts of ash which would be burned to supply energy needs for the process. Corn stover is expected to provide similar ethanol yields as woody biomass feed stocks, though details about yields from the various feed supply stocks are not yet public.

Coskata has a bench scale pilot plant in Warrenville, IL, and its larger 40,000 gallon per year pilot plant became operational in 2009 in Madison, Pennsylvania. Coskata is targeting to design and build a 50 million gallon per year commercial demonstration plant that it expects to be operational in 2011.

Pyrolysis - Dynamotive Energy Systems

Dynamotive Energy Systems Corporation has announced a pyrolysis technology that uses medium temperatures and oxygen free reactions to convert dry waste biomass and energy crops into fuels that can be used in power/heat generation and transportation vehicles. Additionally, the process can make feedstock's that can be used to produce chemicals. The process is flexible on the types of biomass feedstock's that can be processed. The fuel produced from the Dynamotive process is called "BioOil" and contains up to 25% water, though the water is intimately mixed and does not easily separate into another phase with time. Since the BioOil contains significant amounts of water, it is not directly useable as fuel in conventional vehicles and would have to be converted via another catalytic conversion processing step. The additional catalytic step envisioned for this would combust the material into a synthesis gas which would then be converted into diesel fuel or bio-methanol via a catalytic reaction (the BTL process). The diesel fuel produced is expected to be compatible with existing petroleum diesel fuels.

Three products are produced by the Dynamotive process, BioOil (60-75% by weight), char (15-20% wt.) and non-condensable gases (10-20% wt.). The char produced is similar to coke and can be used as fuel by other industries while the gases yielded from the process can be used to supply about 75% of the energy requirements of the pyrolysis process. The pyrolysis process operates at reactor temperatures of about 400-500 degrees Celsius.

Dynamotive has two small demonstration plants. One demonstration plant is located in Guelph, Ontario, Canada and its capacity is 66,000 dry tons of biomass a year with an energy output equivalent to 130,000 barrels of oil. The other of its demonstration plants is located in West Lorne, Ontario, Canada. This plant started operation in early 2005 using waste sawdust as a feedstock. The West Lorne plant has a capacity to convert 130 tonnes of biomass into BioOil per day which, if proportional to the Guelph plant, translates to an energy-equivalent of 84,500 barrels of oil per year. The BioOil production capacity between the two plants is estimated at around 9 MGY of BioOil, but both plants are currently operating at a fraction of their rated capacity. However, according to a recent press release, Dynamotive has contracts in place to supply a U.S.-based client with at least nine shipments of BioOil in 2010. Although Dynamotive has been working on a technology for converting BioOil to a transportation fuel, they have not announced plans for building such a facility

Biochemical Ethanol - POET

POET has over twenty years of producing conventional ethanol in 23 plants in seven states with production capability of one billion gallons of ethanol annually. POET has expanded their production capability to include cellulosic ethanol technology. POET's cellulosic technology will make ethanol from plant materials like corn stalks, switch grass, wood chips and refuse. In February 2007, POET was selected by DOE for an award totaling $80 million for federal funding for a commercial cellulosic ethanol plant, which will be located in Emmetsburg, Iowa. As such, POET will be one of the first to build a cellulosic plant on a commercial scale. POET's commercial demonstration plant is projected to produce 25 million gallons per year and start up in 2011. It will make cellulosic ethanol from plant materials such as corn cobs and perhaps other cellulosic feedstocks.

Biochemical Ethanol – Iogen, KL Energy, DuPont Danisco, Fiberight

Like Poet, Iogen is pursuing a biochemical cellulosic ethanol technology very similar to the biochemical pathway described in previously in Section 1.4.3 utilizing their own proprietary enzymes. Iogen opened the first commercial demonstration cellulosic ethanol plant in North America. Iogen's plant located in Ottawa, Canada has been producing cellulosic ethanol from wheat straw since 2004. Iogen has slowly been ramping up production at its 0.5 MGY plant. According to the company's website, they produced approximately 24,000 gallons in 2004 and 34,000 gallons in 2005. Production dropped dramatically in 2006 and 2007 but came back strong with 55,000 gallons in 2008. Up to the last quarter of 2009, Iogen has produced over 127,000 gallons of ethanol from their demonstration plant.

Iogen also recently became the first cellulosic ethanol producer to sell its advanced biofuel at a retail service station in Canada. Their cellulosic ethanol was blended to make E10 available for sale to the consumers at an Ottawa Shell station. Iogen also recently announced plans to build its first commercial scale plant in Prince Albert, Saskatchewan, in the 2011/2012 timeframe.

KL Energy Corporation (KL Energy), through its majority-owned Western Biomass Energy, LLC (WBE) located in Upton, WY, is designed to convert wood products and wood waste products into ethanol using a biochemical pathway similar to that described previously in Section 1.4.3. Since the end of construction in September 2007, equipment commissioning and process revisions continued until the October 2009 startup. The plant was built as a 1.5 MGY demonstration plant and was designed to both facilitate research and operate commercially. It is KL Energy's intent that WBE's future use will involve the production and sale of small but commercial-quality volumes of ethanol and lignin co-product. The company's current 2010 production goal is for WBE to generate RINs under the RFS2 program.

DuPont Danisco Cellulosic Ethanol, LLC (DDCE), a joint venture between Dupont and Danisco, is another company pursuing biochemical conversion of cellulosic material into ethanol. DDCE received funding from the State of Tennessee and the University of Tennessee to build a small 0.25 MGY demonstration plant in Vonore, TN, to pursue switchgrass-to-ethanol production. According to DDCE, construction commenced in October 2008 and the plant is now mechanically complete and currently undergoing start-up operations. The facility is scheduled to come online in January and the company hopes to operate at or around 50% of production capacity in 2010. According to the DDCE, the objective in Vonore is to validate processes and data for commercial scale-up.

Fiberight, LLC (Fiberight) is yet another company pursing cellulosic ethanol from a biochemical process, but using MSW as a feedstock. According to Fiberight, they have been operating a pilot-scale facility in Lawrenceville, VA, for three years. They have developed a proprietary process that not only fractionates MSW but biologically converts the non-recyclable portion into cellulosic ethanol and biochemicals. Fiberight recently purchased a shut down corn ethanol plant in Blairstown, IA, and plans to convert it to become MSW-to-ethanol capable. According to the company, construction is currently underway and the goal is to bring the 2 MGY demo plant online by February or March, 2010. Fiberight's long-term goal is to expand the Blairstown plant to a 5-8 MGY capacity and build other small commercial plants around the country that could convert MSW into fuel.

Thermochemical Ethanol - Range Fuels and Enerkem

Range Fuels produces cellulosic ethanol via a two step thermochemical process. Their technology converts biomass to syngas followed by catalytic conversion of the syngas to alcohols. Range claims that their technology is capable of producing more ethanol than other cellulosic technologies based on yields per energy input. They utilize a two step process which can use many forms of non food biomass, such as agriculture waste, wood, and corn stocks. Additionally, the technology can process feed stocks with variable water content.

In the Range process, biomass feedstock are converted by heat, pressure and steam into syngas, which is then scrubbed and cleaned before entering into the second stage. The second stage uses catalyst to convert the syngas into methanol, which are then converted in an additional reactor into ethanol. Overall, the Range process is simple as no enzymes or living organisms are used for the main conversion reactions.

Range has operated a pilot plant for over 7 years using over 20 different nonfood feedstocks. Range broke ground building its first commercial plant late in late 2008 and is expected to be operational in 2010. This plant will be located in Soperton, Georgia and is partially funded from proceeds of a DOE grant. The plant will use wood, grasses, and corn stover as feedstocks. In its initial phase, the Range plant is expected to produce 4 million gallons per year of methanol. After the company is confident in its operations, Range will begin efforts to expand the plant and add additional reaction capacity to convert the methanol to ethanol.

Enerkem is another company like Range Fuels pursuing cellulosic ethanol production via the thermochemical route. The Canadian-based company was recently announced as a recipient of a $50 million grant from DOE to build a 10 MGY woody biomass-to-ethanol plant in Pontotoc, MS. The U.S. plant is not scheduled to come online until 2012, but Enerkem is currently building a 1.3 MGY demonstration plant in Westbury, Quebec. According to the company, plant construction in Westbury started in October 2007 and the facility is currently scheduled to come online around the middle of 2010. While it's unclear at this time whether the cellulosic ethanol produced will be exported to the United States, Enerkem has expressed interest in selling its fuel commercially.

Reforming of Sugars to Gasoline - Virent Bioreforming

Virent is pursuing a process called “Bioforming” which functions similarly as the gasoline reforming process used in the refining industry. While refinery-based reforming raises natural gasoline’s octane value and produces organic chemicals, benzene, xylene and toluene as a byproduct, Bioforming reforms biomass-derived sugars into hydrocarbons for blending into gasoline and diesel fuel. The process however, operates at much lower temperatures and pressures than reforming used by the refining industry. The Bioforming process is being developed through a partnership with Shell, Cargill, Honda and the University of Wisconsin. Virent currently has 16 pilot plants in operation. At this stage, though, the data is limited. It appears that Bioforming is a promising technology, as production costs estimates are low in comparison to many other renewable and biomass production processes while the products are compatible with traditional petroleum stocks.

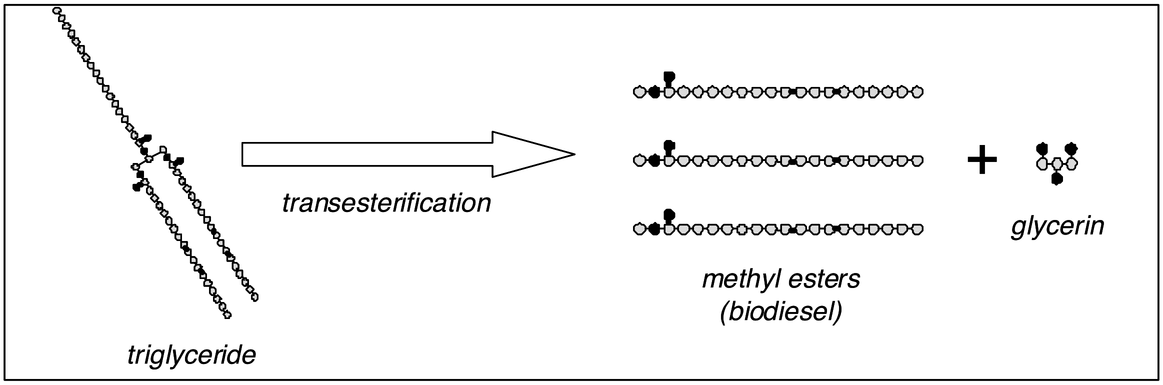
Biomass feedstocks for the Bioforming process are sugar feeds, such a corn syrup, sucrose, glycerol, sorbitol, xylose, glucose, cellulose and hemi cellulose. These are primarily converted into gasoline and diesel fuel, though other hydrocarbons such as jet fuel, LPG, benzene, toluene, xylene, hydrogen, natural gas can also be produced. Water is also produced, as the reforming process removes oxygen from the sugar feeds. The resulting properties and energy content of gasoline and diesel produced though are physically comparable to those yielded from refining industry. Variable operating costs are low because no distillation equipment is needed to separate the produced gasoline, diesel and other hydrocarbons, as these separate naturally from the aqueous solutions generated in the reforming process. The net energy costs are also low due to low operating pressures and temperatures.

1.4.4 Biodiesel & Renewable Diesel Production

1.4.4.1 Biodiesel

Plant oils and animal fats are triglycerides, a molecule consisting of a group of three hydrocarbon chains (saturated or olefinic) linked to a three-carbon backbone via carboxylic acid esters (see Figure 1.4-9). Biodiesel is made by removing the chains from the triglyceride molecules and adding methanol to their ends to form methyl esters. Glycerin is formed as a co-product from the three-carbon backbones that remain. For relatively pure triglycerides, such as virgin plant oils, the primary reaction is catalyzed by an alkaline pH and takes place in a stirred vessel at mild temperature and pressure conditions.

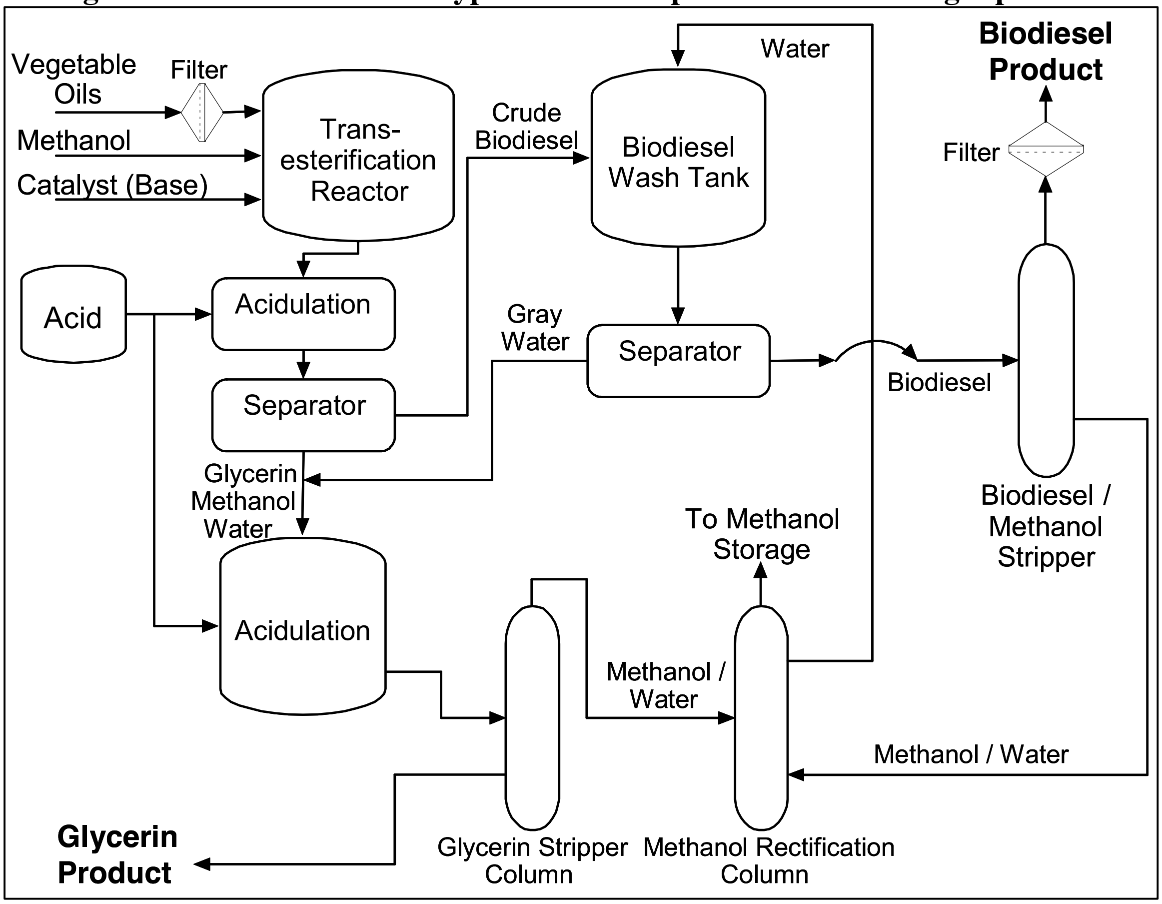
Figure 1.4-9. Overview of biodiesel conversion process



In the case of feedstocks containing more than a few percent free fatty acids (FFAs), such as rendered fats, waste greases, or corn oil extracted after ethanol production, addition of base will result in the formation of soap, an undesirable process contaminate when present above trace levels. To avoid this, these feedstocks must first undergo an acid pre-treatment step to esterify the FFAs before proceeding to the base-catalyzed triglyceride transesterification reaction. Feedstocks with small amounts of FFAs may be converted in a basic environment if the soaps can be removed from the fuel product.

Once the chemical conversions are complete, the mixture is neutralized, washed, and co-product and unreacted alcohol and catalyst are recovered. At that point the biodiesel is subjected to quality control testing and then released for sale. Figure 1.4-10 shows a process flow diagram for a typical biodiesel production process that uses virgin plant oil as feedstock; processes using waste fats or greases would include an acid esterification step upstream of the transesterification reactor shown here. Plants that also produce other oleochemicals often have distillation equipment at the end of the process capable of purifying the methyl esters to a high degree or separating them by molecular weight. These plants may use this equipment to produce a very high purity biodiesel product. We estimate that only a very small fraction of biodiesel production is distilled. [241]

Figure 1.4-10. Schematic of typical biodiesel production from virgin plant oil



Some differences exist between large and small plants that are worth mentioning given the very wide range of plant capacities existing in this industry. Larger plants (greater than 10 million gallons per year) are more likely to employ continuous flow processes, which afford certain efficiencies of scale and steady-state operation. On the other hand, small plants (less than one million gallons per year) are most likely to produce fuel batch-by-batch, which may give them more flexibility to change feedstock types or slow output on short notice. Smaller plants are less likely to be able to afford an on-site laboratory or quality control specialist, which may cause them hardship as fuel quality standards tighten and/or are more stringently enforced. Third-party labs exist for this purpose, but they pose challenges such as significant per-test costs and multi-day turnaround times that require holding of product batches until results are received.

The biodiesel production process is relatively simple and economical, and there is already sufficient existing U.S. capacity to produce all the biodiesel required to meet the biomass-based diesel standard put forth in EISA. Thus, we do not expect large changes in the process technology used to make biodiesel going into the future. That said, it is worth noting some potential changes as existing plants strive to comply with changing fuel quality standards, or as new plants are occasionally built to take advantage of specific market niches.

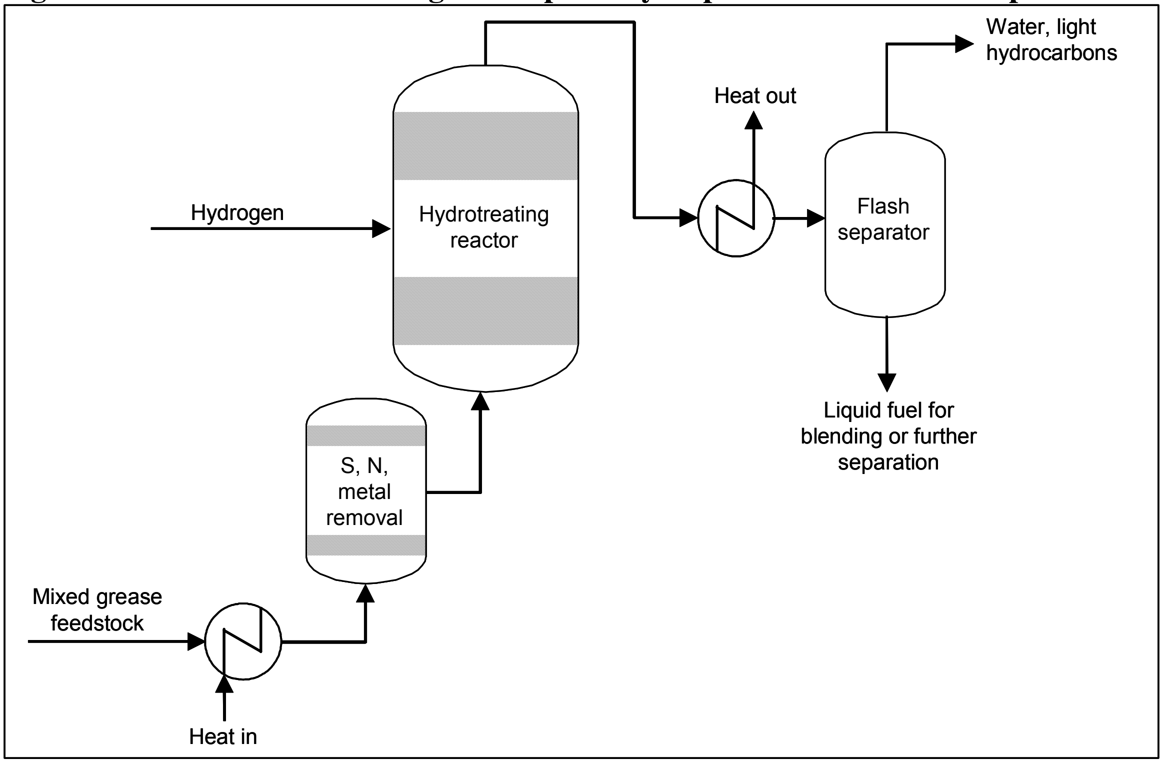
One such change may be an increase in distillation of biodiesel. EPA requires biodiesel to meet the ASTM D-6751 specification for B100 in order to be legally blended into diesel fuel for use in vehicles. Earlier this year, ASTM amended this specification to require a cold filter plugging test, which effectively mandates very low levels of FFAs, sterol glucosides, and partially-converted triglycerides in the finished biodiesel. There are a variety of process parameters a biodiesel producer can adjust to reduce the levels of these compounds in the finished fuel, but one very effective way to ensure a high purity product is through distillation. At this time it is unclear to what extent distillation will be relied upon for compliance with the amended biodiesel specification. An increase in distillation would increase per-gallon energy inputs to the process significantly.

Some industry forecasts suggest animal fats and waste greases will make up an increasing share of biodiesel feedstocks due to their lower costs and lower upstream GHG impacts. Because most fats and greases contain significant levels of FFAs, this shift will cause more plants to use acid pre-treatment, increasing process complexity and per-gallon energy use.

1.4.4.2 *Renewable Diesel*

The renewable diesel production process converts vegetable oils and animal fats into diesel fuel using thermal depolymerization, which is similar to hydrotreating used in petroleum refining to remove sulfur. The process uses hydrogen and catalyst to remove oxygen from the triglyceride molecules in the feedstocks oils via a decarboxylation and hydro-oxygenation reaction, yielding some light petroleum products and water as co-products. The reactions can also saturate the olefin bonds in the feedstock oils, converting them to paraffins; additional steps can also be taken to isomerize a portion of the paraffins to create fuels with varying properties. All of these reactions consume significant amounts of hydrogen. The yield of these reactions to the primary product (diesel) depends on the process conditions, as some of the carbon backbone of the oils can be cracked to naphtha and lighter products with higher severity. For our analysis we assume approximately 90% yield to diesel, with the remainder split between light fuel gas and naphtha. Figure 1.4-11 shows a flow diagram of the primary steps of renewable diesel production.

Figure 1.4-11. Process flow diagram of primary steps in renewable diesel production



Renewable diesel can be produced either at a stand-alone facility or within the boundaries of an existing petroleum refinery. For the stand-alone facility, feedstock is brought in and finished fuel is transported out to market. This type of facility may be co-located with a rendering facility or a chemical operation with excess hydrogen to minimize feedstock transportation and storage costs. For production within the boundaries of a refinery, the feed material may either be processed in a segregated unit (new or revamped), or co-processed with petroleum in an existing unit. In any case, the feedstock will require pre-treatment in a unit that removes contaminates such as sulfur, nitrogen, and trace metals that may poison hydrotreating catalysts.

For a period during 2007 and 2008, ConocoPhilips produced some (300-500 bbl/day) renewable diesel at their Borger, Texas, refinery from beef tallow generated by Tyson Foods, Inc. in Amarillo, Texas. [242] In fall of 2008, Dynamic Fuels, LLC (a joint venture of Syntroleum Corp. and Tyson Foods, Inc.) announced construction of a 75 million gallon per year plant (5,000 bbl/day) in Geismar, Louisiana, that will use Tyson meat processing fats as feedstock to Syntroleum's Bio-Synfining process. Start-up is scheduled for mid-2010, with the primary product being high-quality diesel fuel that will be fungible within the existing petroleum supply system. [243] This facility plans to utilize supplies of hydrogen available in the industrial area where it will be located, as well as rail and shipping infrastructure already in place nearby. [244]

Syntroleum Corp was founded in 1984 and holds a number of patents in gas-to-liquids and biomass-to-liquids conversion processes. One such process has the trade name Synfining, and upgrades Fischer-Tropsch paraffins to isomers with properties more favorable for diesel fuel.

They have further adapted this process to use a variety of fats and oils as feedstocks, calling it Bio-Synfining. It is this technology that will be used in the Geismar facility.

Looking internationally, the Finnish company Neste Oil began operating a 3,200 bbl/day process in Finland in 2007 to convert vegetable oils into renewable diesel. This company has plans to construct similar facilities in Singapore and the Netherlands by 2010, and eventually plans to bring on-line plants that will convert biomass to liquid fuels using gasification. [245]

Since thermochemical production of hydrocarbon fuels from fats and biomass is a relatively new endeavor to conduct on a commercial scale, we expect continued innovation and fine-tuning of the technology as these processes evolve from their roots in Fischer-Tropsch and petroleum hydrotreating processes. (This discussion ties in with cellulosic diesel in Section 1.4.3.2.)

1.5 Biofuel Industry Characterization & Projected Growth

In this section we discuss the current state of the biofuel industry and how production might grow in the future under the RFS2 program based on our volume assumptions. The bulk of the discussion focuses on corn ethanol, imported sugarcane-based ethanol and conventional FAME-based biodiesel, today's most established U.S. biofuel sources. However, we also discuss renewable diesel, cellulosic diesel, algae-based biodiesel and other up-and-coming second generation biofuels that are likely to develop during the course of the RFS2 program.

In the subsections that follow, we'll discuss corn ethanol and how the industry might look once it finishes building out production capacity to 15 billion gallons and employs more advanced processing technologies. From there we will discuss the availability of imported ethanol from Brazil and Caribbean Basin Initiative (CBI) countries to help meet the advanced biofuel standard. Domestic sugarcane- and sweet sorghum-based ethanol plants could also contribute to meeting the advanced biofuel standard in EISA. Following this discussion, we will characterize the present state of the cellulosic biofuel industry and talk about the potential timeline for commercialization based on projected industry plans and technological breakthroughs aided by state and federal grants, tax incentives, and loan guarantee programs. As part of this discussion we will describe our assessment of the cellulosic industry in the context of setting the standard for 2010. Finally, we will conclude our industry characterization by discussing the present state of the biomass-based diesel industry and how we expect biodiesel production to grow in the future along with renewable diesel and algae-based biodiesel.

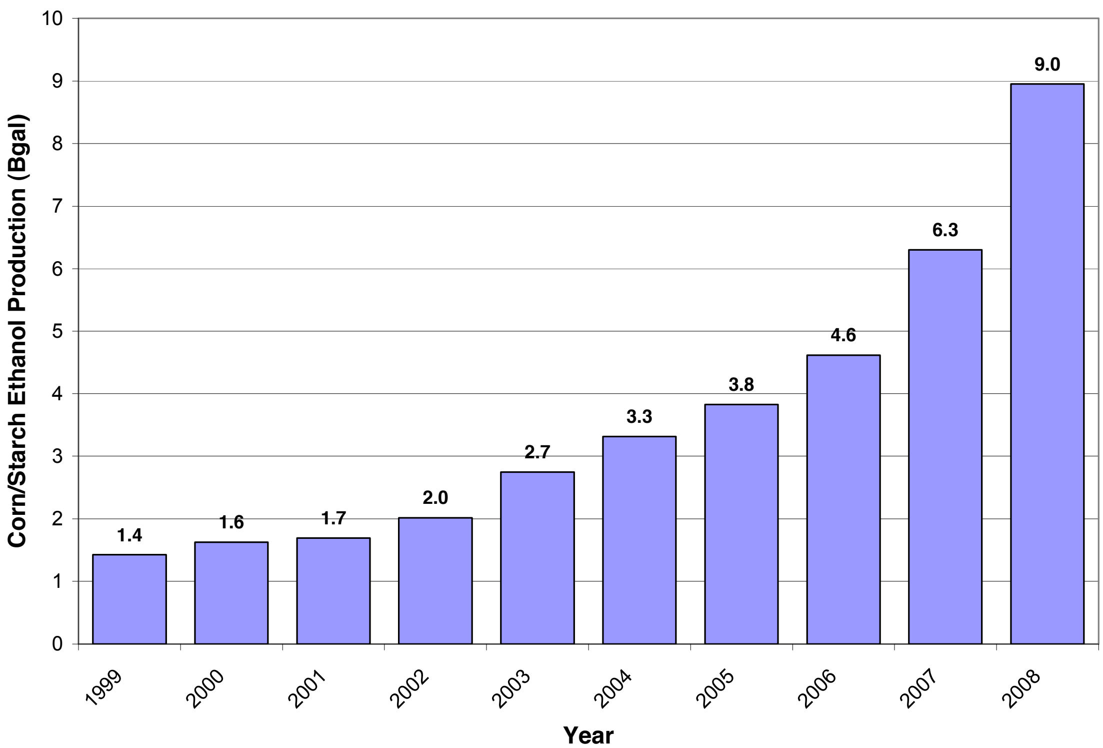
1.5.1 Corn Ethanol

The majority of domestic biofuel production currently comes from plants processing corn and other similarly-processed grains in the Midwest. However, there are a handful of plants located outside the Corn Belt and a few plants processing simple sugars from food or beverage waste. In this subsection, we will talk about the present state of the corn ethanol industry and how we expect things might change in the future under the RFS2 program.

1.5.1.1 Historic/Current Production

The United States is currently the largest ethanol producer in the world. In 2008, the U.S. produced nine billion gallons of fuel ethanol for domestic consumption, the majority of which came from locally-grown corn.[26,246] The nation is currently on track for producing over 10 billion gallons by the end of 2009.[27,247] Although the U.S. ethanol industry has been in existence since the 1970s, it has rapidly expanded in recent years due to the phase-out of methyl tertiary butyl ether (MTBE), elevated crude oil prices, state mandates and tax incentives, the introduction of the Federal Volume Ethanol Excise Tax Credit (VEETC)[28], the implementation of the existing RFS1 program[29] and the new volume requirements established under EISA[248]. As shown in Figure 1.5-1, U.S. ethanol production has grown exponentially over the past decade.

Figure 1.5-1.
Historical Growth in U.S. Corn/Starch Ethanol Production[249]



[26] Based on historical transportation ethanol use less imports reported by EIA.
[27] Based on projected transportation ethanol use less imports reported by EIA. Actual year-end data for 2009 for unavailable at the time of this FRM assessment.
[28] On October 22, 2004, President Bush signed into law H.R. 4520, the American Jobs Creation Act of 2004 (JOBS Bill), which created the Volumetric Ethanol Excise Tax Credit (VEETC). The $0.51/gal ethanol blender credit replaced the former fuel excise tax exemption, blender's credit, and pure ethanol fuel credit. However, the 2008 Farm Bill modified the alcohol credit so that corn ethanol gets a reduced credit of $0.45/gal and cellulosic biofuel gets a credit of $1.01/gal.
[29] On May 1, 2007, EPA published a final rule (72 FR 23900) implementing the Renewable Fuel Standard (RFS) required by the Energy Policy Act of 2005. The RFS requires that 4.0 billion gallons of renewable fuel be blended into gasoline/diesel by 2006, growing to 7.5 billion gallons by 2012.

As of November 2009 there were 180 corn/starch ethanol plants operating in the U.S. with a combined production capacity of approximately 12 billion gallons per year.[30,250] This does not include idled ethanol plants, discussed later in this subsection. The majority of today's ethanol production (91.5% by volume) is produced exclusively from corn. Another 8.3% comes from plants processing a blend of corn and/or similarly-processed grains (milo, wheat, or barley). The remainder comes from small plants processing waste beverages or other waste sugars and starches. A summary of U.S. ethanol production by feedstock is presented in Table 1.5-1.

Table 1.5-1.
Current Corn/Starch Ethanol Production Capacity by Feedstock

Plant Feedstock (Primary Listed First)	Capacity MGY	% of Capacity	No. of Plants	% of Plants
Corn[a]	10,994	91.5%	155	86.1%
Corn, Milo[b]	817	6.8%	15	8.3%
Corn, Wheat	130	1.1%	1	0.6%
Milo	3	0.0%	1	0.6%
Wheat, Milo	50	0.4%	1	0.6%
Waste Beverages[c]	20	0.2%	5	2.8%
Waste Sugars & Starches[d]	7	0.1%	2	1.1%
Total	**12,020**	**100%**	**180**	**100%**

[a]Includes one facility processing seed corn, one facility operating a pilot cellulosic butanol plant, one facility with plans to build a pilot cellulosic ethanol plant, and two facilities with plans to build small commercial cellulosic ethanol plants in the future.
[b]Includes one facility processing a small amount of molasses in addition to corn and milo.
[c]Includes two facilities processing brewery waste.
[d]Includes one facility processing potato waste that intends to add corn in the future.

As shown in Table 1.5-1, of the 180 operating plants, 173 process corn and/or other similarly processed grains. Of these facilities, 162 utilize dry-milling technologies and the remaining 11 plants rely on wet-milling processes. Dry mill ethanol plants grind the entire kernel and generally produce only one primary co-product: distillers' grains with solubles (DGS). The co-product is sold wet (WDGS) or dried (DDGS) to the agricultural market as animal feed. However, there are a growing number of plants using front-end fractionation to produce food-grade corn oil or back-end extraction to produce fuel-grade corn oil for the biodiesel industry. A company called GreenShift has corn oil extraction facilities located at five

[30] Our November 2009 corn/starch ethanol industry characterization was based on a variety of sources including plant lists published online by the Renewable Fuels Association and Ethanol Producer Magazine, information from ethanol producer websites including press releases, and follow-up correspondence with producers. The baseline does not include ethanol plants whose primary business is industrial or food-grade ethanol production nor does it include plants that might be located in the Virgin Islands or U.S. territories. Where applicable, current/historic production levels have been used in lieu of nameplate capacities to estimate production capacity.

ethanol plants in Michigan, Indiana, New York and Wisconsin.[31,251] Collectively, these facilities are designed to extract in excess of 7.3 million gallons of corn oil per year. Primafuel Solutions is another company offering corn oil extraction technologies to make existing ethanol plants more sustainable. For more information on corn oil extraction and other advanced technologies being pursued by today's corn ethanol industry, refer to Section 1.4.1 of the RIA

In contrast to traditional dry mill plants, wet mill facilities separate the kernel prior to processing into its component parts (germ, fiber, protein, and starch) and in turn produce other co-products (usually gluten feed, gluten meal, and food-grade corn oil) in addition to DGS. Wet mill plants are generally more costly to build but are larger in size on average. As such, 11.4% of the current grain ethanol production comes from the 11 wet mill facilities listed in Table 1.5-2.

Table 1.5-2.
Existing Wet Mill Corn Ethanol Plants

Ethanol Plant/Company	Location	Capacity MGY	% of Tot Capacity
Archer Daniels Midland[a]	Cedar Rapids, IA	250	2.1%
Archer Daniels Midland[a]	Clinton, IA	190	1.6%
Archer Daniels Midland[a]	Columbus, NE	95	0.8%
Archer Daniels Midland[a]	Decatur, IL	290	2.4%
Archer Daniels Midland[a]	Marshall, MN	40	0.3%
Aventine Renewable Energy	Pekin, IL	100	0.8%
Cargill, Inc.	Eddyville, IA	35	0.3%
Cargill, Inc.	Blair, NE	185	1.5%
Grain Processing Corp	Muscatine, IA	20	0.2%
Penford Products	Cedar Rapids, IA	45	0.4%
Tate & Lyle	Loudon, TN	126	1.0%
Total		**1,376**	**11.4%**
[a]Estimated plant capacities.			

The remaining seven ethanol plants process waste beverages or sugars/starches and operate differently than their grain-based counterparts. These small production facilities do not require milling and operate a simpler enzymatic fermentation process. Due to their limited feedstock supplies and niche markets, these plants have much smaller ethanol production capacities than traditional dry and wet mill corn ethanol plants. A summary of today's average ethanol plant size by processing technology is found in Table 1.5-3 below.

[31] Two plants in Michigan and one in each of the other three states. All company information based on GreenShift's Q2 2009 SEC filing.

Table 1.5-3.
Average Corn/Starch Plant Sizes

Processing Technology	Capacity MGY	% of Capacity	No. of Plants	% of Plants	Avg. Size MGY
Dry Milling[a]	10,618	88.3%	162	90.0%	65.5
Wet Milling[a]	1,376	11.4%	11	6.1%	125.1
Other[b]	26	0.2%	7	3.9%	3.8
Total	**12,020**	**100.0%**	**180**	**100.0%**	**66.8**

[a]Includes a total of three corn ethanol plants with plans to process cellulosic feedstocks in the future. To the extent that cellulosic facilities are integrated with existing processes, these plants will need additional front-end technology to supplement existing dry milling equipment.
[b]Facilities that do not process traditional grain-based crops and thus do not require milling. Includes plants processing waste beverages or sugars and starches.

Ethanol production is a relatively resource-intensive process that requires the use of water, electricity, and steam. Steam needed to heat the process is generally produced on-site or by other dedicated boilers.[32] The ethanol industry relies primarily on natural gas. Of today's 180 ethanol production facilities, an estimated 151 burn natural gas[33] (exclusively), three burn a combination of natural gas and biomass, one burns natural gas and coal (although natural gas is the primary fuel), one burns a combination of natural gas, landfill biogas and wood, and two burn natural gas and syrup from the process. We are aware of 17 plants that burn coal as their primary fuel and one that burns a combination of coal and biomass.[34] Our research suggests that three corn ethanol plants rely on a combination of waste heat and natural gas and one plant does not have a boiler and relies solely on waste heat from a nearby power plant. Overall, our research suggests that 27 plants currently utilize cogeneration or combined heat and power (CHP) technology, although others may exist.[35,252] CHP is a mechanism for improving overall plant efficiency. Whether owned by the ethanol facility, their local utility, or a third party, CHP facilities produce their own electricity and use the waste heat from power production for process steam, reducing the energy intensity of ethanol production.[36] A summary of the energy sources and CHP technology utilized by today's ethanol plants is found in Table 1.5-4.

[32] Some plants pull steam directly from a nearby utility.
[33] Facilities were assumed to burn natural gas if the plant boiler fuel was unspecified or unavailable on the public domain.
[34] Includes corrections from NPRM based on new information obtained on Cargill plants and Blue Flint ethanol plant.
[35] CHP assessment based on information provided by EPA's Combined Heat and Power Partnership, literature searches and correspondence with ethanol producers.
[36] For more on CHP technology, refer to Section 1.4.1.3.

Table 1.5-4.
Current Corn/Starch Ethanol Production Capacity by Energy Source

Plant Energy Source (Primary Listed First)	Capacity MGY	% of Capacity	No. of Plants	% of Plants	CHP Tech.
Coal[a]	1,758	14.6%	17	9.4%	8
Coal, Biomass	50	0.4%	1	0.6%	0
Natural Gas[b]	9,627	80.1%	151	83.9%	13
Natural Gas, Biomass[c]	115	1.0%	3	1.7%	1
Natural Gas, Coal	35	0.3%	1	0.6%	1
Natural Gas, Landfill Biogas, Wood	110	0.9%	1	0.6%	0
Natural Gas, Syrup	101	0.8%	2	1.1%	0
Waste Heat[d]	50	0.4%	1	0.6%	1
Waste Heat[d], Natural Gas	175	1.5%	3	1.7%	3
Total	**12,020**	**100.0%**	**180**	**100.0%**	**27**

[a]Includes four plants that are permitted to burn biomass, tires, petroleum coke, and wood waste in addition to coal and one facility that intends to switch to biomass in the future.

[b]Includes two facilities that might switch to biomass, one facility that intends to burn thin stillage and biogas, and two facilities that were once considering switching to coal in the future.

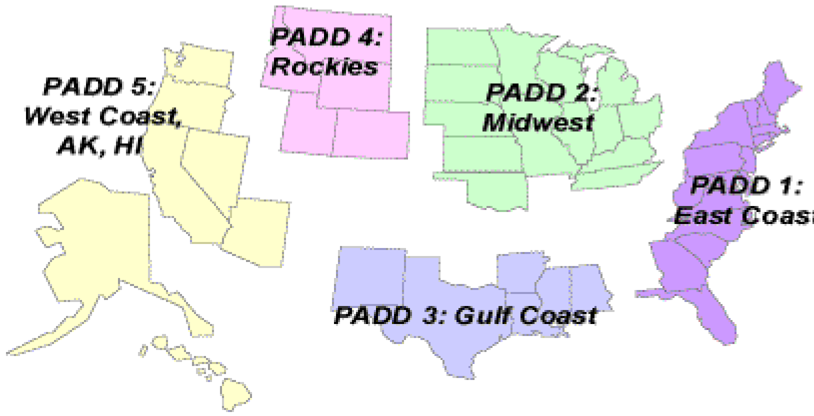
[c]Includes one facility processing bran in addition to natural gas.

[d]Waste heat from utility partnerships.

During the ethanol fermentation process, large amounts of carbon dioxide (CO_2) gas are released. In some plants, the CO_2 is vented into the atmosphere, but where local markets exist, it is captured, purified, and sold to the food processing industry for use in carbonated beverages and flash-freezing applications. We are currently aware of 40 fuel ethanol plants that recover CO_2 or have facilities in place to do so. According to Airgas, a leading gas distributor, the U.S. ethanol industry currently recovers 2 to 2.5 million tons of CO_2 per year which translates to about 5-7% of all the CO_2 produced by the industry.[253]

Since the majority of ethanol is made from corn, it is no surprise that most of the plants are located in the Midwest near the Corn Belt. Of today's 180 ethanol production facilities, 163 are located in the 15 states comprising PADD 2. For a map of the Petroleum Administration for Defense Districts or PADDs, refer to Figure 1.5-2.

Figure 1.5-2.
Petroleum Administration for Defense Districts



As a region, PADD 2 accounts for over 94% (or 11.3 billion gallons) of today's estimated ethanol production capacity, as shown in Table 1.5-5.

Table 1.5-5.
Current Corn/Starch Ethanol Production Capacity by PADD

PADD	Capacity MGY	% of Capacity	No. of Plants	% of Plants
PADD 1	150	1.3%	3	1.7%
PADD 2	11,329	94.2%	163	90.6%
PADD 3	294	2.4%	4	2.2%
PADD 4	152	1.3%	7	3.9%
PADD 5	95	0.8%	3	1.7%
Total	**12,020**	**100.0%**	**180**	**100.0%**

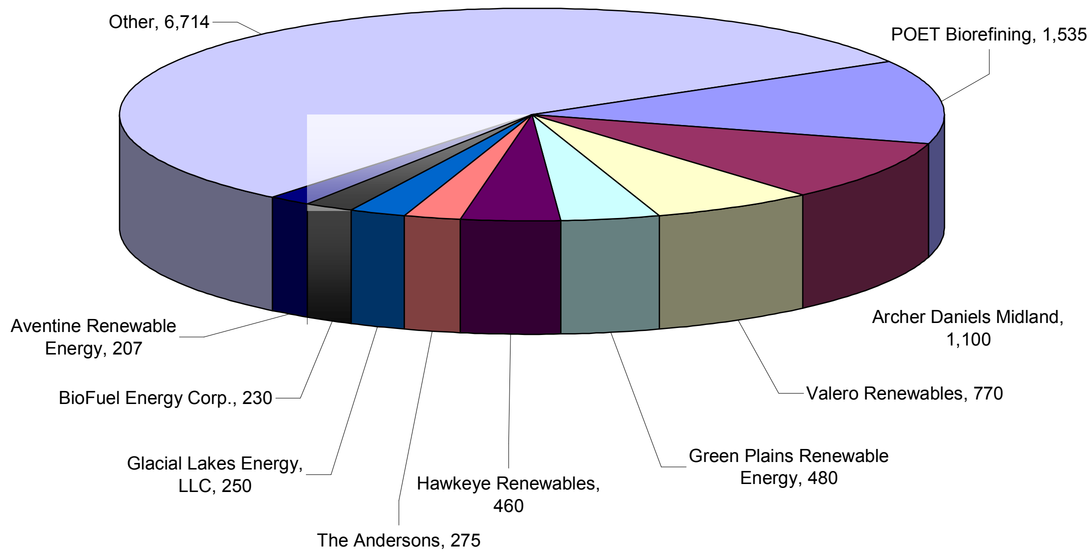
Leading the Midwest in ethanol production are Iowa, Nebraska, Illinois, Minnesota, and South Dakota. Together, these five states' 109 ethanol plants account for over two-thirds (or about 8.2 billion gallons) of the nation's ethanol production capacity. However, although the majority of ethanol production comes from PADD 2, there are a growing number of plants situated outside the traditional Corn Belt. Our November 2009 industry assessment indicates that Arizona, California, Colorado, Georgia, Idaho, Mississippi, New York, Oklahoma, Oregon, Texas and Wyoming all have one or more operational ethanol plants. Some of these facilities ship in feedstocks (namely corn) from the Midwest, others rely on locally grown/produced feedstocks, while others rely on a combination of the two. A summary of the online ethanol production capacity by state is presented in Table 1.5-6.

Table 1.5-6.
Current Corn/Starch Ethanol Production Capacity by State

State	Capacity MGY	% of Capacity	No. of Plants	% of Plants
Iowa	3,214	26.7%	39	21.7%
Nebraska	1,560	13.0%	23	12.8%
Illinois	1,342	11.2%	13	7.2%
Minnesota	1,113	9.3%	20	11.1%
South Dakota	987	8.2%	14	7.8%
Indiana	716	6.0%	9	5.0%
Wisconsin	529	4.4%	9	5.0%
Kansas	439	3.6%	11	6.1%
North Dakota	355	3.0%	5	2.8%
Ohio	320	2.7%	5	2.8%
Missouri	261	2.2%	6	3.3%
Texas	240	2.0%	3	1.7%
Tennessee	236	2.0%	2	1.1%
Michigan	217	1.8%	4	2.2%
Colorado	138	1.1%	5	2.8%
Georgia	100	0.8%	2	1.1%
Mississippi	54	0.4%	1	0.6%
New York	50	0.4%	1	0.6%
Arizona	50	0.4%	1	0.6%
Kentucky	40	0.3%	2	1.1%
Oregon	40	0.3%	1	0.6%
Wyoming	9	0.1%	1	0.6%
California	5	0.0%	1	0.6%
Idaho	5	0.0%	1	0.6%
Oklahoma	2	0.0%	1	0.6%
Total	**12,020**	**100.0%**	**180**	**100.0%**

The U.S. ethanol industry is currently comprised of a mixture of company-owned plants and locally-owned farmer cooperatives (co-ops). The majority of today's ethanol production facilities are company-owned and, on average, these plants are larger in size than farmer-owned co-ops. Accordingly, these facilities account for about 80% of today's online ethanol production capacity.[254] Furthermore, nearly 30% of the total domestic product comes from 40 plants owned by just three different companies – POET Biorefining, Archer Daniels Midland (ADM), and Valero Renewables. For a summary of ethanol production capacity by company, refer to Figure 1.5-3 below.

Figure 1.5-3.
Current Corn/Starch Ethanol Production Capacity by Company



Valero entered the ethanol industry in March of 2009 when it acquired seven ethanol plants from former ethanol giant, Verasun. The oil company currently has agreements in place to purchase three more ethanol plants that would bring the company's ethanol production capacity to 1.1 billion gallons per year.[37,255] However, ethanol plants are much smaller than petroleum refineries. Valero's smallest petroleum refinery in Ardmore, OK has about twice the throughput of all its ethanol plants combined.[256] Still, as obligated parties under RFS1 and RFS2, the refining industry continues to show increased interest in biofuels. Suncor and Murphy Oil recently joined Valero as the second and third oil companies to purchase idled U.S. ethanol plants. Many refiners are also supporting the development of cellulosic biofuels and algae-based biodiesel.

1.5.1.2 Forecasted Production Under RFS2

As highlighted earlier, domestic ethanol production is projected to grow to over 10 billion gallons in 2009. And with over 12 billion gallons of capacity online as of November 2009, ethanol production should continue to grow in 2010, provided plants continue to produce at or above today's production levels. In addition, despite current market conditions (i.e., poor ethanol margins), the ethanol industry is expected to grow in the future under the RFS2 program. Although there is not a set corn ethanol requirement, EISA allows for 15 billion gallons of the 36-billion gallon renewable fuel standard to be met by conventional biofuels. We expect that

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[37] Valero recently announced that it has purchase agreements in place to acquire the last two Verasun plants in Linden, IN and Bloomington, OH and the former Renew Energy plant in Jefferson Junction, WI.

corn ethanol will fulfill this requirement, provided it is more cost competitive than imported ethanol or cellulosic biofuel in the marketplace.

In addition to the 180 aforementioned corn/starch ethanol plants currently online, 27 plants are presently idled.[38] Some of these are smaller ethanol plants that have been idled for quite some time, whereas others are in a more temporary "hot idle" mode, ready to be restarted. In response to the economic downturn, a number of ethanol producers have idled production, halted construction projects, sold off plants and even filed for Chapter 11 bankruptcy protection. Some corn ethanol companies have exited the industry all together (e.g., Verasun) whereas others are using bankruptcy as a means to protect themselves from creditors as they restructure their finances with the goal of becoming sustainable.

Crude oil prices are expected to increase in the future making corn ethanol more economically viable. According to EIA's AEO 2009, crude oil prices are projected to increase from about $80/barrel (today's price) to $116/barrel by 2022.[257] As oil and gas prices rebound, we expect that the biofuels industry will as well. Since our April 2009 industry assessment used for the NPRM, at least nine corn ethanol plants have come back online.

For analysis purposes, we assumed that all 27 idled corn/starch ethanol plants would resume operations by 2022 under the RFS2 program. We also assumed that a total of 11 new ethanol plants and two expansion projects currently under construction or in advanced stages of planning would come online.[258] This includes two large dry mill expansion projects currently underway at existing ADM wet mill plants and two planned combination corn/cellulosic ethanol plants that received funding from DOE. While several of these projects are delayed or on hold at the moment, we expect that these facilities (or comparable replacement projects) would eventually come online to get the nation to approximately 15 billion gallons of corn ethanol production capacity as shown below in Table 1.5-7.

Table 1.5-7.
Potential Corn/Starch Ethanol Industry Expansion Under RFS2

	Plants Currently Online	Idled Plants[a]	Under Construction[b]	Planned Exp. or DOE-Funded Projects[c]	Total
Plant Capacity (MGY)	**12,020**	**1,440**	**1,301**	**166**	**14,927**
No. of Plants	**180**	**27**	**10 new**	**1 new, 2 exp**	**218**

[a]Assumes all idled plants come back online in the future.
[b]Includes construction projects that are currently on hold. Considers two dry mill expansion projects currently underway at existing ADM wet mill sites to be new plants.
[c]Includes an expansion project at an existing corn ethanol plant and two planned combination corn/cellulosic ethanol plants that received funding from DOE.

[38] Based on our November 2009 corn/starch ethanol industry characterization. We are aware of at least one plant that has come back online since then.

While theoretically it only takes 12-18 months to build a corn ethanol plant[39], the rate at which new plant capacity comes online will be dictated by market conditions, which will in part be influenced by the RFS2 requirements. As explained in Section 1.2.2, today's program will create a growing demand for corn ethanol reaching 15 billion gallons by 2016. However, it is possible that market conditions could drive demand even higher. Whether the nation produces additional corn ethanol is uncertain and will be determined by feedstock availability/pricing, crude oil pricing, and the relative ethanol/gasoline price relationship. To measure the impacts of the RFS2 program, we assumed that corn ethanol production would not exceed 15 billion gallons. We also assumed that all growth would come from new plants or plant expansion projects (in addition to idled plants being brought back online). However, it is possible that some of the required growth could come from minor process improvements (e.g., debottlenecking) at existing facilities. Allowing a 5% tolerance on the baseline volume for grandfathering facilities (per §80.1403) could promote such growth.

Once the aforementioned capacity expansion is complete, we estimate that there will be 218 corn/starch ethanol plants operating in the U.S. with a combined production capacity of around 15 billion gallons per year. Much like today's ethanol industry, the overwhelming majority of new plant capacity (almost 88% by volume) is expected to come from corn-fed plants. Another 12% is forecasted to come from plants processing a blend of corn and/or other grains, and a tiny capacity increase is projected to come from an idled cheese whey plant coming back online. A summary of the forecasted ethanol production by feedstock under the RFS2 program is found in Table 1.5-8.

[39] For more information on our estimated plant build rates, refer to Section 1.5.3.4.

Table 1.5-8.
Projected RFS2 Ethanol Production Capacity by Feedstock

	Additional Production		Total RFS2 Estimate	
Plant Feedstock (Primary Listed First)	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**
Barley	65	1	65	1
Corn[a]	2,549	30	13,543	185
Corn, Milo[b]	173	3	990	18
Corn, Wheat	0	0	130	1
Corn, Wheat, Milo	110	2	110	2
Corn, Whey	7	1	7	1
Milo	0	0	3	1
Wheat, Milo	0	0	50	1
Cheese Whey	3	1	3	1
Waste Beverages[c]	0	0	20	5
Waste Sugars & Starches[d]	0	0	7	2
Total	**2,907**	**38**	**14,927**	**218**

[a]Includes one facility processing seed corn, one facility operating a pilot cellulosic butanol plant, two facilities with plans to build pilot cellulosic ethanol plants, and three facilities with plans to build small commercial cellulosic ethanol plants.
[b]Includes one facility processing a small amount of molasses in addition to corn and milo.
[c]Includes two facilities processing brewery waste.
[d]Includes one facility processing potato waste that intends to add corn in the future.

With the exception of one facility[40], all new corn/grain ethanol plants are expected to utilize dry milling technologies and the majority of new production is expected to come from plants burning natural gas. However, we anticipate that two manure biogas plants[41], one biomass-fired plant, and two coal-fired ethanol plants will be added to the mix.[42] Of these new and returning idled plants, we're aware of five facilities currently planning to use CHP technology, bringing the U.S. total to 32 as shown in Table 1.5-9.

[40] Tate and Lyle is currently in the process of building a 115 MGY wet mill corn ethanol plant in Fort Dodge, IA.
[41] One manure biogas plant that is currently idled and another that was under construction but is now on hold.
[42] The two coal fired plants are the aforementioned dry mill expansion projects currently underway at existing ADM sites. These projects commenced construction on or before December 19, 2007 and would therefore should likely be grandfathered under the RFS2 rule. For more on our grandfathering assessment, refer to Section 1.5.1.4 of the RIA.

Table 1.5-9.
Projected Near-Term Corn/Starch Ethanol Production Capacity by Energy Source

Plant Energy Source (Primary Listed First)	**Add'l Production**		**Total RFS2 Estimate**		
	Capacity MGY	**No. of Plants**	**Capacity MGY**	**No. of Plants**	**CHP Tech.**
Biomass	88	1	88	1	1
Coal[a]	550	2	2,308	19	10
Coal, Biomass	0	0	50	1	0
Manure Biogas	139	2	139	2	0
Natural Gas[b]	2,130	33	11,757	184	15
Natural Gas, Biomass[c]	0	0	115	3	1
Natural Gas, Coal	0	0	35	1	1
Natural Gas, Landfill Biogas, Wood	0	0	110	1	0
Natural Gas, Syrup	0	0	101	2	0
Waste Heat[d]	0	0	50	1	1
Waste Heat[d], Natural Gas	0	0	175	3	3
Total	**2,907**	**38**	**14,927**	**218**	**32**

[a]Includes six plants that are permitted to burn biomass, tires, petroleum coke, and wood waste in addition to coal and one facility that intends to switch to biomass in the future.

[b]Includes four facilities that might switch to biomass in the future, one facility that intends to burn thin stillage and biogas, and a total of five facilities that were once considering switching to coal in the future.

[c]Includes one facility processing bran in addition to natural gas.

[d]Waste heat from utility partnerships.

The information presented in Table 1.5-9 is based on the industry's current near-term production plans. However, we anticipate growth in advanced ethanol production technologies under the RFS2 program. Forecasted fuel prices are projected to drive corn ethanol producers to transition from conventional boiler fuels to biomass feedstocks. In addition, fossil fuel/electricity prices will likely drive a number of ethanol producers to pursue CHP technology. For more on our projected 2022 utilization of these technologies under the RFS2 program, refer to Section 1.5.1.3 of the RIA.

Under the RFS2 program, the majority of new ethanol production (almost 70% of added capacity) is expected to originate from PADD 2, close to where the corn is grown. However, there are a number of "destination" ethanol plants being built outside the Midwest in response to state production subsidies, retail pump incentives, and state mandates. A summary of the forecasted ethanol production by PADD under the RFS2 program can be found in Table 1.5-10.

**Table 1.5-10.
Projected RFS2 Corn/Starch Ethanol Production Capacity by PADD**

	Additional Production		Total RFS2 Estimate	
PADD	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**
PADD 1	349	4	499	7
PADD 2	2,011	25	13,340	188
PADD 3	145	2	439	6
PADD 4	50	1	202	8
PADD 5	352	6	447	9
Total	**2,907**	**38**	**14,927**	**218**

Based on current production plans, we project that Iowa, Nebraska, Illinois, Minnesota and South Dakota will continue to dominate ethanol production with a collective production capacity of about 9.5 billion gallons per year. Ethanol production is expected to grow in other Midwest states and there are also a growing number of plants that are being built outside the Corn Belt. After the proposed RFS2 program is fully implemented, we estimate that more than half of the United States will have corn/starch ethanol production. Table 1.5-11 shows our predictions of ethanol production capacity by state (from greatest to smallest) after the RFS2 program is fully implemented.

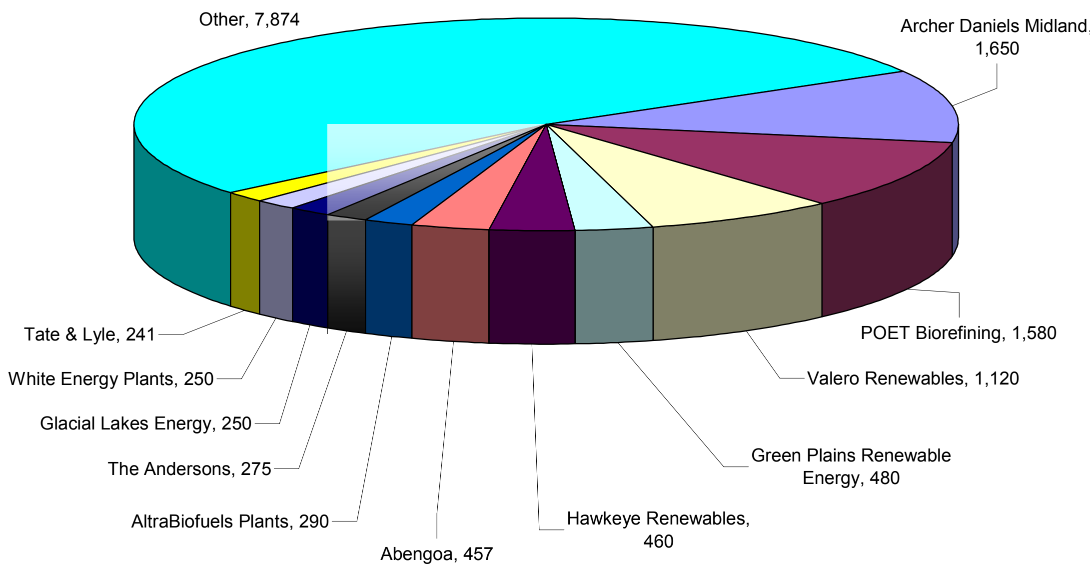
Table 1.5-11.
Projected RFS2 Corn/Starch Ethanol Production Capacity by State

	Additional Production		Total RFS2 Estimate	
State	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**
Iowa	545	3	3,759	42
Nebraska	453	4	2,013	27
Illinois	178	3	1,520	16
Minnesota	28	2	1,141	22
South Dakota	61	1	1,048	15
Indiana	286	3	1,002	12
Kansas	168	3	607	14
Ohio	224	3	544	8
Wisconsin	7	1	536	10
North Dakota	11	1	366	6
Texas	115	1	355	4
Michigan	50	1	267	5
Missouri	0	0	261	6
California	239	5	244	6
Tennessee	0	0	236	2
New York	114	1	164	2
Oregon	113	1	153	2
Colorado	0	0	138	5
Pennsylvania	110	1	110	1
Georgia	0	0	100	2
Virginia	65	1	65	1
North Carolina	60	1	60	1
Idaho	50	1	55	2
Mississippi	0	0	54	1
Arizona	0	0	50	1
Kentucky	0	0	40	2
New Mexico	30	1	30	1
Wyoming	0	0	9	1
Oklahoma	0	0	2	1
Total	**2,907**	**38**	**14,927**	**218**

The majority of future ethanol plants are expected to be company-owned. Of the 38 plants we are expecting to be built or brought back online under the RFS2 program, 36 are expected to be owned by corporations. The leading ethanol producers will likely continue to be

Archer Daniels Midland and POET Biorefining, each with over 1.5 billion gallons of annual corn ethanol production capacity. Valero Renewables is expected to be the third largest ethanol producer with over 1.1 billion gallons of production capacity, provided the most recent ethanol plant acquisition goes through. A summary of the projected ethanol plant ownership under the RFS2 program is found in Figure1.5-4.

Figure 1.5-4.
Forecasted Corn/Starch Ethanol Production Capacity by Company



1.5.1.3 Forecasted Growth in Advanced Processing Technologies

While we can get a good idea of what the ethanol industry will look like in the near term by looking at existing ethanol plants and those planned or under construction, further analysis is needed to forecast what the ethanol industry will look like in 2022. Significant changes in the primary fuel source and overall energy efficiency of ethanol production plants are likely to occur. The high price of natural gas, projected to be $7.75/MMBTU in 2022 in the EIA 2009 Annual Energy Outlook, has many ethanol plants considering alternative fuel sources. Greater biofuel availability and potential low life cycle green house gas emissions incentives may further encourage ethanol producers to transition from fossil fuels to biomass based fuels.

As ethanol plants become more efficient and require less energy, their ability to use biofuels increases. Two of the biggest drawbacks to using biofuels currently are handling and storage costs. Due to the lower density of biofuels, as compared to coal, a larger area is required to store biomass with an equivalent heating value. Handling costs are also increased as a larger volume of fuel must be moved. These negative impacts would be less significant in an ethanol plant using less energy. Lower overall energy use would also allow the energy needs of the ethanol plant to be met entirely, or to a greater extent, by waste products and locally produced biofuels. This would greatly reduce the purchase and transportation costs of the biofuels. If ethanol producers do decide to make a transition to biofuels, is likely that plants currently using natural gas would transition to biogas, and those using coal would transition to solid biomass. This is primarily due to their ability to make these transitions without investing in new boiler equipment. The same factors that may cause ethanol producers to increase biofuels usage, higher fossil fuel costs and lower lifecycle green house gas emissions, are expected to increase the number of ethanol producers using combined heat and power (CHP) technology. Projections for the primary feedstock and use of CHP technology from 2020 to 2030 are summarized in Table 1.5-12 below.

Table 1.5-12.[259]
Projected Primary Fuel Sources and CHP Usage

	2020	**2022**	2025	2030
Natural Gas Boiler	54%	**49%**	42%	31%
Natural Gas CHP	11%	**12%**	13%	15%
Coal Boiler	0%	**0%**	0%	0%
Coal CHP	4%	**4%**	4%	4%
Biomass Boiler	10%	**11%**	12%	15%
Biomass CHP	9%	**10%**	12%	15%
Biogas Boiler	12%	**14%**	16%	20%

The energy efficiency of ethanol plants is also expected to change significantly. New technologies are expected to both increase the efficiency of units currently used in ethanol production, as well as provide energy-saving alternatives to conventional production practices. Increasing energy efficiency is a priority in many ethanol plants as is can dramatically increase profitability by reducing energy costs, the second highest cost of ethanol production behind raw materials. Several groups are currently working on technologies that could impact the ethanol industry. The Department of Energy's (DOE) Super Boiler program is expected to produce boilers with an efficiency of 94% by 2020. The National Electrical Manufacturers Association's (NEMA) premium efficiency motors are expected to be adopted more widely in the coming years. Electricity generation efficiency is also expected to increase at plants with CHP technology. The projected energy savings from the energy efficiency improvements to units used in conventional ethanol plants in 2022 relative to 2007 is 32.1%. The projected energy savings from 2015 to 2030 are summarized in Table 1.5-13 below.

Table 1.5-13.[260]
Projected Energy Savings from Conventional Production Equipment

	2007	2015	2020	**2022**	2025	2030
Boiler, Efficiency	82.0%	86.0%	90.0%	**91.6%**	94.0%	94.0%
Energy Savings Relative to 2007	-	1.2%	8.9%	**10.5%**	12.8%	12.8%
Motor, Efficiency	90.0%	92.0%	93.0%	**93.8%**	95.0%	95.0%
Energy Savings Relative to 2007	-	2.2%	3.2%	**4.0%**	5.3%	5.3%
10 MW Industrial Turbine, Efficiency	31.0%	33.0%	34.0%	**34.0%**	34.0%	34.0%
Energy Savings Relative to 2007	-	6.1%	8.8%	**8.8%**	8.8%	8.8%

The same factors that drive ethanol producers to increase the energy efficiency of their equipment may also move them to consider energy saving changes to the ethanol production process. Several process changes, including raw starch hydrolysis, corn fractionation, corn oil extraction, and membrane separation, are likely to be adopted to varying degrees. The degree to which they are adopted will depend on many factors, including technology availability, capital cost of implementation, energy cost savings, and co-product revenue generation. A description of each of these technologies, including the challenges and benefits of their implementation, can be found in Section 1.4.1.3. The adoption of these technologies are expected to decrease the average thermal energy use of dry mill ethanol plants by 11.8% and to increase the average electrical energy use by 13.1%. These numbers are based on a plant that is drying 100% of its distillers' grains with solubles (DGS). Plants that dry less than 100% of their DGS would likely realize smaller benefits from these technologies. The projected penetration of these technologies, and the associated energy use impact, is summarized in Table 1.5-14 below.

Table 1.5-14.[261]
Projected Energy Savings from Process Changes

Percent of all Plants Adopting Process				
Process Improvement	2020	**2022**	2025	2030
Raw Starch Hydrolysis	20%	**22%**	25%	30%
Corn Fractionation	18%	**20%**	24%	30%
Corn Oil Extraction	65%	**70%**	70%	70%
Membrane Separation	3%	**5%**	5%	5%
Energy Reduction from Base Process (Thermal)				
Raw Starch Hydrolysis	16%	**16.7%**	17%	17%
Corn Fractionation	17.6%	**17.6%**	17.6%	17.6%
Corn Oil Extraction	5.4%	**5.4%**	5.4%	5.4%
Membrane Separation	15.7%	**15.7%**	15.7%	15.7%
Weighted Average Savings (Thermal)	10.3%	**11.8%**	13.0%	14.9%
Energy Reduction from Base Process (Electrical)				
Raw Starch Hydrolysis	0%	**0%**	0%	0%
Corn Fractionation	-29%	**-29%**	-29%	-29%
Corn Oil Extraction	-9.9%	**-9.9%**	-9.9%	-9.9%
Membrane Separation	-7.6%	**-7.6%**	-7.6%	-7.6%
Weighted Average Savings (Electrical)	-11.8%	**-13.1%**	-14.3%	-16.0%

Another factor that plays a significant role in determining the energy usage of ethanol plants is the treatment of the main co-product of the dry mill ethanol production process, distillers' grains with solubles (DGS). The DGS, which is most often sold as feed for cattle, poultry, or swine, can be sold either dry or wet. Wet distillers' grain with solubles (WDGS) can often only be sold locally, as it is difficult to transport and is susceptible to spoilage. Drying the DGS avoids these problems and allows the DGS to be sold in a much wider market; however drying the DGS is an energy intensive process. USDA models suggest that 40.4% of the thermal energy used in an ethanol plant that produces dry DGS is used in the drying process. Plants that do not dry their DGS, or dry only a portion of it, could experience energy savings up to 40.4%. According to a recent industry survey, 37% of all DGS produced by the dry mill ethanol industry is sold wet. We have assumed that this percentage remains constant through 2022 for our energy use projections.

Combining the impacts of these four factors (primary fuel sources, energy savings from efficiency improvements, new technology and process changes, and DGS drying rates) allows us to project the average energy usage of a dry mill ethanol plant in 2022. Table 1.5-15 below outlines the projected average energy usage of dry mill ethanol plants in 2022. The first two lines take into account the projected primary fuel types and energy efficiency improvements. The next two lines adjust the totals to include new technologies and process changes. Finally, the total is calculated by weighting the values for dry and wet DGS according to the production ratio we expect in 2022 (63% dry DGS, 37% wet DGS)[43].

Table 1.5-15
2022 Dry Mill Ethanol Plant Average Energy Usage

	Thermal Energy	Electrical Energy
Dry DGS, includes efficiency improvements	28,977 BTU/Gal	1,515 BTU/Gal
Wet DGS, includes efficiency improvements	17,271 BTU/Gal	1,515 BTU/Gal
Dry DGS, includes process changes	25,570 BTU/Gal	1,714 BTU/Gal
Wet DGS, includes process changes	16,255 BTU/Gal	1,714 BTU/Gal
2022 Average Energy Usage	**22,123 BTU/Gal**	**1,714 BTU/Gal**

In addition to projecting the average energy usage of a dry mill ethanol plant in 2022 we have also projected the energy usage of a "best case scenario" plant. This plant was defined as a plant that used the combination of all the technologies considered that resulted in the lowest overall energy usage, as well as all the energy efficiency improvements discussed above. The technologies used by the best case scenario plant were CHP, dry fractionation, membrane separation, and raw starch hydrolysis. Corn oil extraction was not considered as plants would have either corn oil extraction or dry fractionation but not both, and dry fractionation resulted in greater energy savings. Best case scenario energy usage numbers were calculated for both natural gas and coal/biomass fired plants producing both dry and wet DGS. The results are shown below.

[43] An Excel spreadsheet has been added to the docket showing the energy impact calculations of the technology improvements (EPA-HQ-OAR-2005-0161-2729).

Table 1.5-16
2022 Best Case Natural Gas Dry Mill Plant Energy Usage

	2022 Best Case Scenario (Dry DGS)	
	Thermal	Electrical
2022 Base Plant	28,660 BTU/Gal	2,251 BTU/Gal
2022 Best Case Scenario	16,568 BTU/Gal	1,682 BTU/Gal
	2022 Best Case Scenario (Wet DGS)	
2022 Base Plant	17,081 BTU/Gal	2,251 BTU/Gal
2022 Best Case Scenario	9,932 BTU/Gal	1,682 BTU/Gal

1.5.1.4 Projected Grandfathered Corn Ethanol Volume

As explained in the Section II.B.3 of the preamble, renewable fuel produced from new facilities which commenced construction after December 19, 2007 must achieve at least a 20% reduction in lifecycle greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions in order to generate RINs under the proposed RFS2 program.[44] However, facilities that commenced construction on or before December 19, 2007 are exempt or "grandfathered" from the 20% GHG reduction requirement. In addition, facilities that commenced construction in 2008 or 2009 are grandfathered if they burn natural gas, biomass, or any combination thereof.

The volume of ethanol that is grandfathered under today's RFS2 rule will be determined based on information received during the expanded registration process (refer to Section II.C of the preamble). However, as part of this final rulemaking, we analyzed the volume of corn ethanol that could potentially be grandfathered based on our knowledge of the industry.

To do so, we started with our assessment of corn ethanol plants that were operational, idled or under construction at the time of our November 2009 assessment. As shown in Table 1.5-7, excluding the planned facilities, this amounts to about 14.8 billion gallons of ethanol production capacity. Provided all the plants meet the definition of "commence construction" under §80.1403, the potentially grandfathered volume of ethanol falls just shy of meeting the 15 billion gallon conventional biofuel standard. However, actual baseline volumes established during registration could easily exceed 15 billion gallons. Furthermore, by allowing a 5% tolerance on the baseline volume to account for minor changes during ongoing maintenance of the facilities under §80.1403(a)(1), these plants could readily exceed 15 billion gallons of production.

Further examination suggests that all of today's corn ethanol plants will likely be grandfathered under the RFS2 program because they are either fired with natural gas, biomass or a combination thereof and commenced construction by December 31, 2009 or they burn coal but commenced construction on or before December 19, 2007. A summary of grandfathering assessment logic we applied is found in Figure 1.5-5. The 20 coal-fired plants we considered in greater detail are presented in Table 1.5-17.

[44] In accordance with Section 211(o)(2)(A)(i) of the Clean Air Act as amended by EISA.

Figure 1.5-5.
Potential Grandfathered Volume of Corn Ethanol Under RFS2

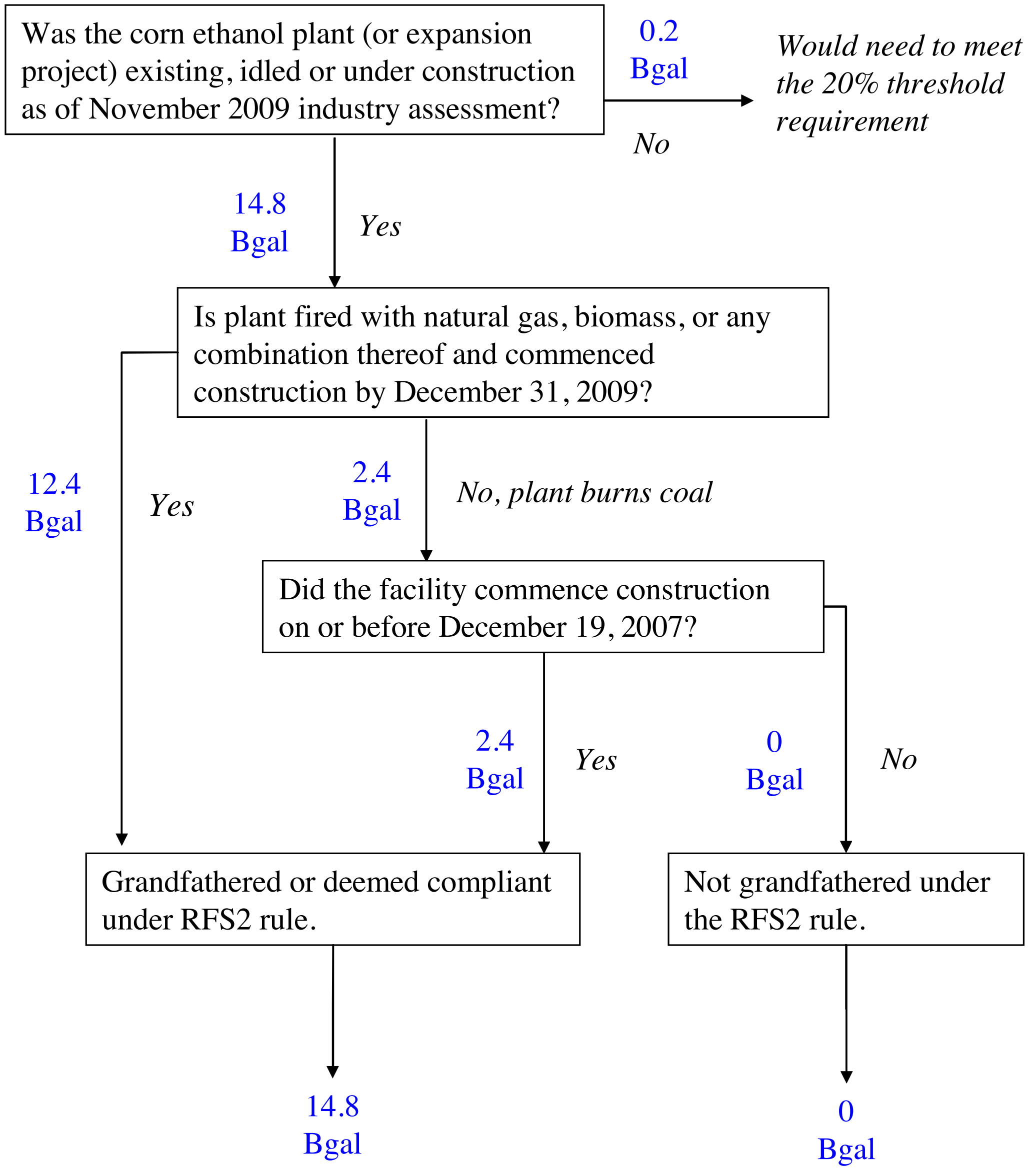


Table 1.5-17.
Coal-Fired Corn Ethanol Plants

Plant/Company	Location	Capacity MGY	On-Line Date
Ag Processing Inc.	Hastings, NE	52	1992
Archer Daniels Midland (ADM)[a]	Cedar Rapids, IA	250	1981
Archer Daniels Midland (ADM)[a]	**Cedar Rapids, IA**	**275**	**Aug-10**
Archer Daniels Midland (ADM)[a]	Clinton, IA	190	1981
Archer Daniels Midland (ADM)[a]	**Columbus, NE**	**275**	**Aug-10**
Archer Daniels Midland (ADM)[a]	Columbus, NE	95	1994
Archer Daniels Midland (ADM)[a]	Decatur, IL	290	1976
Archer Daniels Midland (ADM)	Marshall, MN	40	1988
Archer Daniels Midland (ADM)	Peoria, IL	210	1980
Archer Daniels Midland (ADM)	Walhalla, ND	25	1990
Aventine Renewable Energy[b]	Pekin, IL	100	1981
Cargill[c]	Eddyville, IA	35	1992
Chief Ethanol Fuels Inc.	Hastings, NE	62	1985
Corn LP[d]	Goldfield, IA	50	Dec-05
Grain Processing Corp	Muscatine, IA	20	May-00
Heron Lake BioEnergy, LLC	Heron Lake, MN	50	Oct-07
Lincolnway Energy LLC	Nevada, IA	50	May-06
Red Trail Energy, LLC	Richardton, ND	50	Jan-07
Riverland Biofuels[e]	**Canton, IL**	**38**	**Oct-08**
Southwest Iowa Renewable Energy	**Council Bluffs, IA**	**110**	**Feb-09**
Tate & Lyle	Loudon, TN	126	1982
	Total Coal-Fired Capacity	**2,393**	

[a]Permitted to burn biomass, tires, petroleum coke, and wood waste in addition to coal.
[b]Recently filed for bankruptcy protection.
[c]Burns a combination of natural gas and coal.
[d]Burns a combination of coal and biomass.
[e]Formerly Central Illinois Energy.

As shown above, most of the coal-fired ethanol plants were built well before 2007 and thus should have little problem qualifying as grandfathered under the RFS2 rule. There are essentially four plants that could potentially pose a challenge with respect to the construction cutoff date set by EISA. These facilities, bolded in Table 1.5-17 above, include two dry-mill ADM plant expansion projects currently underway in Cedar Rapids, IA and Columbus, NE as well as Riverland Biofuels in Canton, IL, and Southwest Iowa Renewable Energy in Council Bluffs, IA. However, research and communications with these companies suggest that these plants commenced construction on or before December 19, 2007 and thus should be grandfathered and exempt from the 20% threshold requirement under RFS2.[262]

1.5.2 Imported Ethanol

In order to assess the potential for U.S. imported ethanol, we examined the chief countries that are currently producing or consuming relatively large volumes of ethanol. In particular, we chose to focus on Brazil, the European Union (EU), Japan, India, and China to determine whether each country will likely be an importer or exporter of ethanol in the future. The following sections first describe the ethanol demands of each of these countries due to enacted or proposed mandates and goals as well as their ability to supply those demands with domestically produced ethanol. With the exception of Brazil, we show that the majority of countries analyzed could likely be importers of ethanol in the future and therefore could compete with the U.S. for supplies of ethanol. We conclude our analysis by examining the most likely pathways for imported ethanol to the U.S., namely through the Caribbean Basin Initiative (CBI) and directly from Brazil.

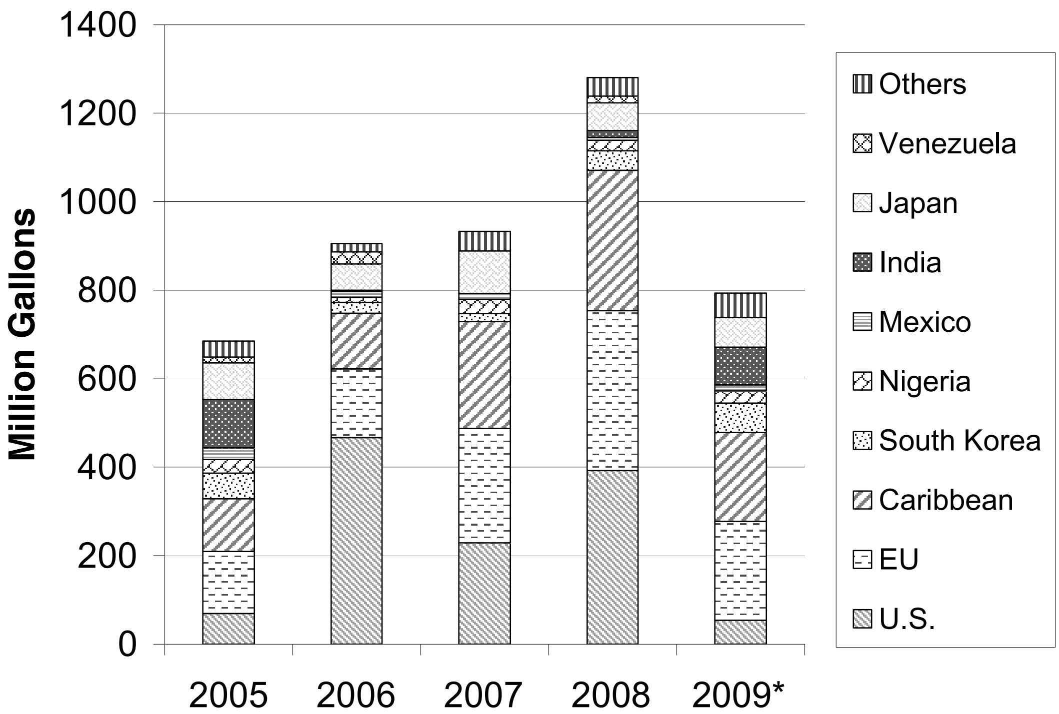
1.5.2.1 Historic/Current Imports and Exports

Brazil

Much of the potential of imported ethanol will depend on the ability for Brazil to supply ethanol to the United States and other countries. This is because Brazil has been a top producer and is the top exporter of ethanol in the world. In fact, many countries are interested in Brazilian produced sugarcane ethanol because it is currently the least costly method for producing ethanol.

Brazil has been steadily increasing its exports of ethanol, with total exports escalating from under 700 million gallons in 2005 to over 1200 million gallons in 2008. As seen in Figure 1.5-6, Brazil exports ethanol to many different countries around the globe. Prior to 2006, the majority of Brazilian ethanol exports flowed to the EU and Caribbean due to favorable economics. In 2006, the majority of Brazilian ethanol exports (52%) went to the U.S as a result of the withdrawal of MTBE from the U.S. gasoline fuel pool and high oil prices. The EU, Caribbean, and U.S. have continued to be major importers of Brazilian ethanol in recent years.

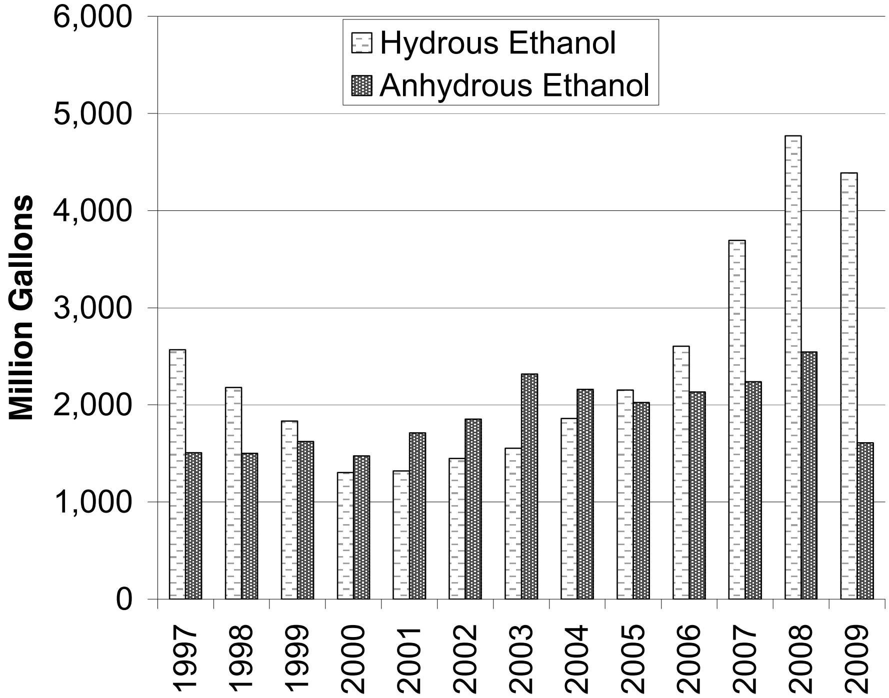
Figure 1.5-6. Brazil Ethanol Exports (Includes all types of ethanol).[263,264,265]



*January 2009-October 2009

Brazil currently produces both hydrous and anhydrous ethanol. Hydrous ethanol contains 96% ethanol and 4% water by volume, whereas anhydrous ethanol is made up of 99.5% ethanol and 0.5% water.[266] While hydrous ethanol is used in Brazil directly in Otto-cycle motors (as 100% ethanol by volume), anhydrous ethanol is mixed with gasoline at 20-25% by volume. Production of anhydrous ethanol to be mixed with gasoline has fallen since the 2005/2006 harvest, on account of the smaller share of cars running exclusively on gasoline. This was especially due to the success of flex vehicles with Brazilian customers.[267] In fact, sales of flex-fuel vehicles (FFVs) in Brazil, those that can use any mixture of gasoline and ethanol from 0 to 100%, have grown dramatically, with domestic FFV sales representing 85% of vehicles sold between January 2009 and October 2009.[268] Hydrous ethanol accounted for 65% of ethanol produced in Brazil in 2008, and 73% of ethanol produced as of December 1, 2009. Figure 1.5-7 shows the historical production of hydrous and anhydrous ethanol in Brazil.

Figure 1.5-7.
Historical Ethanol Production of Hydrous and Anhydrous Ethanol in Brazil.[269]

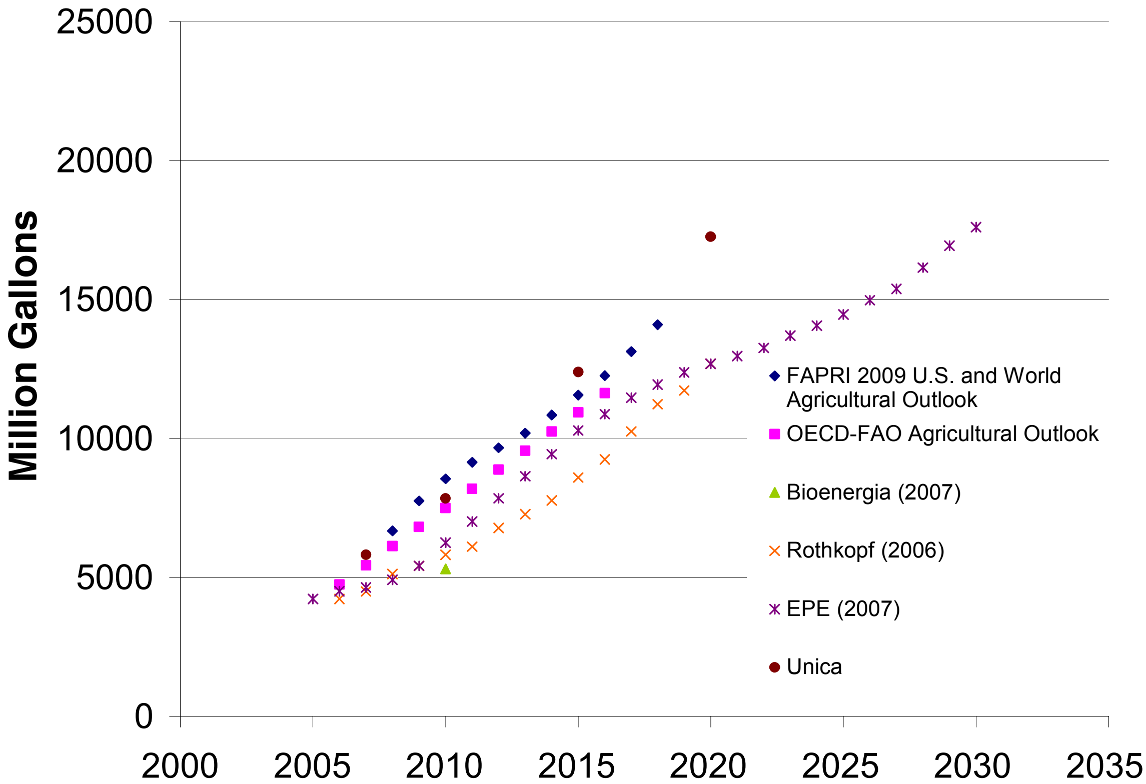


*2009 data is up to date as of 12/01/2009

In contrast to Brazil, ethanol consumed in the U.S. must first be converted to anhydrous ethanol before it can be used in conventional or FFV vehicles. This differs from Brazil because Brazilian FFVs have been designed to use hydrous ethanol, or E100 (100% ethanol by volume) for the conditions in Brazil, whereas U.S. FFVs can only use up to E85 (85% ethanol and 15% gasoline by volume). As a result, if hydrous ethanol is exported from Brazil, it must be dehydrated somewhere else before it can be used in the U.S. This is the case for the majority of ethanol exported from Brazil to the Caribbean, where it is dehydrated and often re-exported to the U.S. for consumption.

In terms of future ethanol production, however, there has been much speculation about Brazil's ability to increase production. Sugarcane analyst Datagro recently stated that Brazil's ethanol fuel production would have to grow by approximately 800 million gallons a year through 2025 to keep up with demand at home and abroad.[270] Estimates of future ethanol production in Brazil vary greatly, see Figure 1.5-8. Brazil's government has adopted plans to meet global demand by tripling production by 2020.[271] This would mean a total capacity of approximately 12.7 billion gallons, to be achieved through a combination of efficiency gains, greenfield projects, and infrastructure expansions. Estimates for the required investment tend to range from $2 billion to $4 billion a year. Other estimates indicate that, based on current projects, the required investment in capacity expansion is $3-4 billion annually.[272] If global demand were to increase much more than Brazil is planning, then capacity would need to expand even further and greater investment would be required.

Figure 1.5-8. Estimated Brazilian Ethanol Production Volumes[273]



To meet the growing demand, the Brazilian sugar and ethanol industry is already rapidly expanding and numerous mills have been planned. Brazil currently has nearly 400 sugar and ethanol mills, with more anticipated over next few years.[274,275,276] Brazil's state-owned development bank BNDES said the country is set to invest $13.1 billion between 2007 and 2011 in 89 new sugar and ethanol mills.[277] Some estimate even more, where investments in sugarcane processing factories are expected to top $23 billion over the next four years.[278] Investments include a project by Odebrecht, a Brazilian engineering company that will invest $2.6 billion dollars over the next decade to build 12-15 plants with a combined capacity to produce ~ 400 million gallons per year of ethanol.[279] Even U.S. ethanol producer ADM is preparing to enter the sugarcane business in Brazil. A recent quote by ADM's senior vice president of strategy, Steve Mills, said that sugarcane ethanol is now "a key component" of ADM's short-term strategy and, "We're devoting a lot of time and energy to this area. We're not talking about something 10 years down the road. It's on the front burner."[280]

In addition to expanding sugarcane production and ethanol plant capacity, Brazil will need to improve its current ethanol distribution infrastructure. Brazil's transport system is predominantly road-based.[281] Railroad infrastructure and use of a waterway system is lacking, as well as very low availability of multi-mode terminals. Logistics represent approximately 22% of the export expenses and is one of the areas where costs need to be reduced in order for Brazilian ethanol to become more competitive abroad.[282]

One way to deal with the lack of infrastructure is to expand the pipeline network. Petrobras, Brazil's largest petroleum refiner is planning to build a pipeline to transport ethanol destined for export from the states of Sao Paulo, Minas Gerais, Mato Grosso, Mato Grosso do Sul, Goias, and Parana. The pipeline is anticipated to go online in October 2010, with $232 million invested in the project. By 2012, Petrobras will spend more than $1.6 billion to improve logistics infrastructure to transport Brazilian ethanol. By 2011, Petrobras has the goal of exporting 920 million gallons per year.[283] One of the pipelines will run from Goias state in Brazil's center-west to Petrobras's Paulinia refinery in Sao Paulo State. The project is called PMCC Projetos de Transporte de Alcool. The line is expected to have the capacity to ship 3.2 million gallons of ethanol annually.[284]

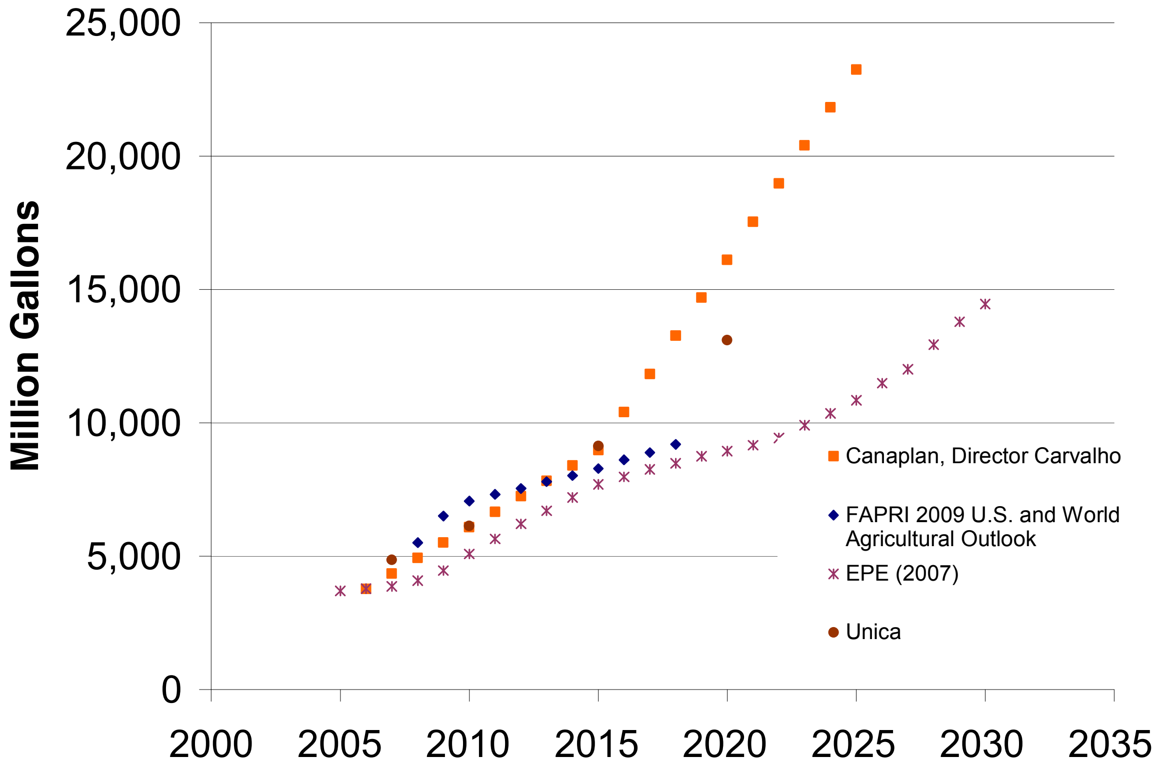
Other competitors include the joint venture from Cosan, Copersucar, and Crystalsev which will make initial investments of $11.5 million apiece to install an ethanol-only pipeline between the oil refinery in Paulinia, to an ethanol offloading terminal on the state's coast. In addition, at least three major private equity groups (Infinity, Clean Energy Brazil, and Brenco) plan to invest $1 billion in a 683-mile pipeline expected to be completed by 2011 with a capacity to deliver 1.1 million gallons of ethanol a year. In total, it is estimated that Brazil will need to invest $1 billion each year for the next 15 years in infrastructure to keep pace with capacity expansion and export demand.[285]

Another area that requires investment is in R&D and education. Currently, Brazil produces only 0.08 engineers for every 1000 people, compared to 0.2 in the U.S., 0.33 in the EU, and 0.8 in Korea.[286] Since certain types of education require a long lead time (e.g., scientific training) Brazil will need to continue to invest in training and professional development for the sector's labor pool to meet the growing demand in the biofuels industry.

Before ethanol can be exported to other countries, Brazil's own domestic fuel consumption must be met. Brazil currently has an ethanol mandate of 25%.[287] The ethanol to gasoline mix is set by the Brazilian government, which has the flexibility to adjust the ethanol mandate from 20-25% by volume.

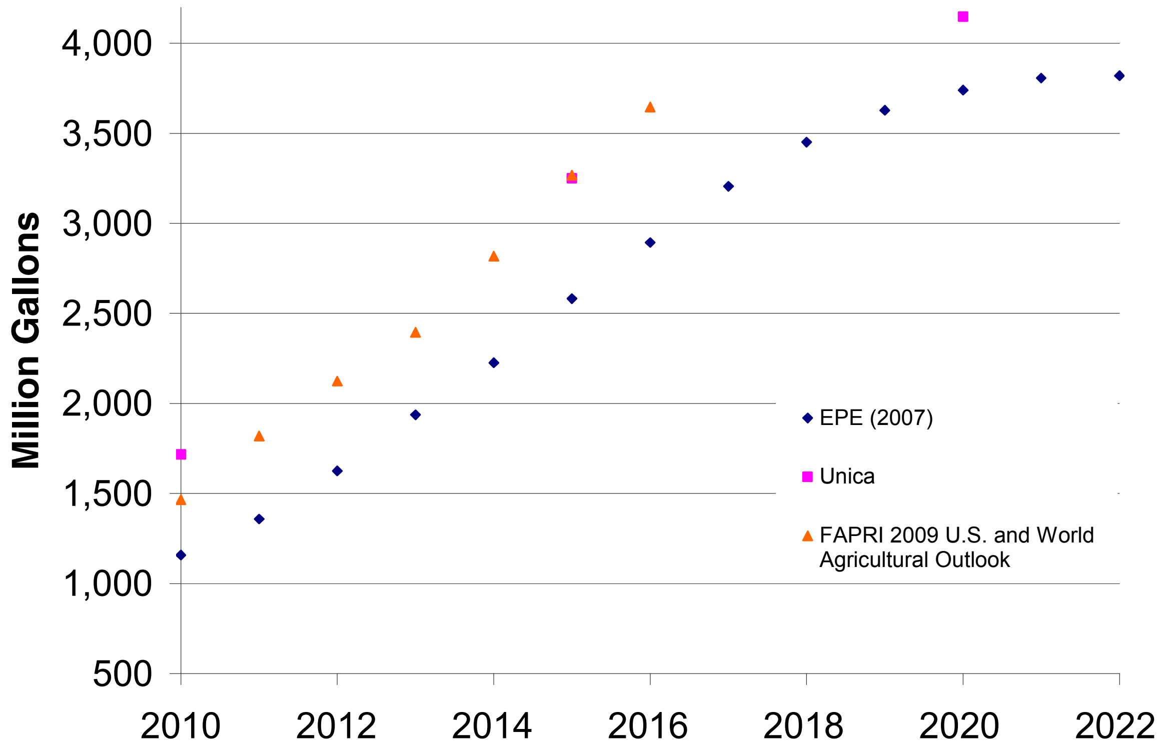
At some point in the future, Brazil's light vehicle fleet may become saturated with FFVs in preference to mainly gasoline fueled vehicles. As such, the rate in domestic demand for ethanol is expected to begin to slow.[288] Thus, as domestic demand begins to level off, some experts believe that there is a significant possibility that exports will become more relevant in market share terms. Figure 1.5-9 shows various estimates for future Brazilian ethanol domestic consumption.

Figure 1.5-9. Estimated Brazilian Ethanol Consumption Volumes [289]



After domestic consumption is met, the rest of the ethanol can be available for exports to other countries. Potential worldwide exports basically equal the total production minus the total consumption. Given the available data, only three sources estimated both production and consumption for some of the years during 2010-2022. As such, these values were used to compute reasonable export volumes from Brazil as seen in Figure 1.5-10. Estimates from EPE and Unica indicate that as much as 3.8-4.2 billion gallons could be exported by Brazil in the 2020/2022 timeframe. Longer timeframe estimates from sugarcane analyst Datagro project international ethanol sales to grow to 6.6 billion gallons by 2025.[290]

Figure 1.5-10. Estimated Brazilian Export Volumes



The European Union (EU)

Although the EU market has largely focused on biodiesel, ethanol has become increasingly important. Fuel ethanol production in the EU has grown from 140 million gallons in 2004 to 754 million gallons in 2008.[291] Germany, Spain, France, Poland, and Hungary represent almost 80% of the production in 2008. Historically, however, ethanol production volumes have been lower than mandatory blending targets.

The EU has set several targets for biofuel consumption over the past few years. In 2001, an EU Directive established that by 2005 biofuels should cover 2% of the total fuel consumption (energy basis), while the target for 2010 was set at 5.75%. However, in recent years the average biofuel contribution has been much less (0.5%, 0.6% and 1% in 2003, 2004, and 2005, respectively).[292] It is also not expected that the EU will achieve its target of 5.75% of road transport by 2010.[293]

In April 2009, the EU Energy and Climate Change Package (CCP) was adopted. This package includes a minimum target requiring 10% renewable energy use in transport by 2020. Most, if not all of this 10% is expected to come from increased biofuel use.[294] The biofuels used must meet certain criteria to be taken into account for the 10% goal, e.g., meet GHG emissions reduction thresholds. The International Energy Outlook (IEO) 2009 forecasts OECD European countries will consume 16.5 quadrillion Btu of transport fuel in 2010, growing to 17.6 quadrillion Btu by 2030.[295] Assuming a split of nearly 70% fuel volume consumed as diesel and

30% consumed as gasoline (current use), a 10% by energy requirement would require roughly 6.8 billion gallons of ethanol in 2022.[45,296] However, this may be a slight overestimate of gasoline use since the overall gasoline consumption in the EU is declining as a result of the increasing popularity of more economic diesel-powered cars. Other sources indicate smaller gasoline consumption volumes are possible by the 2020/2022 timeframe which when translated equals 5.2-5.4 billion gallons of ethanol assuming a 10% energy requirement.[297,298] According to the "FAPRI 2009 U.S. and World Agricultural Outlook", ethanol production in the EU is expected to grow to 1.6 billion gallons by 2018. Taking this into account, the EU would need to import approximately 4-5 billion gallons of ethanol in order to meet the 10% volume requirement if only traditional crops are used.

As of September 2009, the installed capacity of the EU ethanol industry is 1.7 billion gallons, while 0.6 billion gallons are under construction and another 3 billion gallons has been announced.[299,300] Totaling these capacity estimates, the EU would have 5.3 billion gallons ethanol capacity. In the EU, these facilities mainly process wheat, corn and sugar beet derivatives, with a limited amount produced from barley, rye and the surplus of wine alcohol. While not all the announced projects in the EU will be completed, this gives an estimate of how fast and large ethanol production in the EU could grow. If we assumed that the EU could produce this volume by 2022, as little as 1.5 billion gallons would need to be imported from other countries assuming a 6.8 billion gallon demand due to the 10% mandate. Thus, it appears likely from the above analysis that the EU will continue to be a net importer of biofuels under most future scenarios.

Japan

Historically, Japan has not produced much ethanol (24,000 gallons in 2008) and has imported the majority of its consumption.[301,302] Now the government is showing signs of encouraging biofuels production by promoting (not mandating) a 3% blend of ethanol in gasoline. At the very least, a non-mandatory 3% blend will create a demand of 106-132 million gallons of ethanol.[303] This is similar to Japan's Agency for Natural Resources and Energy target to replace 132.1 million gallons of transportation fuel by 2010, using ethanol and biodiesel.[304]

With a 3% ethanol blend, ethanol trade may increase substantially with Japan (this may even reach over 1.5 billion gallons annually if a 10% ethanol blend is implemented nationwide in Japan, approximately 500 million gallons with 3% ethanol blends).[305] While the use of greater than 3% blends in Japan may be unlikely, the Japanese government has mandated that all gasoline powered vehicles are able to run on 10% blends by 2030 and may also enact legislation to require all new vehicles to be E10 compatible by 2012.[306,307]

One challenge with the use of ethanol in Japan is its distribution. As E5 and higher ethanol blends have been shown to be corrosive to aluminum and rubber car parts, Japan is looking into using ETBE blends of 7% and even 20-25% instead of ethanol.[308] The Petroleum Association of Japan has announced that gasoline containing ETBE blends of 7% will be available for general public consumption by 2010. As ETBE is produced using ethanol as a

[45] Assuming energy contents 115,000 Btu/gal for gasoline and 77,012 Btu/gal for denatured ethanol and 17.5 quadrillion Btu in 2022

feedstock, this could create a domestic ethanol demand of 90-100 million gallons.[309] Imports of ETBE were roughly 1.7 million gallons in 2008.[310]

Table 1.5-18 details select ethanol model plants and facilities in Japan. In total, there are close to a dozen ethanol facilities nationwide, however, details on each facility were not fully available and most are considered small-scale.

Table 1.5-18. Select Ethanol Model Plants and Facilities in Japan[311]

Plant	Capacity	Feedstock
Nippon Steel Plant	38,000 gallons/year	Food waste from: supermarkets, restaurants, schools, hospitals
Mitsui Engineering & Shipbuilding Co.	Not available	Agricultural wastes: felled oil palm trunks, empty fruit bunches, fibrous fruit wastes, kernel shells
Shimizucho, public-private partnership between Mitsubishi Corp. and Hokuren	4 million gallons/year	Off-spec wheat and sugarbeets
Tomakomai	4 million gallons/year	Rice
Obihiro City, Hokkaido run by Tokachi Foundation	Small volumes	Wheat
Niigata, joint operation with Zen-noh	Small volumes	Rice

Historically, Japan has relied on nations such as Brazil to supply ethanol, although it is almost all for industrial use. Imports of ethanol for transportation use are currently negligible; however, future imports may be possible from Brazil given the joint ventures established between Japanese and Brazilian firms. In early 2005, Japan and Brazil signed an agreement for a bilateral biofuels program to export Brazilian ethanol and biodiesel to Japan. Japan's investment will be used to install new ethanol facilities, increase acreage of sugarcane production, and modernize the infrastructure necessary for the transportation of ethanol.

One such partnership is between Brazilian oil company, Petrobras, and trading house Mitsui & Co., with financial support from Japan Bank for International Cooperation. The companies are in the process of analyzing 40 projects evaluated at $8 billion which produce alcohol and sugar from sugarcane. According to Paulo Roberto Costa, head of Petrobras' supply division, "Our target is to produce ethanol to be exported *only* to Japan." Petrobras plans to produce a total of 1 billion liters (264 million gallons) of alcohol annually at five processing plants in the states of Mato Grosso, Goias, and Minas Gerais. Each of the five processing plants will produce approximately 50 million gallons per year within the next 2 ½ years, and the whole production will be exported to Japan. In order to convince Japan that Petrobras has adequate ethanol supplies it was noted that their processing facilities will not be able to produce sugar, only alcohol.[312] With this amount (264 million gallons) slated for Japan only, other countries may have to either develop their own contracts with Brazil to ensure a stable supply.

Petrobras also recently bought a 90 percent stake in Exxon Mobil's Okinawa oil refinery that may serve as a staging point for Brazilian ethanol exports to Japan and the rest of Asia. This may help mitigate one of the main problems for Petrobras and other major exporters, a lack of offloading infrastructure.[313]

The prospect for large domestic production of ethanol in Japan appears to be small due to limitations on feedstock. In fact, Japan's first biomass plan, "Biomass Nippon Strategy" unveiled in December 2002 and updated in 2008 reveals that the Government of Japan's (GOJ's) current thinking, given limited agricultural resources, is to focus on cellulosic biofuel as the future for Japan's biofuel production.[314] The Agriculture Ministry states that Japan has enough feedstock to produce 26.4 million gallons per year, however, the Ministry of Environment (MOE) expects Japan to meet only 10% of the 132.1 million gallon target (or 13.2 million gallons) with domestic ethanol production.[315] The Ministry of Agriculture and Fisheries (MAFF), on the other hand, predicts that Japan could reasonably expect to supply approximately 95 million gallons. Even with these higher domestic production estimates, Japan would still be a net importer of fuel ethanol if the biofuels target is met. Thus, the potential estimated demand for imported ethanol ranges from 11 million gallons to 1572 million gallons depending on the type of mandate assumed and the differences in the estimates of domestic ethanol production.

India

India has continued to focus on the use of non-food sources (e.g., sugar molasses) for the production of ethanol for blending with gasoline. The amount of ethanol blended into gasoline in India has fluctuated in the past few years. The government's current target of 5% blending of ethanol with gasoline has been partially successful in years of surplus sugar production, but falters when sugar production declines.[316] Commercial production and marketing of ethanol-blended gasoline started in January 2003 when the Ministry of Petroleum and Natural Gas launched the first phase of the ethanol blended petrol (EBP) program that mandated blending of 5% ethanol in gasoline in 9 states (out of a total of 28) and 4 union territories (UT) (out of a total of 7). In 2004, ethanol blending in gasoline had to be halted because of a lower sugar output due to a drought, which increased prices. However, production started back up in late 2005 when a fuller sugarcane molasses crop became available. Then in September 2006 the government announced the second phase of the EBP that mandates 5% blending ethanol with gasoline in 20 states and 8 union territories.[46] The mandate was effective starting in November 2006 and would have required about 159 million gallons to be used. However, the program only started with 10 states and was not implemented in other states due to high state taxes, excise duties and levies.

Industry sources report that ethanol supplies for the EBP program have come to a virtual halt in most states since October 2008.[317] In fact, industry sources estimate that only 143 million gallons of ethanol have been supplied to the EBP program by the end of April 2009 during the past two and a half years. The government has had plans to extend the ethanol blend ratio to

[46] The number of union territories appears to have changed since 2006.

10% in a third stage once the program is extended to all target states. The original plan was a minimum 10% ethanol blend by October 2008; however, this was put on hold because of the sharp fall in crude oil prices and because of technical concerns raised by the Society of Indian Automobile Manufacturers (SIAM). The main concern is that vehicles with older engines may not be able to use 10% blends without engine modifications (e.g., two-wheelers). In December 2009, India's government has indicated the urgency to kickstart the 5% blending program because the requirement of ethanol has increased to 225 million gallons in the course of the delay in implementation (since 2006).[318] Regardless, the government announced a draft National Biofuel Policy in September 2008 to raise the blending level to 20% of total fuel usage by 2017 (includes biodiesel).[319] Industry sources expect the National Biofuel Policy may be reviewed again soon, however, approval by the Parliament may take some time.

India has about 320 distillers with a production capacity of about 925 million gallons. Due to the government's ethanol policy, over 115 distilleries have modified their plants to include an ethanol production line, with a total production capacity of 396 million gallons per year, enough to meet the estimated demand for E5. Under an E10 mandate, however, the current ethanol production capacity would need to be enhanced.

Some oil companies are instead pushing for imports of ethanol. However, there is an import duty of 28.64% on the cif value for denatured ethanol. The c.i.f. (cost, insurance, and freight) value represents the landed value of the merchandise at the first port of arrival in a given country. In comparison to the U.S. which has a tariff of 54 cents per gallon (with 45 cents per gallon offset by the ethanol blending subsidy) and a smaller ad valorem tax of 2.5% for denatured ethanol, import duties in India are much higher.

The analysis of India's biofuels developments appears to indicate that it will be self-sustaining if E5 is mandated (as noted by the sugar industry). However, as India strives to meet its E10 goal, it may need to rely on imports from other countries. India's own domestic production may grow from its current estimated production of 26 million gallons of ethanol (marketing year 2008/09), with production capacity expanding to 396 million gallons per year. To meet current E5 and E10 mandates, approximately 225 million gallons to 450 million gallons per year of ethanol, respectively, is required (note that this will continue to increase as fuel demands increase). Therefore, depending on the amount of ethanol that India chooses to mandate, India could either be an importer of ethanol or be able to meet its goals with domestically produced ethanol.

China

In 2008, China was the world's fourth largest fuel ethanol producer, producing around 500 million gallons.[320] The majority of fuel ethanol in China is made from corn.[321,322] However, concerns in China about the security of their food supply and the inflationary impact of biofuels which use grains as feedstock have influenced the feedstocks to be used in the future. With a population of 1.3 billion people, corn growers have to meet the demand for food while also providing feedstock for fuel. In addition, they supply livestock feed for which demand is estimated to rise.[323]

In response to these food and feed demands for corn, according to the National Development and Reform Commission (NDRC), China stopped approvals for industrial corn processing for three years and suspended approved projects which had not yet started construction.[324] Since 2007, corn consumption by the deep-processing sector (i.e., transformation of corn into industrial products like ethanol) will be restricted to about 26 percent of China's total corn consumption.

The National Development and Reform Commission (NDRC) stated in their 11th Five Year Plan (2006-2010) that the production of approximately 2 billion gallons of grain-based ethanol will not threaten the country's grain security. In 2005, there were four fuel ethanol plants operating in the country with a production capacity of approximately 300 million gallons: Jilin Fuel Ethanol Co., Anhui BBCA Biochemical Co., Henan Tian Guan Fuel Ethanol Co., and the China Resources Alcohol Co.[325,326] These plants were established after 2000 to address a surplus of grains in China at the time. Since then, total production in 2008 has increased to an estimated 521 million gallons, see Table 1.5-19.[327]

Table 1.5-19. Fuel Ethanol Production in China

Location (Province, City)	Company Name	Principal Feedstock	Estimated 2008 Production (Mgal)	Estimated 2009 Production Capacity (Mgal)
Heilongjiang, Zhaodong	China Resources Alcohol Co.	Corn/Rice	59	59
Jilin, Jilin	Jilin Fuel Ethanol Co.	Corn	155	165
Henan, Nanyang	Henan Tian Guan Fuel-Ethanol Co.	Wheat	135	149
Anhul, Bengbu	Anhui BBCA Biochemical Co.	Corn	132	145
Guangxi	Guangxi COFCO Bio-Energy Co.	Cassava	40	66
Total			521	584

As seen in the above table, several distilleries have been looking into alternative feedstocks.[328] Examples of alternative feedstocks include sorghum, wheat, cassava, and sweet potato. These crops, however, are grown in much smaller quantities than corn. As such, if China ethanol production expands, China may have to rely on imported feedstocks.[329]

China began mandating fuel ethanol blending in gasoline in June 2002.[330] In 2004, the Chinese government introduced an ethanol mandate of 10% (E10) in several provinces-Helongjiang, Jilin, Liaoning, Henan, and Anhui. This mandate was further expanded to 27 cities in the provinces of Shandong, Jiangsu, Hebei, and Hubei in 2006. To keep up with fuel demand, a National Plan calls for fuel ethanol production to rise from approximately 330 million gallons of ethanol per year to 660 million gallons by 2010 and 3.3 billion gallons by 2020.[47,331]

[47] Assuming a conversion of 1 million tonnes of ethanol equals 330 million gallons.

China may soon become a major importer of ethanol, especially if the E10 blend is extended across the country. With a nationwide E10 blend in 2020, biofuels demand would be approximately 7.6 billion gallons of ethanol.[332] Even if the National Plan which calls for China's domestic fuel ethanol production to reach 3.3 billion gallons by 2020 is met, a nationwide E10 blend would result in a supply shortfall of about 4.3 billion gallons of ethanol.[333] Another study, the "FAPRI 2009 U.S. and World Agricultural Outlook" also indicates that China would be a net importer of ethanol in the future (out to 2018), where domestic production only reaches approximately 600 million gallons. Assuming a possible E10 mandate nationwide and the projections for domestically produced ethanol, China would need to import approximately 4.3-7.0 billion gallons of ethanol per year.

Other Countries

Although Brazil is the largest exporter of ethanol, there may still be other countries that could provide additional ethanol to the U.S. In fact, trace amounts of ethanol entered the U.S. market from Argentina, Canada, Netherlands, and Pakistan in the past.[334] The North American Free Trade Agreement (NAFTA) is similar to the Caribbean Basin Initiative (CBI) in that it welcomes tariff-free ethanol imports from Canada and Mexico.

In addition, there may also be other countries that are beginning biofuels programs and could demand smaller volumes of ethanol in the future. We provide a list of the potential mandates and goals for other countries below in Table 1.5-20. This list is not meant to be all-inclusive, but rather a look at biofuel initiatives in other countries.

Table 1.5-20
Potential Mandates and Goals for Various Countries[335,336,337,338,339,340,341,342]

Argentina	Former Argentine President Nestor Kirchner signed a law in February 2007 implementing tax breaks and fuel-content mandates for biofuels. The Biofuels Act includes tax breaks for companies investing in the biofuels sector and mandates 5% ethanol in gasoline by 2010. Analysts estimate that the country will need 270 million liters per year of ethanol (71 million gallons per year) to satisfy the E5 requirements in 2010, which some believe will not be fully complied. In January 2008, Congress passed a law that promotes production of bioethanol from sugarcane, allowing sugar mills to participate under the biofuel promotional regime.
Australia	The Australian government has set a biofuels target of 93 Mgal by 2010 according to the 'Biofuels for Cleaner Transport' 2001 election policy. This target was never mandated in legislative form. Queensland- In early August 2006 a mandate for a minimum of 5% ethanol from December 21, 2010. New South Wales (NSW)- Beginning in September 2007, fuel supplied to wholesalers in New South Wales will be required to contain 2% ethanol. Proponents of ethanol in the region want to increase the mandate to 4% in 2009 and 10% in 2010. Australian Capital Territory (ACT)- The ACT does not plan to mandate ethanol. Generally this territory follows the policies of NSW because most of their fuel supplies are sourced from NSW. Victoria- Biofuels target of 5% of fuel market by 2010 (106 Mgal), this includes biodiesel. South Australia- No plans to mandate of set a target for biofuels use. Northern Territory- No plans to mandate or set a target for biofuels known. Western Australia- Biofuels target of 5% of fuel market by 2010. Tasmania- The alternative fuels policy is currently based on CNG use. No plans to mandate or set a target for biofuels known.
Canada	On June 26, 2008, the Canadian Senate passed Bill C-33, which will require the use of 5% renewable content in gasoline by 2010. Canada's Government General Michaelle Jean signed the bill after it was passed in the senate, making it official. Saskatchewan- Enacted in October 2006 a 7.5% ethanol mandate in gasoline (approximately 131 Mgal) Ontario- Enacted in January 2007 a 5% ethanol mandate in gasoline, tentative increase to 10% by 2010 British Columbia- Bill C-16 to pass soon, 5% ethanol by 2010 to support federal plan Alberta- Has not set its own standard as it prefers a national approach Manitoba- Beginning April 1, 2008, 8.5% in gasoline (approximately 130 Mgal) Quebec- 5% ethanol in gasoline by 2012, expects source to be met with cellulosic ethanol production Nova Scotia- No goals for biofuels New Brunswick- No goals for biofuels Newfoundland Labrador,PIE- Interest on the East Coast, but nothing as of May 2008 North West Territories, Yukon, Nunavut- No goals for biofuels
Columbia	In September 2001, the Colombian Government issued Law 693, which made it mandatory to use 10% ethanol blends in gasoline in cities with populations larger than 500,000 inhabitants by the year 2008. The law went into effect in September 2005. Ethanol production, however, could not cover the entire country's demand, and thus the government established a phase-in period throughout the country for mandatory ethanol use.
Mexico	On February 1, 2008, the Mexican Government published the Biofuels Promotion and Development Law (LPDB) establising legal framework from which all biofuel public policies will develop. The law does not currently state specific mandates for biofuels.

Summary of Potential Import/Export Demands

For the main countries we have analyzed from above, there appears to be a large potential demand from the EU, Japan, India, and China for imported ethanol. See Table 1.5-21 for a summary of potential import demand by 2020/2022. Total import potential demand from all these countries could range from approximately 4.4-14.3 billion gallons. If these countries decide to meet their mandated ethanol blends or enact new mandates, this could greatly increase the amount that each country would demand from other countries. As discussed above, Brazil is only expected to export a total of 3.8-4.2 billion gallons by 2022. This is significantly below the volume we estimated that could be potentially demanded by other countries in the future. Therefore, it is likely that unless Brazil increases production much more than its government projects, the EU, Japan, India, and China will not be able to meet their stated goals. This also indicates that the U.S. will likely compete with other foreign countries for exports from Brazil. This analysis, however, only considers non-cellulosic biofuel potential. If cellulosic biofuel production develops in these countries, it is entirely possible that the biofuel demands could be lower due to greater supplies. We briefly discuss the potential for imported cellulosic feedstocks or biofuels in Section 1.1.2.6.

Table 1.5-21. Potential Import Demand: EU, Japan, India, and China by 2020/2022 (billion gallons).[48]

Country	EU	Japan	India	China	Total
Potential Domestic Production	1.6-5.3	0-0.1	0-0.4	0.6-3.3	
Potential Consumption					
Petrobras Contract	n/a	0.3	n/a	n/a	
E3	n/a	0.5	n/a	n/a	
E5	n/a	n/a	0.2	n/a	
E10 (or 10% by energy for EU)	5.2-6.8	1.6	0.5	7.6	
7% ETBE	n/a	0.1	n/a	n/a	
Potential Import Demand	**0-5.2**	**0.1-1.6**	**0-0.5**	**4.3-7.0**	**4.4-14.3**

1.5.2.2 Projected Growth Under RFS2

As long as imported ethanol is cost-competitive with gasoline, there will continue be a demand for it. As our analysis from above shows, Brazil is the only country that will likely be able to provide a significant volume of ethanol to the U.S. Accordingly, Brazil will ship ethanol to the U.S. and other countries in the most cost-effective way.

The pathway Brazil chooses to ship ethanol will likely depend on the tariffs and taxes put in place by receiving nations. Specifically, the U.S. places a 54 cent tariff on all imported ethanol (as well as a 2.5 percent ad valorem tax for un-denatured ethanol and a 1.9 percent tax for denatured ethanol). A key reason for establishing a tariff was to offset a tax incentive for ethanol-blended gasoline, which is currently set at 45 cents per gallon of pure ethanol.[49] This analysis assumes that both the tax subsidy and the tariff will continue in the future.

The tariff can be avoided by first shipping ethanol to countries under the Caribbean Basin Initiative (CBI) and then to the U.S. Historically, the majority of CBI ethanol to the U.S. comes from dehydrating ethanol from Brazil. Legislation and agreements since the 1980s have waived or significantly reduced the tariff on imports from Canada, Mexico, and those nations covered under the CBI. There are currently nineteen countries that can benefit from the CBI program. These countries are: Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin

[48] Ranges are calculated assuming the potential values for production and consumption
[49] Prior to the 2008 Farm Bill, the tax incentive was set at 54 cents per gallon

Islands, Costa Rica, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Netherlands Antilles, Panama, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago.[343]

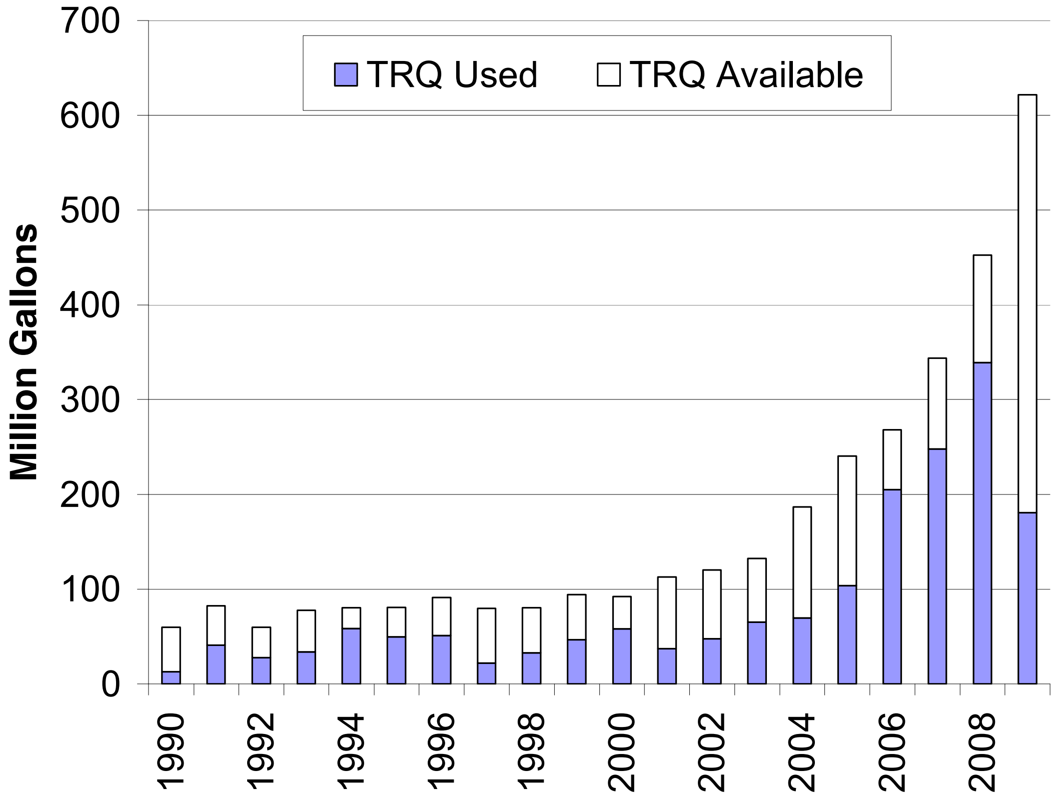
Under the Caribbean Basin Economic Recovery Act (CBERA), which created the CBI, countries in Central America and the Caribbean have had duty-free access to the United States since 1989 for ethanol produced from regional feedstocks. Although most analysts believe there is sufficient land available for sugarcane production in some CBI nations, there has been insufficient economic potential to spur sugarcane planting for ethanol production.[344] Ethanol derived from non-regional feedstocks has been limited to 7 percent of total U.S. ethanol consumption (based on figures from the previous year). There are also country-specific allocations for El Salvador (5.2 million gallons in first year (2006) and an annual increase of 1.3 million gallons per year, not to exceed 10% of CBI quota) and Costa Rica (31 million gallons annually) established by the U.S. Free Trade Agreement with Central America and the Dominican Republic (CAFTA-DR).[345] Since 2007, Costa Rica, El Salvador, Jamaica, Trinidad and Tobago, and the U.S. Virgin Islands are the only countries that have exported ethanol to the U.S. under the CBI quota.

Historically, the CBI nations have had little ethanol production capacity of their own but have supplemented it by importing hydrous Brazilian ethanol where it is further dehydrated before being re-exported to the U.S. duty-free. CBI countries have also relied on surplus wine alcohol from France, Italy, Spain and other Mediterranean countries in the past.[346] According to the United States International Trade Commission, the majority of fuel ethanol imports to the United States came through CBI countries between 1996 and 2003. However, in 2006, CBI ethanol imports to the U.S. totaled over 170 million gallons while imports to the U.S. from Brazil totaled 3 times that amount, or approximately 430 million gallons. This data indicates that in 2006 it was economical to import significant quantities of ethanol directly from other nations due to the withdrawal of MTBE and high oil prices. However, it is not clear on how much of this volume the tariff was paid, as there have been other means for importers to avoid the tariff.

In the past, companies have also imported ethanol from Brazil through a duty drawback.[347] The drawback is a loophole in the tax rules which allowed companies to import ethanol and then receive a rebate on taxes paid on the ethanol when jet fuel is sold for export within three years. The drawback considered ethanol and jet fuel as similar commodities (finished petroleum derivatives).[348,349] However, Senate Representative Charles Grassley from Iowa recently included a provision into the 2008 Farm bill that ended such refunds. The provision states that "any duty paid under subheading 9901.00.50 of the Harmonized Tariff Schedule of the United States on imports of ethyl alcohol or a mixture of ethyl alcohol may not be refunded if the exported article upon which a drawback claim is based does not contain ethyl alcohol or a mixture of ethyl alcohol."[350] The provision became effective on October 1, 2008 and companies have until October 1, 2010 to apply for a duty drawback on prior transactions. With the loophole closed, it is anticipated that there may be less ethanol directly exported from Brazil in the future.[351] World sugar prices are also attributing to a reduction in Brazilian imports.

CBI countries have not yet exceeded the tariff rate quotas (TRQs) for ethanol imports. The TRQ has been limited to 7 percent of total U.S. ethanol consumption (based on figures from the previous year). The fill rate, or percent of the TRQ used, has ranged from 22-77% between 1990 and 2009. See Figure 1.5-11. Thus, there is still considerable room for growth in CBI imported ethanol.

Figure 1.5-11. U.S. Fuel Ethanol CBERA TRQ, 1990-2009*



*2009 TRQ Used data is preliminary. 2010 TRQ Available is 739.8.

In October 2003, the California Energy Commission (CEC) reported four active CBI ethanol dehydration plants, two in Jamaica, one in Costa Rica, and one in El Salvador. At the time, CEC concluded that reprocessing capacity was the limiting factor on CBI imports, with a total of 90 million gallons per year.[352] Since then, several companies have expanded plants or announced new plants as described below:

- *Jamaica*- In 2005, Petrojam Ethanol Limited (PEL), upgraded and expanded their ethanol dehydration plant in Jamaica to a capacity of 40 million .U.S gallons. Currently, the production of anhydrous (fuel grade) ethanol at the plant is based on a marketing agreement with the Brazilian company, Coimex Trading, where the feedstock - hydrous ethanol is supplied from Brazil.[353,354] Jamaica Broilers Group (JBG) launched fuel ethanol production at its 60 million gallon dehydration plant. The first shipment of 5.5 million gallons of ethanol , which arrived in June 2007, was converted to anhydrous ethanol for export to the U.S. JBG had a deal with Bauche Energy for the supply of 50 million gallons of hydrous ethanol out of Brazil for the first year of operation.[355] Jamaica

Ethanol Processing Ltd, which is ED & F Man's subsidiary on the island, has a small plant that dehydrates ethanol from Brazil at a capacity of 55 million gallons.

- *Costa Rica*- LAICA (cane co-op) has a plant currently dehydrating ethanol at 38 million gallons.[356]
- *El Salvador and Panama*- In 2004, it was reported that Cargill and Chevron Texaco had announced plans to construct new dehydration plants in El Salvador and Panama. These plants could produce 60 million gallons per year and between 50 and 100 million gallons per year, respectively.[357] Plants currently in operation include Gasohol de El Salvador (Liza/Vitol) at 100 million gallons per year and ARFS (CASA/Cargill/Crystalsev) at 60 million gallons per year.[358]
- *Trinidad*- EthylChem Inc. has reported plans to build an ethanol dehydration operation at the Petrotrin Refinery in Point-a-Pierre, a southern port city in Trinidad.[359] The cost to build the plant is estimated at $20 million.[360] It is probable, however, that not all the ethanol would be exclusively for U.S. consumption. According to Ron White, the executive director of Ethylchem, "While EthylChem intends to export the fuel to the United States the company is examining the possibility of shipping the product to other markets in the world".[361] Another company, Angostura Ltd., started processing ethanol in 2005.[362] The plant has an overall capacity of 100 million gallons per year, with 50 million gallons per year in the first phase.[363]
- *Others*- An idled ethanol plant in Haiti has attracted some investors and there are also projects in the works in Guyana, the Dominican Republic and Aruba. The U.S. Virgin Islands has one plant dehydrating ethanol at 100 million gallons per year capacity (Geonet).[364] A new ethanol dehydration plant is proposed to be built at the Bulk Terminal Facility near Spring Garden Highway in Barbados.[365] There is a proposal to build a US$36 million ethanol plant near Bridgetown, Barbados. The plant is expected to produce about 132 million gallons by refining ethanol imported from Brazil.[366]

In total, fuel ethanol plant capacity for dehydration in the Caribbean is estimated at 500 million gallons per year. Plans to expand total approximately 200 million gallons.[367] This means that there could be 700 million gallons per year of fuel ethanol capacity in the next few years.

Some stakeholders, however, have expressed concern that the CBI countries are not as stable for investment. Both Brazilian ethanol and European wine alcohol are susceptible to factors including availability, price fluctuations, trade regulations, currency movements and freight rates. Availability of European surplus wine alcohol has diminished since the World Trade Organization (WTO) placed limitations on export subsidies and has found new markets in Spain and Sweden.[368] CBI countries also need to compete for Brazilian ethanol. For example, Angostura's ethanol subsidiary, Trinidad Bulk Traders Ltd., was not profitable in 2006 because it could not get enough fuel from Brazil.[369]

There are other prohibitive factors to CBI ethanol production that exist. For instance, many of the CBI countries have no oil, natural gas or coal. Permitting is often a huge challenge and fresh water is typically scarce.[370]

In addition, increasing significantly beyond the 7% limit may be challenging. Few Caribbean countries are in a position to produce ethanol from domestic feedstocks such as sugarcane. Currently, all three plants exist in Central America (CATSA in Costa Rica, Pantleon Group in Guatemala, and Pellas Group in Nicaragua). Capacity for each plant is approximately 10 million gallons per year. The majority of this domestic fuel ethanol is shipped to the EU for fuel use rather than the U.S. due to higher opportunity prices and similar tariff free treatment.[371] In addition, the governments of Trinidad, St. Kitts and Barbados have already decided the sugar sectors of their islands are not worth further investment. Rum distillers such as Trinidad's Angostura and Jamaica's Appleton Ltd. have also had to import molasses from Fiji for their spirits.[372] Thus, it may take years before Caribbean countries are able to domestically produce large volumes of ethanol. As noted above, however, as dehydration capacity gets close to the U.S. CBI quota, processors may need to consider blending indigenous ethanol.

As a result of the economic benefit of shipping ethanol through CBI nations, we anticipate that the majority of the TRQ will be met in the future. If we assume that 90 percent of the TRQ is met and that total domestic ethanol (corn and cellulosic ethanol) consumed in 2021 was 19.2 Bgal (under the primary control case), then approximately 1.21 Bgal of ethanol could enter the U.S. through CBI countries in 2022.[50] The rest of the Brazilian ethanol exports not entering the CBI will compete on the open market with the rest of the world demanding some portion of direct Brazilian ethanol. As shown in Table 1.5-22, to meet our advanced biofuel standard, we assumed 1.03 billion gallons of sugarcane ethanol would be imported directly to the U.S. in 2022. The total imported ethanol required by the Act was projected for each year based on the required volumes needed to meet the advanced biofuel standard after accounting for the volumes from cellulosic biofuel, biodiesel, and renewable diesel.

Table 1.5-22.
Projected Contribution of Ethanol from CBI Countries and Direct Brazilian exports in 2022 (billion gallons)

Ethanol From CBI Countries	Ethanol Directly From Brazil	Total Imported Ethanol
1.21	1.03	2.24

The amount of Brazilian ethanol available for direct shipment to the U.S. will be dependent on the biofuels mandates and goals set by other foreign countries (e.g., the EU, Japan, India, and China). Our estimates show that there could be a potential demand for imported ethanol of 4.4-14.3 billion gallons by 2020/2022 from these countries as noted in Section 1.5.2.1. This is due to the fact that some countries are unable to produce large volumes of ethanol because of e.g. land constraints or low production capacity. Therefore, unless Brazil or other countries increase biofuels production significantly, there may be a limited supply for imported ethanol to satisfy all foreign country mandates and goals.

1.5.3 Cellulosic Biofuel

[50] Total Domestic Ethanol is based on the amount needed to meet EISA (i.e. for the primary control case in 2021: 15 Bgal Corn Ethanol, 4.15 Cellulosic Ethanol)

The majority of the biofuel currently produced in the United States comes from plants processing first-generation feedstocks like corn, plant oils, sugarcane, etc. Non-edible cellulosic feedstocks have the potential to greatly expand biofuel production, both volumetrically and geographically. Research and development on cellulosic biofuel technologies has exploded over the last few years, and plants to commercialize a number of these technologies are already beginning to materialize. The $1.01/gallon tax credit for cellulosic biofuel that was introduced in the Food, Conservation, and Energy Act of 2008 ("2008 Farm Bill") and recently became effective, is also offering much incentive to this developing industry.[373] In addition to today's RFS2 program which sets aggressive goals for cellulosic biofuel production, the Department of Energy (DOE), Department of Agriculture (USDA), Department of Defense (DOD) and state agencies are helping to spur industry growth.

1.5.3.1 Current State of the Industry

There are a growing number of biofuel producers, biotechnology companies, universities and research institutes, start-up companies as well as refiners investigating cellulosic biofuel production. The industry is currently pursuing a wide range of feedstocks, conversion technologies and fuels. There is much optimism surrounding the long-term viability of cellulosic ethanol and other alcohols for gasoline blending. There is also great promise and growing interest in synthetic hydrocarbons like gasoline, diesel and jet fuel as "drop in" petroleum replacements. Some companies intend to start by processing corn or sugarcane and then transition to cellulosic feedstocks while others are focusing entirely on cellulosic materials. Regardless, cellulosic biofuel production is beginning to materialize.

We are currently aware of 36 small cellulosic biofuel plants operating in North America. This includes process development units with fuel production capabilities, pilot plants, demonstration plants, as well as commercial demonstration plants.[51] These facilities are summarized by fuel type in Tables 1.5-23 and 1.5-24 below. The lists below do not include plants currently processing grains or sugars with plans to transition to cellulosic feedstocks in the future, e.g., Amyris, Gevo/ICM, and Virent.[52] However, we will continue to track these companies during future cellulosic biofuel assessments.

Regardless of their size, the main focus at these facilities is research and development, not commercial production. As shown below, most of the plants are rated at less than 250,000 gallons of cellulosic biofuel per year and that's if they were operated at capacity. However, most only operate intermittently for the purpose of demonstrating that the technologies can be used to produce transportation fuels. As such, some don't even report production capacities. The industry as a whole is still working to increase efficiency, improve yields, reduce costs and prove

[51] Based on research of information available on the public domain and follow-up correspondence with cellulosic biofuel companies.
[52] Both Amyris and ICM have received federal funding to further their cellulosic biofuel efforts. On January 29, 2008, DOE announced that it had awarded ICM a $40 million grant to help build a small cellulosic ethanol plant at an existing corn ethanol plant in St. Joseph, MO. The company is currently piloting butanol production from corn with Gevo. On December 4, 2009, DOE and USDA awarded ICM with another $25 million to further cellulosic ethanol production at the St. Joseph plant. In the same announcement, DOE and USDA awarded Amyris with a $25 million grant to help further cellulosic research at its pilot plant in Emmeryville, CA.

to the public, as well as investors, that cellulosic biofuel is both technologically and economically feasible.

Table 1.5-23. Current Cellulosic Alcohol Plants

Company/Plant Name	Plant Location	Plant Type[a]	Max Cap (MGY)	Online Date	Cell. Biofuel	Cell. Tech.[b]	Cell. Feedstocks[c]			
							AR	EC	W	UW
Abengoa Bioenergy Corporation[d]	York, NE	Pilot	0.02	Sep-07	Ethanol	Bio	X	X		
AE Biofuels	Butte, MT	Demo	0.15	Aug-08	Ethanol	Bio	X	X		
Arkenol Technology Center	Orange, CA	Pilot	N/A	1994	Ethanol	Bio	X			
Auburn University / Masada	Auburn, AL	Pilot	N/A	1995	Ethanol	Bio			X	
Chemrec & Weyerhaeuser	New Bern, NC	Pilot	N/A	1996	Ethanol	Thermo			X	
ClearFuels / Hawaii Natural Energy Institute	Honolulu, HI	Pilot	N/A	2004	Ethanol	Thermo	X			
Cobalt Biofuels	Mountainview, CA	Pilot	0.01	N/A	Butanol	Bio	X		X	
Cornell University Biofuels Research Laboratory	Ithaca, NY	Pilot	N/A	Jan-09	Ethanol	Bio		X	X	
Coskata[e]	Warrenville, IL	Pilot	N/A	Mar-08	Ethanol	Thermo	X			
Coskata[e]	Madison, PA	Demo	0.04	Oct-09	Ethanol	Thermo	X	X	X	X
DOE National Renewable Energy Laboratory	Golden, CO	Pilot	N/A	2001	Ethanol	Bio	X			
Enerkem	Sherbrooke (CAN)	Pilot	N/A	2003	Ethanol	Thermo			X	X
Fiberight[f]	Lawrenceville, VA	Demo (C)	N/A	2005	Ethanol	Bio				X
Fulcrum Bioenergy - Turning Point Ethanol Plant	Durham, NC	Demo	N/A	Mar-09	Ethanol	Thermo				X
Gulf Coast Energy	Livingston, AL	Demo	0.20	Sep-08	Ethanol	Thermo				X
INEOS Bio (formerly BRI)[e]	Fayetteville, AR	Pilot	0.04	1998	Ethanol	Thermo	X		X	X
Iogen Corporation	Ottawa (CAN)	Pilot	N/A	1985	Ethanol	Bio	X		X	
Iogen Corporation	Ottawa (CAN)	Demo (C)	0.50	2004	Ethanol	Bio	X			
KL Energy Corp / WBE	Upton, WY	Demo (C)	1.50	Sep-07	Ethanol	Bio			X	
Lignol Energy	Burnaby (CAN)	Pilot	N/A	Jun-09	Ethanol	Bio	X		X	
Mascoma Corporation	Rome, NY	Pilot	0.20	Dec-08	Ethanol	Bio			X	
Pan Gen Global (formerly Colusa Biomass)	Colusa County, CA	Pilot	N/A	1995	Ethanol	Bio	X			
Pearson Technologies Inc.	Aberdeen, MS	Pilot	N/A	2001	Ethanol	Thermo	X		X	
POET Project Bell[d]	Scotland, SD	Pilot	0.02	Nov-08	Ethanol	Bio			X	
PureVision Technology, Inc[f]	Fort Lupton, CO	PDU	N/A	Mar-09	Ethanol	Bio	X		X	
Range Fuels K2A Optimization Plant	Broomfield, CO	Pilot	N/A	Mar-09	Ethanol	Thermo			X	
SunOpta BioProcess Inc.	Norval (CAN)	Pilot	N/A	2003	Ethanol	Bio	X			
Verenium	Jennings, LA	Pilot	0.05	2006	Ethanol	Bio	X			
Verenium	Jennings, LA	Demo	1.40	Feb-09	Ethanol	Bio	X	X	X	

[a]PDU = Process development unit, Pilot = pilot-scale plant, Demo = demonstration-level plant, Demo (C) = Commercial demonstration plant.

[b]Conversion technology. Bio = Biochemical, Thermo = Thermochemical.

[c]Cellulosic feedstocks. AR = Ag residues, EC = Energy crops, W = Wood waste, chips, mill waste, etc., UW = Urban waste including sorted MSW and C&D debris.

[d]Cellulosic ethanol plant is co-located with an existing corn ethanol plant.

[e]Plant also processes non-cellulosic/renewable feedstocks, e.g., natural gas, coal.

[f]Plant is not currently operational and/or producing fuel at this time.

Table 1.5-24. Current Cellulosic Hydrocarbon Fuel & Pyrolysis Oil Plants

Company/Plant Name	Plant Location	Plant Type[a]	Max Cap (MGY)	Online Date	Cell. Biofuel	Cell. Tech.[b]	Cell. Feedstocks[c]			
							AR	EC	W	UW
Bell Bio-Energy[d]	Fort Stewart, GA	Pilot	0.01	Dec-08	Diesel	Bio			X	X
Cello Energy[d]	Bay Minette, AL	Demo (C)	20.00	Dec-08	Diesel	Cat	X		X	
Clearfuels / Rentech[e]	Commerce City, CO	PDU	N/A	2008	Diesel, Jet	Thermo	X		X	
Dynamotive	West Lorne (CAN)	Demo (C)	3.55	N/A	Py Oil	Thermo			X	
Dynamotive / Evolution Biofuels	Guelph (CAN)	Demo (C)	5.46	Sep-07	Py Oil	Thermo			X	
Terrabon Advanced Biofuels Research Center	Bryan, TX	Pilot	0.13	Apr-09	Gasoline	Bio		X	X	X
ThermoChem Recovery International (TRI)	Durham, NC	Pilot	0.02	Jun-09	Diesel	Thermo	X	X	X	

[a]PDU = Process development unit, Pilot = pilot-scale plant, Demo (C) = Commercial demonstration plant.

[b]Conversion technology. Bio = Biochemical, Cat = Catalytic depolymerization, Thermo = Thermochemical.

[c]Cellulosic feedstocks. AR = Ag residues, EC = Energy crops, W = Wood waste, chips, mill waste, etc., UW = Urban waste including sorted MSW and C&D debris.

[d]Plant is not currently operational and/or producing fuel at this time.

[e]Currently in the process of expanding natural gas-based PDU to a pilot plant that can process biomass feedstocks.

As shown in Tables 1.5-23 and 1.5-24, today's cellulosic biofuel plants are run by a combination of academic, government, and private organizations. Some of the privately-owned companies are existing biofuel producers, but many are start-up companies entering the industry for the first time. The following companies were awarded federal funding to help build their small plants and/or facilitate cellulosic research – Bell Bio-Energy ($1.1 million from the Department of Defense), Clearfuels / Rentech ($2.5 million from the DOE) and Verenium ($10 million from the DOE).[374]

As indicated above, a variety of feedstocks are being investigated for cellulosic biofuel production. There is a great deal of interest in urban waste (MSW and C&D debris) because it is virtually free and abundant in many parts of the country, including large metropolitan areas where the bulk of fuel is consumed. There is also a lot of interest in agricultural residues (corn stover, rice and other cereal straws) and wood (forest thinnings, wood chips, pulp and paper mill waste, and yard waste). However, researchers are still working to find viable harvesting and storage solutions. Others are investigating the possibility of growing dedicated energy crops for cellulosic biofuel production, e.g., switchgrass, energy cane, sorghum, poplar, miscanthus and other fast-growing trees. While these crops have tremendous potential, many are starting with the feedstocks that are available today with the mentality that once the industry has proven itself, it will be easier to secure growing contracts and start producing energy crops. For more information on cellulosic feedstock availability, refer to Section 1.1.2.

The industry is also pursuing a number of different cellulosic conversion technologies and biofuels. Most of the technologies fall into one of two categories: biochemical or thermochemical. Biochemical conversion involves the use of acids and/or enzymes to hydrolyze cellulosic materials into fermentable sugars and lignin. Thermochemical conversion involves the use of heat to convert biomass into synthesis gas or pyrolysis oil for upgrading. A third technology pathway is emerging that involves the use of catalysts to depolymerize or reform the feedstocks into fuel. The technologies currently being considered are capable of producing cellulosic alcohols or hydrocarbons for the transportation fuel market. Many companies are also researching the potential of co-firing biomass to produce plant energy in addition to biofuels. For a more in-depth discussion on cellulosic technologies, refer to Section 1.4.3.

1.5.3.2 Setting the 2010 Standard

The Energy Independence and Security Act (EISA) set aggressive cellulosic biofuel targets beginning with 100 million gallons in 2010. However, EISA also supplied EPA with cellulosic biofuel waiver authority. For any calendar year in which the projected cellulosic biofuel production is less than the minimum applicable volume, EPA can reduce the standard based on the volume expected to be available that year. EPA is required to set the annual cellulosic standard by November 30th each year and should consider the annual estimate made by EIA by October 31st of each year. We are setting the 2010 standard as part of this final rule.

Setting the cellulosic biofuel standard for 2010 represents a unique challenge. As discussed above, the industry is currently characterized by a wide range of companies mostly focused on research, development, demonstration, and financing their developing technologies. In addition, while we are finalizing a requirement that producers and importers of renewable fuel provide us with production outlook reports detailing future supply estimates (refer to §80.1449), we do not have the benefit of this valuable cellulosic supply information for setting the 2010 standard. Finally, since today's cellulosic biofuel production potential is relatively small, and the number of actual potential producers few (as described in more detail below), the overall volume for 2010 can be heavily influenced by new developments, either positive or negative associated with even a single company, which can be very difficult to predict. This is evidenced by the magnitude of changes in cellulosic biofuel projections and the potential suppliers of these fuels since the proposal.

In the proposal, we did a preliminary assessment of the cellulosic biofuel industry to arrive at the conclusion that it was possible to uphold the 100 million gallon standard in 2010 based on anticipated production. At the time of our April 2009 NPRM assessment, we were aware of a handful of small pilot and demonstration plants that could help meet the 2010 standard, but the largest volume contributions were expected to come from Cello Energy and Range Fuels.

Cello Energy had just started up a 20 million gallon per year (MGY) cellulosic diesel plant in Bay Minette, AL. EPA staff visited the facility twice in 2009 to confirm that the first-of-its-kind commercial plant was mechanically complete and poised to produce cellulosic biofuel. It was assumed that start-up operations would go as planned and that the facility would be operating at full capacity by the end of 2009 and that three more 50 MGY cellulosic diesel plants planned for the Southeast could be brought online by the end of 2010.

At the time of our assessment, we were also anticipating cellulosic biofuel production from Range Fuels' first commercial-scale plant in Soperton, GA. The company received a $76 million grant from DOE to help build a 40 MGY wood-based ethanol plant and they broke ground in November 2007. In January 2009, Range was awarded an $80 million loan guarantee from USDA.[53] With the addition of this latest capital, the company seemed well on its way to completing construction of its first 10 MGY phase by the end of 2009 and beginning production in 2010.

Since our April 2009 industry assessment there have been a number of changes and delays in production plans due to technological, contractual, financial and other reasons. Cello Energy and Range Fuels have delayed or reduced their production plans for 2010. Some of the small plants expected to come online in 2010 have pushed back production to the 2011-2012 timeframe, e.g., Clearfuels Technology, Fulcrum River Biofuels, and ZeaChem. Alltech/Ecofin and RSE Pulp & Chemical, two companies that were awarded DOE funding back in 2008 to build small-scale biorefineries appear to be permanently on hold or off the table. In addition, Bell Bio-Energy, a company that received DOD funding has since abandoned plans to build additional cellulosic diesel plants at U.S. military bases.[54]

At the same time, there has also been an explosion of new companies, new business relationships, and new advances in the cellulosic biofuel industry. Keeping track of all of them

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[53] For more information on federal support for biofuels, refer to Section 1.5.3.3.
[54] Bell Bio-Energy is currently investigating other location for turning MSW into diesel fuel according to an October 14, 2009 conversation with JC Bell.

is a challenge in and of itself as the situation can change on a daily basis. EIA recently provided EPA with their first cellulosic biofuel supply estimate required under CAA section 211(o)(7)(D)(i). In a letter to the Administrator dated October 29, 2009, they arrived at a 5.04 million gallon estimate for 2010 based on publicly available information and assumptions made with respect production capacity utilization.[375] A summary of the plants they considered is shown below in Table 1.5-25.

Table 1.5-25.
EIA's Projected Cellulosic Biofuel Plant Production Capacities for 2010

Online	Company	Location	Product	Capacity (million gallons)	Expected Utilization (%)	Production (million gallons)[3]
2007	KL Process Design	Upton, WY	Ethanol	1.5	10	0.15
2008	Verenium	Jennings, LA	Ethanol	1.4	10	0.14
2008	Terrabon	Bryan, TX	Bio-Crude	0.93	10	0.09
2010	Zeachem	Boardman, OR	Ethanol	1.5	10	0.15
2010	Cello Energy	Bay Minette, AL	Diesel	20.0	10[1]	2.00
2010	Range Fuels	Soperton, GA	Ethanol	5.0[2]	50	2.5
	Total			**30.35**		**5.04**

Notes: 1. Cello Energy is assigned a 10-percent utilization factor as they have not been able to run on a continuous basis long enough to apply for a Synthetic Minor Operating Permit or produce significant amounts of fuel during 2009. 2. It is estimated that only half the 2010 projected capacity (10 million gallons per year) will be a qualified fuel. 3. The production from these facilities in 2009 is not surveyed by EIA or EPA.

In addition to receiving EIA's information and coordinating with them and other offices in DOE, we have initiated meetings and conversations with over 30 up-and-coming advanced biofuel companies to verify publicly available information, obtain confidential business information, and better assess the near-term cellulosic biofuel production potential for use in setting the 2010 standard. What we have found is that the cellulosic biofuel landscape has continued to evolve. Based on information obtained, not only do we project significantly different production volumes on a company-by-company basis, but the list of potential producers of cellulosic biofuel in 2010 is also significantly different than that identified by EIA.

Overall, our industry assessment suggests that it is difficult to rely on commercial production from small pilot or demonstration-level plants. The primary purpose of these facilities is to prove that a technology works and demonstrate to investors that the process is capable of being scaled up to support a larger commercial plant. Small plants are cheaper to build to demonstrate technology than larger plants, but the operating costs ($/gal) are higher due to their small scale. As a result, it's not economical for most of these facilities to operate continuously. Most of these plants are regularly shut down and restarted as needed as part of the research and development process. Due to their intermittent nature, most of these plants operate at a fraction of their rated capacity, some less than the 10% utilization rate assumed by EIA. In addition, few companies plan on making their biofuel available for commercial sale.

However, there are at least two cellulosic biofuel companies currently operating demonstration plants in the U.S. and Canada that could produce fuel commercially in 2010. The first is KL Energy Corporation, a company we considered for the NPRM with a 1.5 MGY cellulosic ethanol plant in Upton, WY. This plant was considered by EIA and is included in their final plant summary presented in Table 1.5-25. The second is Iogen's cellulosic ethanol plant in Ottawa, Canada with a 0.5 MGY capacity. Iogen's commercial demonstration plant was referenced by EIA as a potential foreign source for cellulosic biofuel but was not included in their final table. In addition to these online demonstration plants, there are three additional companies not on EIA's list that are currently building demonstration-level cellulosic biofuel plants that are scheduled to come online in 2010. This includes DuPont Danisco Cellulosic Ethanol and Fiberight, companies currently building demonstration plants in the U.S. and Enerkem, a company building a demonstration plant in Canada. Cello Energy's plant in Bay Minette, AL continues to offer additional potential for cellulosic biofuel in 2010. And finally, Dynamotive, a company that currently has two biomass-based pyrolysis oil production plants in Canada is another potential source of cellulosic biofuel in 2010. All seven aforementioned companies are discussed in greater detail below along with Range Fuels.

KL Energy Corporation (KL Energy), through its majority-owned Western Biomass Energy, LLC (WBE) located in Upton, WY, is designed to convert wood products and wood waste products into ethanol. Since the end of construction in September 2007, equipment commissioning and process revisions continued until the October 2009 startup. The plant was built as a 1.5 MGY demonstration plant and was designed to both facilitate research and operate commercially. It is KL Energy's intent that WBE's future use will involve the production and sale of small but commercial-quality volumes of ethanol and lignin co-product. The company's current 2010 goal is for WBE to generate RINs under the RFS2 program.[55]

Iogen is responsible for opening the first commercial demonstration cellulosic ethanol plant in North America. Iogen's plant located in Ottawa, Canada has been producing cellulosic ethanol from wheat straw since 2004. Like KL Energy, Iogen has slowly been ramping up production at its 0.5 MGY plant. According to the company's website, they produced approximately 24,000 gallons in 2004 and 34,000 gallons in 2005. Production dropped dramatically in 2006 and 2007 but came back strong with 55,000 gallons in 2008. Iogen recently produced over 150,000 gallons of ethanol from the demonstration plant in 2009. Iogen also recently became the first cellulosic ethanol producer to sell its advanced biofuel at a retail service station in Canada. Their cellulosic ethanol was blended to make E10 available for sale to consumers at an Ottawa Shell station.[376] Iogen also recently announced plans to build its first commercial scale plant in Prince Albert, Saskatchewan in the 2011/2012 timeframe. Based on the company's location and operating status, Iogen certainly has the potential to participate in the RFS2 program. However, at this time, we are not expecting them to import any cellulosic ethanol into the U.S. in 2010.[56]

DuPont Danisco Cellulosic Ethanol, LLC (DDCE), a joint venture between Dupont and Danisco, is another potential source for cellulosic biofuel in 2010. DDCE received funding from the State of Tennessee and the University of Tennessee to build a small 0.25 MGY demonstration plant in Vonore, TN to pursue switchgrass-to-ethanol production. According to

[55] Based on information provided by Lori Litzen, Environmental Permit Engineer at KL Energy on December 10, 2009.
[56] Based on website information, comments submitted in response to our proposal, and a follow-up phone call with Iogen Executive VP, Jeff Passmore on December 17, 2009.

DDCE, construction commenced in October 2008 and the plant is now mechanically complete and undergoing start-up operations. The facility is scheduled to come online by the end of January and the company hopes to operate at or around 50% of production capacity in 2010. According to the DDCE, the objective in Vonore is to validate processes and data for commercial scale-up, not to make profits. However, the company does plan to sell the cellulosic ethanol it produces.[57]

Enerkem is another company pursuing cellulosic ethanol production. The Canadian-based company was recently announced as a recipient of a joint $50 million grant from DOE and USDA to build a 10 MGY woody biomass-to-ethanol plant in Pontotoc, MS.[377] The U.S. plant is not scheduled to come online until 2012, but Enerkem is currently building a 1.3 MGY demonstration plant in Westbury, Quebec. According to the company, plant construction in Westbury started in October 2007 and the facility is currently scheduled to come online around the middle of 2010. While it's unclear at this time whether the cellulosic ethanol produced will be exported to the United States, Enerkem has expressed interest in selling its fuel commercially.[58]

Additional cellulosic biofuel could come from Fiberight, LLC (Fiberight) in 2010. We recently became aware of this start-up company and contacted them to learn more about their process and cellulosic biofuel production plans. According to Fiberight, they have been operating a pilot-scale facility in Lawrenceville, VA for three years. They have developed a proprietary process that not only fractionates MSW but biologically converts the non-recyclable portion into cellulosic ethanol and biochemicals. Fiberight recently purchased a shut down corn ethanol plant in Blairstown, IA and plans to convert it to become MSW-to-ethanol capable. According to the company, construction is currently underway and the goal is to bring the 2 MGY demonstration plant online by February or March, 2010. If the plant starts up according to plan, the company intends on making cellulosic ethanol commercially available in 2010 and generating RINS under the RFS2 program. Fiberight's long-term goal is to expand the Blairstown plant to a 5-8 MGY capacity and build other small commercial plants around the country that could convert MSW into fuel.[59]

Cello Energy, a company considered in the proposal, continues to be another viable source for cellulosic biofuel in 2010. Despite recent legal issues which have constrained the company's capital, Cello Energy is still pursuing cellulosic diesel production. According to the company, they are currently working to resolve materials handling and processing issues that surfaced when they attempted to scale up production to 20 MGY from a previously operated demonstration plant. As of November 2009, they were waiting for new equipment to be ordered and installed which they hoped would allow for operations to be restarted as early as February or March, 2010. Cello's other planned commercial facilities are currently on hold until the Bay Minette plant is operational.[60]

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[57] Based on a December 16, 2009 telephone conversation with DDCE Director of Corporate Communications, Jennifer Hutchins and follow-up e-mail correspondence.

[58] Based on an October 14, 2009 meeting with Enerkem and follow-up telephone conversation with VP of Government Affairs, Marie-Helene Labrie on December 14, 2009.

[59] Based on a December 15, 2009 telephone conversation with Fiberight CEO, Craig Stuart-Paul and follow-up e-mail correspondence.

[60] Based on a November 9, 2009 telephone conversation with Cello Energy CEO, Jack Boykin.

Another potential supplier of cellulosic biofuel is Dynamotive Energy Systems (Dynamotive) headquartered in Vancouver, Canada. As shown in Table 1.5-24, Dynamotive currently has two plants in West Lorne and Guelph, Ontario, Canada, that produce biomass-based pyrolysis oil (also known as "BioOil") for industrial applications. The BioOil production capacity between the two plants is estimated at around 9 MGY, but both plants are currently operating at a fraction of their rated capacity.[61] However, according to a recent press release, Dynamotive has contracts in place to supply a U.S.-based client with at least nine shipments of BioOil in 2010. If Dynamotive's BioOil is used as heating oil or upgraded to transportation fuel, it could potentially count towards meeting the cellulosic biofuel standard in 2010.

As for the Range Fuels plant, construction of phase one in Soperton, GA, is about 85% complete, with start-up planned for mid-2010. However, there have been some changes to the scope of the project that will limit the amount of cellulosic biofuel that can be produced in 2010. The initial capacity has been reduced from 10 to 4 million gallons per year. In addition, since they plan to start up the plant using a methanol catalyst they are not expected to produce qualifying renewable fuel in 2010. During phase two of their project, currently slated for mid-2012, Range plans to expand production at the Soperton plant and transition from a methanol to a mixed alcohol catalyst. This will allow for a greater alcohol production potential as well as a greater cellulosic biofuel production potential.[62]

Overall, our most recent industry assessment suggests that there are six companies that could potentially produce cellulosic biofuel next year. Together these seven plants, summarized in Table 1.5-26, could have over 30 MGY of cellulosic biofuel plant capacity online by the end of 2010. However, the actual volume of cellulosic biofuel realized under the RFS2 program will likely be much lower, as explained in more detail below.

[61] According to Dynamotive's website, the Guelph plant has a capacity to convert 200 tonnes of biomass into BioOil per day. If all modules are fully operational, the plant has the ability to process 66,000 dry tons of biomass per year with an energy output equivalent to 130,000 barrels of oil. The West Lorne plant has a capacity to convert 130 tonnes of biomass into BioOil per day (which, if proportional to the Guelph plant, translates to an energy-equivalent of 84,500 barrels of oil. According to a November 3, 2009 press release, Dynamotive has contracts in place to supply a U.S.-based client with at least nine shipments of BioOil in 2010.
[62] Based on a November 5, 2009 telephone conversation with Range Fuels VP of Government Affairs, Bill Schafer.

Table 1.5-26
EPA's Cellulosic Biofuel Plant Assessment – Projected Plants/Capacity Online by End of 2010

Company/Plant Name	Plant Location	Plant Type	Max Cap (MGY)	Operational Status	Proj. Op. Date	Cell. Biofuel	Cellulosic Feedstocks
Cello Energy	Bay Minette, AL	Demo (C)	20.00	Currently Off-Line	Mar-10	Diesel	Wood chips, hay
DuPont Danisco (DDCE)	Vonore, TN	Demo	0.25	Undergoing Start-Up	Jan-10	Ethanol	Corn cobs then switchgrass
Dynamotive	West Lorne (CAN)	Demo (C)	3.55	On-Line		Py Oil	Waste wood
Dynamotive	Guelph (CAN)	Demo (C)	5.46	On-Line		Py Oil	Waste wood, wood chips
Enerkem	Westbury (CAN)	Demo	1.30	Under Construction	Jun-10	Ethanol	Treated wood
Fiberight	Blairstown, IA	Demo (C)	2.00	Under Construction	Mar-10	Ethanol	Sorted MSW
KL Energy Corp / WBE	Upton, WY	Demo (C)	1.50	On-Line		Ethanol	Wood chips

Since most of the plants in Table 1.5-26 are still under construction today, the amount of cellulosic biofuel produced in 2010 will be contingent upon when and if these plants come online and whether the projects get delayed due to funding or other reasons. In addition, based on our discussions with the developing industry, it is clear that we cannot count on demonstration plants to produce at or near capacity in 2010, or in their first few years of operation for that matter. The amount of cellulosic biofuel actually realized will depend on whether the process works, the efficiency of the process, and how regularly the plant is run. As mentioned earlier, most small plants, including commercial demonstration plants, are not operated continuously. As such, we cannot base the standard on these plants running at capacity - at least until the industry develops further and proves that such rates are achievable. We currently estimate that production from first-of-it's kind plants could be somewhere in the 25-50% range in 2010. Together, the implementation timelines and anticipated production levels of the plants described above brings the cellulosic biofuel supply estimate to somewhere in the 6-13 million gallon range for 2010.

In addition, it is unclear how much was can rely on Canadian plants for cellulosic biofuel in 2010. Although we currently receive some conventional biofuel imports from Canada and many of the aforementioned Canadian companies have U.S. markets in mind, the country also has its own renewable fuel initiatives that could keep much of the cellulosic biofuel produced from coming to the United States, e.g., Iogen. Finally, it's unclear whether all fuel produced by these facilities will qualify as cellulosic biofuel under the RFS2 program. Several of the companies are producing fuels or using feedstocks which may not in fact qualify as cellulosic biofuel once we receive their detailed registration information. Factoring in these considerations, the cellulosic biofuel potential from the seven plants summarized in Table 1.5-26 could result in several different production scenarios in the neighborhood of the recent EIA estimate. We believe this estimate of 5 million gallons or 6.5 ethanol-equivalent million gallons represents a reasonable yet achievable level for the cellulosic biofuel standard in 2010 considering the degree of uncertainty involved with setting the standard for the first year. As mentioned earlier, we believe standard setting will be easier in future years once the industry matures, we start receiving production outlook reports and there is less uncertainty regarding feasibility of cellulosic biofuel production.

1.5.3.3 Current Outlook for 2011 and Beyond

Since the proposal, we have also learned about a number of other cellulosic biofuel projects in addition to those described above. This includes commercial U.S. production plans by Coskata, Enerkem and Vercipia. However, production isn't slated to begin until 2011 or later and the same is true for most of the other larger plants we're aware of that are currently under development. Nonetheless, while cellulosic biofuel production in 2010 may be limited, it is remarkable how much progress the industry has made in such a short time, and there is a tremendous growth opportunity for cellulosic biofuels over the next several years.

Most of the cellulosic biofuel companies we've talked to are in different stages of proving their technologies. Regardless of where they are at, many have fallen behind their original commercialization schedules. As with any new technology, there have been delays associated with scaling up capacity, i.e., bugs to work out going from pilot to demonstration to commercialization. However, most are saying it's not the technologies that are delaying commercialization, it is lack of available funding. Obtaining capital has been very challenging given the current recession and the banking sector's financial difficulties. This is especially true for start-up companies that do not have access to capital through existing investors, plant profits, etc. From what we understand, banks are looking for cellulosic companies to be able to show that their plants are easily "scalable" or expandable to commercial size. Many are only considering companies that have built plants to one-tenth of commercial scale and have logged many hours of continuous operation.

The government is currently trying to help in this area. To date, the Department of Energy (DOE) and the Department of Agriculture (USDA) have allocated over $720 million in federal funding to help build pilot and demonstration-scale biorefineries employing advanced technologies in the United States.[63,378] The largest installment from Recovery Act funding was recently announced on December 4, 2009 and includes funding for a series of larger commercial demonstration plants including cellulosic ethanol projects by Enerkem and INEOS New Planet BioEnergy, LLC. DOE has also issued grants to help fund some of the first commercial cellulosic biofuel plants. Current recipients include Abengoa Bioenergy, BlueFire Ethanol[64] and POET Biorefining in addition to Range Fuels.[379] The DOE is also in the process of issuing loan guarantees.

The Energy Policy Act of 2005 (EPAct) authorized DOE to issue loan guarantees to eligible projects that "avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases" and "employ new or significantly improved technologies as compared to technologies in service in the United States at the time the guarantee is issued."[380] On October 4, 2007, DOE issued final regulations for its loan guarantee program and invited 16 pre-applicants to submit applications for federal support of innovative clean energy projects. Five of the pre-applicants are/were pursuing cellulosic biofuel production.[381]

Passage of the Recovery Act in 2009 created a new Section 1705 under Title XVII of the Energy Policy Act of 2005 for the rapid deployment of renewable energy projects and related manufacturing facilities, electric power transmission projects and leading edge biofuels projects that commence construction before September 30, 2011.[382] On December 7, 2009, Energy Secretary Steven Chu announced the issue of a final rule amending the Department of Energy's regulations for its Loan Guarantee Program.[383] The revised rule will allow for increased participation in the program by financial institutions and other investors and enable the support of more innovative energy technologies in the United States. Although, to date, DOE has issued a number of solicitations and invited pre-applicants to submit full applications, no cellulosic

[63] On January 29, 2008 DOE announced that it would provide $114 million to fund 4 small scale cellulosic biorefineries. On April 18, 2008, DOE announced that it would provide another $86 million to help fund three additional small-scale plants. On July 14, 2008, DOE announced another $40 million to help fund two more small cellulosic plants. On December 4, 2009, DOE and USDA announced that up to $483 million would be made available to fund 14 pilot-scale and 4 demonstration-scale biorefineries across the country, the majority of which are pursuing cellulosic biofuel production.
[64] Although BlueFire is still working on obtaining financing to build its first demonstration plant, it has received two installments of federal funding towards its first planned commercial-scale plant. The 19 MGY plant in Fulton, MS (originally planned for Southern California) was awarded $40 million from DOE on February 28, 2008 and another $81.1 million from DOE and USDA on December 4, 2009.

biofuel companies have been issued loan guarantees at this time.[65] However, the USDA has begun issuing loan guarantees under the 2008 Farm Bill (explained in more detail below).

The Farm Bill is assisting the cellulosic biofuel industry in many ways. First, it modified the $0.51/gal alcohol blender credit to give preference to ethanol and other biofuels produced from cellulosic feedstocks. Effective January 1, 2009, corn ethanol receives a reduced tax credit of $0.45/gal while cellulosic biofuel earns a credit of $1.01/gal.[66] In addition, the Farm Bill contains provisions that enable USDA to assist with the commercialization of second-generation biofuels, explained in more detail below.

Section 9003, also known as the Biorefinery Assistance Program, promotes the development of new and emerging technologies for the production of advanced biofuels - defined as fuels that are not produced from food sources. The program provides loan guarantees to develop, construct and retrofit viable commercial-scale biorefineries producing advanced biofuels. The maximum loan guarantee is $250 million per project. The program is designed to create energy-related jobs and economic development in rural America. On January 16, 2009, the USDA Rural Development approved its first ever loan guarantee to Range Fuels.[384] As mentioned earlier, Range received an $80 million loan from USDA to help build its Soperton, GA plant.[67] Section 9004 of the 2008 Farm Bill provides payments to biorefineries to replace fossil fuels with renewable biomass. Section 9005 provides payments to producers to support and ensure production of advanced biofuels. And finally, Section 9008 provides competitive grants, contracts and financial assistance to enable eligible entities to carry out research, development, and demonstration of biofuels and biomass-based based products.

In addition to helping fund a series of small cellulosic biofuel plants, the DOE and USDA are helping to fund critical research to help make cellulosic biofuel production more commercially viable. In March 2007, DOE awarded $23 million in grants to four companies and one university to develop more efficient microbes for ethanol refining.[385] In June 2007, DOE and USDA awarded $8.3 million to 10 universities, laboratories, and research centers to conduct genomics research on woody plant tissue for bioenergy.[386] Later that same month, DOE announced its plan to spend $375 million to build three bioenergy research centers dedicated to accelerating research and development of cellulosic ethanol and other biofuels. The centers, which will each focus on different feedstocks and biological research challenges, will be located in Oak Ridge, TN, Madison, WI, and Berkeley, CA.[387] In December 2007, DOE awarded $7.7 million to one company, one university, and two research centers to demonstrate the thermochemical conversion process of turning grasses, stover, and other cellulosic materials into biofuel.[388]

In February 2008, DOE awarded another $33.8 million to three companies and one research center to support the development of commercially-viable enzymes to support cellulose hydrolysis, a critical step in the biochemical breakdown of cellulosic feedstocks.[389] In March

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[65] To the best of our knowledge based on an assessment of DOE press releases.

[66] Refer to Part II, Subparts A and B (Sections 15321 and 15331).

[67] USDA also recently issued a $54.5 million loan guarantee to Sapphire Energy to help demonstrate an integrated algal biorefinery process in Columbus, NM. For more information on Sapphire and other algae-based biodiesel projects, refer to Section 1.5.4.3 of the RIA.

2008, DOE and USDA awarded $18 million to 18 universities and research institutes to conduct research and development of biomass-based products, biofuels, bioenergy, and related processes.[390] In July 2008, DOE and USDA awarded $10 million to 10 universities and research centers to advance biomass genomics to further the use of cellulosic plant material for bioenergy and biofuels.[391] In August 2008, DOE announced the availability of $7 million to seven DOE National Laboratories to accelerate clean energy technologies, including biofuels.[392] In September 2008, DOE announced plans to invest another $4.4 million in six universities to support research and development for cost-effective, environmentally-friendly biomass conversion technologies for turning non-food feedstocks into advanced biofuels.[393] On October 7, 2008, USDA and DOE released the National Biofuels Action Plan (NBAP), an interagency plan detailing the collaborative efforts of Federal agencies needed to accelerate the development of a sustainable biofuels industry.[394] The plan focuses on seven critical areas including sustainability, feedstock production, feedstock logistics, and conversion technology. On the same day, DOE announced a $7 million investment in five research organizations and institutions to advance technologies needed for stabilization of biomass-based fast pyrolysis oils.[395]

In July 2009, DOE and USDA announced the joint selection of two research centers and five universities to receive $6.3 million towards fundamental genomics-enabled research leading to the improved use of plant feedstocks.[396] In August 2009, DOE announced awards totaling $377 million for 46 Energy Frontier Research Centers.[397] The recipients, funded by the Recovery Act, include at least six centers focused on advanced biofuels (totaling more than $100 million). Later that month, DOE announced that $21 million would be made available to five projects to develop supply systems to handle and deliver high tonnage biomass feedstocks for cellulosic biofuels production.[398] In November 2009, DOE and USDA announced 12 projects selected for over $24 million in grants to research and develop technologies to produce biofuels, Bioenergy, and high-value biobased products.[399]

Numerous states are also offering grants and tax incentives to help encourage biofuel production. Most of the efforts are currently centered on expanding existing production and developing sustainable, second-generation feedstocks, technologies and fuels. According to a recent assessment of DOE's Energy Efficiency and Renewable Energy (EERE) website, over 20 states currently offer some form of production incentive for advanced biofuels including, but not limited to, those made from cellulosic materials. The incentives range from grants, loan guarantees and tax breaks for advanced biofuel producers to support for technology and feedstock development.

In addition to the production incentives described above, a group of states in the Midwest have joined together to pursue ethanol and other biofuel production and usage goals as part of the Midwest Governors Association (MGA). States that have signed on to the MGA goals include Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio, South Dakota and Wisconsin. In 2007, the MGA adopted the Midwest Energy Security and Climate Stewardship Platform.[400] The Platform goals are to produce cellulosic ethanol on a commercial level by 2012 and to have E85 offered at one-third of refueling stations by 2025. They also want to reduce the energy intensity of ethanol production and supply 50% of their transportation fuel needs by regionally produced biofuels by 2025. In 2009, the MGA approved a follow-up infrastructure initiative called the Midwestern Energy Infrastructure Accord which includes the governors' support for building out a bio refueling system throughout the region.[401]

The refining industry is also helping to further cellulosic biofuel R&D efforts and fund some of the first commercial plants. Many of the major oil companies have invested in advanced second-generation biofuels over the past 12-18 months. A few refiners (e.g., BP and Shell) have even entered into joint ventures to become cellulosic biofuel producers. General Motors and other vehicle/engine manufacturers are also providing financial support to help with research and development.

A summary of some of the cellulosic biofuel companies with near-term commercialization plans in North America is provided in 1.5-27. The capacities presented represent maximum annual average throughput based on each company's current production plans. However, as noted, capacity does not necessarily translate to production. Actual production of cellulosic biofuel will likely be well below capacity, especially in the early years of production. We will continue to track these companies and the cellulosic biofuel industry as a whole throughout the duration of the RFS2 program. In addition, we will continue to collaborate with EIA in annual standard setting. A more detailed description of the new (commercial demonstration and larger) plants corresponding to these company estimates is provided in Tables 1.5-28 and 1.5-29.

Table 1.5-27. Potential Growth in Cellulosic Biofuel Capacity by Company and Year*

Cellulosic Company	Biofuel(s)	Capacity Expansion Plans (MGY)					
		Today	Dec-10	Dec-11	Dec-12	Dec-13	2014+
Abengoa	Ethanol	0.02	0.02	0.02	16.02	16.02	16.02
AE Biofuels	Ethanol	0.15	0.15	15.15	20.15	20.15	20.15
BlueFire Ethanol	Ethanol	-	-	-	-	-	22.90
Cello Energy	Diesel	-	20.00	20.00	20.00	20.00	120.00
CMEC / SunOpta	Ethanol	-	-	-	-	-	10.00
Coskata	Ethanol	0.04	0.04	0.04	50.04	50.04	100.04
Dynamotive[a]	BioOil	9.00	9.00	9.00	9.00	9.00	9.00
Enerkem	Ethanol	-	1.30	11.30	21.30	21.30	41.30
Fiberight	Ethanol	-	2.00	6.50	6.50	6.50	6.50
Flambeau River Biofuels	Diesel	-	-	-	8.00	8.00	8.00
Fulcrum Bioenergy	Ethanol	-	-	-	10.50	10.50	10.50
Inbicon / Great River Energy	Ethanol	-	-	-	-	20.00	20.00
INEOS Bio / New Planet Energy	Ethanol	-	-	8.00	8.00	8.00	8.00
Iogen	Ethanol	0.50	0.50	0.50	23.50	23.50	23.50
KL Energy	Ethanol	1.50	1.50	1.50	1.50	1.50	6.50
Mascoma Corporation	Ethanol	0.20	0.20	0.20	2.20	20.20	80.20
New Page	Diesel	-	-	-	2.50	2.50	2.50
Ohio River Clean Fuels / Baardb	Diesel, Naphtha	-	-	-	-	-	17.00
Pacific Ethanol	Ethanol	-	-	-	-	-	2.70
POET Biorefining	Ethanol	0.02	0.02	25.02	25.02	25.02	25.02
Range Fuels	Methanol, Ethanol	-	4.00	4.00	30.00	30.00	100.00
Rentech[c]	Diesel	-	-	0.15	7.15	7.15	7.15
Vercipia (Verenium/BP JV)	Ethanol	1.40	1.40	1.40	37.40	37.40	37.40
Maximum Plant Capacity (MGY)		**12.83**	**40.13**	**102.78**	**298.78**	**336.78**	**694.38**

[a]Capacity has been estimated.

[b]Plant will co-process biomass and coal. It is unclear at this time how much fuel would come from biomass and potentially qualify as cellulosic biofuel.

[c]Includes Clearfuels demo plant and Silvagas commercial plant.

*Capacity, not actual production

Table 1.5-28.
Promising New Cellulosic Alcohol Plants

Company/Plant Name	Plant Location	Current Plan Cap (MGY)	Current Plan Op Date	Production Goal Cap (MGY)	Production Goal Op Date	Cell. Biofuel	Cell. Tech.[a]	Cell. Feedstocks[b] AR	EC	W	UW
Abengoa Bioenergy Corporation[ac]	Hugoton, KS	16.00	2012			Ethanol	Bio	X	X		
AE Advanced Fuels - Keyes[c,d]	Keyes, CA	15.00	2011	20.00	2012	Ethanol	Bio	X	X		
BlueFire Ethanol	Lancaster, CA			3.90	TBD	Ethanol	Bio			X	X
BlueFire Ethanol	Fulton, MS			19.00	TBD	Ethanol	Bio			X	
Central Minnesota Cellulosic Ethanol Partners[c]	Little Falls, MN			10.00	TBD	Butanol	Bio			X	
Coskata / U.S. Sugar Corp.	Clewiston, FL	50.00	2012	100.00	TBD	Ethanol	Thermo	X			
Enerkem	Pontotoc, MS	10.00	2012	20.00	2015	Ethanol	Thermo			X	X
Enerkem GreenField Alberta Biofuels (EGAB)	Edmonton (CAN)	10.00	2011	20.00	TBD	Ethanol	Thermo				X
Fiberight (former Xethanol plant)	Blairstown, IA	2.00	End-2010	6.50	2011	Ethanol	Bio				X
Fulcrum Bioenergy - Sierra BioFuels Plant	McCarran, NV	10.50	Mid-2012			Ethanol	Thermo				X
Inbicon / Great River Energy	Spiritwood, ND	20.00	2013			Ethanol	Bio	X			
INEOS Bio / New Planet Bioenergy, LLC	Vero Beach, FL	8.00	End-2011			Ethanol	Thermo	X			X
Iogen Corporation	Prince Albert (CAN)	23.00	2012			Ethanol	Bio	X			
KL Energy Corp	Kremmling, CO	5.00	TBD			Ethanol	Bio			X	
Mascoma Corporation / Frontier Resources	Kinross, MI	2.00	2012	20.00	2013	Ethanol	Bio			X	
Pacific Ethanol	Boardman, OR	2.70	TBD			Ethanol	Bio	X		X	
POET Project Liberty[c]	Emmetsburg, IA	25.00	End-2011			Ethanol	Bio	X			
Range Fuels[e]	Soperton, GA	30.00	2012	100.00	TBD	Methanol	Thermo		X	X	
Vercipia (Verenium/BP JV)	Highland County, FL	36.00	2012			Ethanol	Bio		X		

[a]Conversion technology. Bio = Biochemical, Thermo = Thermochemical.
[b]Cellulosic feedstocks. AR = Ag residues, EC = Energy crops, W = Wood waste, chips, mill waste, etc., UW = Urban waste including sorted MSW and C&D debris.
[c]Cellulosic ethanol plant will be co-located with an existing corn ethanol plant.
[d]Will start off processing corn and then transition to cellulosic feedstocks.
[e]Will start off producing methanol and then switch catalysts and shift to producing a mix of methanol and ethanol.

Table 1.5-29
Promising New Cellulosic Hydrocarbon Plants

Company/Plant Name	Plant Location	Current Plan Cap (MGY)	Current Plan Op Date	Production Goal Cap (MGY)	Production Goal Op Date	Cell. Biofuel	Cell. Tech.[a]	Cell. Feedstocks[b] AR	W	UW
Cello Energy	Georgia (TBA)			50.00	TBD	Diesel	Cat	X	X	
Cello Energy	Alabama (TBA)			50.00	TBD	Diesel	Cat	X	X	
Flambeau River Biofuels[c]	Park Falls, WI	8.00	2012			Diesel	Thermo		X	
New Page - Project Independence[c]	Wisconsin Rapids, WI	2.50	Early-2012			Diesel	Thermo		X	
Ohio River Clean Fuels, LLC / Baard[d]	Wellsville, OH	17.00	2014			Diesel, Naphtha	Thermo	X	X	
Rentech / Rialto Renewable Energy Center	Rialto, CA	7.00	End-2012			Diesel	Thermo			X

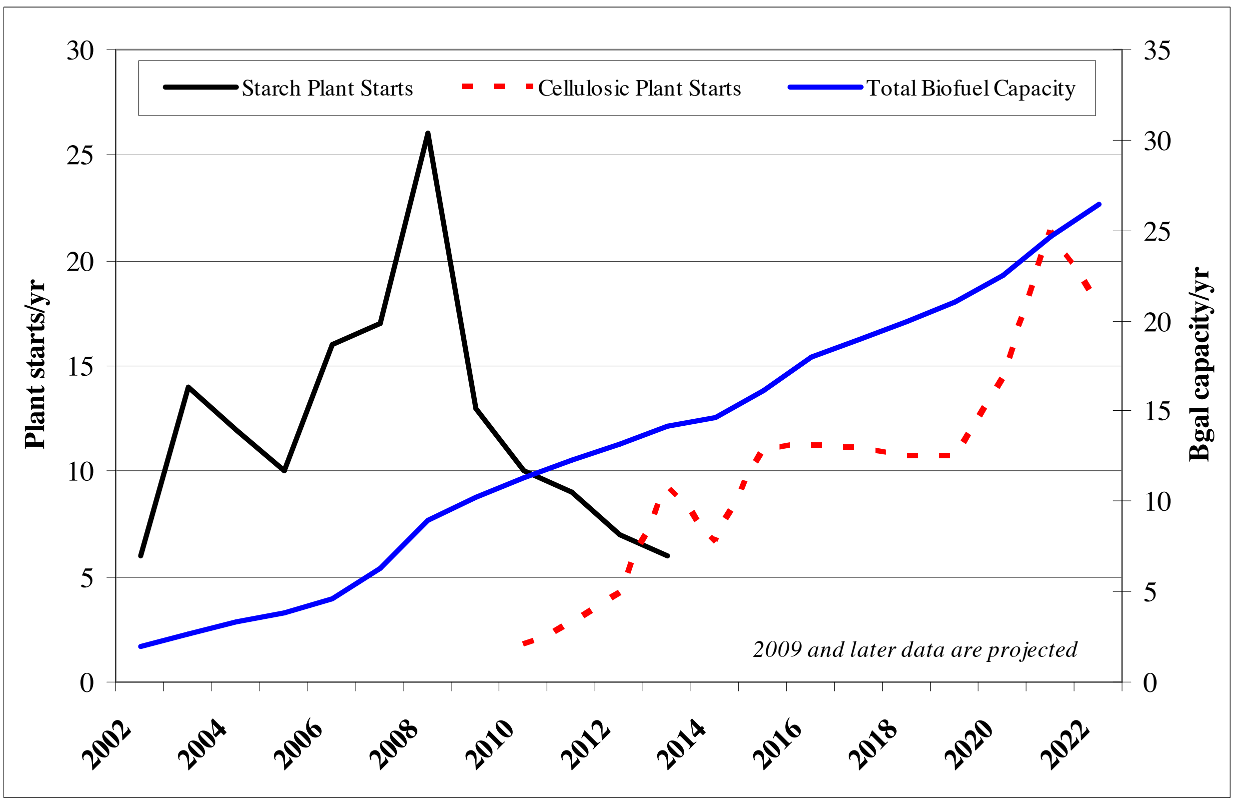
[a]Conversion technology. Cat = Catalytic depolymerization, Thermo = Thermochemical.
[b]Cellulosic feedstocks. AR = Ag residues, W = Wood waste, chips, mill waste, etc., UW = Urban waste including sorted MSW and C&D debris.
[c]Capacities exclude heavy distillate/wax production.
[d]Plant will co-process biomass and coal. It is unclear at this time how much fuel would come from biomass and potentially qualify as cellulosic biofuel.

1.5.3.4 Construction Feasibility for Cellulosic Biofuel Industry

Start-up of cellulosic biofuel plants (alcohol or hydrocarbon) is expected to begin in earnest with a few small plants in 2010-11, followed by addition of industry capacity continuing at an increasing pace due to more plant starts per year as well as increasing plant size. This is typical as an industry progresses up the learning curve, and investors become more confident and are willing to fund larger, more efficient plants. During the period from 2010-12, we also expect a slowing of starch ethanol plant construction, such that engineering and construction personnel and equipment fabricators would potentially be able to transition to work on cellulosic biofuel facilities.

Here we examine the build rate required to construct cellulosic plants in time to meet the standards in Table 1.2-1, and we compare this to the historic build rate of capacity in the starch ethanol industry. Figure 1.5-12 depicts these construction trends.

Figure 1.5-12.
Historic and projected plant starts and projection capacity, 2001-2022.[a]



[a] Volumes do not include biodiesel or renewable diesel.

Historical plant build rates for starch ethanol were derived from capacity information in Figure 1.5-1. Average plant capacity figures were estimated from existing capacity and plant counts, and we project that the recent trend toward larger plant sizes continues going forward. Approximately 200 starch ethanol plants are expected to be operating by 2022.

For cellulosic biofuel plant construction, we assumed new plant size would begin relatively small at 40 million gal/yr for any builds during 2010-13, increasing to 80 million gal/yr for 2014-17, and 100 million gal/yr afterwards. Given the volume standards laid out in the EISA, as well as the volume of cellulosic biofuel projected, we arrive at a maximum required build rate of approximately 2 billion gal/yr from 2018-2022. This is similar to the rate of starch ethanol construction in recent years. Table 1.2-30 shows a summary of the figures used in the analysis.

Table 1.5-30.
Summary of figures used in the cellulosic biofuel plant construction rate analysis, 2001-2022.[a]

	Starch Ethanol				Cellulosic Biofuel			
Year	Build Rate [b] *Starts/yr*	Avg Plant Capacity [c] *Mgal/yr*	Capacity Change *Bgal/yr*	Industry Capacity *Bgal/yr*	Build Rate [b] *Starts/yr*	Avg Plant Capacity [c] *Mgal/yr*	Capacity Change *Bgal/yr*	Industry Capacity *Bgal/yr*
2001				1.7				
2002	6	50	0.3	2.0				
2003	14	50	0.7	2.7				
2004	12	50	0.6	3.3				
2005	10	50	0.5	3.8				
2006	16	50	0.8	4.6				
2007	17	100	1.7	6.3				
2008	26	100	2.6	8.9				
2009	13	100	1.3	10.2				
2010	10	100	1.0	11.2	2	40	0.1	0.1
2011	9	100	0.9	12.1	3	40	0.1	0.2
2012	7	100	0.7	12.8	4	40	0.2	0.4
2013	6	100	0.6	13.4	9	40	0.4	0.7
2014				14.0	7	80	0.5	1.3
2015				15.0	11	80	0.9	2.1
2016				15.0	11	80	0.9	3.0
2017				15.0	11	80	0.9	3.9
2018				15.0	11	100	1.1	5.0
2019				15.0	11	100	1.1	6.1
2020				15.0	14	100	1.4	7.5
2021				15.0	21	100	2.1	9.7
2022				15.0	18	100	1.8	11.4

[a] Figures for 2009 and later are projected; volumes do not include biodiesel or renewable diesel. Year-by-year industry capacity figures were taken from RIA Table 1.2-1.
[b] Build rate is an approximate figure, derived from other figures used in this analysis.
[c] Average plant capacity is an approximate figure based on historical ethanol industry trends.

This analysis suggests that it is feasible to construct plants quickly enough to meet the cellulosic standard if plant starts can reach a rate similar to that of starch ethanol plants in recent years. Given that cellulosic biofuel technology is still developing, some types of plants may be considerably more complex and expensive to construct than starch ethanol plants. Therefore, we believe the market will need to react even more enthusiastically with capital funding, design and construction resources.

1.5.4 Biodiesel & Renewable Diesel

1.5.4.1 Biodiesel

The biodiesel industry differs significantly in profile from the ethanol industry, in that it is comprised of plants with a wide variety of sizes, ranging from less than one million gallons to more than 50 million gallons per year production capacity, using feedstock ranging from virgin soy oil to recycled cooking grease and rendered fats. The industry capacity has expanded rapidly, going from a sparse network of small businesses selling locally to one with large companies selling internationally in less than a decade. As of November 2009, the aggregate production capacity of biodiesel plants in the U.S. was estimated at 2.8 billion gallons per year across approximately 191 facilities, with a mean size of 16 million gallons per year and a median size of just 6 million gallons per year.[402] Table 1.5-31 shows historical aggregate capacity, sales volumes, and other information related to biodiesel production and use.

Table 1.5-31. Recent biodiesel industry production and use trends.[403]

Year	Domestic production capacity	Domestic total production	Apparent capacity utilization	Net domestic biodiesel use	Net domestic use as percent of production
2004	245	28	11%	27	96%
2005	395	91	23%	91	100%
2006	792	250	32%	261	104%
2007	1,809	490	27%	358	73%
2008	2,610	776	30%	413	53%
2009	2,806	475 (est.)	17%	296 (est.)	62%

The average capacity utilization had been steady around 30% during 2006-2008 due to continued expansion of on-line capacity despite apparently adequate existing capacity. Reasons for this include various state incentives to build plants, along with state and federal incentives to blend and sell biodiesel, which have given rise to an optimistic industry outlook over the past several years. However, in 2009 utilization was about half this level, due to a steep decline in exports as a result of European trade barriers enacted early in the year, as well as a drop in U.S. diesel prices which has made biodiesel relatively more expensive.

We can speculate that sustained low capacity utilization has been feasible for this industry because of the relatively low capital cost (typically 5-10% of total per-gallon production cost) of these plants, which enables them to operate only part of the year or at reduced capacity, depending on feedstock prices or other market conditions. Besides fuel, some plants may also produce oleochemicals for use in detergents, lubricants or other products, providing additional sources of revenue for part of the industry.

In order to conduct our emissions and distribution analyses, we needed to have an industry characterization at the time of the fully phased-in program, the year 2022. This was not a simple task because of the apparent feasibility of sustained over-capacity and the variety of useable feedstocks. As discussed in Section 1.2, we project under our primary control case that in order to meet the RFS2 standards, 1.67 billion gallons of biodiesel will be produced in 2022. With this information, we estimated how many plants would continue to produce biodiesel and where they might be located based on three factors: state incentives for production and sales, BQ-9000 certification of existing plants, and capabilities for handling multiple feedstock types. This information was gathered from a database of member plants maintained by the National Biodiesel Board, and a summary of tax incentives from the Department of Energy website. [404] Existing plants with affirmative status for more of these factors were expected to be more likely to survive over those that had fewer. We also projected that a number of very small plants processing waste greases/fats would continue to operate based on local market niches regardless of these criteria.

We project that between now and 2022 the number of plants will decline by about 30%, pushing capacity utilization above 80%. It is expected that plants will continue to operate in 44 states. During this period most plants will have added the pre-treatment and feedstock segregation capacity to process any mix of feedstock types available in their area. Multi-product plants will retain the capacity to produce biodiesel, but it is not expected to be their primary product due to higher margins for more specialized products like surfactants, lubricants, or renewable oleochemical feedstocks for re-sale. Table 1.5-32 summarizes key parameters of the industry as it is currently and in the 2022 forecast.

Table 1.5-32. Summary of Current Biodiesel Industry and Forecast.[405]

	2008	2022
Total production capacity on-line (million gal/yr)	2,610	1,968
Number of operating plants	176	121
Median plant size (million gal/yr)	5	5
Total biodiesel production (million gal)	776	1,670
Average plant utilization	0.30	0.85

1.5.4.2 Renewable Diesel

For a period of time in 2007 and 2008, ConocoPhilips produced small quantities (300-500 bbl/day) of renewable diesel at their Borger, Texas, refinery from beef tallow generated by Tyson Foods, Inc. in Amarillo, Texas. This operation was stopped primarily due to changes in tax law that reduced the subsidy for renewable diesel products being coprocessed with petroleum at refineries. [406]

In fall of 2008, Dynamic Fuels, LLC (a joint venture of Syntroleum Corp. and Tyson Foods, Inc.) announced construction of a 75 million gallon per year plant (5,000 bbl/day) in Geismar, Louisiana, that will use Tyson meat processing byproducts as feedstock to Syntroleum's Bio-Synfining process. Start-up is scheduled for 2010, with the primary product being high-quality diesel fuel that will be fungible within the existing petroleum supply system.[407] The Geismar facility plans to utilize supplies of hydrogen available in the industrial park where it will be located, as well as rail and shipping infrastructure already in place nearby.[408] However, it is not co-located with existing petroleum production, and therefore would be considered a stand-alone facility in our analyses (thus meeting the definition of non-coprocessed fuel eligible to generate RINs counting toward the biomass-based diesel standard).

Our industry projection is based on the expectation of that Dynamic Fuels, LLC, (or another company) will construct and operate two facilities like the one underway in Geismar, LA, during our analysis period.[409] It is conceivable that more facilities will be built by Dynamic Fuels or other companies (such as Neste), or that some renewable diesel will be imported into the U.S., but we felt there was too much uncertainty to project volumes, given the large capacity for biodiesel production already on-line. Also, considering tax subsidy and RIN incentives putting co-processed renewable diesel at a disadvantage, we've chosen to assume all renewable diesel is produced in stand-alone facilities.

1.5.4.3 Algae-Based Biofuel

Recently, there has been a renewed interest in the production of algae-based biofuels and a growth in the number of potential technology providers. To give a sense of the size of the industry, we've developed a list of over 70 companies from various locations around the world and summarized a basic description of their technologies for algae production (Table 1.5-33). This list is current as of November 2009 and is based mainly on biofuel magazines and articles that are supplemented with company websites. As new information is available on a near daily basis, it is possible that we have not included newly formed companies or those not highly publicized.

Companies that have announced plans for algae-based biofuel production include: Sapphire Energy for 135 MMgal by 2018 and 1 Bgal by 2025, Petrosun for a 30 MMgal/yr facility, Solazyme for 100 MMgal by 2012/13, and U.S. Biofuels for 4 MMgal by 2010 and 50 MMgal by full scale. It is important to realize that future projections are highly uncertain, and we have taken into account the best information we could acquire at the time. For more information on algae as a feedstock for biofuel, refer to Section 1.1.3.4.

In recent months, there have also been grants given to technologies based on algae. On December 4, 2009, the Department of Energy announced that it awarded several algae-based technology providers. This included the following companies: Algenol Biofuels ($25 million grant for a pilot scale project located in Freeport, Texas), Solazyme ($22 million grant for a pilot scale project located in Riverside, Pennsylvania) and Sapphire Energy ($50 million grant for a demonstration scale project located in Columbus, New Mexico).

Table 1.5-33. Companies Developing Algae Production Technologies[68]

Company Name	Technology	Headquarters & Facilities
A2BE Carbon Capture	Closed PBR algae system recycling CO2 from industries.	Boulder, Colorado
Advanced Lab Group	Polyethylene film for closed PBRs, wants to reduce costs for harvesting and dewatering, heat venting for closed systems, and reduce oil extraction and process costs.	Santa Monica, California
Alfa Laval	Algae/water separability tests using different centrifuge test units.	Headquarters in Sweden
Algae Venture Systems	Develops harvesting, dewatering, and drying of algae technology.	Marysville, Ohio
AlgaeLink	Uses photobioreactor (PBR) technology and has expertise in extracting oil and biomass. Offers algae production capacity for a farm of 250 ton dry algae per day.	Dutch-based, plant in the Netherlands
Algenol Biofuels	Direct to ethanol process, using algae, sunlight, CO2, and seawater. Produces ethanol at rate of 6,000 gallons per acre per year, targeting 10,000 gallons per acre per year. Ethanol is produced inside each algae cell. Uses hybrid algae in sealed, clear plastic photobioreactors.	Plans first US plant in Florida or Texas. One in development in Sonora, Mexico with company called BioFields. Corporate headquarters in Naples, Florida. Goal is to have 4 sites in US by 2010, target Florida, Texas, Arizona, New Mexico. Announced on June 29, 2009, demo plans of 3,100 bioreactors on a 24-acre site at Dow's Freeport, Texas site.
Aquaflow Bionomic Corporation	Produce biofuel from wild algae harvested from open air environments, clean-up algae-infested polluted water systems.	New Zealand
Aquatic Energy	Proprietary strain of algae for continuous outdoor growth, filed patents for growth and harvesting techniques. Interested in developing, constructing, and operating open pond algae farms.	Headquarters in Lake Charles, Louisiana; Couple of acre pilot facility in Lake Charles

[68] Although we provide this summary here, we caveat that we have not confirmed the statements made on the company websites or on the data collected from news magazine/articles. For latest information please refer to the company's website or contact the company's representatives. Blanks occur where information was not available or found.

Aurora Biofuels	Use genetically-modified algae to generate oil for production of biodiesel. Uses seawater-fed, open ponds. Has produced slightly under 1,000 gallons oil per year from 1/8th acre surface area. The company estimates that will translate into 6,000 gallons/yr/acre at commercial size. The company uses waste water technology and a wet extraction process instead of the traditional process of centrifugation and drying. On August 18, 2009 announced that it had optimized particular algae strains to more than double their uptake of carbon dioxide.	Headquarters in Alameda, California ;Developed at the University of California at Berkeley; Pilot-Scale facility in Florida
AXI LLC	Developing various strains of algae for the production of biofuels.	Quincy, Massachusetts
BARD, LLC	BARD's closed loop photo-bioreactor technology can produce 66 million gallon of algae oil in 7 acres of land, which is 8,571,428 gallon of algae oil per acre. The pilot facility will begin by producing 43,070 gallons of algae oil / biodiesel per annum using only six modules of photo-bioreactors covering 84 square feet.	Commercial scale algae system pilot facility located in the Commonwealth of Pennsylvania also plans for plant in Ohio.
Bellona	Supports algae in photobioreactors which can deliver food, fodder and fuel.	Norway
Bio Algene	Use algae to generate oil for production of biodiesel and extract oil by breaking cell wall. Algae cultivation to remediate pollution, produce fuel and other bioproducts. Company has developed methods to accelerate algae growth and is investigating different harvesting methods.	Headquarters near Seattle
Biocentric Energy	Manufactures and sells closed loop algae bioreactor systems for commercialization.	California
Biofuel Systems Group Limited	Use phytoplankton to produce biodiesel. Design and build biodiesel processing systems.	England

Biolight Harvesting	Develop renewable fuels and chemicals from blue-green algae. Biolight is focused on brackish water and agricultural runoff as a long-term medium for cultivation.	California; 40-acre pilot facility in California's Imperial Valley
Bionavitas	High-volume production of algae using biofactories and fiber-optic lights in algaculture system. Claims to have a cost-efficient way to deliver light to biomass. Light Immersion Technology (LIT).	Redmond, Washington
BioProcess Algae LLC	Photobioreactor systems coupled next to an ethanol facility which provides water, heat, and CO2.	Pilot project anticipated to be in Shenandoah, Iowa
Blue Marble Energy	Convert algal biomass to energy by creating, centralizing, and harvesting wild algae blooms. BME’s proprietary AGATE (Acid, Gas, and Ammonia Targeted Extraction) system processes nearly any organic feedstock, utilizing cultured strains of bacteria to perform fermentation (like brewing beer) to produce a wide variety of biochemicals; can utilize wet biomass, bypassing energy-intensive drying	Seattle, Washington
Bodega Algae LLC	Developer of scalable algae photobioreactors. Developing proprietary light technology to enhance growth of algae.	Headquarters in Boston, Massachusetts
Canadian Pacific Algae Inc.	Grower and producer of phytoplankton (marine microalgae), current research center uses eight - 1 million liter tanks.	Nanaimo, British Columbia
Carbon Capture Corp.	Operates open algae ponds. In the business of processing algal-derived renewable diesel, butanol, biomethane and jet fuel propellant.	La Jolla, California; 40-acre Algae Research Center, part of a 326-acre R&D facility in Imperial Valley, California
Cellena	Open pond and PBR technology. Developing process for extracting algae oil without chemical use, drying or an oil press. Kona facility will grow only non-modified, marine microalgae in a hybrid system.	Hawaii; Building an open-pond demo facility in Hawaii - Kona Pilot Facility on Big Island began on January 16, 2008.

Circle Biodiesel and Ethanol Corporation	Have manufactured an algae photobioreactor for the production of algae. Also has an algae harvesting system for the extraction of algae oil for algae biodiesel or algae biofuel. Algae harvesting system retails for $195,000 US dollars, can process one gallon of algae oil per minute.	Headquarters in San Marcos, California
Desert Sweet Biofuels	Using a combination of gasification and pyrolysis in such a way as to produce biochar, a byproduct is electricity. One low cost algae production system currently being developed is vectoring algae through Daphnia.	Gila Bend, Arizona
Diversified Energy Corp.	Has licensed technology from XL Renewables under the name Simgae for simple algae.	Gilbert, Arizona
Dynamic Biogenics	Utilizes photobioreactors.	Headquarters in Sacramento, California
ENN		Hebei Province, China
General Atomics	Developing improved processes for growing and extracting oil from algae in open ponds.	San Diego, California
Genifuel	Licensed method to convert algae into renewable natural gas. Uses wet biomass like algae in a gasifier - Catalytic Hydrothermal Gasifier (CHG). The gasifier was developed by PNNL. Focus on outdoor ponds or inexpensive troughs.	
Global Green Solutions Inc.	Focused initially on biodiesel feedstock. Developed Vertigro, self-contained algae growing system.	Vancouver, British Colombia
Green Plains	Fourth largest ethanol producer in North America. Focus on photobioreactor systems. The pilot plant is planned to be used for animal feed, at least initially.	Shenandoah, Iowa; pilot project expected to be operational by July 2009
Green Star Products	Developed formulas to increase algae growth rates, Montana Micronutrient Booster (MMB). Developed wet-algae stripping technology.	Headquarters in San Diego, California. Had plans to move algae facility to Utah.

GreenShift	Has license agreement with Ohio University for bioreactor.	Corporate offices in New York, New York; Engineering located in Alpharetta, Georgia
HeroBX (formerly Lake Erie Biofuels)	Investigating algae as a feedstock, conducting a vetting process with PBRs.	Erie, Pennsylvania
HR Biopetroleum Inc.	Focus on earth-marine microalgae plants to produce biofuel feedstocks and animal nutrition products. The company offers algae products, such as algae oil, biodiesel, and animal feed proteins; carbohydrates for the production of ethanol and petroleum-based products; and military jet fuel. The technology is focused on coupling PBRs with open pond systems.	Hawaii
Infinifuel Biodiesel	Focusing on algae for biodiesel using algae ponds.	Headquarters in Dayton, Nevada
Ingrepro	Focused on open-pond systems. Suggests that best business model will remediate waters, integrate heat, and produce multiple products.	Netherlands; Plans to build algae facilities in Malaysia
International Energy Inc.	PBR	Washington, DC
Inventure Chemical Technology	Patent-pending algae-to-jet fuel product. The company provides expertise in both process conversion and plant design and construction.	Gig Harbor, Washington
Kai BioEnergy	Continuous, open pond system that produces bio crude oil from microalgae. Technology claims to overcome risk of algae contamination and allows for high yield growth of a dominant species.	Del Mar, California and Hawaii
Kelco	Harvests natural kelp beds.	San Diego, California
Kent BioEnergy	Develops open pond algae farm, experience in aquaculture.	San Diego, California; 160-acre process development/production facility south of Palm Springs
Live Fuels Inc.	Open-pond algae bioreactors to create green crude, not ethanol or biodiesel. Up to 20,000 gallons per acre predicted for algae yield. The	Headquarters in Menlo Park, California; Original plans to grow algae in ponds at the Salton Sea, an inland saline lake in

	company grows a mix of native algae species in 45 acres of open saltwater ponds. To harvest the algae, the company uses “algae grazers” such as filter-feeding fish species and other aquatic herbivores. The fish, including those from the Tilapia or sardine families, collect and clean the algae through structures in their mouths, according to the company. They swallow it and the algae is digested and concentrated in the fish’s flesh. To extract the oil, the fish are cooked and pressure is applied, resulting in Omega-3 fatty acids and other oils used as feedstocks for renewable fuels.	Southern California, but has shifted to Texas. Will begin pilot operations at its test facility in Brownsville, Texas. The results of the pilot project will be used to commercialize the process along the coast of Louisiana.
Martek Biosciences Corporation	Martek currently produces algae in a closed, dark system where the algae are fed sugars in a fermentation process similar to yeast growing on corn sugar, in contrast to the photosynthetic processes being developed by others in the algae-to-fuel race. The sugar-to-biodiesel pathway will use advanced biological science to convert sugars derived from biomass into lipids which are then converted into fuel molecules through chemical or thermocatalytic processes.	Maryland
MBD Energy	Algae grown in waste water with high concentration of CO2 from a nearby power plant. Algae are harvested to produce algae oil and algae meal.	East Melbourne, Australia
Neptune Industries	Has a patented system to use fish waste for the growth of algae for biofuels and methane gas.	Boca Raton, Florida
Odyssey Oil and Energy Inc.	Company focuses on carbon sequestration and generation of renewable energy. PBR technology, ALG Bio Oil Ltd.	Pretoria, South Africa

OriginOil	The company's bioreactor attempts to speed the growth of algae in a tank by blending light emitted from a rotating shaft with nutrients. The process does not require chemicals, initial dewatering, or high capex for heavy machinery. The company's technology combines electromagnetism and pH modification to break down cell walls, releasing algal oil within the cells. The oil rises to the top for skimming and refining, while the remaining biomass settles to the bottom for further processing as fuel and other valuable products.	Los Angeles, California
Petroalgae	Developing a commercialized system of technologies to grow and harvest oil from algae. Certain initial alga strains originated at the National Renewable Energy Lab ("NREL"). Selected and utilizes strains of algae to optimize growth and harvest characteristics for different applications and different geographic environments.	Based in Melbourne, FL; Pilot plant in Fellsmere; Plans to complete a 20-acre demo algae farm by end of 2009.
PetroSun		Scottsdale, Arizona, factory in Rio Honda, Texas
Phycal	Aims to harvest oil from algae without killing it, by bathing in solvents that remove the oil. Olexal non-destructive extraction "milking" process.	Highland Heights, Ohio; Pilot by end of 2009. Sub-pilot scale in Ohio and R&D lab in St. Louis. Pilot facility in Hawaii planned to begin operations in 2010.
Plankton Power	Closed ponds and integrated PBR, continuous process with low energy algal separation, oil extraction.	Wellfeet, Massachusetts
Primafuel	Grown in shallow ponds with sunlight and fertilizers as inputs; Fertilizers are grass clippings and wood biomass.	Signal Hill, CA Lund, Sweden
Renewed World Energies	Reportedly, the only fully automated and modular photo-bioreactor currently available, yields algae oil and cake. Captures nitrogen oxides and CO2 from flue	Georgetown, South Carolina

	gases.	
SAIC	Focus on creation of algae-based jet fuel	Headquarters in McLean, Virginia; locations in 150 cities worldwide
Sapphire Energy	Plans to grow algae in open ponds of unusable water. Algae-based based fuels developed include gasoline, diesel, and aviation fuels.	San Diego, California; Demo in Las Cruces, California
SCIPIO Biofuels	Continuously circulating photobioreactors and continuous algae harvester. The company says it will target whatever fuel is demanded, be it jet fuel, ethanol, biodiesel, or biobutanol.	Headquarters in Laguna Hills, California Plans for facility in Greensburg, Kansas
Seambiotic	Produces marine algae for a variety of applications, health foods, chemicals, medical products, and biofuels. Uses raceway/paddle-wheel open-pond algae cultivation.	Ashkelon, Israel
Solazyme	Grows algae in the dark using standard industrial bioproduction equipment, where the algae are fed a variety of non-food and waste biomass materials including cellulosic biomass and low-grade glycerol.	Headquarters in San Francisco, California
Solena Group	Plasma technology to gasify algae and other organics into energy outputs. Algae would be grown in big plastic containers and fed sunlight and sodium bicarbonate. Biomass is converted to syngas to produce electricity.	Headquarters in Washington D.C.; European Office in Madrid, Spain
Solix Biofuels	Harvest oil, uses PBR; After oil is extracted the rest can be used as animal feed and ethanol. Claims to use less water than other processes.	Headquarters in Fort Collins, Colorado. Announced in 2008 that it will build its first large scale facility at nearby New Belgian Brewery, where CO2 produced will be used to feed the algae. Plans for a Coyote Gulch Demonstration Facility, which will be operational by late summer 2009. The Utes chipped in more than $20 million and the land

		for the project in Southwest Colorado.
StellarWind Bioenergy	The company is using its proprietary PhycoGenic Reactor and PhycoProcessor systems as well as a RecyCO2Tron system for CO2 recovery. The PhycoProcessor is an oil recovery system. Their resource recovery system coverts algae biomass into methane, charcoal, fertilizer, or syngas.	Indianapolis, Indiana
SunEco Energy	Harvesting and growth of native algae species in open ponds, claims to can produce at least 33,000 gallons of biocrude per acre-foot per year.	Headquarters in Chino, California; Operations in Niland, California
Synthetic Genomics	Synthetic is collaborating with Exxon Mobil to research and develop the most advanced algae. In the future hope to mass farm the oil from algae.	La Jolla, California
Texas Clean Fuels	Developing photobioreactors and equipment for algae farms. Their product line, known as MOPS (Micro Organism Production System)	Headquarters in Rockwall, Texas
Univenture	Algae harvesting system that could reduce energy cost due to harvesting, dewatering, and drying of algae using a novel absorbent moving belt harvester.	Operations in Ohio, Ireland, China
US Biofuels	PBR	Negotiating with Co-op Greenhouse regarding locations in Fresno, the Imperial Valley, and Palmdale.
Valcent Products Inc.	Creates, designs, and develops patents e.g. vertical bioreactors in a closed loop.	Headquarters in El Paso, Texas
Vertigro Energy	Closed-loop vertical algae growth system.	San Diego, California; commercial-scale bioreactor pilot project in El Paso, Texas

W2 Energy Inc.	SunFilter technology: a tubular algae bioreactor; Inside the bioreactor, low-power ultraviolet lights, in combination with the gases, feed the algae so it grows and fills the tubes with blooms. When the blooms have reached an appropriate density, a set of magnetic rings inside the tubes scrapes the blooms clean and pushes the algae to the upper manifold, where compressed air pushes it out. The algae is then compressed, dried and then either gasified or fed into a biodiesel reactor to produce biodiesel. W2 also has developed a multi-fuel reactor to produce ultra-low sulfur diesel, a blend of JP8 jet fuel or gasoline; a plasma-assisted gasifier; a SteamRay rotary system engine that converts energy from steam or fuel combustion into a rotary force; small energy generating systems; and the Non-Thermal Plasmatron.	Carson City, NV; Plans for bioreactor running in Guelph, Ontario in mid-Sept 2009
XL Renewables (formerly XL Dairy Group)	Patent-pending hybrid algae system that can operate as a closed or open system. Focuses on creating renewable energy using dairy waste streams. Wants to produce algae biomass for animal feeds (high omega-oil content). Their Super Trough System design is expected to provide annual algae yield of 300 dry tons/acre.	Phoenix, Arizona; Developing a 400-acre integrated biorefinery located in Vicksburg, Arizona. Algae Development Center in Cas Grande, Arizona.

1.6 Biofuel Distribution

1.6.1 Biofuel Distribution Overview

The current motor fuel distribution infrastructure has been optimized to facilitate the movement of petroleum-based fuels. Consequently, there are very efficient pipeline-terminal networks that move large volumes of petroleum-based fuels from production/import centers on the Gulf Coast and the Northeast into the heartland of the country. In contrast, the most biofuel volumes are produced in the heartland of the country and need to be shipped to the coasts, flowing roughly in the opposite direction of petroleum-based fuels. The location of renewable fuel production plants is often dictated by the need to be close to the source of the feedstocks used rather than to fuel demand centers or to take advantage of the existing pipeline distribution system for petroleum products.[69]

To varying degrees, the physical/chemical nature of some biofuels also limit the extent to which they can be shipped/stored fungibly with petroleum-based fuels. The vast majority of biofuels are currently shipped by rail, barge and tank truck to petroleum terminals. All biofuels currently are blended with petroleum-based fuels prior to use. Most biofuel blends can be used in conventional vehicles. However, E85 can only be used in flex-fuel vehicles, requires specially-constructed retail dispensing/storage equipment, and may require special blendstocks at terminals. These factors limit the ability of biofuels to utilize the existing petroleum fuel distribution infrastructure. Hence, the distribution of renewable fuels raises unique concerns and in many instances requires the addition of new transportation, storage, blending, and retail equipment.

Significant challenges must be faced in reconfiguring the distribution system to accommodate the large volumes of biofuels that we project would be used to meet the proposed standards. Considerable efforts are underway by individual companies in the fuel distribution system, consortiums of such companies, industry associations, independent study groups, and inter-agency governmental organizations to evaluate what steps might be necessary to facilitate the necessary upgrades to the distribution system to support compliance with the volumes of biofuels required by the RFS2 standards.[70] EPA will continue to participate in or monitor these efforts as appropriate.

Considerations related to the distribution of ethanol, cellulosic distillate fuel, renewable diesel fuel, and biodiesel are discussed in the following sections as well as the changes to each segment in the distribution system that would be needed to support the volumes that we project would be used to satisfy the RFS2 standards. The costs associated with making the necessary changes to the fuel distribution infrastructure are discussed in Section 4.2 of this RIA. The importation of ethanol into the U.S. is discussed in Section 1.5.2 of this RIA.

1.6.2 Biofuel Shipment to Petroleum Terminals

Pipelines are the preferred method of shipping large volumes of petroleum products over long distances because of the relative low cost and reliability. Ethanol currently is not commonly shipped by pipeline because it can cause stress corrosion cracking in pipeline walls and its affinity for water and solvency can result in product contamination concerns.[410] Shipping ethanol in pipelines that carry distillate fuels as well as gasoline also presents unique difficulties in coping with the volumes of a distillate-ethanol mixture which would typically result.[71] We

[69] A discussion of the projected locations of ethanol production facilities can be found in Chapter 1.5 of this RIA.
[70] For example, the "Biomass Research and Development Board", an inter-governmental group co-chaired by USDA and DOE., includes a group that is focused on evaluating biofuels distribution infrastructure issues. http://www.usbiomassboard.gov/distribution_infrastructure.htm
[71] Different grades of gasoline and diesel fuel are typically shipped in multi-product pipelines in batches that abut each other. To the extent possible, products are sequenced in a way to allow the interface mixture between batches

believe that it is currently not possible to re-process this mixture in the way that diesel-gasoline mixtures resulting from pipeline shipment are currently handled.[72] The Pipeline Research Council International (PRCI) in coordination with the Pipeline and Hazardous Materials Safety Administration (PHMSA), and the Association of Oil Pipelines (AOPL) are conducting research to address the safety and technical challenges to pipeline transportation of ethanol.[411] A short gasoline pipeline in Florida is currently shipping batches of ethanol and other more extensive pipeline systems have feasibility studies underway.[412] Thus, existing petroleum pipelines in some areas of the country may play an increasing role in the shipment of ethanol. Evaluations are also currently underway regarding the feasibility of constructing a new dedicated ethanol pipeline from the Midwest to the East coast.[413] Substantial issues would need to be addressed before construction on such a pipeline could proceed, including those associated with securing new rights-of-ways and establishing sufficient surety regarding the return on the several billion dollar investment.

We expect that cellulosic distillate fuels and renewable diesel fuel will not have materials compatibility issues with the existing petroleum fuel distribution infrastructure. Thus, there may be more opportunity for these biofuels to be shipped by pipeline. However, the location of ethanol and cellulosic distillate/renewable diesel production facilities relative to the origination points for existing petroleum pipelines will be a limiting factor regarding the extent to which pipelines can be used. The gathering of ethanol from production facilities located in the Midwest and shipment by barge down the Mississippi for introduction to pipelines in the Gulf Coast has been discussed by industry. This approach might also be considered for cellulosic distillate fuel when such plants are constructed. However, the additional handling steps to bring the ethanol or cellulosic distillate fuel to the pipeline origin points in this manner could negate the potential benefit of shipment by existing petroleum pipelines compared to direct shipment by rail.

Biodiesel is currently not widely shipped by pipeline due to concerns that it may contaminate jet fuel that is shipped on the same pipeline and potential incompatibility with pipeline gaskets and seals. Segments of Kinder Morgan's Plantation pipeline are currently shipping B5 blends, and its Oregon Pipeline that runs from Portland to Eugene is currently shipping B2 blends.[414] These systems do not handle jet fuel. The shipment of biodiesel by pipeline may become more widespread and might be expanded to systems that handle jet fuel. However, the relatively small production volumes from individual biodiesel plants and the widespread location of such production facilities may tend to limit the extent to which biodiesel may be shipped by pipeline. Rail cars, barges, and tank trucks that transport biodiesel over long distances will need to be heated/insulated in cold climates to prevent gelling.

Due to the uncertainties regarding the extent to which pipelines might participate in the transportation of biofuels in the future, we assumed that biofuels will continue to be transported by rail, barge, and truck to petroleum terminals as the vast majority of biofuel volumes are today.

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to be cut into one of the adjoining products. In cases where diesel fuel abuts gasoline in the pipeline, the resulting mixture must typically be reprocessed into its component parts by distillation for resale as gasoline and diesel fuel.

[72] We believe that it is not currently possible to separate ethanol from a gasoline/diesel mixture sufficiently by distillation. Hence, a significant amount of ethanol may remain in the gasoline and diesel fractions separated by distillation. Gasoline-ethanol mixtures can be blended into finished gasoline provided the applicable maximum allowed ethanol concentration is not exceeded. However, diesel-ethanol mixtures can not be used as motor fuel.

To the extent that pipelines do play an increasing role in the distribution of ethanol, this may improve reliability in supply and reduce distribution costs.

Apart from increased shipment by pipeline, biofuel distribution, and in particular ethanol distribution, can be further optimized primarily through the expanded use of unit trains. Unit trains are composed entirely of 70-100 ethanol tank cars, and are dedicated to shuttle back and forth to large hub terminals. In the future, unit trains might also be used for the shipment of cellulosic distillate fuel. Unit trains can be assembled at a single production plant or if a group of plants are not large enough to support such service individually, can be formed at a central facility which gathers fuel from a number of producers. The Manly Terminal in Iowa, accepts ethanol from a number of nearby smaller ethanol production facilities for shipment by unit train. Regional (Class 2) railroad companies are an important link bringing ethanol to gathering facilities for assembly into unit trains for long-distance shipment by larger (Class 1) railroads. We anticipate that the vast majority of new ethanol and cellulosic distillate facilities will be sized to facilitate unit train service. We do not expect that biodiesel facilities will be of sufficient size to justify shipment by unit train. In the NPRM, we projected that unit train receipt facilities would be located at petroleum terminals and existing rail terminals. Based on industry input regarding the logistical hurdles in citing unit train receipt facilities at petroleum/existing rail terminals, we expect that such facilities will be constructed on dedicated property with rail access that is as close to petroleum terminals as practicable.[73]

Shipment of biofuels by manifest rail to existing rail terminals will continue to be an important means of supplying biofuels to distant markets where the volume of the production facility and/or the local demand is not sufficient to justify shipment by unit train. Manifest rail shipment refers to the shipment of biofuel in rail tanks cars that are incorporated into trains which are composed of a variety of other commodities. Shipments by barge will also play an important role in those instances where production and demand centers have water access and in some cases as the final link from a unit train receipt facility to a petroleum terminal. Direct shipment by tank truck from production facilities to petroleum terminals will also continue for shipment over distances shorter than 200 miles.

We project that most biofuel volumes shipped by rail will be delivered to petroleum terminals by tank truck.[74] We expect that this will always be the case for manifest rail shipments. In the NPRM we projected that trans-loading of biofuels from rail cars to tank trucks would be an interim measure until biofuel storage tanks were constructed.[75] Based on industry input, we now expect trans-loading will be a long-term means of transferring manifest rail car shipments of biofuels received at existing rail terminals to tank trucks for delivery to petroleum terminals. We also anticipate that trans-loading will be used at some unit train receipt facilities, although we expect that most of these facilities will install biofuel storage tanks from which tank trucks will be filled for delivery to petroleum terminals. Imported biofuels will typically be

[73] Existing unit train receipt facilities have primarily followed this model. See the US Development Group's interactive map of their ethanol unit train receipt facilities at http://www.us-dev.com/terminals.htm
[74] At least one current ethanol unit train receipt facility has a pipeline link to a nearby terminal. To the extent that additional unit train receipt facilities could accomplish the final link to petroleum terminals by pipeline, this would significantly reduce the need for shipment by tank truck.
[75] Trans-loading refers to the direct transfer of the contents of a rail car to a tank truck without the intervening delivery into a storage tank.

received and be further distributed by tank truck from petroleum terminals that already have receipt facilities for waterborne fuel shipments.

Our analysis of the shipment of ethanol and cellulosic distillate fuels to petroleum terminals is based on the Oakridge National Laboratory (ORNL) analysis of ethanol transportation activity under the EISA that was conducted for EPA.[415] The ORNL analysis contains detailed projections of which transportation modes and combination of modes (e.g. unit train to barge) are best suited for delivery of ethanol to specific markets considering ethanol source and end use locations, the current configuration and projected evolution of the distribution system, and cost considerations for the different transportation modes. The NPRM analysis assumed that all biofuel volumes other than biodiesel would be ethanol. For this FRM, we analyzed three scenarios under which varying volumes of cellulosic distillate fuel would take the place of ethanol production volumes to satisfy the RFS2 requirements. However, due to the timing of the various analyses for the FRM, the NPRM projections of the location of ethanol production facilities and end use areas contained in the NPRM had to be used as the inputs into the ORNL analysis. Our use of the ORNL analysis to evaluate the distribution impacts for the final rule assumes that cellulosic distillate production plants would take the place of some of the ethanol production plants projected in the NPRM. It further assumes that cellulosic distillate fuel use would coincide with the ethanol end-use areas projected in the NPRM.

The extent to which new cellulosic distillate fuel and cellulosic ethanol production facilities are more dispersed than projected in the NPRM, distribution for ethanol from new production facilities and from all cellulosic distillate facilities might be simplified as the fuel has more opportunity to be used locally. Cellulosic distillate fuel distribution may also be further simplified to the extent that in the future it is blended with petroleum-based diesel fuel in higher blend-ratios than the 20% blends currently registered by EPA. An increased blend ratio for cellulosic distillate fuel would tend to enhance the ability for its use close to the place of manufacture rather than having to be spread more widely over a larger petroleum diesel pool.

We projected the volumes of biodiesel that would be used on a State-by-State basis to meet anticipated State biodiesel mandates/incentives and the estimated demand for biodiesel as a blending component in heating oil. Using the estimated locations of biodiesel production facilities and their volumes, we evaluated the most efficient means of meeting this projected demand while minimizing shipping distances (and cost). The remaining biodiesel production volume from these production facilities that was needed to meet the RFS2 mandated volume was assumed to be used in the same State where it was produced up to the point where the State's entire diesel fuel pool contained 5% biodiesel. We believe that this should provide a somewhat conservatively high estimate of biodiesel distribution costs since biodiesel might be used in excess of 5% even absent a State mandate. If a State was already saturated with 5% biodiesel, the remaining volume was assumed to be shipped out of State within a 1,000 mile shipping distance. A 1,000 mile shipping distance was selected to ensure that all biodiesel not used to satisfy a State mandate or for bio-heat could find a market. It is likely that some fraction would not need to travel quite as far. Therefore, this assumption is also likely to result in a conservatively high estimate of biodiesel freight costs. It was assumed that biodiesel production volumes will continue to be insufficiently concentrated to justify shipment by unit train. Where distances are beyond 300 miles, shipment by manifest rail was assumed to be the preferred option other than in cases on the East coast where there were apparent barge routes from production to demand centers. In case where biodiesel is shipped by manifest rail, it was assumed that it would be trans-loaded at a rail terminal for further shipment by tank truck to a petroleum terminal. Additional discussion of our estimate of how increased biodiesel volumes used to comply with the RFS2 standards would be transported to petroleum terminals can be found in Section 4.2 of this RIA on biodiesel freight costs.

We anticipate that the deployment of the necessary distribution infrastructure to accommodate the shipment of biofuels to petroleum terminals is achievable. We believe that construction of the requisite rail cars, barges, tank trucks, tank truck and rail/barge/truck receipt facilities is within the reach of the corresponding construction firms. Although shipment of biofuels by rail represents a major fraction of all biofuel ton-miles, it is projected to account for approximately 0.4% of all rail freight by 2022.[76] Many improvements to the freight rail system will be required in the next 15 years to keep pace with the large increase in the overall freight demand. Given the broad importance to the U.S. economy of meeting the anticipated increase in freight rail demand, and the substantial resources that seem likely to be focused on this cause, we believe that overall freight rail capacity would not be a limiting factor to the successful implementation of the biofuel requirements under EISA.

1.6.3 Changes in Freight Tonnage Movements Due to RFS2

In order to estimate the freight rail system impacts associated with biofuels transport under RFS2, we commissioned an analysis by Oak Ridge National Laboratories (ORNL) to examine fuel ethanol transportation, activity, and potential distribution constraints for the North American freight rail system.[416] The analysis found that biofuels transport is expected to constitute approximately 0.4% of the total freight tonnage for all commodities transported by the freight rail system through 2022. The results suggest that it should be feasible for the freight rail system to accommodate the additional biofuels freight associated with the RFS2.

For the analysis, we provided the estimated location of ethanol production facilities, sources of ethanol imports, and state-level consumption for the annual volumes of ethanol that we estimated would be consumed in response to the EISA.[77] We also provided the projected volumes of biodiesel and non-co-processed renewable diesel fuel that would be used. Due to the uncertainty associated with non-ethanol biofuels, biodiesel and non-co-processed renewable diesel fuel volumes were assumed to originate from the ethanol production facilities and follow projected ethanol use patterns in the analysis. This assumption seems reasonable, given the relatively small volumes of these non-ethanol biofuels relative to ethanol.

Rail traffic information from the 2006 Surface Transportation Board Carload waybill sample was incorporated into ORNL's North American Transportation Infrastructure Network Model to provide a baseline approximation of the current day freight rail system unstressed by the transport of EISA-mandated biofuels volumes. Freight rail activity for the unstressed baseline model was projected for 2012, 2014, and 2022 using information from the Commodity

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[76] See Section 1.6.3. of this RIA for a discussion of the increase in freight traffic due to the transport of the biofuels needed to comply with the RFS2 standards
[77] These inputs are summarized in the ORNL final report.

Origin-Destination Database of DOT's Freight Analysis Framework version 2 (FAF2) to identify potential distribution constraints for the North American freight rail system. FAF2 integrates data from a variety of sources to estimate commodity flows by different modes of transportation and related freight transportation activity among states, regions, and major international gateways. FAF2 provides freight transportation forecasts through 2035.

To estimate potential future constraints of the freight rail system, EISA-mandated biofuels volumes were superimposed onto the unstressed Infrastructure Network model for 2012, 2012, and 2022. For each forecast year, total biofuels demand includes biodiesel and non-co-processed renewable diesel fuel demand. As such, total biofuel demand for the forecast years were assumed to be 14.6, 17.5, and 35.1 billion gallons, respectively. See the ORNL report for additional assumptions and modeling details.

On average, 84% of the nation's freight rail system will not be affected by biofuels shipments under the RFS2 scenarios considered, according to the ORNL analysis. The 16% which will be impacted will see a 2.5% increase in freight rail traffic associated with biofuels shipments, on average.[78] Approximately 85% of all ethanol shipments are expected to originate in the Midwest, with approximately 24%, 15%, 13%, 8% and 6% of all unit train shipments of ethanol originating from Iowa, Nebraska, Illinois, Minnesota, and Indiana, respectively. The balance is expected to originate from the surrounding Midwestern states.

As such, the 16% of the freight rail system that is expected to see an increase in biofuels shipments under RFS2 will see it concentrated along rail corridors radiating out of the Midwest. Most high-volume ethanol movements are estimated to occur from the Midwest producing regions to high-demand regions, such as the northeast, west, and south. For instance, Midwest ethanol shipments destined for the west constitute about 19% of all ethanol shipments. Shipments destined from the Midwest to the Northeast constitute about 10% of all ethanol shipped while shipments to the southeast constitute another 10%. Shipments to the southwest constitute 7% of overall ethanol shipments as do shipments to the south. Interstate shipments account for 17% of all ethanol shipped. Shipments originating and terminating in the Midwest constitute approximately 31% of all ethanol unit train shipments. For all scenarios, the EISA-related transport impacts on the freight rail system were negligible.

The results of the analysis suggest that any additional stress placed upon the North American freight rail system by biofuels transport under EISA would have minimal impacts on transportation infrastructure overall since freight associated with biofuels constitutes only a small portion of the total freight tonnage for all commodities. The results of this analysis suggest that it should be feasible for the distribution infrastructure upstream of the terminal to accommodate the additional freight associated with this RFS2.

1.6.4 Rail Transportation System Accommodations

Many improvements to the freight rail system will be required in the next 15 years to keep pace with the large increase in the overall freight demand. Much of the projected increase in rail freight demand is associated with the expected rapid growth of inter-modal rail transport.

[78] The overall increase in freight tonnage is 0.4% (2.5% x 16%)

Most of the needed upgrades to the freight rail system are not specific to the transport of renewable fuels and would be needed irrespective of the need for increased biofuel transport under the EISA. The modifications required to satisfy the increase in demand include upgrading tracks to allow the use of heavier trains at faster speeds, the modernization of train braking systems to allow for increased traffic on rail lines, the installation of rail sidings to facilitate train staging and passage through bottlenecks.

Some industry groups[79] and governmental agencies in discussions with EPA and in testimony provided for the Surface Transportation Board (STB) expressed concerns about the ability of the rail system to keep pace with large increase in demand without the implementation of the RFS2 standards. A 27% overall increase in rail fright traffic is projected by 2022 without considering the potential impact of compliance with the RFS2 program. For example, the electric power industry has had difficulty keeping sufficient stores of coal in inventory at power plants due to rail transport difficulties and has expressed concerns that this situation will be exacerbated if rail congestion worsens. One of the more sensitive bottleneck areas with respect to the movement of ethanol from the Midwest to the East coast is Chicago. The City of Chicago commissioned its own analysis of rail capacity and congestion, which found that the lack of rail capacity is "no longer limited to a few choke points, hubs, and heavily utilized corridors." Instead, the report finds, the lack of rail capacity is "nationwide, affecting almost all the nation's critically important trade gateways, rail hubs, and intercity freight corridors." This is due, in part, to the lack of critical linkages between the 27 major rail yards located in the Chicago-land area.

To help improve east-west rail connections through the city, federal, state, and local officials announced an agreement in 2006 to invest $330 million over three-years in city-wide rail infrastructure designed to improve the flow of rail traffic through the area. The State of Illinois, the City of Chicago, and seven Class I rail carriers, as well as Amtrak and Metra, the area's transit system, also committed $1.5 billion in improvements. Chicago is the largest rail hub in the country with more than 1,200 trains passing through it daily carrying 75% of the nation's freight valued at $350 billion; 37,500 rail freight cars pass through the city every day projected to increase to 67,000 by 2020. Chicago is the only city where all six Class I railroads converge and exchange freight. The plan calls for the creation of five rail corridors to aid in alleviating the bottleneck.

Significant private and public resources are focused on making the modifications to the rail system to cope with the increase in demand. Rail carriers report that they typically invest 16 to 18 billion dollars a year in infrastructure improvements.[417] Substantial government loans are also available to small rail companies to help make needed improvements by way of the Railroad Rehabilitation and Improvement Finance (RRIF) Program[80], administered by Federal Railroad

[79] Industry groups include the Alliance of Automobile Manufacturers, American Chemistry Council, and the National Industrial Transportation League; governmental agencies include the Federal Railroad Administration (FRA), the General Accountability Office (GAO), and the American Association of State Highway Transportation and Officials (AASHTO). Testimony for the STB public hearings includes Ex Parte No. 671, *Rail Capacity and Infrastructure Requirements* and Ex Parte No. 672, *Rail Transportation and Resources Critical to the Nation's Energy Supply*.

[80] The RRIF program was established by the Transportation Equity Act for the 21st Century (TEA-21) and amended by the Safe Accountable, Flexible and Efficient Transportation Equity Act: a Legacy for Users (SAFETEA-LU).

Administration (FRA), as well as Section 45G Railroad Track Maintenance Credits, offered by the Internal Revenue Service (IRS).

The RRIF program offers loans to railroads for a variety of capital purposes including track and equipment rehabilitation at "cost of money" for 25 year terms. Typically, short line railroads cannot secure this kind of funding in the private markets. Under this program, FRA is authorized to provide direct loans and loan guarantees up to $35.0 billion. Up to $7.0 billion is reserved for projects benefiting freight railroads other than Class I carriers. However, the program has lent less than $650 million to non-passenger rail carriers since 2002, according to the FRA/RRIF website.

The American Association of State Highway Transportation Officials (AASHTO) estimates that between $175 billion and $195 billion must be invested over a 20-year period to upgrade the rail system to handle the anticipated growth in freight demand, according to the report's base-case scenario.[418] The report suggests that railroads should be able to provide up to $142 billion from revenue and borrowing, but that the remainder would have to come from other sources including, but not limited, to loans, tax credits, sale of assets, and other forms or public-sector participation. Given the reported historical investment in rail infrastructure, it may be reasonable to assume that rail carriers would be able to manage the $7.1 billion in annual investment from rail carriers that AASHTO projects would be needed to keep pace with the projected increase in freight demand.

The Association of American Railroads (AAR) estimates[419] that meeting the increase in demand for rail freight transportation will require an investment in infrastructure of $148 billion (in 2007 dollars) over the next 28 years and that Class I railroads' share is projected to be $135 billion, with $13 billion projected for short line and regional freight railroads.

In testimony before the STB, Class I railroads committed to working with all parties in the ethanol logistical chains to provide safe, cost-effective, and reliable ethanol transportation services as well as to resolve past freight rail capacity difficulties. Presumably, this commitment extends to the projected three-percent increase in overall freight tonnage envisioned herein.

However, the Government Accounting Office (GAO) found that it is not possible to independently confirm statements made by Class I rail carriers regarding future investment plans.[81] In addition, questions persist regarding allocation of these investments, with the Alliance of Automobile Manufacturers, American Chemistry Council, National Industrial Transportation League, and others expressing concern that their infrastructural needs may be

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RRIF funding may be used to: acquire, improve, or rehabilitate intermodal or rail equipment or facilities, including track, components of track, bridges, yards, buildings and shops; refinance outstanding debt incurred for the purposes listed above; and develop or establish new intermodal or railroad facilities.

[81] The railroads interviewed by GAO were generally unwilling to discuss their future investment plans with the GAO. Therefore, GAO was unable to comment on how Class I freight rail companies are likely to choose among their competing investment priorities for the future, including those of the rail infrastructure, GAO testimony Before the Subcommittee on Surface Transportation and Merchant Marine, Senate Committee on Commerce, Science, and Transportation, U.S. Senate, *Freight Railroads Preliminary Observations on Rates, Competition, and Capacity Issues,* Statement of JayEtta Z. Hecker, Director, Physical Infrastructure Issues, GAO, GAO-06-898T Washington, D.C.: June, 21, 2006).

neglected by the Class I railroads in favor of more lucrative intermodal traffic. Moreover, the GAO has raised questions regarding the competitive nature and extent of Class I freight rail transport. This raises some concern that providing sufficient resources to facilitate the transport of increasing volumes of ethanol and biodiesel might not be a first priority for rail carriers. In response to GAO concerns, the Surface Transportation Board (STB) agreed to undertake a rigorous analysis of competition in the freight railroad industry.[82]

Given the broad importance to the U.S. economy of meeting the anticipated increase in freight rail demand, and the substantial resources that seem likely to be focused on this cause, we believe that overall freight rail capacity would not be a limiting factor to the successful implementation of the biofuel requirements under the RFS2 standards. Evidence from the recent ramp up of ethanol use has also shown that rail carriers are enthusiastically pursuing the shipment of ethanol, although there is some indication that the Class I freight rail industry will expect ethanol to primarily be shipped by unit train from facilities that assemble unit trains which are developed and paid for by the ethanol industry.

Class 2 railroads have been particularly active in gathering sufficient numbers of ethanol cars to allow Class 1 railroads to ship ethanol by unit train. Based on this recent experience, we believe that biofuels will be able to compete successfully with other commodities in securing its share of freight rail service.

While many changes to the overall freight rail system are expected to occur irrespective of today's final rule, several biofuel-specific modifications will be needed. Additional unit train and manifest rail receipt facilities will be needed to handle the volumes of ethanol and cellulosic distillate fuel that we project will be used to comply with the RFS2 standards. In the NPRM, we projected that unit train receipt facilities would be located at petroleum terminals and existing rail terminals. Based on industry input regarding the logistical hurdles in citing unit train receipt facilities at petroleum/existing rail terminals, we expect that such facilities will be constructed on dedicated property with rail access that is as close to petroleum terminals as practicable.[83] We assumed that under the primary mid-ethanol and the low-ethanol control scenarios that all unit train and manifest rail receipt facilities would be capable of handling the receipt of both ethanol and cellulosic distillate fuel. There is no cellulosic distillate fuel under the high-ethanol scenario, thus all unit train receipt facilities would be dedicated to handling ethanol under the high-ethanol control scenario.

In the NPRM, we assumed that some new manifest rail receipt facilities for biofuels would be located at petroleum terminals. Since the NPRM we received industry input that it is unlikely that additional manifest rail receipt facilities could be located at petroleum terminals due to a lack of reasonable access to a rail line. Consequently, we are now assuming that additional manifest rail receipt facilities for biofuels would be placed at exiting rail terminals. We are assuming that biofuels will continue to be trans-loaded directly from rail cars to tank trucks at rail terminals for shipment to petroleum terminals as is the case today, thereby obviating the need

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[82] GAO, *Freight Railroads: Industry Health Has Improved, but Concerns about Competition and Capacity Should Be Addressed,* GAO-07-94 (Washington, D.C.: Oct. 6, 2006); GAO, *Freight Railroads: Updated Information on Rates and Other Industry Trends*, GAO-07-291R Freight Railroads (Washington, D.C.: Aug. 15, 2007).

[83] Existing unit train receipt facilities have primarily followed this model.

for biofuel storage at rail terminals.[84] Some manifest rail receipt facilities would also handle biodiesel as well as ethanol, and cellulosic distillate fuel/renewable diesel fuel.

As part of Oakridge National Laboratory's study for EPA on the projected patterns of ethanol distribution from producer to terminal under the EISA, ORNL estimated the number of unit train receipt facilities.[420] The ORNL study used our NPRM estimate that all biofuel used to comply with the EISA (other than biodiesel) would be ethanol. Because unit train receipt facilities would handle both ethanol and cellulosic distillate fuel, the number of these facilities that would be needed is driven by the combined volume of these fuels that we project would used. Therefore, the ORNL estimate of the number of unit train receipt facilities for the NPRM control case is still very useful in estimating the number of such facilities under the control cases examined in this final rule. The NPRM control scenario assumed the use of 34.14 BGal/yr of ethanol by 2022. Under the high-ethanol control scenario in this final rule (FRM), we estimate that 33.24 BGal/yr of ethanol would be used by 2022. Given their similarity, we assumed that the ORNL results for the NPRM would be applicable to the FRM high-ethanol scenario for estimating the number of unit train receipt facilities required.

Based on our analysis of a spreadsheet used in the ORNL analysis, we determined that ORNL estimated that there would be approximately 210 unit train receipt facilities under the NPRM control case.[421] The ORNL estimate was based on an assumption by ORNL regarding the minimum annual throughput needed to justify the construction of a unit train facility (~20 MGal/yr) which we now believe to understate the throughput needed. Since the completion of the ORNL study, we received input from industry experts who are familiar with the construction of ethanol unit train receipt facilities that the minimum annual throughput for such a facility is approximately 230 million gallons per year. This minimum throughput volume assumes a fortuitous grouping of circumstances including low cost of the land needed, and ease of construction of the rail spur to the facility to a rail line. To provide a more realistic estimate under varied conditions, we assumed a minimum throughput volume of 280 MGal/yr.

We evaluated the location and annual throughput volumes of the unit train receipt facilities projected by ORNL. We consolidated the volumes from the smaller facilities projected by ORNL regionally to satisfy a minimum throughput volume of 280 MGal/yr while maintaining a reasonable trucking distance (<200 miles) from unit train facilities to petroleum terminals. Based on this analysis, we arrived at an estimate of 40 unit train receipt facilities to support the volumes of ethanol and cellulosic distillate fuel that we project would be used under the EISA. We estimated the additional transport by tank truck from these unit train facilities to petroleum terminals that would be needed to compensate for the reduced number of unit train receipt facilities compared to the ORNL study.[85]

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[84] In the NPRM, we assumed that trans-loading would only continue only until biofuel storage tanks could be constructed at rail terminals. Input from industry indicates that trans-loading will continue to be employed in the future. This input also indicates that construction of biofuel storage tanks at rail terminals is unlikely due to space and other constraints.

[85] See Section 1.6.6 for a discussion of the tanker trucks needed to support the distribution of biofuels under the EISA. For a discussion of our estimation of ethanol and cellulosic distillate freight costs, see Sections 4.2.1.2 and 4.2.2.2 respectively in this RIA. The attribution of the costs of unit train facilities to the volumes of ethanol and cellulosic distillate fuel is discussed in Sections 4.2.1.1.2 and 4.2.2.1.3

We assumed that 40 unit train facilities would be needed under each of the 3 control scenarios that we evaluated. This may somewhat overstate the number needed under the primary mid-ethanol and the low ethanol scenarios since the total volume of ethanol and cellulosic distillate fuel is somewhat lower under these scenarios relative to the high-ethanol scenario. However, we believe that this is an appropriate approach since it provides some margin to compensate for the potential that there may be some instances where a unit train receipt facility may only handle ethanol or cellulosic distillate fuel (potentially increasing the overall number of unit train facilities needed slightly). We estimate that there would be 9 unit train receipt facilities to support the transport of biofuels under the AEO reference case and 3 under the RFS1 reference case. For the AEO reference case, this includes those unit train receipt facilities currently in place and those under construction. To estimate the number unit train facilities under the RFS1 reference case, we evaluated how many of these type of facilities were in place or under construction when historic ethanol consumption levels were consistent with the RFS1 case. Under the RFS1 reference case, we attributed the need for 37 additional biofuel unit train receipt facilities (40-3) to the implementation of the EISA. Under the AEO reference case, we attributed 31 additional unit train receipt facilities (40-9) to the EISA.

The construction of each of these unit train receipt facilities would require: the acquisition of land near a rail line and within trucking distance of the petroleum terminals that would be served, the construction of a rail spur and internal tracks to handle unit trains, facilities for the high-speed unloading of rail cars and loading of tank trucks, biofuel storage tanks and/or pipelines to ship biofuel to nearby petroleum terminals, and other miscellaneous biofuel handling equipment. For our analysis, we assumed that all unit train rail receipt facilities would construct biofuel storage tanks. Biofuels would be unloaded from unit trains into these storage tanks before being loaded into tank trucks for shipment to petroleum terminals. To the extent that some facilities are able to link to nearby petroleum terminals by pipeline or employ trans-loading, there would be less need for storage tanks at unit train receipt facilities. A large petroleum fuel terminal and transportation company recently announced a joint venture with a leading biofuel unit train receipt facility developer to facilitate the rapid expansion of ethanol logistics facilities throughout the U.S.[422]

A spreadsheet used in the ORNL analysis indicates that ORNL estimated that there would be 56 manifest rail receipt facilities for biofuels under the NPRM control case.[423] To provide some margin to compensate for the potential need for additional manifest rail receipt facilities beyond that indicated by the ORNL analysis, we used the estimate of 56 manifest rail facilities for each of the 3 FRM control scenarios relative to the RFS1 reference case.[86] We estimated that an additional 43 manifest rail receipt facilities would be needed to support the transport of biofuels for the three FRM control cases relative to the AEO reference case. We arrived at this estimate by subtracting the number of manifest rail receipt facilities that could be attributed to the incremental increase in biofuel shipment volumes in going from the RFS1 to the AEO reference case from the number of facilities attributed to the EISA under the RFS1

[86] No deduction to the number of manifest rail receipt facilities attributed to the EISA was made based on the number of such facilities that would have been in place to support the transport of the volumes of biofuels corresponding to the RFS1 reference case.

reference case (56-13).[87] The construction of a new manifest rail receipt facilities at a rail terminal would involve the acquisition of a mobile trans-loading platform including fuel and fuel vapor transfer hoses, the preparation of spill containment for the area where trans-loading would take place, accommodations for recordkeeping and the preparation of bills of lading, and the installation of other miscellaneous equipment to support the trans-loading process.

A substantial number of additional rail cars would be needed to transport the volumes of ethanol, cellulosic distillate fuel, renewable fuel, and biodiesel that are projected to be used in response to the RFS2 standards. Biodiesel rail cars typically have a deliverable volume of 25,600 gallons, whereas the deliverable volume for ethanol rail cars is typically 29,000. We assumed that rail cars similar to those used for the transport of ethanol would be used to handle cellulosic distillate and renewable diesel fuels. Our estimation of the rail cars needed to transport ethanol and cellulosic distillate fuel under the 3 control scenarios is based on an interpolation of the results from the ORNL analysis for the NPRM control case (34.14 BG/yr of ethanol by 2022) and AEO reference case (13.18 BG/yr of ethanol by 2022). The underlying assumption in this approach is that the overall number of rail cars needed varies by the total volume of biofuel projected to be used under a given control scenario. Based on this approach, we estimate that 40,400 rail cars would be needed to transport the volumes of ethanol and cellulosic distillate fuel/renewable diesel fuel under the high-ethanol scenario, 36,200 under the primary mid-ethanol scenario, and 34,400 under the low-ethanol scenario**.** We subtracted the number of rail cars needed under the two reference cases to determine the incremental number of rail cars attributed to compliance with the EISA (see Table 1.6-1).

Table 1.6-1.
Additional Rail Cars Needed by 2022 for Shipment of the Incremental RFS2 Volumes of Ethanol, and Cellulosic Distillate Fuel/Renewable Diesel Fuel

	Number of Rail Cars	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	24,600	12,600
Mid-Ethanol Scenario	20,400	8,300
High Ethanol Scenario	18,500	6,500

We estimated the number of rail cars that would be needed to transport biodiesel using the projected volume of biodiesel that we expect would be shipped by manifest rail and the assumed rail car volume and cycle time. We assumed a cycle time of one month for shipment by manifest rail car. We believe this is a conservatively high estimate given current industry experience and the potential for improvement in the future. We estimate that 1,370 rail cars would be needed by 2022 to transport the volume of biodiesel that we project will be used to satisfy the RFS2 standards. We estimate that 250 rail cars would be needed by 2022 to transport

[87] The number of manifest rail receipt facilities attributed to the incremental increase in biofuel shipment volumes in going from the RFS1 to the AEO reference case was calculated by volume weighting.

the volume of biodiesel projected under the RFS1 reference case and 310 rail cars under the AEO reference case. Consequently, we attribute the construction of an additional 1,130 biodiesel rail cars to the implementation of the EISA under the RFS1 reference case and 1,060 under the AEO reference case. The total additional number of rail cars for the transport of ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel that we attribute to the implementation of the EISA is presented in Table 1.6-2.

Table 1.6-2.
Additional Rail Cars Needed by 2022 for Shipment of All Incremental RFS2 Biofuel Volumes

	Number of Rail Cars	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	25,800	13,700
Mid-Ethanol Scenario	21,500	9,400
High Ethanol Scenario	19,700	7,500

Our analysis of ethanol, biodiesel cellulosic distillate, and renewable diesel fuel rail car production capacity indicates that access to these cars should not represent a serious impediment to meeting the requirements under the RFS2 standards. Ethanol tank car production has increased approximately 30% per year since 2003, with over 21,000 tank cars expected to be produced in 2007. To accommodate the increased demand for ethanol tank cars, rail car producers converted existing boxcar production facilities to tank production facilities and brought on additional work shifts to adjust to rapidly changing to market conditions.

With the recent economic downturn, the backlog for railcars has decreased significantly. For example, the backlog for railcars of a major producer was approximately 7,000 railcars in 2009, but dropped to approximately 1,200 railcars scheduled for delivery in 2010. This has led to the closure of several railcar production facilities. We believe that the excess railcar production capacity will allow the industry to rapidly respond to potential increases in railcar demand due to ethanol, biodiesel, cellulosic distillate, and renewable diesel fuels, when the need arises.

1.6.5 Marine Transportation System Accommodations

The American Waterway's Association expressed concerns about the need to upgrade the inland waterway system in order to keep pace with the anticipated increase in overall freight demand. The majority of these concerns have been focused on the need to upgrade the river lock system on the Mississippi river to accommodate longer barge tows and on dredging inland waterways to allow for movement of fully loaded vessels. We do not anticipate that a substantial fraction of biofuels will be transported via these arteries. Thus, we do not believe that the ability to ship biofuels by inland marine will represent a serious barrier to the implementation of the requirements under RFS2 standards. Substantial quantities of the corn ethanol co-product dried distiller grains (DDG) is expected to be exported from the Midwest via the Mississippi river as the US demand for DDG becomes saturated. We anticipate that the volume of exported DDG would take the place of corn that would be shifted from export to domestic use in the production of ethanol. Thus, we do not expect the increase in DDG exports to result in a substantial increase in river freight traffic.

A number of new barges would be needed to transport the volumes of biofuels that are projected to be used in response to the RFS2 standards. We assumed the use of tank barges with a carrying capacity of 10,000 barrels (42,000 gallons). We understand that the tank barge industry is trending towards the use of tank barges with a carrying capacity of 30,000 barrels. Thus, our assumed use of 10,000 barrel barges may overstate the number of barges that would be needed. Our estimation of the barges needed to transport ethanol and cellulosic distillate fuel under the 3 control scenarios is based on an interpolation of the results from the ORNL analysis for the NPRM control case (34.14 BG/yr of ethanol by 2022) and AEO reference case (13.18 BG/yr of ethanol by 2022). The underlying assumption in this approach is that the over all number of barges needed varies by the total volume of ethanol and cellulosic distillate fuel projected to be used under a given control scenario. Based on this approach, we estimate that 167 barges would be needed to transport the volumes of ethanol and cellulosic distillate fuel/renewable diesel fuel under the high-ethanol scenario, 150 under the primary mid-ethanol scenario, and 143 under the low-ethanol scenario. We subtracted the number of barges needed under the two reference cases to determine the incremental number of rail cars attributed to compliance with the EISA (see Table 1.6-3).

Table 1.6-3.
Additional Barges Needed by 2022 for Shipment of the Incremental RFS2 Volumes of Ethanol, and Cellulosic Distillate Fuel/Renewable Diesel Fuel

	Number of Barges	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	95	45
Mid-Ethanol Scenario	78	28
High Ethanol Scenario	71	21

We estimated the number of barges that would be needed to transport biodiesel using the projected volume of biodiesel that we expect would be shipped by barge and the assumed barge volume and cycle time. We assumed a 2 week barge cycle time, which we understand to be typical given the markets where we expect most barge shipments would occur.[88] We estimate that 41 barges would be needed by 2022 to transport the volume of biodiesel that we project will be used to satisfy the RFS2 standards. We estimate that 7 barges would be needed by 2022 to transport the volume of biodiesel projected under the RFS1 reference case and 9 barges under the

[88] We believe most barge shipments of biofuels would originate and terminate in the Northeast. Cycle time refers to the time needed to complete one delivery and return to the origin including the time to prepare for the next shipment.

AEO reference case. Consequently, we attribute the construction of an additional 34 biodiesel barges to the implementation of the EISA under the RFS1 reference case and 32 under the AEO reference case. The total additional number of barges for the transport of ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel that we attribute to the implementation of the EISA is presented in Table 1.6-4.

Table 1.6-4.
Additional Barges Needed by 2022 for Shipment of All Incremental RFS2 Biofuel Volumes

	Number of Barges	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	129	67
Mid-Ethanol Scenario	112	60
High Ethanol Scenario	105	53

The U.S. tank barge fleet currently numbers 3,600.[424] In 2004, over 500 barges of all types were added to the U.S. barge fleet. Given the gradual ramp up in demand for shipment of biofuels by barge over time, we believe that the addition to the fleet of the barges estimated to be needed to transport biofuels can be accommodated by the industry.

As discussed in Section 1.5.2. of this RIA, we are projecting significant imports of ethanol by 2022. To estimate which ports would receive ethanol imports we gave priority to ports that have a history of receiving ethanol imports from Brazil and Caribbean Basin Initiative Counties[89] according to company-level historical fuel import data from the Energy Information Administration (EIA).[425] Additional ports were selected from those that have a history of receiving finished gasoline imports. Ports were selected in States that could not satisfy their internal ethanol demand from in-State production and from those ports that were closest to large demand centers. We estimate that a total of 30 ports would receive imported ethanol by 2022. The list of ethanol import ports was provided to ORNL as an input to the ethanol transportation analysis that they conducted for EPA.[426] Under the high-ethanol option, we estimate that the 18 ports which did not receive ethanol in the past would need to install/modify ethanol receipt facilities including piping, pumps, vapor handling systems, and ethanol storage tanks while ports that had received ethanol in the past would primarily need to install additional ethanol storage tanks. We project that under the primary mid-ethanol scenario that 15 new ethanol import locations would be added and that under the low ethanol scenario there would be 14 new ethanol import locations. We used these estimates relative to both the RFS1 and AEO reference cases since we expect that the increase in ethanol imports would most appropriately be attributed to the incremental increase in ethanol use levels above those reflected under both the AEO and RFS1 reference cases. We believe that all the ports where ethanol would be imported would be

[89] Caribbean Basin Initiative countries receive special exemptions from U.S. ethanol import tariffs (See Section 1.5 of this RIA regarding the source of ethanol imports and for additional discussion regarding how we estimated where ethanol imports would enter the U.S..

incorporated into existing petroleum terminals. Hence, the need for additional ethanol storage as well as outgoing ethanol shipping facilities would be covered within the context of our estimation of the upgrades needed to petroleum terminal facilities.

As part of Oakridge National Laboratory's study for EPA on the projected patterns of ethanol distribution from producer to terminal under the EISA, ORNL estimated the number of barge receipt facilities that would be needed to support biofuel shipments within the U.S.[427] Based on our analysis of a spreadsheet used in the ORNL analysis, we determined that ORNL estimated that there would be approximately 57 barge facilities under the NPRM control case.[428] Since the NPRM control case has a somewhat higher total biofuel volume than under the FRM high-ethanol control scenario, we believe that the ORNL estimate of the number of barge receipt facilities needed for the NPRM control scenario provides a reasonable (although perhaps conservatively high) estimate of the number of such facilities that would be needed under the high-ethanol scenario.

We assumed that all biofuel barge receipt facilities would handle ethanol and cellulosic distillate fuel and that some of these facilities would handle biodiesel. To compensate for the potential that there may be some instances where a manifest rail receipt facility might handle ethanol but not cellulosic distillate fuel or vice-versa (perhaps increasing the number of unit train facilities slightly), we assumed that 57 manifest rail receipt facilities would also be needed under the mid-ethanol and low-ethanol scenarios. Our analysis of the aforementioned ORNL spreadsheet indicates that ORNL estimated there would be approximately 4 barge receipt facilities under the RFS1 reference case. Therefore, we estimate that an additional 53 barge receipt facilities would need to be configured to receive biofuels in order to facilitate compliance with the RFS2 program relative to the RFS1 reference case. By interpolating between the ORNL results for the RFS1 reference case and the NPRM control case, we estimated that 16 barge receipt facilities would be needed under the AEO reference case. Therefore, we estimate that an additional 41barge receipt facilities would need to be configured to receive biofuels in order to facilitate compliance with the RFS2 program relative to the AEO reference case

We believe that barge receipt facilities that receive shipments of biofuels would be those that already handle the receipt of petroleum-based fuels and which are incorporated into petroleum terminals or would be linked to unit train receipt facilities. Such facilities would need to install/modify piping, pumps, vapor handling systems. The need for biofuel storage tanks and other facilities to handle the storage and transfer of biofuels to other means of distribution at such is addressed within the context of the additional facilities needed at petroleum terminals and unit train facilities.

1.6.6 Road Transportation System Accommodations

A substantial number of tank trucks would be needed to distribute the additional volume of biofuels that we project would be used to meet the RFS2 volumes. In all cases, a tank truck capacity of 8,000 gallons was assumed. Larger tank trucks are permitted in some areas, so this assumption will tend to overestimate of the number of tank trucks needed. We assumed that tank trucks similar to those used for the transport of ethanol would be used to handle cellulosic distillate and renewable diesel fuels.

Our estimation of the tank trucks needed to transport ethanol and cellulosic distillate fuel under the 3 control scenarios is based on an interpolation of the results from the ORNL analysis for the NPRM control case (34.14 BG/yr of ethanol by 2022) and AEO reference case (13.18 BG/yr of ethanol by 2022). The underlying assumption in this approach is that the overall number of tank trucks needed varies by the total volume of ethanol and cellulosic distillate fuel projected to be used under a given control scenario. We increased the estimated number of tank trucks needed from that which we arrived at from this interpolation to compensate for our reduction in the number of unit train facilities that would be constructed from the estimate in the ORNL study.

The volume of biofuels shipped to the unit train facilities under the ORNL analysis which we consolidated into larger unit train receipt facilities represents 41% of the total volume shipped to unit train facilities (12.6 BG/yr out of 21.4 BG/yr in 2022 under the NPRM control case). We compared the location of the 170 unit train facilities that we consolidated into the remaining 40 such facilities from the ORNL analysis to the location of the petroleum terminals that these facilities were intended to service. Based on this comparison, we estimated that 41% of the volume of biofuels shipped by unit train would need to be shipped 3 times farther on average to reach the petroleum terminals serviced than under the ORNL analysis. We assumed that this would result in a 3 fold increase in the number of trucks needed to take this volume from the unit train facility to the petroleum terminal.[90] The majority of the number tank trucks which ORNL estimated would be needed are attributed to the transport of biofuels from rail receipt facilities to petroleum terminals. Consequently, we believe that a reasonable (albeit conservatively high) estimate of the increase in the number of tank trucks that would be needed due to our decrease in the number of unit train facilities can be arrived at by multiplying the fraction of biofuels shipped by unit train that is attributed to consolidated unit train terminals (41% of the total volume shipped by unit train) by the average increase in shipping distance for the affected volume (factor of 3). By so doing, we arrived at an estimate that the reduction in the number of unit train receipt facilities would result in a 23% increase in the number of tank trucks needed compared to that indicated by interpolation of the results from the ORNL study

Based on this approach, we estimate that 1,940 tank trucks would be needed to transport the volumes of ethanol and cellulosic distillate fuel/renewable diesel fuel under the high-ethanol scenario, 1,720 under the primary mid-ethanol scenario, and 1,620 under the low-ethanol scenario. We subtracted the number of tank trucks which ORNL estimated would be needed under the two reference cases to determine the incremental number of tank trucks attributed to compliance with the EISA (see Table 1.6-5).

[90] This may somewhat overstate the number of additional tank trucks needed given that the tank truck loading/unloading time remains constant. ORNL assumed a relatively short shipping distance from rail receipt facility to petroleum terminal.

Table 1.6-5.
Additional Tank Trucks Needed by 2022 for Shipment of the Incremental RFS2 Volumes of Ethanol, and Cellulosic Distillate Fuel/Renewable Diesel Fuel

	Number of Biofuel Tank Trucks	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	1,490	1,080
Mid-Ethanol Scenario	1,230	820
High Ethanol Scenario	1,120	710

To estimate the number of tank trucks needed to transport biodiesel to petroleum terminals we assumed 6 shipments per day per truck from production facilities to terminals. We believe that a short shipping distance for tank truck transport from biodiesel production facilities is justified based on the widespread dispersion and the fact that some would be located at petroleum terminals. We estimate that 150 tank trucks would be needed by 2022 to transport the volume of biodiesel that we project will be used to satisfy the RFS2 standards. We estimate that 30 tank trucks would be needed by 2022 to transport the volume of biodiesel projected under the RFS1 reference case and 35 tank trucks under the AEO reference case. Consequently, we attribute the construction of an additional 130 biodiesel tank trucks to the implementation of the EISA under the RFS1 reference case and 120 under the AEO reference case. The total additional number of tank trucks for the transport of ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel that we attribute to the implementation of the EISA is presented in Table 1.6-6.

Table 1.6-6.
Additional Tank Trucks Needed by 2022 for Shipment of All RFS2 Incremental Biofuel Volumes

	Number of Biofuel Tank Trucks	
	Reference Case used for Comparison	
	RFS1	AEO 2007
Low-Ethanol Scenario	1,610	1,200
Mid-Ethanol Scenario	1,350	940
High Ethanol Scenario	1,240	830

In Section 1.6.8 of this RIA we discuss our estimation of the number of tank trucks than might potentially be needed to transport butane to terminals for E85 blending. The results of this analysis are presented in Table 1.6-7.

Table 1.6-7.
Estimated Number of Tank Trucks Needed for Shipment of Butane[a]

	Number of Tank Trucks Needed to Transport Butane		
	Low-Ethanol Scenario	Primary Mid-Ethanol Scenario	High-Ethanol Scenario
Tank Truck (8,200 gallons)	2,165	3,280	5,530

[a] If a solution to the current difficulty in blending E85 to meet minimum volatility specifications can not be arrived upon by ASTM International to allow the use of commonly available gasoline blendstocks.

Concerns have been raised in the trade press regarding the ability of the trucking industry to attract a sufficient number of drivers to keep pace with demand. We used estimates of the number of truck drivers required to transport biofuels from the ORNL report as a basis for our estimate of the number of truck drivers that would be needed to transport the additional volume of biofuels attributed to the RFS2 program. Given the volume of butane required for blending into E85, typical travel distances, etc., we estimated that the number of truck drivers required to transport butane was approximately 1,500. Similar inputs were used to estimate the number of truck drivers required to transport non-ethanol biofuels; this number was approximately 300. When combined with the estimates from ORNL, the number of truck drivers required to transport biofuel feedstocks and finished product is approximately 5,300 drivers.[91]

According to a 2005 study commissioned by the American Trucking Association (ATA), the motor carrier industry will face a shortage of qualified professional long-haul truck drivers by 2014.[429] In the study, ATA found that the long-haul, heavy-duty truck transportation industry in the United States is currently experiencing a national shortage of 20,000 truck drivers and, if the current trend continues, that shortage of long-haul truck drivers could increase to 111,000 by 2014. ATA projected the need for additional 54,000 drivers each year. The trucking industry is active in a number of efforts to attract and retrain a sufficient number of new truck drivers including ATA's National Truck Driver Recruiting Campaign and Driver Tuition Finance Program.

As discussed above, we estimate that the growth in the transportation of biofuels by truck through 2022 due to the RFS2 standards would result in the need for a total of approximately 5,300 additional trucks drivers for the transport of biofuel feedstocks and finished products. Given the relatively small number of new truck drivers needed to transport the volumes of biofuels projected to be used to comply with the RFS2 standards through 2022 compared to the total expected increase in demand for drivers over the same time period (>750,000), we do not expect that the implementation of the RFS2 standards would substantially exacerbate the potential for an overall shortage of truck drivers. Discussions with transport industry officials support this conclusion. However, specially-certified drivers are required to transport biofuels because these fuels are classified as hazardous liquids. Thus, there may be a heightened level of concern about the ability to secure a sufficient number of such specially-certified drivers to

[91] This is the maximum number of drivers that would be needed under any control scenario. Somewhat fewer drivers would be needed under the mid-ethanol and low-ethanol scenarios.

transport biofuels. The trucking industry is involved in efforts to streamline the certification of drivers for hazardous liquids transport. We do not anticipate that the need for special hazardous liquids certification for biofuels truck drivers of would substantially interfere with the ability to transport the projected volumes of biofuels by tank truck. We project that tank truck deliveries of biofuels would typically be accomplished within an 8 hour shift allowing the driver to return home each evening.[92] The ATA sponsored study indicated that there was particular difficulty in attracting and retaining drivers for long haul routes the keep the driver away from home overnight. Thus, driving a tank truck (with typical 8 hour shift) may be relatively more attractive compared to a long haul truck driving position.

Truck transport of biofuel feedstocks to production plants and finished biofuels and co-products from these plants naturally is concentrated on routes to and from these production plants. This may raise concerns about the potential impact on road congestion and road maintenance in areas in the proximity of these facilities. We do not expect that such potential concerns would represent a barrier to the implementation of the RFS2 standards. Distant truck traffic associated with the plant will be diffuse. Hence, we expect that impacts associated with such distant traffic are negligible. Routes in close proximity to plants may require repaving as a result of construction traffic associated with the facility. As such, the repaved routes would be more capable of handling additional truck traffic associated with production at the plants. The improved routes can also be expected to provide benefits for communities in close proximity to the production plant as well as lower maintenance costs. The potential impact on local road infrastructure and the ability of the road net to be upgraded to handle the increased traffic load is an inherent part in the placement of new biofuel production facilities. Consequently, we expect that any issues or concerns would be dealt with at the local level. The transport of biofuel feedstocks is discussed in Section 1.3.3 of this RIA.

1.6.7 Petroleum Terminal Accommodations

Petroleum terminals will need to install additional storage capacity to accommodate the volume of ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel that we anticipate will be used in response to the RFS2 standards. We estimate that it would be necessary to maintain an inventory level of 15% of the annual consumption of a given biofuel at the terminal level in order to provide a sufficient downstream buffer to ensure consistent supply. We chose a working inventory level of 15% rather than the 10% that is typical for petroleum-based fuels to compensate for the potential increase in temporary disruptions in biofuel delivery compared to petroleum-based fuels. We believe that this is appropriate due to the reliance on rail, barge, and truck for the transport of biofuels in our analysis as opposed to use of pipelines for the shipment of petroleum-based fuels. The need for additional biofuel storage volume at terminals to provide a buffer for interruptions in delivery may be reduced somewhat to the extent that pipelines play a role in the distribution of biofuels. We further estimate that an additional 30% of storage capacity would be needed as working space to accommodate biofuel deliveries.[93] Our estimates of the biofuel storage capacity needed at petroleum terminals by 2022 to facilitate the

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[92] A small fraction of biofuels deliveries may require a sleep-over on the road of the driver due to limitations on the amount of time a driver can spend behind the wheel in a day.
[93] Petroleum terminals typically allow an additional 30 percent of storage capacity (in relation to the amount provided for working inventory) to accommodate the receipt of petroleum products.

distribution of the volume of biofuels that we project would be used to meet the RFS2 volumes are based on the application of these working inventory and working space estimates. These estimates are presented in Table 1.6-8.

Table 1.6-8.
Total Biofuel Storage Capacity needed at Petroleum Terminals by 2022 to Handle the RFS2 Volumes

	Biofuel Tankage (Mbbl)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Ethanol	81.2	103.9	149.7
Cellulosic Distillate Fuel/ Renewable Diesel Fuel	43.0	30.3	NA
Biodiesel	7.2	7.2	7.2

To estimate of the additional biofuel storage tank capacity that should be attributed to the incremental RFS2 biofuel volumes relative to the 2 reference cases, we subtracted the volume which would have been in place regardless of the RFS2 program under the 2 reference cases. The same working inventory and working space estimates were used to estimate the volume of biofuel storage under the reference cases.

Overall demand for the gasoline motor vehicle fuel is expected to remain relatively constant through 2022 whereas demand for compression ignition vehicle fuel is anticipated to increase by over 10% over the same time period.[430] We expect that much of the demand for new ethanol storage capacity could be accommodated by modifying storage tanks that had previously been used for the gasoline that would be displaced by ethanol. Due to the lower energy density of ethanol relative to gasoline (67%), we project that only 67% of the demand for new ethanol storage might potentially be accommodated by modifying existing gasoline tanks for ethanol service. Likewise, we anticipate that much of the demand for cellulosic distillate fuel/renewable diesel fuel storage capacity might be satisfied by dedicating storage tanks that would have been constructed to store petroleum-based diesel fuel to instead store these biofuels. Due to the anticipated lower energy density of cellulosic distillate fuel relative to petroleum-based diesel fuel (~90% of petroleum-based diesel fuel), we project that only 90% of the demand for new cellulosic distillate/renewable diesel fuel storage might potentially be accommodated by modifying existing gasoline tanks for cellulosic distillate/renewable diesel fuel service. To provide some margin to compensate for the need for a greater degree of new tank construction than that indicated by the above analysis, we assumed that 5% of the tanks which might have been rededicated tanks previously used for petroleum-based fuels would instead be new construction. The rededication to ethanol service of storage tanks previously used to store gasoline involves lining the tank and other miscellaneous modifications to ensure the tank is compatible with ethanol. We assume that no changes would be needed to petroleum-based diesel fuel storage tanks to allow them to be used to store cellulosic distillate fuel/renewable diesel fuel. Since biodiesel storage tanks need to be insulated and heated under cold conditions, we assumed that all of the need for additional biodiesel storage capacity would be satisfied through new construction.

The volume of new biofuel storage capacity that we project would be needed as a result of the implementation of the EISA under the 2 reference cases is presented in Tables 1.6-9 and 1.6-10.

Table 1.6-9.
Additional Biofuel Storage Capacity at Petroleum Terminals by 2022 to Meet the EISA Volumes Relative to the RFS1 Reference Case[a]

	Biofuel Tankage (Mbbl)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Ethanol, Total	48.5	70.2	116.9
Ethanol, New Construction	17.6	25.5	42.5
Ethanol, Retrofitted Tanks	30.9	44.7	74.4
Cellulosic Distillate Fuel/Renewable Diesel Fuel, Total	43.0	30.3	NA
Cellulosic Distillate Fuel/Renewable Diesel Fuel, New Construction	6.2	4.4	NA
Cellulosic Distillate Fuel/Renewable Diesel Fuel, Rededicated Tanks	36.8	25.9	NA
Biodiesel, New Construction	5.9	5.9	5.9
All Biofuels, New Construction	29.7	35.8	48.4
All Biofuels, Retrofitted Tanks	30.9	44.7	74.4
All Biofuels, Redicated Tanks	36.8	25.9	0

[a] "Retrofitted" refers to tanks that need significant changes to be made suitable for biofuel storage. "Rededicated" refers to tanks that need essentially no changes to be made suitable for biofuel storage.

Table 1.6-10.
Additional Biofuel Storage Capacity at Petroleum Terminals by 2022 to Meet the EISA Volumes Relative to the AEO Reference Case[a]

	Biofuel Tankage (Mbbl)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Ethanol, Total	20.0	41.7	88.5
Ethanol, New Construction	12.7	26.5	56.3
Ethanol, Retrofitted Tanks	7.3	15.2	32.2
Cellulosic Distillate Fuel/Renewable Diesel Fuel, Total	43.0	30.3	NA
Cellulosic Distillate Fuel/Renewable Diesel Fuel, New Construction	6.2	4.4	NA
Cellulosic Distillate Fuel/Renewable Diesel Fuel, Rededicated Tanks	36.8	25.9	NA
Biodiesel, New Construction	5.5	5.5	5.5
All Biofuels, New Construction	24.4	36.4	61.8
All Biofuels, Retrofitted Tanks	7.3	15.2	32.2
All Biofuels, Rededicated Tanks	36.8	25.9	0

[a] "Retrofitted" refers to tanks that need significant changes to be made suitable for biofuel storage. "Rededicated" refers to tanks that need essentially no changes to be made suitable for biofuel storage.

Concerns have been raised by terminal operators in the Eastern U.S. about the ability of some terminals to install the needed storage capacity due to space constraints and difficulties in securing permits.[431] We acknowledge that it may not be possible for some terminals that have become surrounded by urban growth over time to install additional storage tanks within the boundaries of their existing facilities. However, we believe that there are ways to manage this situation. The areas served by existing terminals often overlap. In such cases, one terminal might be space constrained while another serving the same area may be able to install the additional capacity to meet the increase in demand. Terminals with limited biofuel storage could receive truck shipments of ethanol from terminals with more substantial biofuel storage capacity. In cases where it is impossible for existing terminals to sufficiently expand their storage capacity due to a lack of adjacent available land or difficulties in securing the necessary permits or to make arrangements to sufficiently reduce the need for such additional storage, new satellite storage or new separate terminal facilities may be need for additional biofuel storage. However, we believe that there will be few (if any) such situations.

As discussed below, we project that all terminals that distribute gasoline would install ethanol blending capability in response to the RFS2 standards. We estimate that approximately 91% of terminals that distribute diesel would install biodiesel blending/storage capability under the RFS2 standards. Therefore, in the case of biodiesel, those terminals that would experience that most difficulty in installing new storage capacity would have some opportunity to forgo bringing biodiesel into their terminal

Another question is whether the storage tank construction industry would be able to keep pace with the increased demand for new tanks that would result from today's proposal. The storage tank construction industry recently experienced a sharp increase in demand after years of relatively slack demand for new tankage. Much of this increase in demand was due to the unprecedented increase in the use of ethanol. Storage tank construction companies have been increasing their capabilities which had been pared back during lean times. Given the projected gradual increase in the need for biofuel storage tanks, it seems reasonable to conclude that the storage tank construction industry would be able to keep pace with the projected demand.

Petroleum terminals would need to install additional equipment to blend ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel into petroleum-based fuels. In the case of ethanol other miscellaneous upgrades to piping, pumps, seals, and vapor recovery systems would also be needed to ensure ethanol compatibility. In the case of biodiesel, piping and blending systems would need to be heated/insulated under cold conditions. All terminals with biofuel blending capability would need to provide facilities for receipt of biofuels via tank truck.

There are currently 1,063 petroleum terminals that carry gasoline.[432] We project that 899 of these terminals (85% of the total) would install E10 blending equipment absent the implementation of the RFS2 requirements in order to support the consumption of 13.18 BGY of ethanol by 2022 under the AEO reference case. This is based on 85% of the gasoline needing to be blended with ethanol in order to consume 13.18 BGY of ethanol considering the projected use levels of E10 versus E85 and total motor vehicle fuel consumption in 2022.[433] We project that essentially all gasoline would be either E10 or E85 by 2022 under the RFS2 standards. Thus, we estimate that all terminals would need to have ethanol blending capability to support the use of the volume of ethanol we project would be used under the RFS2 standards. Based on our projection that 899 terminals would install ethanol blending capability absent the RFS2 standards under AEO reference case, we estimate that 164 terminals would need to install ethanol blending equipment to meet the RFS2 volumes relative to the AEO reference case.

The estimated number of terminals that would need to install ethanol blending capability as a result of the RFS2 standards relative to the RFS1 reference case is based on an extrapolation of the estimate for the AEO reference case. The volume of ethanol projected to be used under the RFS1 reference case is 53% of the volume projected to be used under the AEO reference case. We estimated that the number of terminals that blend ethanol under the RFS1 reference case is 53% of the number under the AEO reference case (899 x 53% = 481). Based on this, we estimate that an additional 582 terminals would install ethanol blending capability to meet the RFS2 volumes under the RFS1 reference case.

We estimate that E85 would need to be reasonably available in 70% of the nation in order to support the use of the projected volume of E85 needed to comply with the RFS2 standards under the high-ethanol scenario.[94] To provide a conservatively high estimate, we are projecting that 90% of all gasoline terminals (931) would need to install E85 blending capability by 2022 under the high-ethanol scenario. The remaining terminals (132 out of a total of 1,063) would only have E10 blending capability in 2022 under the high-ethanol scenario.

Under the primary mid-ethanol scenario, we estimate that 60% of the nation would need to have reasonable access to E85 in order to support the use of the projected volume of E85 needed to comply with the RFS2 standards. Our estimate of the number of terminals that would need to install E85 blending capability under the mid-ethanol scenario is based on the ratio of the percent of the country which would need to have reasonable access to E85 under the mid-ethanol scenario relative to the high-ethanol scenario. By multiplying our 90% estimate of the number of terminals that would need to install E85 under the high-ethanol scenario by 60%/70%, we arrived at an estimate of 77% of all gasoline terminals (820) having E85 access under the mid-ethanol scenario. Under the low-ethanol scenario, we estimate that 40% of the nation would need to have reasonable access to E85 in order to support the use of the projected volume of E85 needed to comply with the RFS2 standards. We used the same approach outlined above to estimate that 51% of all gasoline terminals (547) would install E85 blending capability under the low-ethanol scenario.

We estimate that the terminals which would have installed E10 blending capability absent the RFS2 standards would upgrade their E10 blending facilities to accommodate E85 as well as E10. This is based on the assumption that those terminals that were the first to blend E10 would also be the first to begin blending E85. Input from terminal operators indicates that the modification of E10 blending equipment to handle E85 primarily involves an upgrade to the blending equipment software.[95] We estimate that the vapor recovery systems at all terminals that had not received ethanol before would need to be upgraded to handle ethanol-blended gasoline.

[94] A discussion of our E85 use projections is contained in chapter 1.7 of this RIA.
[95] Additional ethanol storage and modifications to terminal piping would also be needed to supply additional quantity of ethanol needed to blend E85.

The potential need to provide special blendstocks at petroleum terminals for the manufacture of E85 is discussed in Section 1.6.8 of this RIA.

Our estimate of the number of terminals that would install biodiesel blending capability under the RFS2 standards is based on an extrapolation of the analysis conducted for the NPRM. We estimate that 853 terminals handle diesel fuel.[434] We estimate that approximately 62.5 billion gallons of diesel fuel would be used in 2022.[96] Thus, the average diesel throughput per terminal would be approximately 73.2 MGY. In the NPRM analysis, we estimate that on a national average basis biodiesel would represent approximately 2.9% of the diesel fuel pool. For the purposes of our calculation of the number of terminals that would carry biodiesel, we assumed that 2.9% of the diesel fuel they dispense would be biodiesel. This is likely to result in a conservatively high number of terminals that would need to carry biodiesel, since those terminals that do carry biodiesel would be expected too blend at higher than the national average concentration. Assuming that 2.9% of a terminal's diesel fuel throughput would be biodiesel, we arrive at an estimate that 377 terminals would need to blend biodiesel to support the projected use of 810 MGY of biodiesel assumed to be used by 2022 under the RFS2 standards in the NPRM.

We estimated the number of terminals that would need to blend biodiesel for our FRM analysis by increasing the NPRM estimate in proportion to volume of biodiesel that we project would be used in the FRM by 2022 relative to that projected in the NPRM (1,671 Mgal/yr / 810 Mgal/yr). By so doing, we estimate that 777 terminals will be needed to blend biodiesel by 2022 to support the use of the biodiesel volume projected to be used in this FRM. We estimate that 200 terminals would need to store/blend biodiesel in order to support the use of volume of biodiesel that we estimate would be used as a result of the RFS2 standards relative to the AEO 380 MGY 2022 baseline. Thus, we project that 637 additional terminals would blend biodiesel as a result of the RFS2 standards under the RFS1 reference case and 600 under the AEO reference case.

The Independent Fuel Terminals Operators Association (IFTOA) stated that terminals are concerned that the market would not be able to adapt in time to ensure that the necessary distribution infrastructure accommodations are in place to support compliance with the timetable for the implementation of the RFS2 standards.[435] Based on this concern, in a presentation at the recent SAE government-industry conference IFTOA suggested that EPA should consider reducing and or slowing the pace of the implementation of the RFS2 standards in order to allow the market sufficient time to adjust.[436] We believe that given the time over which biofuel volumes ramp up under the RFS2 standards, it should be feasible for terminals to adapt sufficiently within the time frame established by the EISA.

1.6.8 Potential Need for Special Blendstocks at Petroleum Terminals for E85

ASTM International is considering a proposal to lower the minimum ethanol concentration in E85 to facilitate meeting ASTM minimum volatility specifications in cold

[96] A discussion of our estimate of biodiesel use in relation to the use of petroleum-based diesel is contained in Section 1.5.4 of this RIA.

climates and when only low vapor pressure gasoline is available at terminals.[97] Commenters on the ASTM proposal have stated that the current proposal to lower the minimum ethanol concentration to 68 volume percent may not be sufficient for this purpose. ASTM International may consider an additional proposal to further decrease the minimum ethanol concentration. Absent such an adjustment, a high-vapor pressure petroleum-based blendstock such as butane would need to be supplied to most petroleum terminals to produce E85 that meets minimum volatility specifications. In such a case, butane would need to be transported by tank truck from petroleum refineries to terminals and storage and blending equipment would be needed at petroleum terminals.

Automated inline butane blending systems located at terminals can be used to blend butane into gasoline before it is blended with denatured ethanol. Such systems consist of inline RVP analyzers which sample gasoline being transferred from storage tanks to loading racks where it is to be mixed with ethanol to produce E85.

The analyzers determine the RVP of the incoming gasoline stream and use this information to determine the volume of butane which must be blended with the gasoline down stream of the analyzer required to meet the volatility specification for the finished product. The analyzer, variable frequency butane pump, and supporting equipment are self-contained on a skid-mounted unit, and require at least one 60,000 gallon butane storage tank.

We estimated the number of automated inline butane blending systems, butane storage tanks, tanks trucks, railcars, trans-loading facilities, and other facility changes needed for butane blending as follows. Of the existing 1,063 terminals, two-thirds (709 terminals) are assumed to require butane in order to blend E85 that is complaint with ASTM International volatility specifications. All 709 terminals are assumed to require new butane blending equipment. Of these terminals, twenty-five percent (177) are assumed to receive butane via railcar and seventy-five percent (532) are assumed to receive butane via tank truck. Of the 177 terminals that receive butane via railcar, fifty-percent are assumed to have butane directly off-loaded to tank storage. In the case of the other fifty-percent of the terminals, butane is assumed to be trans-loaded from railcars to tank trucks for final delivery to terminals. This requires that each terminal have a skid-mounted inline butane blending system and two 60,000 gallon butane tanks. Usable tank volumes are assumed to be 51,000 gallons per tank. Tank trucks are assumed to carry 8,200 gallons of butane. Railcars are assumed to carry 31,500 gallons of butane.

Our estimates of the number of tank trucks and railcars required to deliver butane varies by control scenario (see Table 1.6-11).

[97] Minimum volatility specifications were established by ASTM to address safety and vehicle driveability considerations.

Table 1.6-11.
Estimated Number of Tank Trucks and Rail Cars Needed for Shipment of Butane

	Number of Tank Trucks and Rail Cars Needed to Transport Butane		
	Low Case	Medium Case	High Case
Tank Truck (8,200 gallons)	2,165	3,280	5,530
Railcar (31,500 gallons)	236	358	602

Instead of lowering the minimum ethanol concentration of E85, some stakeholders are discussing establishing a new high-ethanol blend for use in flex-fuel vehicles. Such a fuel would have a minimum ethanol concentration that would be sufficient to allow minimum volatility specifications to be satisfied while using finished gasoline that is already available at petroleum terminals.[98] E85 would continue to be marketed in addition to this new fuel for use in flex-fuel vehicles when E85 minimum volatility considerations could be satisfied.

We believe that industry will resolve the concerns over the ability to meet the minimum volatility needed for high-ethanol blends used in flex-fuel vehicles in a manner that will not necessitate the use of high-vapor pressure blendstocks in their manufacture. Nevertheless, petroleum terminals may find it advantageous to blend butane into E85 because of the low cost of butane relative to gasoline provided that the cost benefit outweighs the associated butane distribution costs.[99]

1.6.9 Need for Additional E85 Retail Facilities

The number of additional E85 retail facilities needed to consume the volume of ethanol used under EISA varies substantially depending on the control case. As discussed in Section 1.7.1.2 of this RIA, we estimate that end-users would need to have reasonable access to E85 in 70% of the nation by 2022 under the high-ethanol scenario given our projections regarding the population of flexible fuel vehicles (FFVs) and E85 refueling frequencies.[437] Under the primary mid-ethanol scenario we estimate that reasonable access would be needed in 60% of the nation, and 40% under the low-ethanol scenario.

We define reasonable access as one in four gasoline retail facilities offering E85 in a fashion consistent with the way they currently offer gasoline. We selected one in four based on a review of the number of facilities that have been postulated to be needed to support the introduction of alternative fuels vehicles such as hydrogen and natural gas vehicles, the number of facilities that currently offer diesel fuel, and industry estimates regarding the number of E85 facilities that would be needed. One-in-five to one-in-three retail facilities has been discussed as a reasonable rule of thumb regarding the number of retail facilities needed to support the widespread introduction of alternative fuel vehicles.

[98] Such a new fuel might have a lower ethanol concentration of 60% and a maximum ethanol concentration of 85%.
[99] EPA may consider reevaluating its policies regarding the blendstocks used in the manufacture of E85 to facilitate this practice.

We estimate that approximately one in three fuel retail facilities (32%) offered diesel fuel in 1999 based on our review of fuel retailer survey data.[438] The National Association of Convenience Stores (NACS) reported that in 2006, 36.6% of the respondents to their survey offered diesel fuel.[439] We believe that given that NACS members typically do not include truck stop operators (who all offer diesel fuel) that that it is most likely that the number of diesel fuel retailers has increased since 1999. Since fuel retailers make most of their money from in-store sales as opposed to fuel sales, it seems likely that more retailers recognized an opportunity to attract additional customers by offering diesel fuel since 1999. In any event, the number of diesel fuel refueling facilities available in 1999 or 2006 has not hindered the use of diesel fuel vehicles. Unlike diesel fuel vehicles that can refuel only on diesel fuel or alternative fuel vehicles that can only be fueled on the alternative fuel, flex fuel vehicles can refuel on gasoline as well as E85. Thus, we believe that fewer E85 stations should be necessary than were provided for diesel fuel.[100]

At the same many time fleet operators were divesting of their in-house fueling facilities because of new environmental regulations, most retailers were installing equipment to blend mid-grade gasoline at the pump rather than store a separate mid-grade gasoline. This allowed for a significant number of retailers to begin offering diesel fuel at relatively low capital cost by converting storage tanks that had been dedicated to mid-grade gasoline storage to diesel fuel service. A number of retail facilities (40% of the total that installed diesel fuel tanks had low annual diesel throughput volumes of less than 60,000 gallons per year in 2000.[440] Only 5% of total diesel retail sales are estimated to be sold at these low-volume retailers. Given that the installation of some diesel retail facilities was not strictly driven on the expectation or realization of substantial throughput, it seems reasonable to assume that some fraction of low-volume retailers may not be absolutely necessary to ensure adequate diesel availability. Therefore, somewhat less than 32% of retail facilities might actually be needed to ensure adequate diesel fuel availability. We believe that this comparison to the number of diesel fuel retail facilities available supports our estimate that one in four retail facilities would be sufficient to provide reasonable access to E85.

The National Petroleum News (NPN) estimates that there were a total of 161,768 gasoline retail facilities in the United States in 2008.[441] We multiplied the one-in-four reasonable access assumption by the percentage of the retail market that would need to have reasonable access to E85 and the total number of retail facilities to arrive at our estimate of the number of E85 retail facilities needed under a given RFS2 control scenario. Under the high-ethanol scenario, we estimate that a total of 28,309 E85 refueling facilities would be needed. Under the primary mid-ethanol scenario, we estimate that 24,265 facilities would be needed, and that 16,177 facilities would be needed under the low-ethanol scenario.

In order to provide for sufficient E85 throughput while maintaining timely access of customers to an E85 dispenser, we estimated that all E85 retail facilities would have 3 E85 dispensers under the high-ethanol scenario.[101] Under the primary mid-ethanol scenario, we estimate that half of E85 retail facilities would have a single dispenser and the other half would

[100] Particularly since we do not assume that flex-fuel vehicles would refuel on E85 all the time. A discussion of E85 refueling rates is contained in Section 1.7.1.2.4 of this RIA.
[101] Each dispenser has two E85 refueling positions.

have 2 dispensers. Under the low-ethanol scenario, we estimate that all E85 retail facilities would have a single dispenser. These estimates are based on ensuring that E85 throughput per refueling position is consistent with historical data for gasoline throughput per refueling position. We believe that this approach provides an estimate consistent with ensuring that consumers have reasonable access to a E85 refueling position while providing the retailer with sufficient throughput to justify their investment in installing E85 refueling facilities.

The National Association of Convenience Stores (NACS) reports throughput per refueling position.[442] For all types of fuel dispensed, NACS reports that from 2001 through 2006, the annual throughput varied from approximately 142,000 to 164,000 gallons per refueling position. These data include reports on the sales of all fuels including premium, mid-grade, and regular gasoline, diesel fuel and other fuels. The most appropriate comparison would be made to throughput from refueling positions that dispense only regular gasoline since the use of E85 would primarily displace regular gasoline sales. However, this is not possible given that most gasoline is dispensed from blender pumps that can dispense any gasoline grade. Hence, we choose to make the comparison to throughput over dispensers that offer all gasoline grades, which may tend to underestimate the potential utilization rate of dispenser that dispenses only regular grade gasoline.

NACS reports that there is an average of 8.6 refueling positions at the retail facilities that responded to their survey. NACS reports that 36.6% of stores sold diesel fuel and 15.1% sold "other" fuels (i.e. not diesel, regular, mid-grade, or premium gasoline).[102] To estimate how many refueling positions are dedicated to diesel fuel and "other" fuels, we assumed that retailers offer diesel fuel from one pump with two nozzles, and other fuels from one pump with one nozzle. By multiplying the percentage of retailers that offer diesel fuel/other fuel by the assumed refueling positions for these fuels where they are present, we arrived at an estimate of 0.9 refueling positions per facility on average dedicated to diesel fuel and other fuel. This translates to an average of 7.7 refueling positions per facility that dispenses gasoline. NACS reports that 92.7% of fuel volumes sold by respondents to their survey is gasoline (of all grades). By dividing 92.7% of the total average throughput for all fuels per facility reported by NACS by 7.7 refueling positions, we arrived at an estimate of annual gasoline throughput per nozzle of 177,000 gallons for 2003.[103]

The National Ethanol Vehicle Coalition (NEVC) estimates there are currently 2,095 E85 refueling facilities.[443] However, the NEVC estimate includes E85 refueling facilities that are not open to the general public. "NEAR85" estimates that there are currently 1,293 E85 retail facilities.[444] The Near85 estimate includes only retail facilities. Based on these data, we are assuming that there are approximately 1,300 E85 retail facilities currently in service. By increasing the number of E85 retail facilities by the same proportion as the growth in ethanol use under the AEO reference from now until 2022, we estimate that 4,500 E85 refueling facilities would be in place by 2022 absent the RFS2 standards. We estimate that there would be 1,210 E85 refueling facilities under the RFS1 reference case. We arrived at this estimate by a review of historical data regarding the number of E85 retail facilities that were in place when ethanol use levels matched those under the RFS1 reference case. We assume that all E85 retail facilities

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[102] In many cases, we expect that the "other" fuel is kerosene.
[103] The year 2003 had the highest average throughput per refueling position over the years 2001- 2006.

under the REFS1 and AEO reference cases would have a single E85 dispenser (with 2 refueling positions).

To estimate the E85 refueling facility changes which that may be needed to reach the RFS2 volumes, we compared the changes needed to support the use of the total volume of E85 projected to be used under the 3 control scenarios to the E85 refueling facilities needed under the 2 reference cases. Our estimates of the of the E85 facility changes that will take place to reach the RFS2 volumes are contained in Tables 1.6-12 and 1.6-13

Table 1.6-12.
Additional E85 Retail Facilities Needed by 2022 to Reach the RFS2 Volumes Relative to the RFS1 Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
New E85 Installation with 1 Dispenser	15,000	10,900	0
New E85 Installation with 2 Dispensers	0	12,100	0
New E85 Installation with 3 Dispensers	0	0	27,100
Addition of 2 Dispensers to Retail Facility that had 1 Dispenser	0	0	1,200

Table 1.6-13.
Additional E85 Retail Facilities Needed by 2022 to Reach the RFS2 Volumes Relative to the AEO Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
New E85 Installation with 1 Dispenser	11,700	7,600	0
New E85 Installation with 2 Dispensers	0	12,100	0
New E85 Installation with 3 Dispensers	0	0	23,800
Addition of 2 Dispensers to Retail Facility that had 1 Dispenser	0	0	4,500

On average, approximately 1,520 additional E85 facilities will be needed each year from 2010 through 2022 under our primary scenario relative to the AEO reference case. Under the high and low-ethanol scenarios, an additional 1,820 and 900 E85 retail facilities per year would be needed respectively. Under the high-ethanol scenario, 4,500 facilities would also need to be upgraded to provide 3 E85 dispensers rather than a single dispenser. Under the high ethanol case and to a lesser extent under the primary case, this represents an aggressive timeline for the addition of new E85 facilities given that the small number of E85 retail facilities in service today. Nevertheless, we believe the addition of these numbers of new E85 facilities may be possible for the industries that manufacture and install E85 retail equipment. Underwriters Laboratories requires that E85 refueling dispenser systems must be certified as complete units.[104] To date, no complete E85 dispenser systems have been certified by UL. We understand that all

[104] See http://ulstandardsinfonet.ul.com/outscope/0087A.html

the fuel dispenser components with the exception of the hoses that connect to the refueling nozzle have successfully passed the necessary testing. There does not appear to be a technical difficulty in finding hoses that can pass the required testing. Therefore, we anticipate this situation will be resolved once the demand for new E85 facilities is demonstrated. Hence, we believe that the current lack of a UL certification for complete E85 dispenser systems will not impede the installation of the additional E85 facilities that we projected will be needed.

Petroleum retailers expressed concerns about their ability to bear the cost of installing the needed E85 refueling equipment given that most retailers are small businesses and have limited capital resources. They also expressed concern regarding their ability to discount the price of E85 relative to E10 sufficiently to persuade flexible fuel vehicle owners to choose E85 given the lower energy density of ethanol. Today's rule does not contain a requirement for retailers to carry E85. We understand that retailers will only install E85 facilities if they can be assured of sufficient E85 throughput to recover their capital costs and that this could become an issue. However, if obligated parties are going to comply with the RFS2 standards, they will have to find a way to get the appropriate incentives to retailers. In addition, the projections regarding the future cost of gasoline relative to ethanol indicate that as crude oil prices rise it may be possible to price E85 more profitably. While the $3 billion total cost for E85 refueling facilities is a substantial sum under our primary E85 facility scenario, it equates to 3 cents per gallon of E85 throughput.[105] We expect that larger fuel retailers would be most likely to install new E85 refueling facilities. Therefore, the smallest retailers would not need to install E85 facilities. Government incentives are also available to help defer the cost of installing E85 retail equipment and expansions of these incentives are under consideration.[106] Given the projections regarding ethanol pricing relative to gasoline and other factors that may tend to encourage ethanol consumption, we believe that it may be possible for retailers to price E85 in such a way as to facilitate the sale of the E85 volumes that we estimate would be used to facilitate meeting the RFS2 volumes.[107]

1.6.10 Fuel Distribution Accommodations to Support the Introduction of E15 Should a Waiver be Granted

We evaluated the changes to the fuel distribution system that might be needed to support the introduction of E15 if a waiver is granted by EPA in order to provide the basis for a preliminary cost analysis regarding such changes. Our nation's system of gasoline fuel regulation, fuel production, fuel distribution, and fuel use is built around gasoline with ethanol concentrations limited to E10. As a result, while a waiver may legalize the use of mid-level ethanol blends under the CAA, there are a number of other actions that would have to occur to bring mid-level blends to retail. This discussion focuses on the changes which may impact the costs associated with the introduction of E15. A number of changes/accommodations would also be needed to federal, state, and local regulations.

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[105] Our estimates of the cost of the E85 retail facilities that would be needed to support the use of the volume of ethanol that we project would be used under the RFS2 standards is contained in Section 4.2 of this RIA. E85 retail costs were amortized over 15 years at a 7% cost of capital.

[106] See Section 1.7.1.2.3 of this RIA for a discussion of government incentives to install E85 retail refueling equipment.

[107] This issue is discussed in Section 1.7.1.2.5 of this RIA.

The CAA provides a 1 pound RVP waiver for ethanol blends of 10 volume percent or less. This waiver was granted at a time when ethanol use was not widespread. Thus, the environmental considerations at the time were relatively minor. Now that the nation is moving to E10 nationwide, the 1 psi waiver may have significant environmental implications for all conventional gasoline. Lacking a similar RVP waiver, a special low-RVP gasoline blendstock would be needed at terminals to allow the formulation of mid-level ethanol blends that are compliant with EPA RVP requirements. Providing such a separate gasoline blendstock would present significant logistical challenges and costs to the fuel distribution system. It should be possible for refiners to formulate a gasoline blendstock that would be suitable for manufacturing both mid-level ethanol blends and E10 at the terminal. While this would avoid the logistical problems associated with maintaining separate blendstocks, there could be additional refining costs.

Assuming that refiners develop a common gasoline blendstock for both E10 and E15, the accommodations that would be needed to the fuel distribution infrastructure to facilitate the introduction of a mid-level ethanol blend would primarily be limited to vehicle refueling facilities. Some terminal operators may need to modify their ethanol blending facilities to allow the in line blending of a mid-level ethanol blend. However, in most if not all cases this would only involve a modification to the software for the blending system to allow a mid-level as well as an E10 or E0 blend rate rather than necessitating a physical change to the system. Terminal operators would also need to provide for the receipt and storage of the greater volumes of ethanol needed to manufacture a mid-level ethanol blend.[108]

Fuel retailers would need to ensure that the equipment used to store and dispense E15 is suitable for this purpose. EPA's Office of Underground Storage Tanks (OUST) requires that underground storage tank (UST) systems must be compatible with the substance stored in the system. A number of authorities require that fuel retailers use equipment that has been certified as compatible with the fuel being sold. Such a certification is required by the Occupational Safety and Health Administration (OSHA), many local fire marshals, tank insurance and state tank fund policies, and the provisions contained in many business loan agreements.

Underwriters Laboratories (UL) is the leading safety certification organization and is often specifically referenced in regulations and insurance policies. UL stated that they have data which indicates that the use of fuel dispensers certified for up to E10 blends could dispense blends up to a maximum ethanol content of 15 volume percent without causing critical safety concerns.[109] Based on these data, UL stated that it would support a decision by Authorities who Have Jurisdiction (AHJs, e.g. state and local fire marshals) to permit equipment originally certified for up to E10 blends to be used to dispense up to 15 volume percent ethanol.[110] However, UL stated that it could not recertify equipment that was originally certified for up to

[108] The need for additional facilities to receive, store, and blend ethanol is anticipated in any event due to the projected need for expanded use of E85 to meet the renewable fuel volume requirements under EISA.
[109] The UL announcement can be found at http://www.ul.com/newsroom/newsrel/nr021909.html
[110] The reference of up to 15 volume percent ethanol by UL does not equate to E15. Variability in the test method for ethanol content and other factors mean that in-use fuel blends with a nominal ethanol content of 15 % could at times exceed 15 volume percent.

E10 blends for a higher ethanol blend.[111] Furthermore, the UL announcement did not address underground storage systems (storage tank, piping, valves, pumps, fittings, leak detection, etc.).

Evaluations are currently underway by EPA's Office of Underground Storage Tanks (OUST) in coordination with the Department of Energy (DOE) and UL regarding the compatibility of existing UST systems to store mid-level ethanol blends. Based on this evaluation, OUST could prepare guidance to states on how facilities with UST systems that store a mid-level ethanol blend could demonstrate compliance with the EPA requirement that such systems are compatible with the substance stored in the system.[112] The Department of Energy in coordination with UL is conducting testing to evaluate the suitability of existing retail fuel dispensing equipment to accommodate a mid-level ethanol blend.[113] Depending on the results of the OUST and DOE/UL efforts, the authorities referenced above may be encouraged to allow the use of certain existing equipment originally certified for E10 to handle a mid-level ethanol blend. One potential approach in lieu of requiring a UL certification might be for AHJs to require that fuel retailers have records to establish what type of equipment is present and to obtain manufacture certifications that the equipment is suitable for a mid-level ethanol blend.

Documenting the manufacturer and model number of the various components of their fuel storage and dispensing equipment may be a relatively simple undertaking for newer stations that have records readily on hand. However, for older stations that may have had multiple owners, it may be difficult to assemble a full list of their fuel handling components. For above ground components (i.e. the dispenser), a potential gap in the records could be resolved by a visual inspection. However, with respect to underground components there may no be practical way to identify certain components without breaking concrete. The most difficulty is likely to be faced in identifying the type of seals, gaskets, pipe joints, and bonding materials used by the contractors who installed the equipment.[114] Many UST installation companies and components manufactures may have gone out of business, further complicating the process of identifying what hardware is installed and obtaining a manufacture certification of compatibility. This may tend to limit the ability to introduce a mid-level ethanol blend to newer fuel retailers and larger chain retailers who may have more complete records. However, such retailers are also likely to have a relatively high fuel sales compared to the fuel retailer population as a whole. Thus, the ability to introduce a mid-level ethanol blend at such retailers could potentially support the sale of a substantial volume of such a fuel.

If a partial waiver is granted which provides for the use of a mid-level ethanol blend in a subset of vehicles, then E10 would need to continue to be made available for use in vehicles/equipment not covered by the waiver.[115] We believe that this might be most practicably

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[111] UL announced a separate retail dispenser certification pathway for ethanol blends up to E25 in August of 2009 (http://www.ul.com/global/eng/pages/corporate/newsroom/newsitem.jsp?n=ul-announces-new-certification-path-for-ethanol-fuel_20090810122400). This is addition to the UL certification pathways to cover up to E10 blends and to cover E85 and lesser ethanol blends.

[112] The EPA OUST requirement is located at 40 CFR Part 280.32. Enforcement of this requirement is typically delegated to the State level.

[113] This is the above ground equipment commonly referred to as the fuel pump stand or fuel dispenser.

[114] These are the UST components where there may be the most concern regarding compatibility with a mid-level ethanol blend.

[115] E0 will also be needed for use in gasoline piston engine aircraft.

accomplished by switching some or all dispensers of regular gasoline at a retail facility to handle the mid-level ethanol blend.[116] The premium dispenser could continue to handle E10 (or E0) for use in legacy vehicles/equipment.[117] Some of the nonroad equipment currently requires the use of a premium grade fuel. Thus, premium gasoline would continue to be the "universal fuel" as it is today, capable of being used in any gasoline vehicle or equipment. Some retailers who have multiple regular grade storage tanks may choose to offer both an E15 and E10 regular grade in order to offer a less expensive E10 fuel to customers that do not require the use of premium but are not covered by a partial waiver. In most cases this would likely involve breaking concrete to separate tanks that are currently interconnected.

If the OUST and DOE evaluations show that current retail fuel equipment is largely compatible with a mid-level ethanol blend, it may be possible for a substantial number of retail facilities to introduce a mid-level ethanol blend at a modest cost. If some components of the above ground existing retail hardware are found to be incompatible with a mid-level ethanol blend, it may be possible for them to be replaced through normal attrition. For example the "hanging hardware" which includes the nozzle and hose from the dispenser is typically replaced every 3 to 5 years. If more extensive modifications are shown to be necessary, the costs could approach those necessary to introduce E85. If this is the case, the costs would tend to inhibit the rapid introduction of a mid-level ethanol blend. The potential costs to the fuel distribution system associated with the introduction of E15 are discussed in Section 4.2.1.1.

1.7 Ethanol Consumption Feasibility

1.7.1 Background

Over the past decade, ethanol use has grown rapidly due to oxygenated fuel requirements, MTBE bans, tax incentives, state mandates, the first federal renewable fuels standard ("RFS1"), and rising crude oil prices. Although the cost of crude has come down since reaching record levels in 2008, uncertainty surrounding pricing and the environmental implications of fossil fuels has continued to drive ethanol use.

As shown in Table 1.7-1, a record 9.5 billion gallons of ethanol were blended into U.S. gasoline in 2008 and EIA is forecasting additional growth in the years to come. According to their recently released Short-Term Energy Outlook (STEO), EIA is forecasting 0.7 million barrels of daily ethanol use in 2009, which equates to 10.7 billion gallons. The October 2009 STEO projects that total ethanol usage (domestic production plus imports) will reach 12.1 billion gallons by 2010.[445]

[116] Commenters stated that this arrangement could encourage misfueling if the "premium grade" E10 was substantially more costly than the "regular grade" E15.

[117] The state of Oregon recently amended its requirement that all gasoline contain 10 percent ethanol to allow premium grade gasoline which does not contain ethanol to be sold for use in specified equipment/vehicles which may not be ethanol tolerant (including gasoline piston engine aircraft) http://www.leg.state.or.us/09reg/measures/hb3400.dir/hb3497.en.html

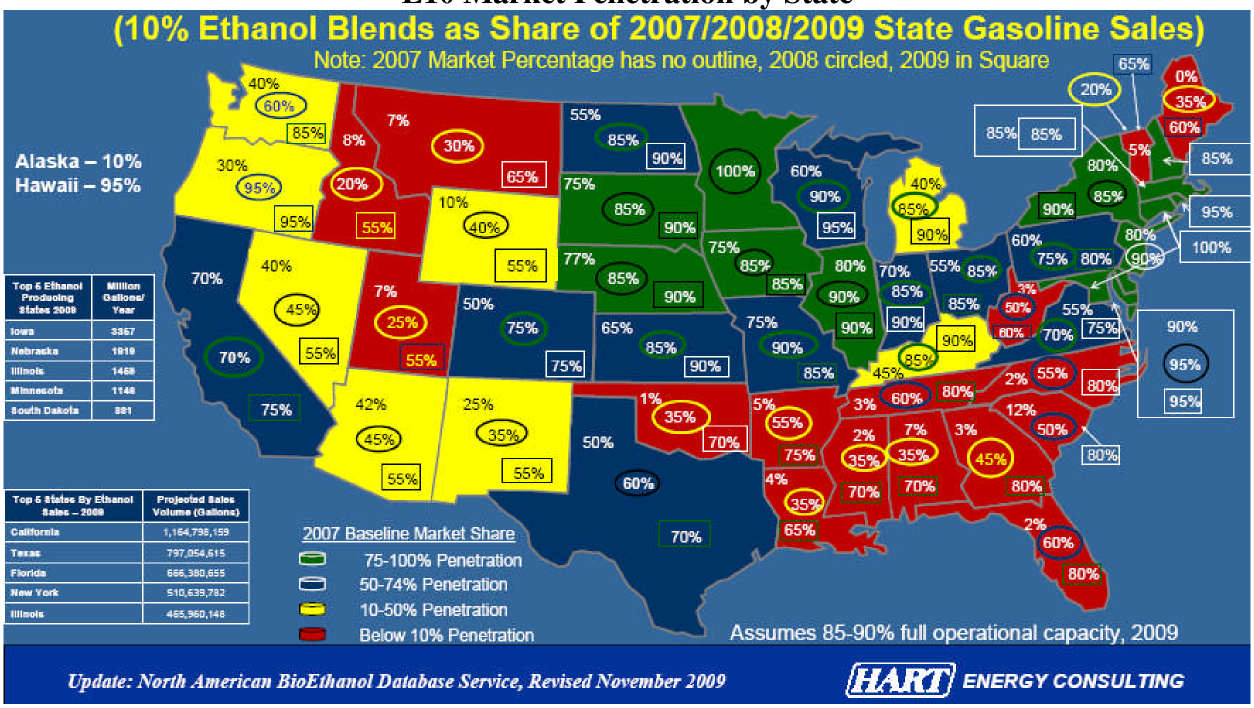
Table 1.7-1.
U.S. Ethanol Consumption

	Ethanol Usage (Bgal)		
Year	**Production**	**Net Imports**[b]	**Total**[a]
1999	1.4	0.0	**1.4**
2000	1.6	0.0	**1.6**
2001	1.7	0.0	**1.7**
2002	2.0	0.0	**2.0**
2003	2.7	0.0	**2.8**
2004	3.3	0.1	**3.5**
2005	3.8	0.1	**4.0**
2006	4.6	0.7	**5.3**
2007	6.3	0.4	**6.7**
2008	9.0	0.5	**9.5**

[a]EIA Monthly Energy Review September 2009 (Table 10.2)
bEIA website (http://tonto.eia.doe.gov/dnav/pet/hist/mfeimus1a.htm)

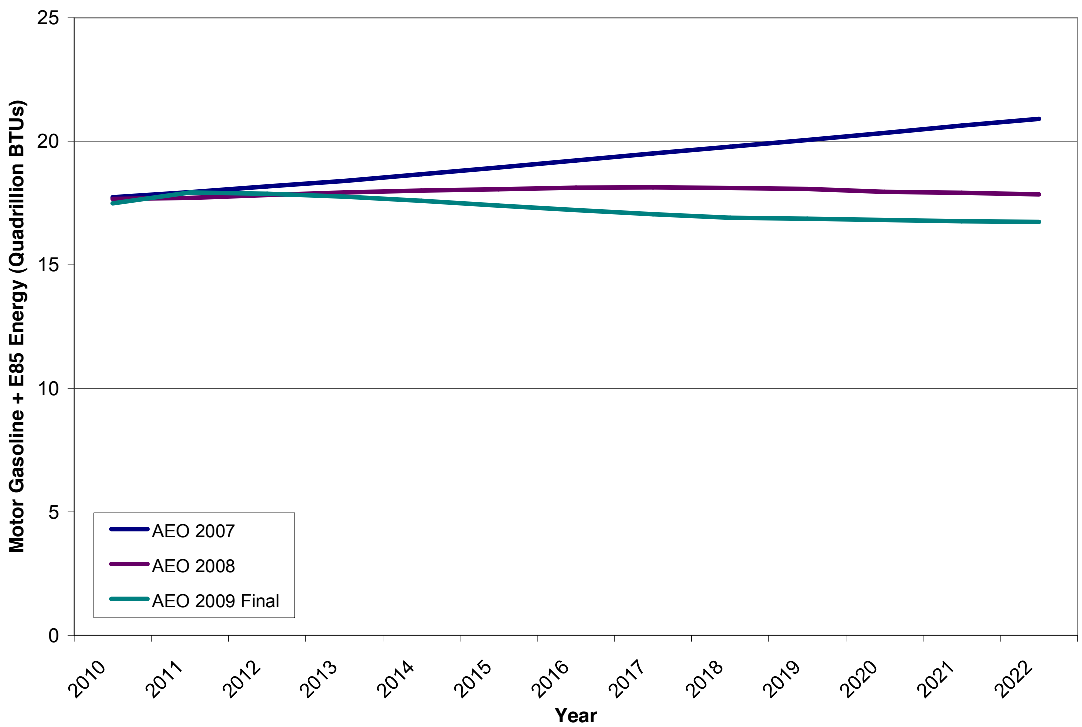
The National Petrochemical and Refiners Association (NPRA) estimates that ethanol is currently blended into about 75 percent of all gasoline sold in the United States.[446] The vast majority is blended as E10 or 10 volume percent ethanol, although a small amount is blended as E85 for use in flexible fuel vehicles (FFVs). California, the largest U.S. consumer of gasoline is yet to reach 100% E10 saturation. Historically, the state has only blended ethanol into gasoline at 5.7 vol%, limited by its Predictive Model blending constraints. However, California has since adjusted its model and effective January 1, 2010, ethanol blending is expected to increase to 10%.[118] A publication by Hart Energy Consulting estimating ethanol penetration by state is provided in Figure 1.7-1.[447]

Figure 1.7-1.
E10 Market Penetration by State



Complete saturation of the gasoline market with E10 is referred to as the ethanol "blend wall." The height of the blend wall in any given year is directly related to gasoline demand. In AEO 2009, EIA projects that gasoline energy demand will peak around 2013 and then start to taper off due to vehicle fuel economy improvements. As shown below in Figure 1.7-2, not only is EIA forecasting a flattening of gasoline energy demand in the future due to vehicle improvements, AEO 2009 also shows an additional decline due to the recent economic downturn. This is a considerably different projection of the future than EIA made in their prior forecasts. Although we have presented AEO 2008 and AEO 2007 for illustrative purposes, the final release of AEO 2009 (April 2009 – ARRA Update) is the basis for all energy and ethanol consumption calculations utilized in this analysis.

Figure 1.7-2.
Projected Gasoline Energy Demand[448]



Based on the gasoline demand projections in AEO 2009, the maximum amount of ethanol that can be blended into gasoline as E10 will be around 14-15 billion gallons, depending on the year (refer ahead to Figure 1.7-3). There are many challenges associated with getting beyond the ethanol blend wall and consuming more than 14-15 billion gallons including rapid growth in FFV/E85 infrastructure, problems with meeting ASTM specs, testing and potential approval of mid-level blends, etc. As such, as discussed in Sections 1.4.3 and 1.5.3, a growing number of companies are investigating non-ethanol biofuels (e.g., cellulose-based diesel, gasoline, etc.) as a mechanism for meeting the cellulosic biofuel standard. The benefit of synthetic hydrocarbon fuels is that there is virtually no blend wall issue, they are fungible with existing fuel infrastructure and they can be priced at parity with petroleum at retail. In many ways, they are essentially drop-in replacements for gasoline and diesel. However, like all second-generation biofuels, there are technological and financial hurdles that need to be overcome before biomass-based synthetic hydrocarbon fuels can be brought to market.

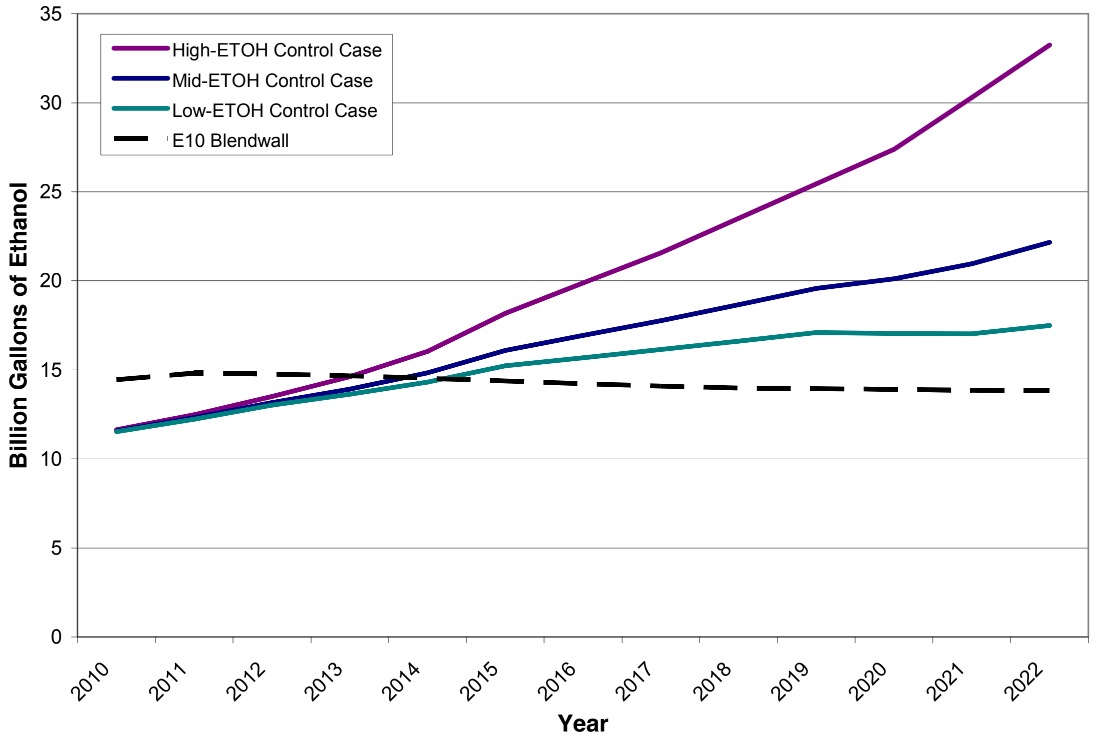
These factors make it difficult to project the mix of renewable fuels types that will be used in the future to meet the RFS2 standards. To address the uncertainty of which fuels will be used, we have analyzed three control cases with varying levels of ethanol as part of this final rule. As shown below in Table 1.7.2, total ethanol usage (corn, imported and cellulosic) could range from 17.5 to 33.2 billion gallons in 2022.

Table 1.7-2.
Potential Ethanol Usage Scenarios Under RFS2

Scenario	2022 Total Ethanol Use
RFS1 Reference Case	7.1
AEO 2007 Reference Case	13.2
Low-ETOH Control Case	17.5
Mid-ETOH Control Case (Primary)	**22.2**
High-ETOH Control Case	33.2

Under the primary control case, ethanol consumption will need to be about three times higher than RFS1 levels, more than twice as much as today's levels, and 9 billion gallons higher than the ethanol consumption predicted to occur in 2022 absent RFS2 (according to AEO 2007). A summary of the projected ramp up in ethanol usage in each of these three cases compared to the blend wall is provided in Figure 1.7-3. For more information on how the control case volumes were derived, refer to Section 1.2 of the RIA.

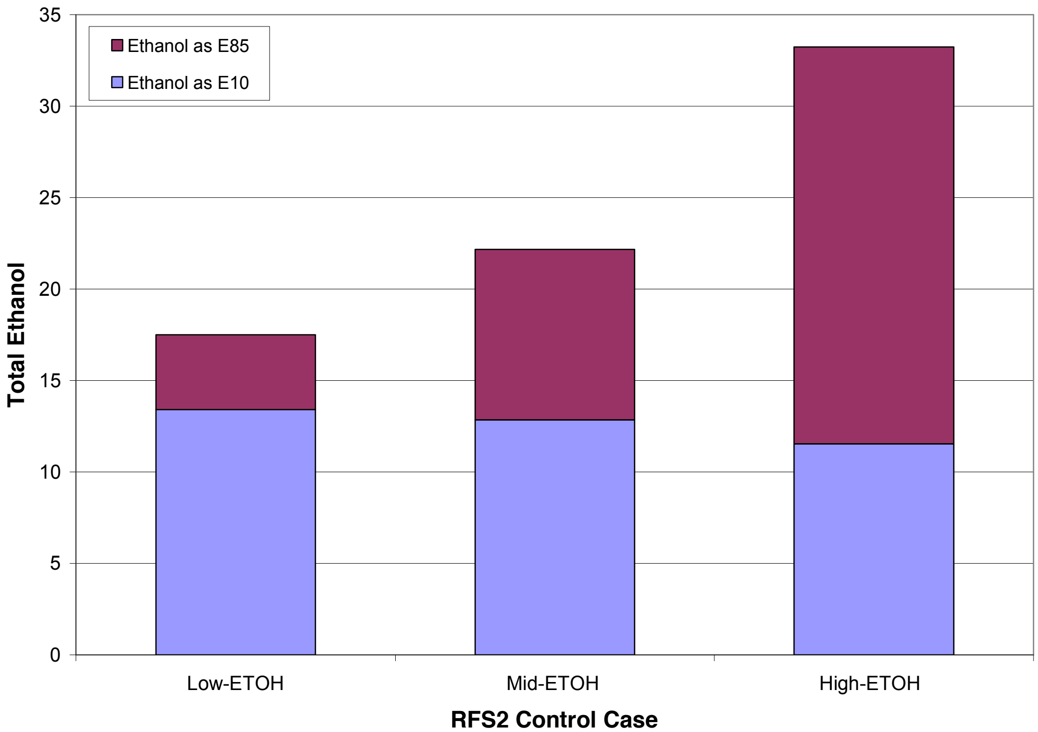
Figure 1.7-3.
Projected Increase in Ethanol Under RFS2



As shown above in Table 1.7-2, all three ethanol usage scenarios modeled require the nation to get beyond the E10 blend wall. As expected, the more aggressive the ethanol usage, the sooner the nation will hit the blend wall. As shown above, the nation is expected to hit the blend wall in 2013 under our high-ethanol control case, in 2014 under our primary mid-ethanol control case and closer to 2015 under our low-ethanol control case. Regardless, to meet today's RFS2 requirements using increased volumes of ethanol we are going to need to see growth in FFV and E85 infrastructure and increases in FFV E85 refueling rates (consideration of mid-level blends is discussed below in Section 1.7.6 below). However, the amount of change needed is proportional to the amount of ethanol we rely on versus other renewable fuels. As expected, the low-ethanol case would require only moderate changes in FFV/E85 infrastructure and refueling whereas the high-ethanol case would require very dramatic changes and likely a mandate.

Once the nation gets past the blend wall, more ethanol will need to be blended as E85 and less as E10. FFV owners who were formerly refueling on E10 will need to start filling up on E85. As shown in Figure 1.7-4, under our primary mid-ethanol control case, we project that 12.9 billion gallons of ethanol would be blended as E10 and 9.3 billion gallons would be blended as E85 to reach the 22.2 billion gallons in 2022.

Figure 1.7-4.
Ethanol by Blend in 2022



In the subsections that follow, we will present the FFV and E85 infrastructure assumptions made for the final regulatory impact analysis and the corresponding FFV E85 refueling rates that would be required to reach the ethanol volumes described above. We will also discuss some of the retail and other changes that might be needed to encourage E85 usage.

It is possible that conventional gasoline (E0) could co-exist with E10 and E85 for some time. However, for analysis purposes, we have assumed that E10 would replace E0 as expeditiously as possible and that all subsequent ethanol growth would come from E85. Furthermore, we assumed that no ethanol consumption would come from the mid-level ethanol blends (E15 or E20) since they are not currently approved for use in non-FFVs. However, in light of the Growth Energy waiver request[449], we discuss how approval of E15 for use in conventional vehicles could help the nation postpone the blend wall in Section 1.7.6.

1.7.2 Projected Growth in Flexible Fuel Vehicles

Over the years there have been several policy attempts to increase FFV sales including Corporate Average Fuel Economy (CAFE) credits[119] and government fleet alternative-fuel

[119] Under the CAFE program, the production of FFVs provides credits toward meeting the required standards. However, the EPCA incrementally phases out these credits through MY 2019, after which they are no longer available to help demonstrate CAFE compliance. EPA recently proposed similar FFV credits as part of their Rulemaking to Establish Light-Duty Vehicle GHG Emission Standards and Corporate Average Fuel Economy

vehicle requirements. As a result, there are an estimated 8 million FFVs on the road today, up from just over 7 million in 2008.[120,450] While this is not insignificant in terms of growth, FFVs continue to make up less than 4 percent of the total gasoline vehicle fleet.

According to EPA certification data, over one million FFVs were sold in both 2008 and 2009. Despite the recession and current state of the auto industry, automakers are incorporating more and more FFVs into their light-duty production plans. While the FFV system (i.e., fuel tank, sensor, delivery system, etc.) used to be an option on some vehicles, most are moving in the direction of converting entire product lines over to E85-capable systems. Still, the number of FFVs that will be manufactured and purchased in future years is uncertain.

To measure the impacts of increased volumes of renewable fuel, we considered three different FFV production scenarios that might correspond to the three biofuel control cases analyzed for the final rule. For all three cases, we assumed that total light-duty vehicle sales would follow AEO 2009 trends. The latest EIA report suggests lower than average sales in 2008-2013 (less than 16 million vehicles per year) before rebounding and growing to over 17 million vehicles by 2019 as shown below in Figure 1.7-5.[451] These vehicle projections are consistent with EPA's recently proposed Light-Duty Vehicle GHG Rule.[452]

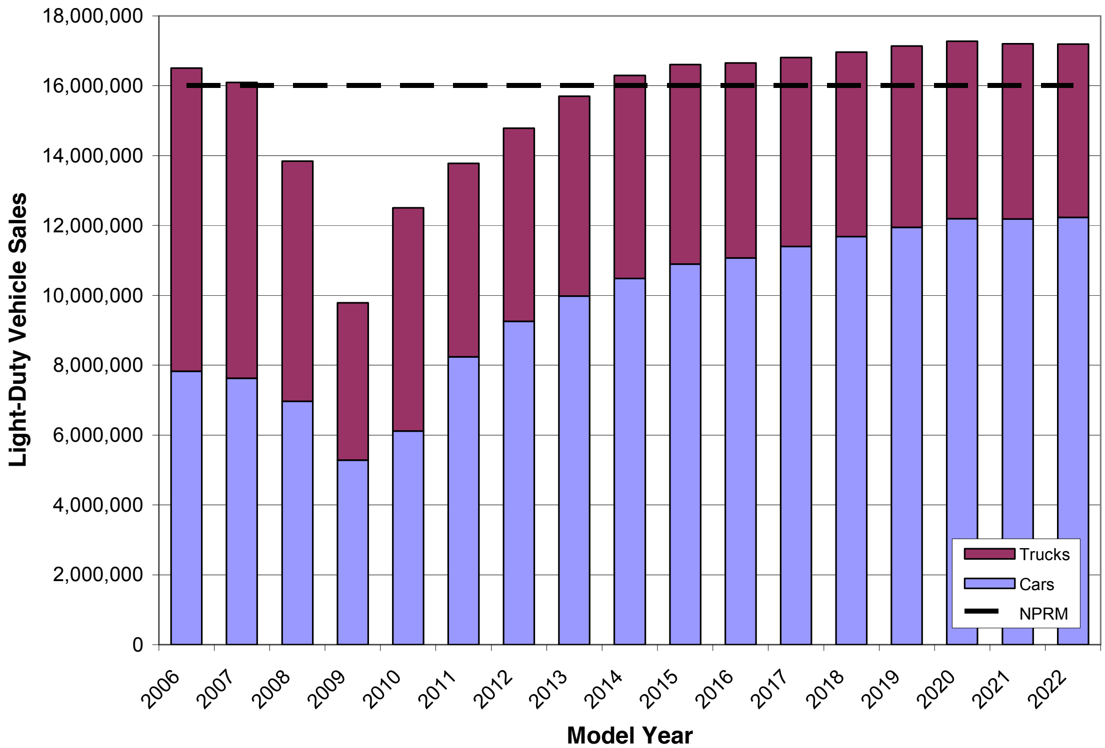
We also applied the AEO 2009 projected car/truck sales split adjusted for NHTSA's new car definition beginning in 2011.[121] Accordingly, by 2022, cars are expected to comprise over 70% of new light-duty vehicle sales. With respect to in-use vehicle stock, we relied on historical car/truck sales reported by DOE's Energy Efficiency and Renewable Energy (EERE) combined with vehicle survival rates taken from the proposed Light-Duty Vehicle GHG Rule.[453,454]

Standards (74 FR 49454 September 28, 2009). Under the proposed program, FFV credits would remain available for 2016 and later model years, but the credits would be based on demonstrated E85 usage.

[120] FFV sales based on DOE's Energy Efficiency and Renewable Energy (EERE) for 1998-2005 and EPA's vehicle certification data for 2006-2008. In-use FFV estimates based on vehicle survival rates taken from EPA's proposed Light-Duty Vehicle GHG Rule.

[121] According to NHTSA's Final Rule on 2011 MY Vehicles (74 FR 14196 March 30, 2009), starting in MY 2011, 2WD versions of SUVs are no longer classified as off-highway capable light trucks under 49 CFR § 523.5(b), simply because the SUV also comes in a 4WD version. Based on an estimate used in EPA's Proposed Light-Duty Vehicle GHG Rule, approximately 22% of the forecasted AEO 2009 light-duty truck sales are cars based on the new NHTSA definition.

Figure 1.7-5.
Assumed Light Duty Vehicle Production



Although we assumed that total vehicle and car/truck sales would be the same in all three cases, we assumed varying levels of FFV production. For our low-ethanol control case, we assumed steady FFV growth according to AEO 2009 predictions.[455] For our primary mid-ethanol control case, we assumed increased FFV sales under the presumption that GM, Ford and Chrysler (referred to hereafter as the "Detroit 3") would follow through with their commitment to produce 50% FFVs by 2012. Despite the current state of the economy and the hardships facing the auto industry, the Detroit 3 appear to still moving forward with their voluntary FFV commitment.[456] And finally, for our high-ethanol control case, we assumed a theoretical 80% FFV mandate based on the Open Fuel Standard Act of 2009 that was reintroduced in Congress on March 12, 2009.[457] Based on reduced vehicle sales and gasoline demand, we believe an FFV mandate would be the only viable means for consuming the 32.2 billion gallons of ethanol in 2022 required under the high-ethanol control case.

For the two reference cases, we assumed more modest, business-as-usual FFV sales. For the RFS1 reference case, we assumed that automakers would continue to make about 8% of all light-duty vehicles FFVs (current 2008 marketshare based on EPA certification data). For the AEO 2007 reference case, we assumed FFV growth according to EIA's AEO 2007.[458] The annual FFV sales assumptions for our three control cases and two reference cases are presented below in Table 1.7-3. More information on FFV cost and assumptions made with respect to our primary mid-ethanol control case is presented below.

We estimate that the cost to produce FFVs could be anywhere from $50 to $100 per vehicle, depending on the vehicle and how many FFV-capable systems the automaker is producing. Current estimates suggest that the per-FFV cost could easily be as high as $100.[122,459] However, in the event of a hypothetical mandate, automakers would likely find a more economical way to mass produce the necessary ethanol-compatible fuel tanks, sensors, etc. As such, we assigned higher per-vehicle FFV production costs in the low-ethanol control case and lower production costs in the high-ethanol case. For more on this rationale and the resulting FFV production costs, refer to Section 4.2 of the RIA.

Table 1.7-3.
Annual FFV Sales Assumptions

	Reference Cases		**Control Case FFV Production**		
	RFS1 Based on Today's Marketshare	**AEO 2007** Based on AEO 2007 Predictions	**Low-ETOH** Based on AEO 2009 Predictions	**Mid-ETOH** Based on 50% Domestic 3 Commitment	**High-ETOH** Based on OFS Mandate in Congress
2010	983,267	1,669,998	1,253,426	1,848,835	3,617,298
2011	1,083,940	1,746,847	1,598,610	2,661,252	5,439,471
2012	1,162,875	1,768,321	1,903,862	3,523,548	7,393,103
2013	1,234,554	1,795,684	2,251,284	3,740,737	9,418,573
2014	1,281,162	1,826,871	2,523,575	3,881,960	11,403,172
2015	1,306,173	1,817,706	2,693,557	3,957,744	13,286,614
2016	1,309,814	1,817,699	2,761,794	3,968,776	13,323,649
2017	1,321,421	1,826,073	2,804,322	4,003,948	13,441,727
2018	1,334,395	1,834,957	2,929,336	4,043,259	13,573,697
2019	1,348,016	1,855,352	2,825,574	4,084,529	13,712,247
2020	1,358,903	1,899,794	2,771,285	4,117,519	13,822,998
2021	1,352,943	1,913,799	2,669,883	4,099,459	13,762,369
2022	1,351,996	1,913,938	2,607,584	4,096,590	13,752,738

For our primary mid-ethanol control case, we assumed that the Detroit 3 would continue to comprise 45% of total light-duty vehicle sales – 2008 production levels less Hummer, Landrover, Jaguar, Saab, Saturn, and Volvo (brands that were recently or are in the process of being sold off). We assumed that domestic automakers would continue to dominate truck sales and car sales would gradually increase to allow the Detroit 3 to continue to maintain 45% marketshare in future years. With respect to FFV sales, we assumed that the Detroit 3 would follow through with their FFV commitment and increase FFV production from 16% of total sales in 2008 to 50% of total sales in 2012. With respect to vehicle type, we assumed that about two-thirds of the Detroit 3's FFV sales would be trucks – based on historical sales and 2009 MY offerings.

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[122] According to DOE and others, conventional gasoline engines need to be slightly modified (at an additional cost of about $100) to handle higher blends of ethanol.

We assumed that non-domestic automakers would continue to maintain 55% marketshare in 2009 and beyond (based on adjusted 2008 production levels). Although non-domestic automakers have not made any official FFV production commitments, Nissan, Toyota, Mercedes, Izuzu, and Mazda all included at least one flexible fuel vehicle in their 2009 model year offerings.[460] We do not currently anticipate that the non-domestic automakers will follow through with an FFV commitment. However, it seems reasonable that we could expect a small amount of FFV growth in the future. As such, for our primary mid-ethanol control case, we assumed that non-domestic FFV production would grow from 1% in 2008 to 2% in 2009 and future years based on current FFV offerings. With respect to FFV vehicle type, we assumed about equal car and truck FFV sales (52% and 48%, respectively) based on 2008 sales.

Under our primary mid-ethanol scenario, as shown in Table 1.7-3, Detroit 3 and non-domestic FFV sales amount to just over 4 million per year in 2017 and beyond. This is less aggressive than the assumptions made in the NPRM. At that time, we were expecting more cellulosic ethanol which could justify higher FFV production assumptions. We assumed that not only would the Detroit 3 fulfill their 50% by 2012 FFV production commitment, non-domestic automakers might follow suit and produce 25% FFV in 2017 and beyond. We also assumed that annual light-duty vehicle sales would continue around the historical 16 million vehicle mark resulting in 6 million FFVs in 2017 and beyond.

Based on our revised vehicle/FFV production assumptions coupled with vehicle survival rates, VMT and fuel economy estimates applied in the recently proposed Light-Duty Vehicle GHG Rule, we estimate that the maximum percentage of fuel (gasoline/ethanol mix) that could feasibly be consumed by FFVs in 2022 would be about 20% under our mid-ethanol control case. Under our low-ethanol control, the 2022 fuel fraction was estimated at 14%. And under the high-ethanol control case, with the FFV mandate, the fuel fraction was 56% in 2022. A summary of the FFV fuel fraction over time for each of these scenarios is presented in Figures 1.7-6 through 1.7-8.

Figure 1.7-6

Low-ETOH / Low-FFV Fuel Fraction

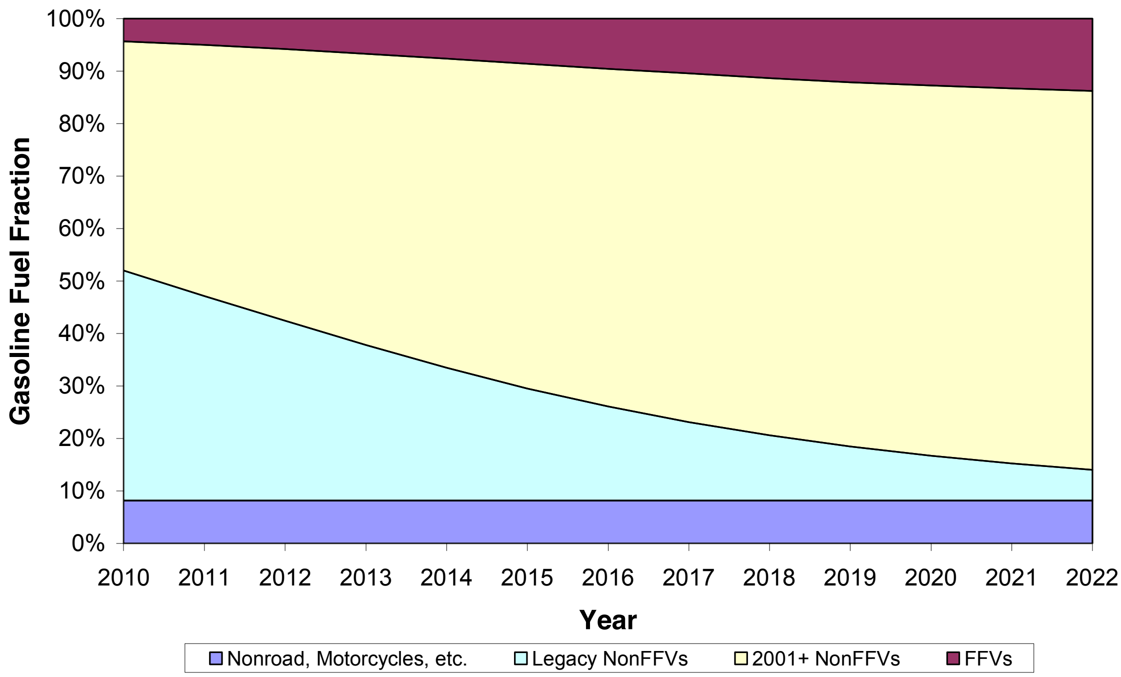


Figure 1.7-7

Mid-ETOH / Mid-FFV Fuel Fraction

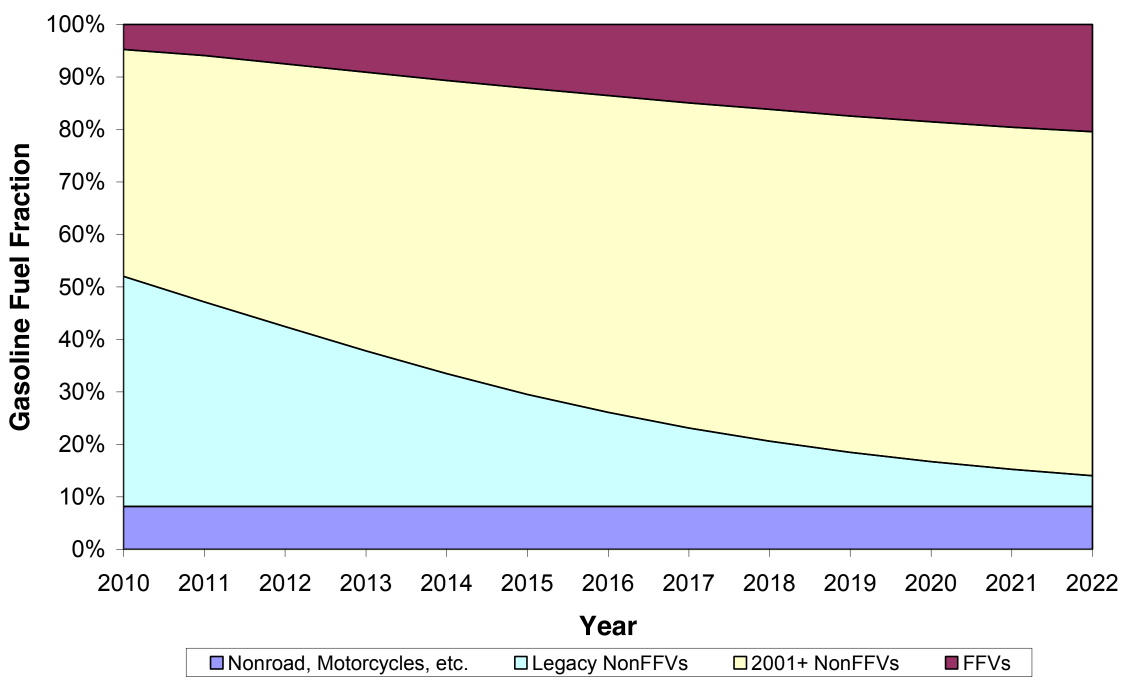
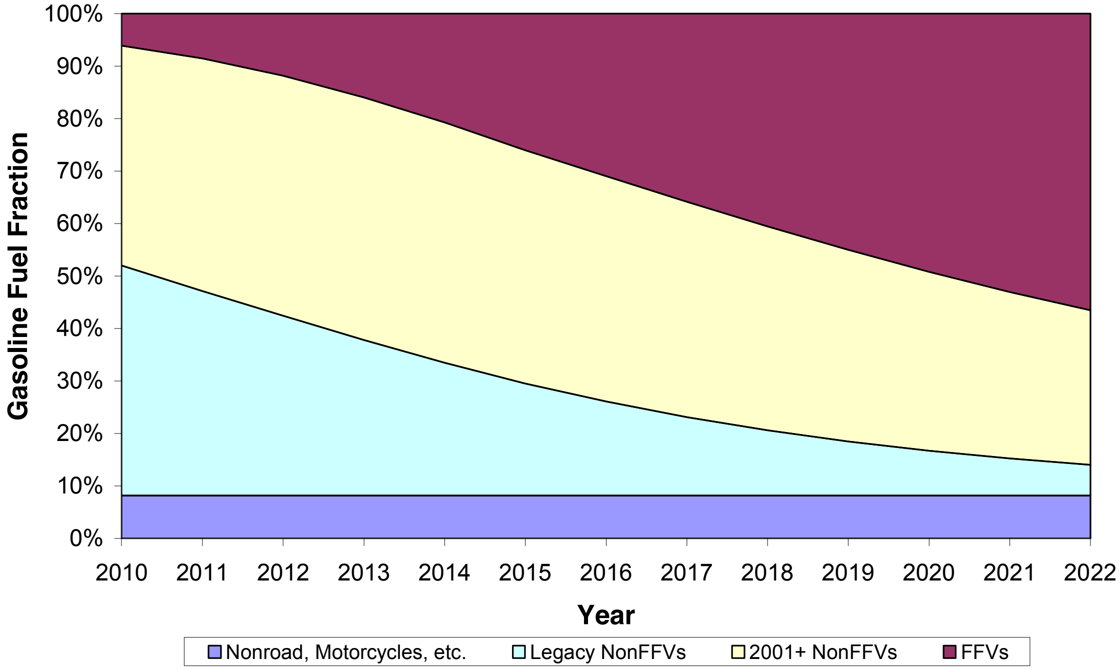


Figure 1.7-8

High-ETOH / High-FFV Fuel Fraction



As shown above, we split the non-FFV fuel fraction into multiple categories to help determine the number of engines/vehicles that might be capable of handling E15 in the event of a waiver. The basis for these assumptions and more information on the data sources is presented in Section 1.7.6.

1.7.3 Projected Growth in E85 Access

According to the National Ethanol Vehicle Coalition (NEVC), there are currently 2,100 gas stations offering E85 in 44 states plus the District of Columbia.[461] While this represents significant industry growth, it still only translates to 1.3% of U.S. retail stations nationwide carrying the fuel.[123] As a result, most FFV owners clearly do not have reasonable access to E85. For our FFV/E85 analysis, we have defined "reasonable access" as one-in-four pumps offering E85 in a given area.[124] Accordingly, just over 5% of the nation currently has reasonable access to E85, up from 4% in 2008 (based on a mid-year NEVC pump estimate).[125]

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[123] Based on National Petroleum News gasoline station estimate of 161,768 in 2008.

[124] For a more detailed discussion on how we derived our one-in-four reasonable access assumption, refer to Section 1.6 of the RIA. For the distribution cost implications as well as the cost impacts of assuming reasonable access is greater than one-in-four pumps, refer to Section 4.2 of the RIA.

[125] Computed as percent of stations with E85 (2,101/161,768 as of November 2009 or 1,733/161,768 as of August 2008) divided by 25% (one-in-four stations).

There are a number of states promoting E85 usage by offering FFV/E85 awareness programs and/or retail pump incentives. A growing number of states are also offering infrastructure grants to help expand E85 availability. Currently, 10 Midwest states have adopted a progressive Energy Security and Climate Stewardship Platform.[126,462] The platform includes a Regional Biofuels Promotion Plan with a goal of making E85 available at one third of all stations by 2025. In addition, the American Recovery and Reinvestment Act of 2009 (ARRA or Recovery Act) recently increased the existing federal income tax credit from $30,000 or 30% of the total cost of improvements to $100,000 or 50% of the total cost of needed alternative fuel equipment and dispensing improvements.[463]

Given the growing number of subsidies, it is clear that E85 infrastructure will continue to expand in the future. However, like FFVs, we expect that E85 station growth will be somewhat proportional to the amount of ethanol realized under the RFS2 program. As such, we analyzed three different E85 growth scenarios for the final rule that could correspond to the three different RFS2 control cases. As an upper bound for our high-ethanol control case, we maintained the 70% access assumption we applied for the NPRM. This translates to about 1:6 stations nationwide.

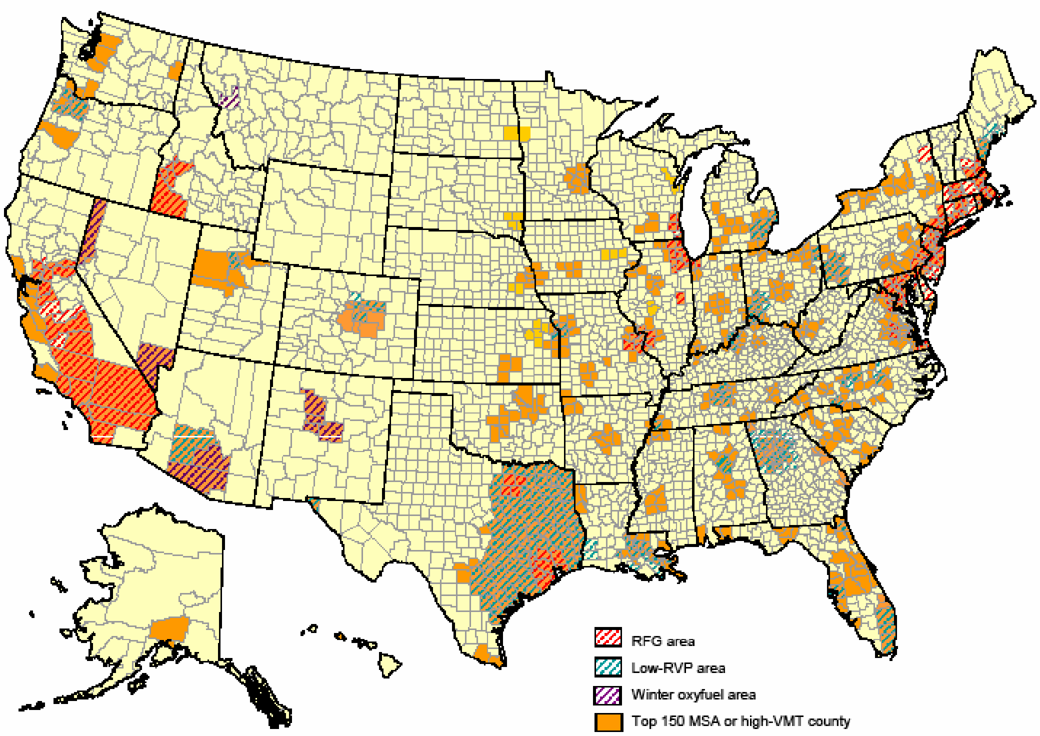
[126] The following states have adopted the plan: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Ohio, South Dakota and Wisconsin.

As explained in the NPRM, one way to provide 70% of the nation with reasonable 1-in-4 access would be to make it available in urban areas. For analysis purposes, we defined "urban" areas as:

- The top 150 metropolitan statistical areas according to the U.S. Census Bureau and/or counties with the highest 150 VMT projections according the EPA MOVES model.
- Federal RFG areas
- Winter oxy-fuel areas
- Summertime low-RVP areas
- Other relatively populated cities in the Midwest. Cities with populations greater than 100,000 people in states with a potential ethanol surplus in 2022.

For an illustration of the urban areas representing about 70% of the nation's VMT, refer to Figure 1.7-9

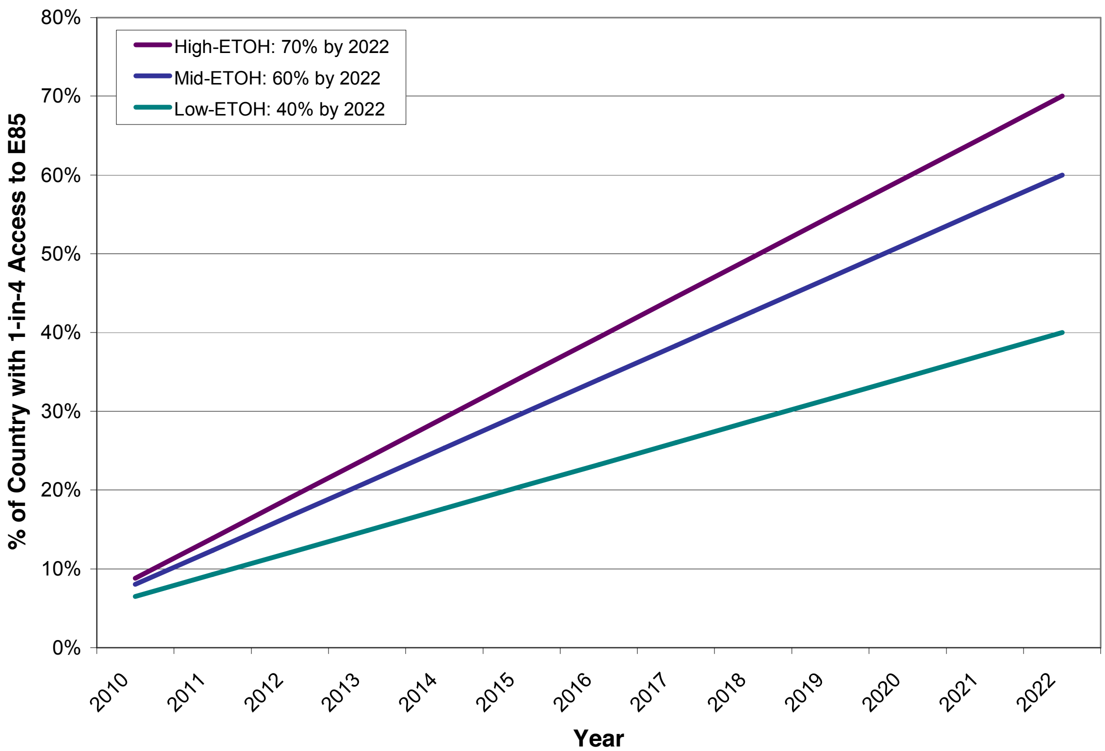
Figure 1.7-9.
A Look at 70% E85 Access - Concentrating Pumps in Urban Areas



For our other control cases we assumed access to E85 would be lower with the logic that retail stations (the majority of which are independently owned and operated and net around

$30,000 per year) would not invest in more E85 infrastructure than what was necessary to meet the RFS2 requirements. As explained in Section 4.2.1.1.9 of the RIA, the cost to install E85 could be anywhere from $131,000 to $177,000 per station depending on the configuration and number of dispensers. For our primary mid-ethanol control case we assumed reasonable access would grow from 4% in 2008 to 60% in 2022 and for our low-ethanol control case we assumed that access would only grow to 40% by 2022. As a simplifying assumption, we assumed a linear phase-in as shown below in Figure 1.7-10. As discussed in Section 1.6, we believe these E85 growth scenarios are possible based on our assessment of distribution infrastructure capabilities. For more on the number of new E85 stations compared to the reference cases and the associated cost, refer to Section 4.2.1.1.9 of the RIA.

Figure 1.7-10.
Projected Growth in 1-in-4 Station Access to E85



1.7.4 Required Increase in E85 Refueling Rates

As mentioned earlier, there were just over 7 million FFVs on the road in 2008. If all FFVs refueled on E85 100% of the time, this would translate to about 8.3 billion gallons of E85 use. This is based on the assumption that the average FFV in 2008 traveled about 16,500 miles and got about 19 miles per gallon of gasoline under actual in-use driving conditions.[127,464] The

[127] Fleet average VMT and MPG estimates based on modeling assumptions used in the proposed Light-Duty Vehicle GHG Rule.

estimate also assumes is takes about 1.3 gallons of E85 for an FFV to travel the same distance as a gallon of gasoline due to the difference in energy density of the fuels.[128]

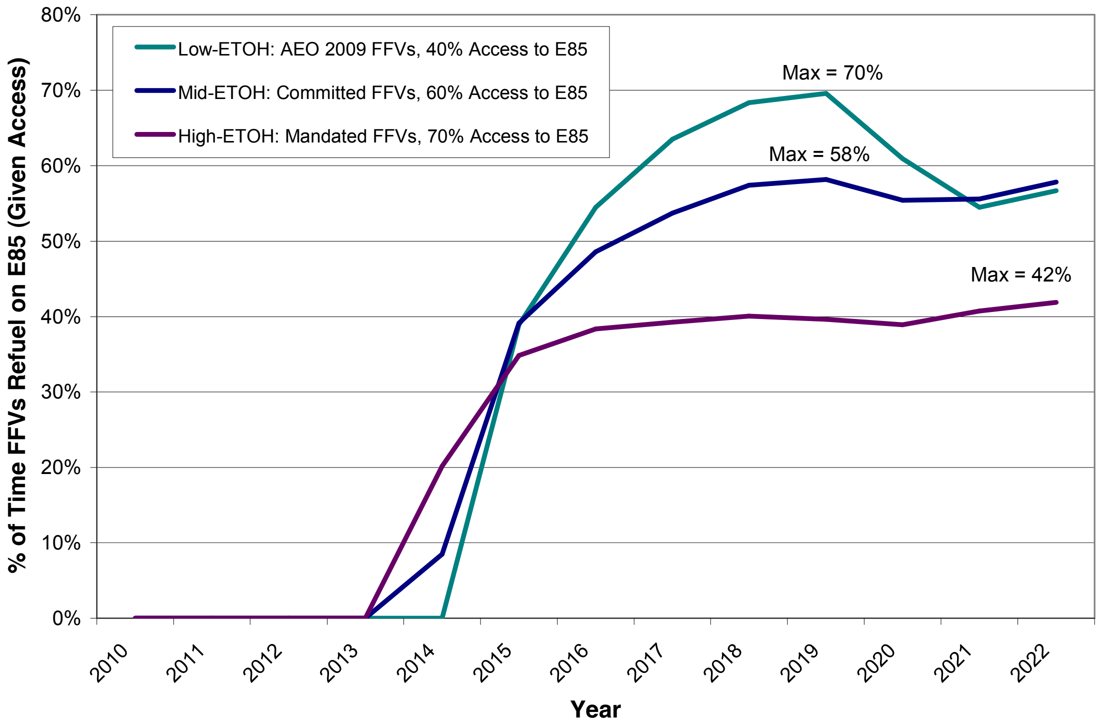
Although we computed the theoretical E85 usage potential to be around 8.3 billion gallons in 2008, according to EIA, actual E85 usage was only about 12 million gallons in 2008.[129,465] This means that, on average, FFV owners were only tapping into about 0.15% of their vehicles' E85/ethanol usage potential. Assuming only 4% of the nation had reasonable one-in-four access to E85 in 2008 (as discussed in Section 1.7.3), this equates to an estimated 4% E85 refueling frequency for those FFVs that had reasonable access to the fuel.

There are several reasons behind today's low E85 refueling frequency. For starters, many FFV owners may not know they are driving a vehicle that is capable of handling E85. As mentioned earlier, more and more automakers are starting to produce FFVs by engine/product line, e.g., all 2008 Chevy Impalas are FFVs.[466] Consequently, consumers (especially brand loyal consumers) may inadvertently buy a flexible fuel vehicle without making a conscious decision to do so. And without effective consumer awareness programs in place, these FFV owners may never think to refuel on E85. In addition, FFV owners with reasonable access to E85 and knowledge of their vehicle's E85 capabilities may still not choose to refuel on E85. They may feel inconvenienced by the increased refueling requirements. Based on its lower energy density, FFV owners will need to stop to refuel 22% more often when filling up on E85 over E10 (and 24% more often when refueling on E85 over conventional gasoline).[130] In addition, some FFV owners may be deterred from refueling on E85 out of fear of reduced vehicle performance or just plain unfamiliarity with the new motor vehicle fuel. However, as we move into the future, we believe the biggest determinant will be price – whether E85 is priced competitively with gasoline based on its reduced energy density (discussed in more detail below).

To comply with the RFS2 program and consume 17.5 to 33.2 billion gallons of ethanol by 2022, not only will we need more FFVs and more E85 retailers, we'll also need to see a dramatic increase in the FFV E85 refueling frequency relative to today. Based on the FFV and retail assumptions presented in Sections 1.7.2 and 1.7.3, our analysis suggests that FFV owners with reasonable access to E85 would need to refuel on it 42-70% of the time, depending on the scenario (refer to Figure 1.7-11). This is a significant increase from today's estimated 4% refueling frequency.

[128] Assuming E85 contains approximately 74 vol% denatured ethanol on average (77,012 BTU/gal) and 26 vol% E0 gasoline (115,000 BTU/gal) based on EIA's AEO 2009 assumption.
[129] 0.007 quadrillion BTUs of ethanol from E85 (from AEO 2009) converted into Bgal using EIA's HHV (84,262 BTU/gal) and divided by 0.74 (EIA's assumed average ethanol content of E85).
[130] Assuming E85 contains approximately 74 vol% denatured ethanol on average (77,012 BTU/gal) and 26 vol% E0 gasoline (115,000 BTU/gal) based on EIA's AEO 2009 assumption. For analysis purposes, E10 was assumed to contain 10 vol% denatured ethanol and 90 vol% E0 gasoline.

Figure 1.7-11.
Necessary FFV E85 Refueling Rates
(Given 1-in-4 Access to Fuel)



As shown above, modeling an FFV mandate and E85 station access reaching 70% by 2022, results in the lowest required FFV E85 refueling frequency (42%) for the high-ethanol control case. Similarly, the infrastructure assumptions modeled for the low-ethanol control case resulted in the highest required FFV E85 refueling frequency (70%). While this may seem counter-intuitive, the result is a product of the competing and variable modeling assumptions used. Had we elected to hold FFV production and E85 access constant for all three control cases (i.e., applied more aggressive infrastructure assumptions across the board), we would have come up with the lowest required FFV E85 refueling frequency for low-ethanol case and the highest requirements for the high-ethanol case. The computed required refueling frequency would also look more linear. However, this would mean large investments in FFV production and E85 refueling infrastructure despite low demand for E85. We figured that, at costs of up to $100 per FFV and as much as $177,000 per E85 station, the nation would not build more FFV/E85 infrastructure than what was needed to meet the RFS2 requirements Regardless, in order for any significant increase in FFV E85 refueling rates to occur, there will need to be an improvement in the current E85/gasoline price relationship.

1.7.5 Market Pricing of E85 Versus Gasoline

According to an online fuel price survey, E85 is currently priced almost 40 cents per gallon or about 15% lower than regular grade conventional gasoline.[467] But this is still about 30 cents per gallon higher than conventional gasoline on an energy-equivalent basis. To increase our nation's E85 refueling frequency to the levels described above, E85 needs to be priced competitively with (if not lower than) conventional gasoline based on its reduced energy content, increased time spent at the pump, and limited availability. Overall, we estimate that E85 would need to be priced about 25% lower than E10 at retail in 2022 in order for it to make sense to consumers (as outlined below).

First, E85 needs to be priced lower than E10 based on its reduced energy density. For our ethanol consumption analysis and this E85/gasoline price assessment, denatured ethanol was assumed to have a lower heating value of 77,012 BTU/gal based on the new 2% denaturant requirement.[131,468] Conventional gasoline (E0) was assumed to have an average lower heating value of 115,000 BTU/gal. E10 was assumed to contain 10 vol% denatured ethanol and 90 vol% gasoline and E85 was assumed to contain 74 vol% denatured ethanol and 26 vol% gasoline on average (based on EIA's AEO 2009 report).[469] As shown below, E85 would need to be priced about 78% lower than E10 based on its reduced energy density.

$$\frac{E85EnergyDensity}{E10EnergyDensity} = \frac{0.74 * 77{,}012BTU / gal + 0.26 * 115{,}000BTU / gal}{0.10 * 77{,}012BTU / gal + 0.90 * 115{,}000BTU / gal} = 78.1\%$$

In 2022, based on EIA's $116/barrel crude oil projections, wholesale gasoline (E10) is expected to be priced at $3.42/gallon.[132] Factoring in transportation costs, taxes, and mark-up at retail (about $0.60/gallon total), gasoline can be expected to be priced at $4.02/gallon at retail in 2022. To be cost-competitive with gasoline, E85 would have to be priced at least 78% lower than E10 at retail, or around $3.14/gallon.

In addition, we need to take the value of FFV owners' time into consideration because they could be spending 22% more time at the pump if they are refueling exclusively on E85. In the U.S., a person's time is currently valued at around $30 per hour. This value of time (VOT) estimate was based on an average of values identified in a review of economics literature and is consistent with 2005 Brownstone and Small VOT estimates.[470] Adjusting the 2005 VOT estimate to 2007 dollars, yields a $31.61 per hour estimate. Assuming it takes about six minutes for a 15-gallon refill, E85 needs to be priced an additional $0.05 per gallon less than E10

Finally, we accounted for the fact that, as an alternative fuel, it is unlikely that E85 will ever be available nationwide. As mentioned above, the greatest access we anticipate FFV owners will have to E85, is one-in-four stations offering the fuel. And that will likely only be in select areas of the country. And unlike diesel fuel, FFV owners are not required to fill up on it. So in order to get consumers to want to refuel on E85 over gasoline, there needs to be an additional price incentive at the pump according to a 1997 Oakridge National Lab report.[133,471]

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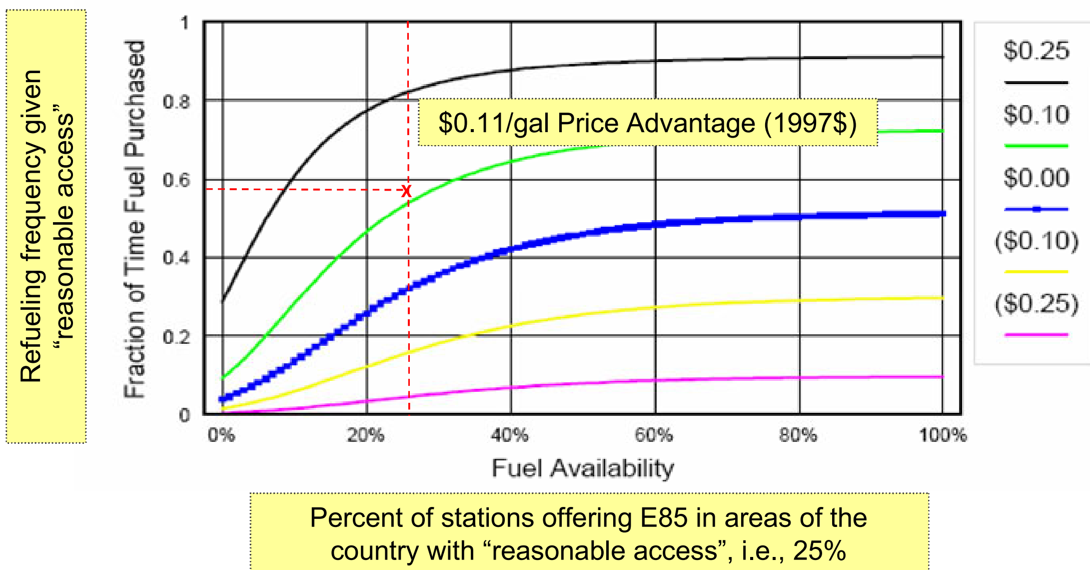
[131] The 2008 Farm Bill1 contained a provision that stipulates the full value of the Volumetric Ethanol Excise Tax Credit (VEETC) is only available to blenders when using fuel ethanol denatured at a maximum of 2%.
[132] Refer to Table 4.4-9 in Section 4.4 of the RIA.
[133] Although the 1997 David Greene study was based on asking consumers about a hypothetical fuel that "works just as well as gasoline", we assumed that Figure 6 from the report (pictured) could also be used to determine the retail price incentive given to E85 to account for its limited availability . As explained in the preceding text, this was in addition to the incentives assigned to E85 to account for its reduced energy density and additional time spent at the pump.

As shown below in Figure 1.7-12, if an alternative fuel is only available at 25% of stations and you want people to refuel on it about 58% of the time in 2022 (as is, under our primary mid-ethanol control case), it needs to be given an $0.11/gallon price advantage (1997$). Inflating the 1997 David Greene estimate to 2007 dollars, E85 would need to be priced an additional 14 cents per gallon lower than E10.

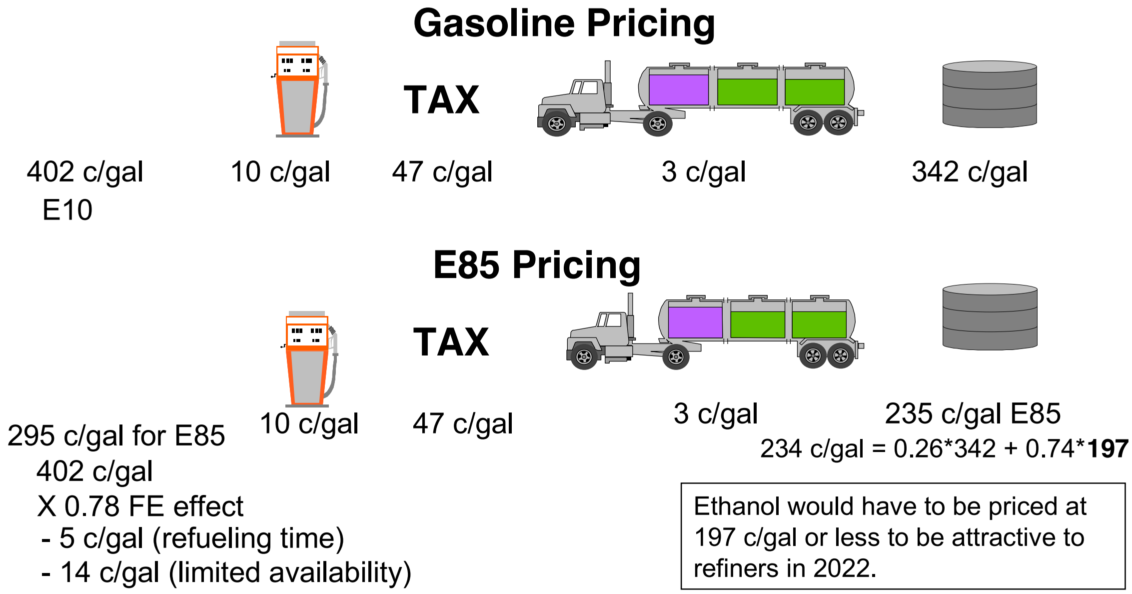
Figure 1.7-12.
Required Price Incentive for Alternative Fuels with Limited Availability



Overall, our retail price analysis suggests that E85 would need to be priced around $2.95 per gallon ($3.14/gal - $0.05/gal - $0.14/gal) in order for it to be competitive with $4.02 gasoline in 2022. Essentially, E85 would need to be priced at least 25% lower than gasoline at retail outlets in order for consumers to want to choose it regularly.

However, ultimately it comes down to what refiners are willing to pay for ethanol blended as E85. The more ethanol you try to blend as E85, the more devalued ethanol becomes as a gasoline blendstock. Changes to state and Federal excise tax structures could help promote ethanol blending as E85. But for the most past, as long as crude oil prices remain high (as projected by AEO 2009), it should look attractive to refiners as a blendstock. Based on our retail cost calculations, summarized in Figure 1.7-13 below, ethanol would have to be priced at $1.97/gallon in order for it to be attractive to refiners for E85 blending in 2022.

Figure 1.7-13.
Required Ethanol Pricing Needed in 2022 to Encourage E85 Blending



According to the DTN Ethanol Center, the current rack price for ethanol is around $2.20/gallon.[472] However, as explained in Section 4.4 of the RIA, we project the average ethanol delivered price (volume-weighted average production cost of corn, cellulosic and imported ethanol plus distribution) will come down to around $1.67/gallon in 2022 under our mid-ethanol primary control case.[134] Therefore, while gasoline refiners and markets will always have a greater profit margin selling ethanol in low-level blends to consumers based on volume, they should be able to maintain a profit selling it as E85 in the future.

1.7.6 Consideration of >10% Ethanol Blends

On March 6, 2009, Growth Energy and 54 ethanol manufacturers submitted an application for a waiver of the prohibition of the introduction into commerce of certain fuels and fuel additives set forth in section 211(f) of the Act. This application seeks a waiver for ethanol-gasoline blends of up to 15 percent ethanol by volume.[473] On April 21, 2009, EPA issued a Federal Register notice announcing receipt of the Growth Energy waiver application and soliciting comment on all aspects of it.[474] On May 20, 2009, EPA issued an additional Federal Register notice extending the public comment period by an additional 60 days.[475] The comment period ended on July 20, 2009, and EPA is now evaluating the waiver application and considering the comments which were submitted.

In a letter dated November 30, 2009, EPA notified the applicant that, because crucial vehicle durability information being developed by the Department of Energy would not be available until mid-2010, EPA would be delaying its decision on the application until a sufficient amount of this information could be included in its analysis so that the most scientifically supportable decision could be made.[476] As the current Growth Energy waiver application is still

[134] Refer to Table 4.4-4 in Section 4.4 of the RIA.

under review, EPA believes it is appropriate to address aspects of the mid-level blend waiver in its decision announcement on the waiver application as opposed to dealing with the comments and evaluation of the potential waiver in today's final rule.

Although EPA has yet to make a waiver decision, since its approval could have a significant impact on our analyses that are based on the use of E85, as a sensitivity analysis, we have evaluated the impacts that E15 could have on ethanol consumption feasibility. More specifically, we have assessed the impacts of a partial waiver for newer technology vehicles consistent with the direction of EPA's November 30, 2009 letter.

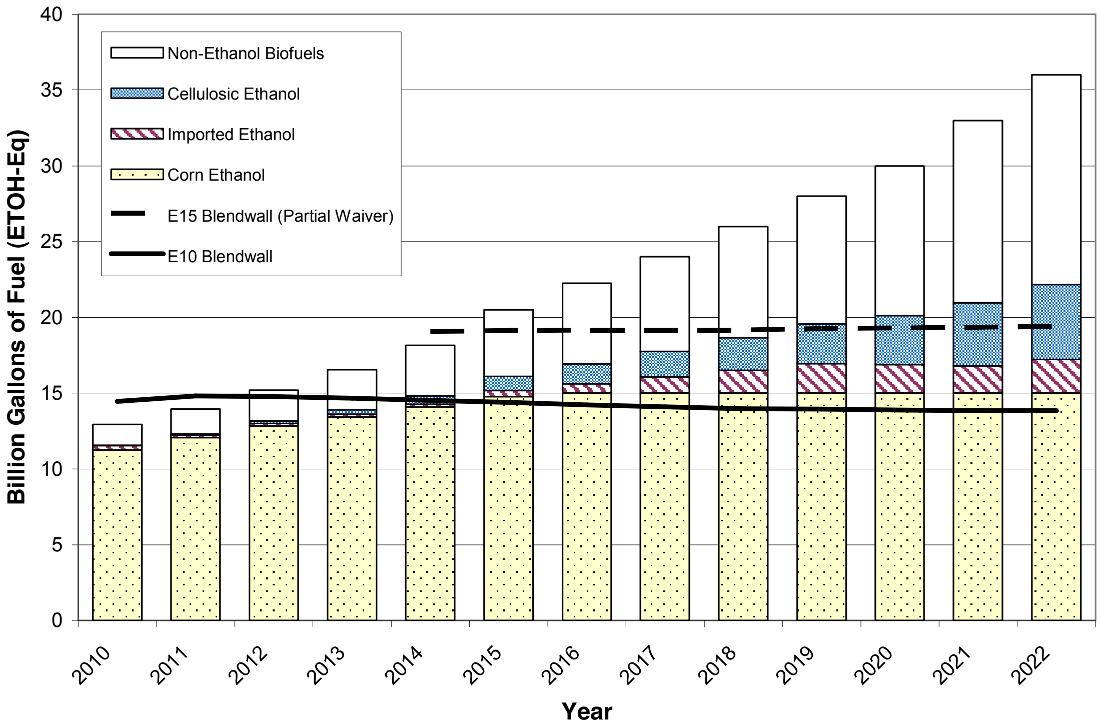
For our analysis, we assumed that E10 would need to continue to co-exist for legacy and non-road equipment based on consumer demand regardless of any waiver decision. As shown in Figures 1.7-5 through 1.7-7, we assumed that the percentage of gasoline energy consumed by nonroad, heavy-duty gasoline vehicles, and motorcycles would be about 8% based on information obtained from ORNL's Transportation Energy Data Book.[477] For analysis purposes, we assumed E10 would be marketed as premium-grade gasoline (the universal fuel), E15 would be marketed as regular-grade gasoline (to maximize ethanol throughput) and, like today, midgrade would be blended from the two fuels to make a 12.5 vol% blend (E12.5). In addition, we assumed that some E15-capable vehicles would continue to choose E10 or E12.5 based on today's premium and midgrade sales shown below in Table 1.7-4.

Table 1.7-4.
Mid-level Ethanol Blend Assumptions

Grade of Gasoline	% of CG Sales*	Ethanol Content
Regular	86.5%	10.0%
Midgrade	5.0%	12.5%
Premium	8.5%	15.0%
*Petroleum Marketing Annual 2008, Table 45		

In the event of a partial waiver, it is unclear how long it would take for E15 to be fully deployed or whether it would ever be available nationwide. For analysis purposes, we made the simplifying assumption that E15 would be fully phased in and available at all retail stations nationwide by the time the nation hit the blend wall, or by around 2014 for our primary mid-ethanol control case shown in Figure 1.7-14.

Figure 1.7-14
Max E15 Ethanol Consumption Compared to Mid-Ethanol Control Case



As modeled, a partial waiver for E15 could increase the ethanol consumption potential from conventional vehicles to about 19 billion gallons. Under our primary control case (shown in Figure 1.7-14), E15 could postpone the blend wall by up to five years, or to 2019. Although E15 would fall short of meeting the RFS2 requirements under this scenario, it could provide interim relief while the country ramps up non-ethanol cellulosic biofuel production and/or expands E85/FFV infrastructure.

Under our low-ethanol case, a partial waiver for E15 could eliminate the need for additional FFV/E85 infrastructure all together. Similarly, for our high-ethanol case, E15 could eliminate the need for FFV or E85 infrastructure mandates or postpone the blend wall by about 3 years from about 2013 to 2016. These scenarios are shown in Figures 1.7-15 and 1.7-16.

Figure 1.7-15
Max E15 Ethanol Consumption Compared to Low-Ethanol Control Case

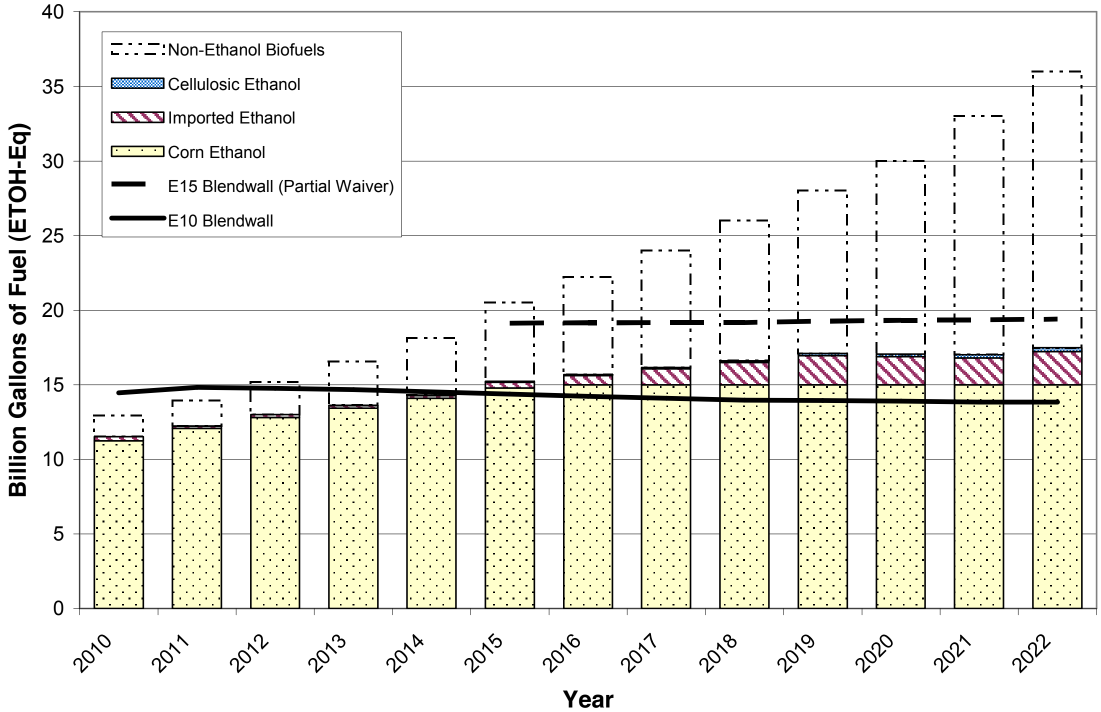
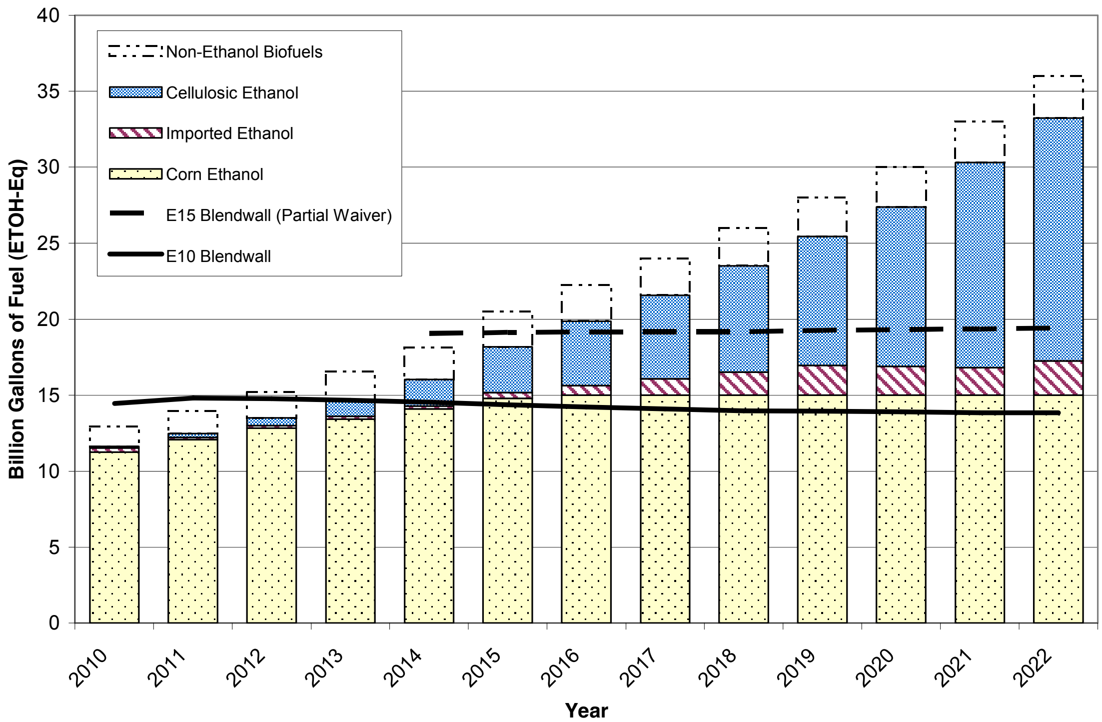


Figure 1.7-16
Max E15 Ethanol Consumption Compared to High-Ethanol Control Case



1.8 Inputs Used for the Air Quality Modeling

The information presented in Section 1.5 reflects our most current assessment of the renewable fuels industry and our projections through 2022 to meet the RFS2 standards. In addition, Section 1.7 reflects our most current assessment on how the renewable fuel might be consumed and the associated challenges, e.g., E10 blend wall, etc. The information presented in these sections serves as the basis for various final rulemaking impact analyses, including cost. However, the air quality modeling and some of the fuel distribution analyses had to begin prior to this assessment being completed. As a result, they relied on industry assessments carried out for the NPRM. This section presents the relevant NPRM assessment which served as the basis for these analyses.

1.8.1 Ethanol Inputs

1.8.1.1 Corn Ethanol Inputs

1.8.1.1.1 Existing Corn/Starch Ethanol Production

At the time of our May 2008 corn ethanol plant assessment used for air quality modeling, there were 158 fuel ethanol plants operating in the U.S. with a combined production capacity of

9.2 billion gallons per year.[135478479] The majority of ethanol (nearly 89% by volume) was produced exclusively from corn. Another 11% came from a blend of corn and/or similarly processed grains (milo, wheat, or barley) and less than half a percent was produced from cheese whey, waste beverages, and sugars/starches combined. A summary of the feedstocks utilized by the U.S. ethanol industry as of May 2008 is found in Table 1.8-1.

Table 1.8.1
May 2008 Corn/Starch Ethanol Production Capacity by Feedstock

Plant Feedstock (Primary Listed First)	Capacity MGY	% of Capacity	No. of Plants	% of Plants
Corn[a]	8,141	88.8%	131	82.9%
Corn, Milo[b]	704	7.7%	14	8.9%
Corn, Wheat	130	1.4%	1	0.6%
Corn, Wheat, Milo	115	1.3%	2	1.3%
Milo	3	0.0%	1	0.6%
Wheat, Milo	50	0.5%	1	0.6%
Cheese Whey	8	0.1%	2	1.3%
Waste Beverages[c]	13	0.1%	4	2.5%
Waste Sugars & Starches[d]	7	0.1%	2	1.3%
Total	**9,169**	**100%**	**158**	**100%**

[a]Includes one facility processing seed corn, one facility also operating a pilot-level cellulosic ethanol plant, and six facilities with plans to build pilot-level cellulosic ethanol plants or incorporate biomass feedstocks in the future.
[b]Includes one facility processing small amounts of molasses in addition to corn and milo.
[c]Includes two facilities processing brewery waste.
[d]Includes one facility processing potato waste that intends to add corn in the future.

The corn ethanol industry relies primarily on natural gas. At the time of our May 2008 plant assessment, 134 of the 158 corn/starch ethanol plants burned natural gas (exclusively).[136] In addition, three burned a combination of natural gas and biomass, one burned a combination of natural gas, landfill syngas and wood, while one burned a combination of natural gas and syrup from the process. In addition, 18 plants burned coal as their primary fuel and one burned a combination of coal and biomass. Our research suggested that 24 plants utilized cogeneration or combined heat and power (CHP) technology at the time of our assessment. A summary of the

[135] Our May 2008 corn/starch ethanol industry characterization was based on a variety of data sources including: Renewable Fuels Association (RFA) Ethanol Biorefinery Locations (updated April 2, 2008); Ethanol Producer Magazine (EPM) Current plant list (last modified on April 14, 2008), and ethanol producer websites. The baseline does not include ethanol plants whose primary business is industrial or food-grade ethanol production. Where applicable, ethanol plant production levels were used in lieu of nameplate capacities to estimate plant production. The baseline does not include U.S. plants that were idled as of May 2008 or plants that might be located in the Virgin Islands or U.S. territories.

[136] Facilities were assumed to burn natural gas if the plant boiler fuel was unspecified or unavailable on the public domain.

energy sources and CHP technology utilized by the U.S. ethanol industry as of May 2008 is found in Table 1.8-2.

Table 1.8.2.
May 2008 Corn/Starch Ethanol Production Capacity by Energy Source

Plant Energy Source (Primary Listed First)	Capacity MGY	% of Capacity	No. of Plants	% of Plants	CHP Tech.
Coal[a]	1,720	18.8%	18	11.4%	8
Coal, Biomass	50	0.5%	1	0.6%	0
Natural Gas[b]	7,141	77.9%	134	84.8%	15
Natural Gas, Biomass[c]	113	1.2%	3	1.9%	1
Natural Gas, Landfill Syngas, Wood	100	1.1%	1	0.6%	0
Natural Gas, Syrup	46	0.5%	1	0.6%	0
Total	**9,169**	**100.0%**	**158**	**100.0%**	**24**

[a]Includes four plants that are permitted to burn biomass, tires, petroleum coke, and wood waste in addition to coal and one facility that intends to transition to biomass in the future.
[b]Includes one facility that intends to burn thin stillage biogas, five facilities that intend to transition to coal, and one facility that intends to switch to biomass in the future.
[c]Includes one facility processing bran in addition to natural gas.

Besides a few plants located outside of the Corn Belt, the majority of ethanol is produced in PADD close to where the corn is grown. At the time of our May 2008 ethanol industry characterization, PADD 2 accounted for 94% (or 8.6 billion gallons) of the estimated ethanol production capacity as shown in Table 1.8.-3 below.

Table 1.8-3.
May 2008 Corn/Starch Ethanol Production Capacity by PADD

PADD	Capacity MGY	% of Capacity	No. of Plants	% of Plants
PADD 1	50	0.5%	2	1.3%
PADD 2	8,619	94.0%	140	88.6%
PADD 3	170	1.9%	3	1.9%
PADD 4	160	1.7%	7	4.4%
PADD 5	171	1.9%	6	3.8%
Total	**9,169**	**100.0%**	**158**	**100.0%**

Leading the Midwest in ethanol production were Iowa, Nebraska, Illinois, South Dakota and Minnesota. Together, these five states' 93 ethanol plants accounted for 67 percent of the nation's ethanol production capacity in May 2008. For a map of the ethanol plant locations and a summary of ethanol production capacity by state, refer to Figure 1.8.1 and Table 1.8.4 below.

Figure 1.8.1.
May 2008 Corn/Starch Ethanol Plant Locations

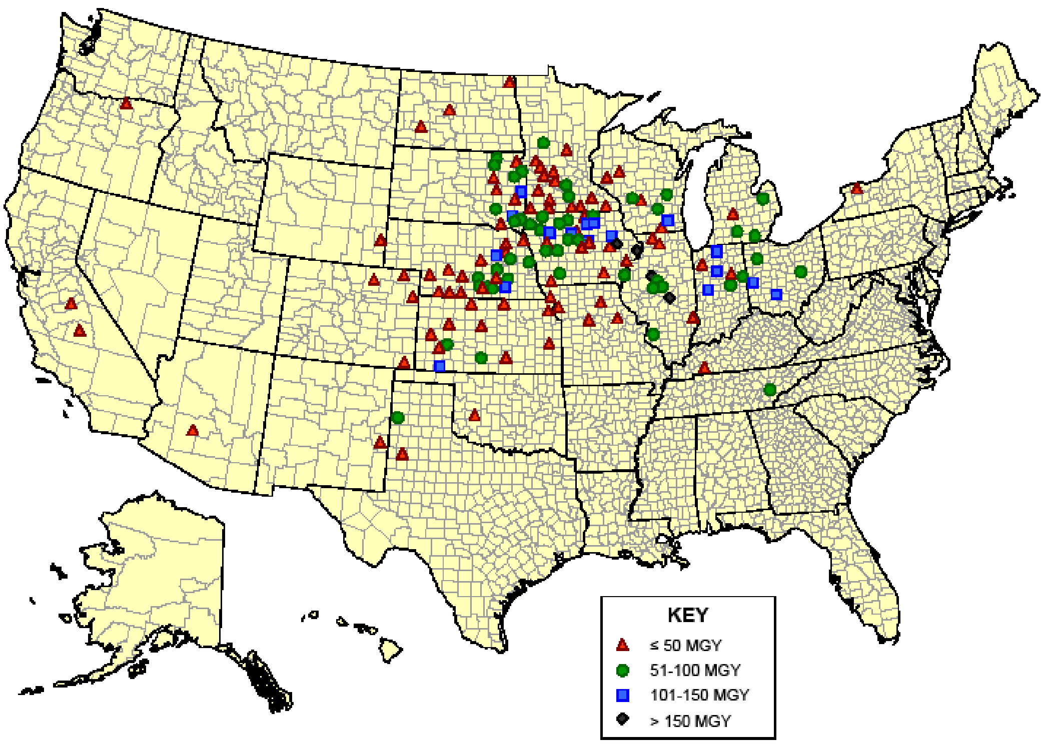


Table 1.8-4
May 2008 Corn/Starch Ethanol Production Capacity by State

State	Capacity MGY	% of Capacity	No. of Plants	% of Plants
Iowa	2,282	24.9%	30	19.0%
Nebraska	1,278	13.9%	22	13.9%
Illinois	941	10.3%	9	5.7%
South Dakota	892	9.7%	14	8.9%
Minnesota	749	8.2%	18	11.4%
Indiana	540	5.9%	7	4.4%
Wisconsin	479	5.2%	8	5.1%
Kansas	464	5.1%	12	7.6%
Ohio	345	3.8%	4	2.5%
Michigan	214	2.3%	4	2.5%
Missouri	202	2.2%	5	3.2%
Colorado	146	1.6%	5	3.2%
Texas	140	1.5%	2	1.3%
North Dakota	125	1.4%	3	1.9%
California	81	0.9%	4	2.5%
Tennessee	66	0.7%	1	0.6%
New York	50	0.5%	1	0.6%
Arizona	50	0.5%	1	0.6%
Kentucky	40	0.4%	2	1.3%
Oregon	40	0.4%	1	0.6%
New Mexico	30	0.3%	1	0.6%
Wyoming	9	0.1%	1	0.6%
Idaho	5	0.1%	1	0.6%
Oklahoma	2	0.0%	1	0.6%
Georgia	0	0.0%	1	0.6%
Total	**9,169**	**100.0%**	**158**	**100.0%**

1.8.1.1.2 Forecasted Growth in Corn/Starch Ethanol Production Under RFS2

According to our industry assessment, there were 59 ethanol plants under construction or expanding as of May 2008 with a combined production capacity of 5.2 billion gallons per year.[137] These projects were at various phases of construction from conducting land stabilization work, to constructing tanks and installing ancillary equipment, to completing start-up activities. We assumed that all this capacity would eventually come online as well as a number of other projects that were at advanced stages of planning at the time of our May 2008 industry assessment.

Once all the aforementioned projects are complete, we projected that there would be 216 corn/starch ethanol plants operating in the U.S. with a combined production capacity of about 15 billion gallons per year. Much like today's ethanol production facilities, the overwhelming majority of new plant capacity (95% by volume) was expected to come from corn-fed plants. The remainder was forecasted to come from plants processing a blend of corn and milo. A summary of the forecasted ethanol production by feedstock under the RFS2 program based on our May 2008 plant assessment is found in Table 1.8-5.

Table 1.8-5.
Projected RFS2 Ethanol Production Capacity by Feedstock
(Based on May 2008 Ethanol Industry Characterization)

	New Plants/Exp.		**Total RFS2 Est.**	
Plant Feedstock (Primary Listed First)	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**
Corn[a]	5,526	54	13,666	185
Corn, Milo[b]	303	4	1,007	18
Corn, Wheat	0	0	130	1
Corn, Wheat, Milo	0	0	115	2
Milo	0	0	3	1
Wheat, Milo	0	0	50	1
Cheese Whey	0	0	8	2
Waste Beverages[c]	0	0	13	4
Waste Sugars & Starches[d]	0	0	7	2
Total	**5,829**	**58**	**14,998**	**216**

[a]Includes one facility processing seed corn, one facility also operating a pilot-level cellulosic ethanol plant, and six facilities with plans to build pilot-level cellulosic ethanol plants or incorporate biomass feedstocks in the future.
[b]Includes one facility processing small amounts of molasses in addition to corn and milo.
[c]Includes two facilities processing brewery waste.
[d]Includes one facility processing potato waste that intends to add corn in the future.

[137] Based on Renewable Fuels Association (RFA), Ethanol Biorefinery Locations – Under Construction/Expansions (updated April 4, 2008); Ethanol Producer Magazine (EPM), Under Construction plant list (last modified on April 14, 2008), ethanol producer websites, and follow-up correspondence with ethanol producers.

Based on May 2008 industry plans, the majority of new corn/grain ethanol production capacity (82% by volume) was predicted to come from new or expanded plants burning natural gas. Additionally, we forecasted one new plant burning a combination of natural gas and syrup (from the process) and an expansion at an existing facility burning natural gas and biomass. Our predictions also suggest two new coal-fired ethanol plants and three expansions at existing coal-fired plants.[138] Finally, we projected three new plants burning alternative fuels – one relying on manure biogas, one burning biomass, and one burning a combination of biomass and thin stillage from the process.[139] Our research indicated that nine of the 58 new plants would utilize cogeneration, bringing the total number of CHP facilities to 33. A summary of the forecasted ethanol plant energy sources in 2022 under the RFS2 program is found in Table 1.8-6.

Table 1.8-6.
Projected Near-Term Corn/Starch Ethanol Production Capacity by Energy Source (Based on May 2008 Ethanol Industry Characterization)

	New Plants/Exp.		Total RFS2 Est.		
Plant Energy Source (Primary Listed First)	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**	**CHP Tech.**
Biomass	88	1	88	1	0
Coal[a]	740	4	2,460	22	12
Coal, Biomass	0	0	50	1	0
Manure Biogas	115	1	115	1	0
Natural Gas[b]	4,776	50	11,917	184	19
Natural Gas, Biomass[c]	40	0	153	3	1
Natural Gas, Landfill Biogas, Wood	0	0	100	1	0
Natural Gas, Syrup	50	1	96	2	0
Thin Stillage Biogas, Biomass	20	1	20	1	1
Total	**5,829**	**58**	**14,998**	**216**	**33**

[a]Includes four existing plants and two under construction facilities that are permitted to burn biomass, tires, petroleum coke, and wood waste in addition to coal. Also includes one facility that intends to transition to biomass in the future.
[b]Includes one facility that intends to burn thin stillage biogas, six facilities that intend to transition to coal, and one facility that intends to switch to biomass in the future.
[c]Includes one facility processing bran in addition to natural gas.

The information presented in Table 1.8-6 is based on near-term production plans at the time of our May 2008 industry assessment. However, we anticipate additional growth in advanced ethanol production technologies in the future under the RFS2 program. For more on our projected 2022 utilization of these technologies under the RFS2 program, refer to Section 1.5.1.3.

[138] We anticipate that all the coal-fired corn ethanol plants would be grandfathered under the RFS2 program. For more on our grandfathering assessment, refer to Section 1.5.1.4.
[139] Thin stillage is a process liquid with 5–10 percent solids taken out of the distillers grains via centrifuge. However, construction on this alternatively fuel ethanol plant near Heyburn, ID was since terminated. Accordingly, this plant was not included in our November 2009 RFS2 projections.

Based on our May 2008 assessment, 85% of new ethanol production capacity under RFS2 is expected to originate from PADD 2. For a summary of this and other forecasted PADD-level production projections, refer to Table 1.8-7.

Table 1.8-7.
Projected RFS2 Corn/Starch Ethanol Production Capacity by PADD
(Based on May 2008 Ethanol Industry Characterization)

	New Plants/Exp.		Total RFS2 Est.	
PADD	**Capacity MGY**	**No. of Plants**	**Capacity MGY**	**No. of Plants**
PADD 1	214	2	264	4
PADD 2	5,002	47	13,620	187
PADD 3	215	2	385	5
PADD 4	70	2	230	9
PADD 5	328	5	499	11
Total	**5,829**	**58**	**14,998**	**216**

Our May 2008 assessment suggested that Iowa, Nebraska, and Illinois would continue to dominate ethanol production under RFS2 with a collective annual production capacity of about 7.5 billion gallons. Minnesota and Indiana were projected to be the fourth and fifth largest ethanol producers. A map of the forecasted corn ethanol plant locations based on our May 2008 assessment is provided in Figure 1.8-2 and a summary of the ethanol production capacity by state is presented in Table 1.8-8.

Figure 1.8-2
Projected RFS2 Corn/Starch Ethanol Plant Locations
(Based on May 2008 Ethanol Industry Characterization)

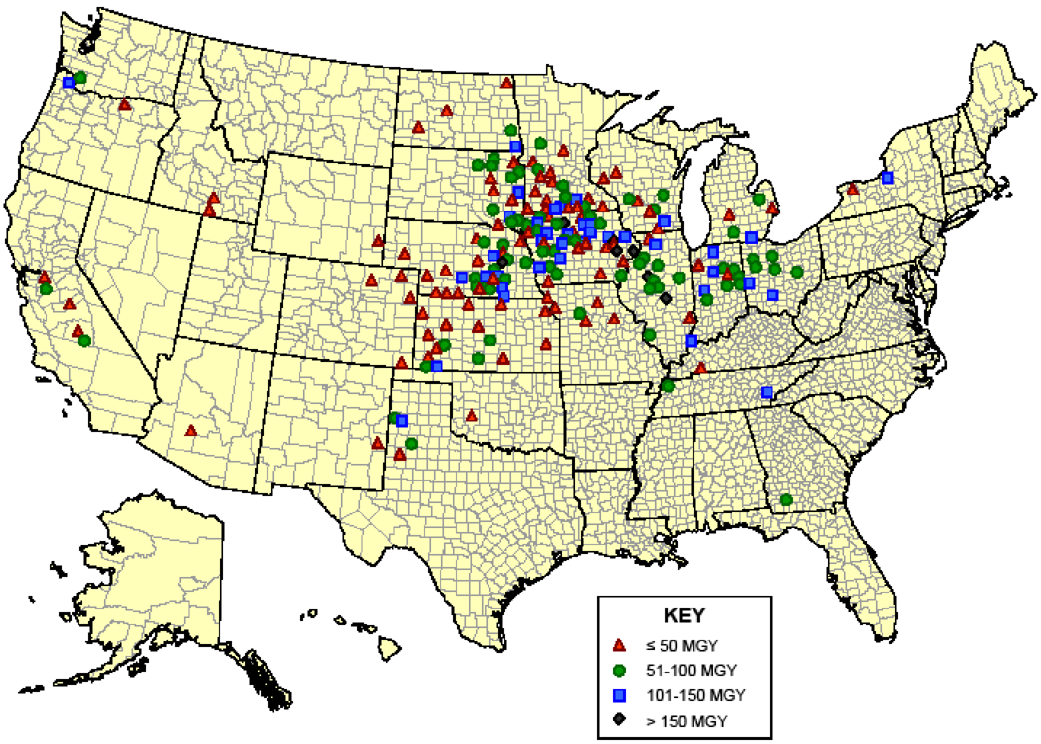


**Table 1.8-8.
Projected RFS2 Corn/Starch Ethanol Production Capacity by State
(Based on May 2008 Ethanol Industry Characterization)**

State	New Plants/Exp. Capacity MGY	New Plants/Exp. No. of Plants	Total RFS2 Est. Capacity MGY	Total RFS2 Est. No. of Plants
Iowa	1,573	13	3,854	43
Nebraska	959	7	2,237	29
Illinois	465	4	1,406	13
Minnesota	440	4	1,189	22
Indiana	470	5	1,010	12
South Dakota	100	1	992	15
Kansas	203	4	667	16
Wisconsin	70	1	549	9
Ohio	185	3	530	7
Texas	215	2	355	4
North Dakota	210	2	335	5
Michigan	107	1	321	5
Missouri	60	1	262	6
California	160	3	241	7
Tennessee	160	1	226	2
New York	114	1	164	2
Oregon	113	1	153	2
Colorado	0	0	146	5
Georgia	100	1	100	2
Idaho	70	2	75	3
Washington	55	1	55	1
Arizona	0	0	50	1
Kentucky	0	0	40	2
New Mexico	0	0	30	1
Wyoming	0	0	9	1
Oklahoma	0	0	2	1
Total	**5,829**	**58**	**14,998**	**216**

1.8.1.2 Projected Ethanol Import Locations

A discussion of the sugarcane ethanol imports that might come directly from Brazil versus through the CBI countries is contained in Section 1.5.2. However, to provide upstream inputs for AQ modeling and distribution purposes, we needed to estimate imports based on their country of origin and projected U.S. destination, i.e., port location.

1.8.1.2.1 Origin of Projected Imports

To estimate the future breakdown of ethanol imports from CBI countries by country of origin, we evaluated historical ethanol import data from the International Trade Commission (ITC) and trends regarding potential growth in such imports. Table 1.8-9 contains 2005-2007 data from the ITC on ethanol imports from CBI countries.[480] Table 1.8-10 contains January – March 2008 data from the ITC on ethanol imports from CBI countries.[481]

Table 1.8-9. Ethanol Imports from CBI Countries 2005-2007

	2005		2006		2007	
	% of CBI imports	Volume (Million Gallons)	% of CBI imports	Volume (Million Gallons)	% of CBI imports	Volume (Million Gallons)
Costa Rica	32%	33.4	22%	35.9	17%	39.3
El Salvador	23%	23.7	23%	38.5	32%	73.3
Jamaica	35%	36.3	40%	66.8	33%	75.2
Trinidad and Tobago	10%	10	15%	24.8	19%	42.7

Source: International Trade Commission

Table 1.8-10. Ethanol Imports from CBI Countries, January through March 2008

	January		February		March	
	% of CBI imports	Volume (Million Gallons)	% of CBI imports	Volume (Million Gallons)	% of CBI imports	Volume (Million Gallons)
Costa Rica	26%	5.4	27%	5.4	0	0
El Salvador	13%	2.6	0	0	23%	4.6
Jamaica	19%	4.0	32%	6.4	39%	7.9
Trinidad and Tobago	20%	4.1	21%	4.2	29%	6
Virgin Islands	22%	4.6	21%	4.2	9%	1.9

Source: International Trade Commission

Based on our review of the January through March 2008 data, we assumed that ethanol exports from the Virgin Islands would continue to grow to equal those of Trinidad and Tobago in 2022. By accommodating this assumption into our review of 2005 though 2007 historical ethanol import data, we arrived at our projections regarding the future breakdown of ethanol imports from CBI countries which is contained in Table 1.8-11

Table 1.8-11.
Projected Future Breakdown of
Ethanol Imports from CBI Countries

	% of Total Ethanol Imports from CBI Countries
Costa Rica	20%
El Salvador	20%
Jamaica	30%
Trinidad and Tobago	15%
Virgin Islands	15%

1.8.1.2.2 Destination of Projected Imports

As explained above, to determine where imported ethanol might enter the United States, we started by looking at historical ethanol import data and made assumptions as to which countries would likely contribute to the CBI ethanol volumes and to what extent.

From there, we looked at 2006-2007 import data and estimated the general destination of Brazilian ethanol and the five contributing CBI countries' domestic imports.[482] Based on these countries' geographic locations and import histories, we estimated that in 2022 82% of the ethanol would be imported to the East and Gulf Coasts and the remaining 18% would go to the West Coast and Hawaii. The destination of imports from Brazil and the CBI countries in 2022 is detailed in Table 1.8-12.

Table 1.8-12
2022 Projected Destination of Ethanol Imports from Brazil
and CBI Countries Based on 2006-2007 Import Data

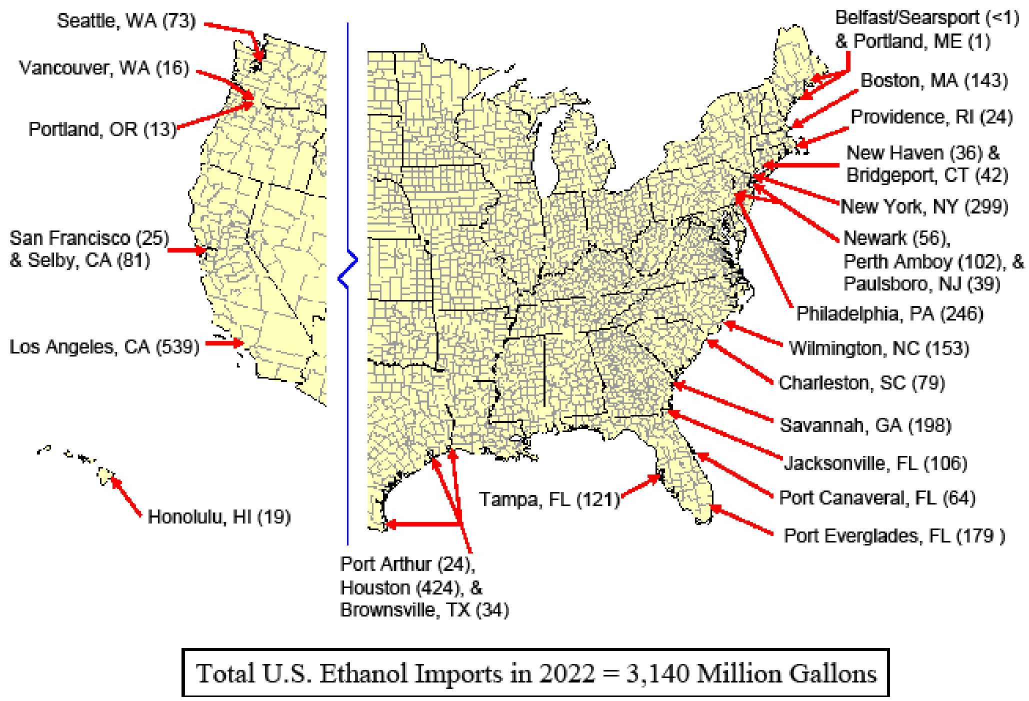
Origin	Destination of Ethanol Imports (% of imported volume)		
	West Coast	Hawaii	East & Gulf Coasts
Costa Rica	83%	35%	47%
El Salvador	18%	9%	88%
Jamaica	3%	0%	17%
Trinidad & Tobago	0%	32%	68%
Virgin Islands	3%	9%	88%
Brazil (direct)	7%	0%	93%
Total	11%	7%	82%

Source: Energy Information Administration historical gasoline and ethanol import data:
http://www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli_historical.html

To estimate the 2022 ethanol import locations on a finer level, we looked at coastal ports that had received ethanol or finished gasoline imports in 2006. We chose to include ports which imported finished gasoline (in addition to ethanol) because we believe finished gasoline will be one of the first petroleum products to be replaced under the proposed RFS2 rule. And presumably, these ports cities already have existing gasoline storage tanks that could be retrofitted to accommodate fuel ethanol. All together, we arrived at 28 potential ports in 16 coastal states that could receive ethanol imports in 2022 (refer to Figure 1.8-3 below).[140]

To determine how much ethanol would arrive at each port location, we started by examining each receiving state's imported ethanol consumption potential. To do this, we considered each state's maximum ethanol consumption potential (based on projected gasoline energy demand) and deducted the projected 2022 corn and cellulosic ethanol production (detailed in Sections 1.8.1.1 and 1.8.1.3, respectively). Once we determined the amount of imported ethanol that each state would receive in 2022 under RFS2, for states with multiple ethanol ports, we allocated the ethanol among port locations based on each port county's relative energy demand - using projected 2022 vehicle miles traveled (VMT) from EPA's MOVES model 2022 VMT. A summary of the projected ethanol imports volumes by port location is found in Figure 1.8-3.

Figure 1.8-3.
Projected RFS2 Ethanol Import Locations and Volumes (Million Gallons)[141]



[140] We are considering adding Hampton Roads, VA and Baltimore, MD to the list of future ethanol import locations and may adjust our analysis for the final rule accordingly.
[141] We are considering adding Hampton Roads, VA and Baltimore, MD to the list of future ethanol import locations and may adjust our analysis for the final rule accordingly.

1.8.1.3 Cellulosic Ethanol Plant Siting

As explained in Section 1.5.3, cellulosic biofuel production capacity needs to expand greatly in order to meet the cellulosic biofuel mandate of 16 billion gallons by 2022. While current production plans provide an initial idea of the types of feedstocks and potential plant locations that are being considered by biofuel producers, future production will be highly dependent on acquiring relatively cost-effective feedstocks in sufficient quantities.

A wide variety of feedstocks can be used for cellulosic biofuel production, including agricultural residues, forestry biomass, the certain renewable portions of municipal solid waste and construction and demolition waste and energy crops. These feedstocks are currently much more difficult to convert into ethanol than traditional starch/corn crops or at least require new and different processes because of the more complex structure of cellulosic material.

1.8.1.3.1 Summary of Plant Siting Results

As long lead times were required for our air quality modeling, it was necessary to use available data at the time on the likely cellulosic feedstocks and projected locations of cellulosic facilities for production of 16 billion gallons cellulosic biofuel by 2022. Our original plant siting analysis for cellulosic ethanol facilities used the most current version of outputs from FASOM at the time, which was from April 2008. Therefore, the version used for the majority of other analyses in the rest of this package is different from the results presented below.

Our cellulosic ethanol plant siting analysis assumed that the following cellulosic feedstock and volumes would be used, as shown in Table 1.8-13.

Table 1.8-13.
Cellulosic Feedstocks Assumed to Meet EISA in 2022
(NPRM version for AQ Modeling)

Feedstock	**Volume (Ethanol-equivalent Bgal)**
Agricultural Residues	9.1
Corn Stover	7.8
Sugarcane Bagasse[142]	1.2
Sweet Sorghum Pulp	0.1
Forestry Biomass	3.8
Urban Waste	2.2
Dedicated Energy Crops (Switchgrass)	0.9
Total	16.0

[142] Bagasse is a byproduct of sugarcane crushing and not technically an agricultural residue. Sweet sorghum pulp is also a byproduct of sweet sorghum processing. We have included it under this heading for simplification due to sugarcane being an agricultural feedstock.

Future cellulosic biofuel plant siting was based on the types of feedstocks that would be most economical as shown in Table 1.8-13, above. As cellulosic biofuel refineries will likely be located close to biomass resources in order to take advantage of lower transportation costs, we've assessed the potential areas in the U.S. that grow the various feedstocks chosen. To do this, we used data on harvested acres by county for crops that are currently grown today, such as corn stover and sugarcane (for bagasse).[483] In some cases, crops are not currently grown, but have the potential to replace other crops or pastureland (e.g., dedicated energy crops). We used the output from our economic modeling (FASOM) to help us determine which types of land are likely to be replaced by newly grown crops. For forest residue biomass, the U.S. Forest Service provided supply curve data by county showing the available tons produced. Urban waste (MSW wood, paper, and C&D debris) was estimated to be located near large population centers. Refer to Section 1.8.1.3.2 below for more detailed information.

Using feedstock availability data by county/city, we located potential cellulosic sites across the U.S. that could justify the construction of a cellulosic plant facility. Table 1.8-14 shows the volume of cellulosic facilities by feedstock by state projected for 2022. Table 1.8-15 lists the 180 cellulosic ethanol facilities that we project could potentially be used to produce 16 Bgal of cellulosic biofuel by 2022. The total volumes given in Table 1.8-14 match the total volumes given in Table 1.8-15 within a couple hundred million gallons. As these differences are relatively small, we believe the cellulosic facilities sited are a good estimate of potential locations. See Figure 1.8-4 for a visual representation of the locations of these facilities.

Table 1.8-14.
Projected Cellulosic Ethanol Volumes by State (million gallons in 2022)

State	Total Volume	Ag Volume	Energy Crop Volume	Urban Waste Volume	Forestry Volume
Alabama	532	0	0	140	392
Arkansas	298	0	0	0	298
California	450	0	0	221	229
Colorado	28	0	0	28	0
Florida	421	390	0	31	0
Georgia	437	0	0	67	370
Illinois	1,525	1,270	0	198	58
Indiana	1,109	948	0	101	60
Iowa	1,697	1,635	0	32	30
Kansas	310	250	0	29	32
Kentucky	70	70	0	0	0
Louisiana	1,001	590	0	103	308
Maine	191	0	0	2	189
Michigan	505	283	0	171	51
Minnesota	876	750	0	50	76
Mississippi	214	0	0	22	192
Missouri	654	504	0	78	72
Montana	92	0	0	9	83
Nebraska	956	851	0	31	75
Nevada	17	0	0	17	0
New Hampshire	171	0	35	29	107
New York	72	0	0	72	0
North Carolina	315	0	0	98	217
Ohio	598	410	0	156	32
Oklahoma	793	0	777	0	16
Oregon	244	0	0	44	200
Pennsylvania	42	0	0	42	0
South Carolina	213	0	0	57	156
South Dakota	434	350	0	6	78
Tennessee	97	0	0	19	78
Texas	576	300	0	131	145
Virginia	197	0	0	95	102
Washington	175	0	0	17	158
West Virginia	149	0	101	0	48
Wisconsin	581	432	0	43	106
Total Volume	16,039	9,034	913	2,139	3,955

**Table 1.8-15.
Projected Cellulosic Facilities
(million gallons in 2022)**

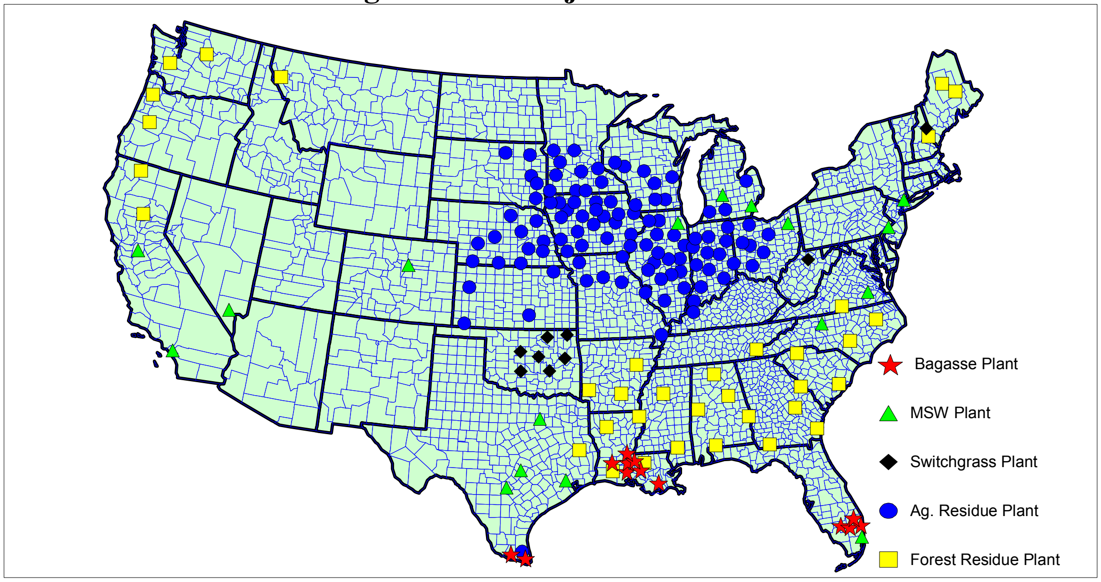
County	State	Total Volume (million gallons/yr)
Escambia	Alabama	112
Greene	Alabama	108
Morgan	Alabama	96
Russell	Alabama	101
Talledega	Alabama	115
Cleveland	Arkansas	99
Howard	Arkansas	97
Woodruff	Arkansas	102
Butte	California	94
Orange	California	133
San Joaquin	California	120
Siskiyou	California	102
Adams	Colorado	28
Broward	Florida	31
Hendry	Florida	90
Palm Beach	Florida	100
Palm Beach	Florida	100
Palm Beach	Florida	100
Glynn	Georgia	108
Grady	Georgia	130
Richmond	Georgia	101
Treutlen	Georgia	98
Bureau	Illinois	130
Carroll	Illinois	77
Champaign	Illinois	89
Coles	Illinois	77
De Witt	Illinois	100
Du Page	Illinois	128
Grundy	Illinois	77
Iroquois	Illinois	80
Knox	Illinois	89
Menard	Illinois	99
Montgomery	Illinois	78
Morgan	Illinois	67
Ogle	Illinois	95
Richland	Illinois	81
Shelby	Illinois	68
Tazewell	Illinois	107
Washington	Illinois	85
Benton	Indiana	92
Clinton	Indiana	80
Daviess	Indiana	93
De Kalb	Indiana	91
Fulton	Indiana	74
Jasper	Indiana	82

Jennings	Indiana	94
Madison	Indiana	78
Morgan	Indiana	100
Parke	Indiana	92
Union	Indiana	82
Vanderburgh	Indiana	74
Wells	Indiana	77
Benton	Iowa	69
Buchanan	Iowa	83
Buena Vista	Iowa	84
Cerro Gordo	Iowa	79
Chickasaw	Iowa	82
Des Moines	Iowa	87
Dubuque	Iowa	70
Franklin	Iowa	80
Grundy	Iowa	83
Guthrie	Iowa	85
Ida	Iowa	88
Mahaska	Iowa	80
Muscatine	Iowa	83
O Brien	Iowa	80
Page	Iowa	81
Palo Alto	Iowa	75
Pottawattamie	Iowa	84
Sioux	Iowa	72
Story	Iowa	89
Union	Iowa	76
Webster	Iowa	86
Logan	Kansas	75
Nemaha	Kansas	78
Sedgwick	Kansas	71
Stevens	Kansas	87
Webster	Kentucky	70
Bienville	Louisiana	115
E. Baton Rouge	Louisiana	106
E. Carroll	Louisiana	103
Jeff Davis	Louisiana	87
Allen	Louisiana	50
Avoyelles	Louisiana	100
Iberville	Louisiana	90
La Fourche	Louisiana	50
Lafayette	Louisiana	100
Pt. Coupe	Louisiana	100
St Landry	Louisiana	100
Penobscot	Maine	100
Piscataquis	Maine	91
Calhoun	Michigan	109
Ionia	Michigan	117
Tuscola	Michigan	105
Van Buren	Michigan	89

Wayne	Michigan	85
Chippewa	Minnesota	92
Dakota	Minnesota	114
Dodge	Minnesota	86
Faribault	Minnesota	88
Lyon	Minnesota	84
Martin	Minnesota	95
Rock	Minnesota	73
Sibley	Minnesota	102
Stearns	Minnesota	68
Stevens	Minnesota	76
Forrest	Mississippi	107
Grenada	Mississippi	107
Audrain	Missouri	86
Chariton	Missouri	74
Clark	Missouri	89
Gentry	Missouri	95
New Madrid	Missouri	84
Ray	Missouri	100
St. Louis	Missouri	125
Sanders	Montana	92
Boone	Nebraska	98
Custer	Nebraska	84
Harlan	Nebraska	78
Hitchcock	Nebraska	83
Holt	Nebraska	91
Lancaster	Nebraska	74
Lincoln	Nebraska	81
Nuckolls	Nebraska	76
Saunders	Nebraska	100
Wayne	Nebraska	96
York	Nebraska	94
Clark	Nevada	17
Carroll	New Hampshire	136
Carroll	New Hampshire	35
West Chester	New York	72
Cumberland	North Carolina	110
Forsyth	North Carolina	104
Martin	North Carolina	102
Auglaize	Ohio	80
Clinton	Ohio	100
Franklin	Ohio	77
Logan	Ohio	75
Portage	Ohio	98
Richland	Ohio	83
Wood	Ohio	85
Craig	Oklahoma	130
Grady	Oklahoma	108
Hughes	Oklahoma	91
Kingfisher	Oklahoma	110

Lincoln	Oklahoma	120
Muskogee	Oklahoma	118
Osage	Oklahoma	116
Lane	Oregon	126
Yamhill	Oregon	118
Montgomery	Pennsylvania	42
Berkeley	South Carolina	105
Spartanburg	South Carolina	108
Day	South Dakota	85
Edmunds	South Dakota	80
Kingsbury	South Dakota	98
Lake	South Dakota	83
Turner	South Dakota	89
Monroe	Tennessee	97
Angelina	Texas	114
Bexar	Texas	16
Cameron	Texas	100
Dallas	Texas	52
Harris	Texas	80
Hidalgo	Texas	100
Travis	Texas	14
Willacy	Texas	100
Halifax	Virginia	98
Prince George	Virginia	99
Chelan	Washington	78
Thurston	Washington	97
Harrison	West Virginia	149
Calumet	Wisconsin	91
Dane	Wisconsin	76
Dunn	Wisconsin	63
Eau Claire	Wisconsin	65
Grant	Wisconsin	68
Jefferson	Wisconsin	94
Marquette	Wisconsin	65
Wood	Wisconsin	59
Total		16039

Figure 1.8-4. Projected Cellulosic Facilities



1.8.1.3.2 Assumptions and Details of Plant Siting Analysis

An important assumption in our siting analysis is that an excess of feedstock would have to be available for producing the biofuel. Banks are anticipated to require excess feedstock supply as a safety factor to ensure that the plant will have adequate feedstock available for the plant, despite any feedstock emergency, such as a fire, drought, infestation of pests etc. For our analysis we assumed that twice the feedstock of MSW, C&D waste, and forest residue would have to be available to justify the building of a cellulosic ethanol plant. For corn stover, we assumed 50 percent more feedstock than necessary. We used a lower safety factor for corn stover because it could be possible to remove a larger percentage of the corn stover in any year (usually only 50 percent or less of corn stover is assumed to be sustainably removed in any one year).[143]

Another assumption that we made is that if multiple feedstocks are available in an area, each would be used as feedstocks for a prospective cellulosic ethanol plant. For example, a particular area might comprise a small or medium sized city, some forest and some agricultural land. We would include the MSW and C&D wastes available from the city along with the corn stover and forest residue for projecting the feedstock that would be processed by the particular cellulosic ethanol plant.

Each of the cellulosic plants was chosen to produce approximately 100 million gallons per year of ethanol. In some cases we had to resort to lower volumes due to limited resources in a given area. In other cases, we used greater than 100 million gallons per year because relatively close materials were available that would otherwise go unused. In addition, we limited biomass transport distances to be approximately 100 miles each way or less (radius from proposed facility), as large transport distances are economically prohibitive. We found that the majority of

[143] The FASOM results do not take into consideration these feedstock safety margins. Safety margins were used, however, for the plant siting analysis described in this section.

corn stover cellulosic facilities required smaller transport distances than the assumed 100 mile limit due to relatively close proximity to available feedstocks. Forest residues, on the other hand, typically required greater distances as collectable material appeared to be sparser.

Our analyses also take into account the locations of planned cellulosic facilities as well as any corn facilities or pulp and paper mills when we project where cellulosic plants are located into the future. While not all planned cellulosic facilities will likely come to fruition, it was important to look at the locations of these facilities as their locations are likely to be chosen for good reasons (i.e. close to resources, infrastructure in place, etc.). We analyzed current corn facilities and pulp and paper mill sites as well since they are likely to be close to their respective feedstocks (i.e. corn stover and wood residues) and could have many synergies with cellulosic biofuel production, such as shared steam and electricity production. However, this does not mean that we placed cellulosic facilities at all the locations where there are current corn facilities and pulp and paper mills. The locations are only used to help select areas that could be preferential towards building a cellulosic facility.

It is important to note, that there are many more factors other than feedstock availability to consider when eventually siting a plant. We have not taken into account, for example, water constraints, availability of permits, and sufficient personnel for specific locations. Nevertheless, our plant siting analysis provides a reasonable approximation for analysis purposes since it is not intended to predict precisely where actual plants will be located. Other work is currently being done that can help address some of these issues.[484]

For this analysis, we estimated MSW and C&D wood waste by state (similar to the analysis described in Section 1.1.2.4) and calculated the tons of MSW and C&D wood waste material generated per person per state. We used the estimate of MSW and C&D wood waste material generated per person per state (i.e. tons/person) along with data on the population sizes of the largest cities within the state to allocate the total waste material in a state to specific cities. Assuming that the majority of this waste is of negligible cost to a potential ethanol producer, we calculated a minimum size for a cellulosic plant dedicated to MSW and C&D wood waste for various locations in the U.S. Sizes ranged from 9-60 million gallons per year.

We did not consider small cities that might be able to justify a cellulosic ethanol plant because some other source of biomass is also available that, when combined with the MSW and C&D wood waste, can supply the cellulosic ethanol plant with sufficient feedstock. However, where non-MSW and C&D wood waste feedstocks are not available, we needed to estimate what the minimum plant size that would be competitive with other cellulosic ethanol plants.

We conducted this analysis early on before NREL provided us with the cost information for a biochemical cellulosic ethanol plant. Instead we used a representation made by NREL in 2007 for of a thermochemical ethanol plant. Using that cellulosic plant model we estimated the production cost for a 100 million gallon per year thermochemical plant which processed a cellulosic feedstock. We conducted this analysis in different parts of the country using different capital cost factors that account for how capital costs vary in different parts of the country. The different regions were Petroleum Administration for Defense Districts (PADDs) for which we have plant installation costs. In each part of the country, we estimated the cost of the ethanol produced processing the cellulosic feedstock assuming that the feedstock cost about $70 per dry ton. Next, we set the feedstock costs to zero cost in our cost spreadsheet and determined at what plant size, when scaling the capital costs as the plant size became smaller, the resulting cellulosic production costs matched those of the non-MSW and C&D wood waste plants. See Table 1.8-16.

Table 1.8-16.
Breakeven Plant Size for MSW and C&D Wood Waste Cellulosic Ethanol Plants

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	CA
Ethanol Production Cost (c/gal)	1.33	1.24	1.10	1.29	1.19	1.57
Breakeven Plant Size (million gals/yr)	28	19	9	23	15	60

We then identified the cities that had large enough MSW and C&D wood waste to justify a dedicated cellulosic facility. By dedicated cellulosic facility, we mean that only MSW and C&D wood waste is used as a feedstock, as opposed to a facility that has multiple mixed feedstocks. Nineteen facilities were identified to meet such criteria, as shown in Table 1.8-17. The total contribution from dedicated cellulosic MSW and C&D wood waste is approximately 640 million gallons.

Table 1.8-17.
Projected Dedicated Cellulosic MSW and C&D Wood Waste Facilities by Location and Size for 2022

	State	County	City	PADD	Size of Facility (Mgal)
1	Alabama	Jefferson	Birmington	3	11
2	Arizona	Maricopa	Phoenix	5	20
3	California	Los Angeles	Los Angeles	5	56
4	California	Riverside	Riverside	5	24
5	California	San Francisco	San Francisco	5	17
6	Colorado	Adams	Denver	4	28
7	Florida	Miami	Fort Lauderdale	1	31
8	Georgia	Cobb	Atlanta	1	43
9	Illinois	Cook	Chicago	2	79
10	Michigan	Oakland	Detroit	2	33
11	Nevada	Clark	Las Vegas	5	17
12	New York	New York City	New York	1	72
13	Oregon	Clackamas	Portland	4	15
14	Pennsylvania	Philadelphia	Philadelphia	1	42
15	Texas	Dallas	Dallas	3	52
16	Texas	Fort Bend	Houston	3	49
17	Texas	Bexar	San Antonio	3	16
18	Texas	Travis	Austin	3	14
19	Washington	King	Seattle	5	17

We did assume that in areas with other cellulosic feedstocks (forest and agricultural residue), that the MSW would be used even if the MSW could not justify the installation of a plant on its own. Therefore, we estimated that urban waste could help contribute to the production of approximately 2.2 billion gallons of ethanol.[144]

The results from the April 2008 version of the agricultural modeling (FASOM) suggested that corn stover will make up the majority of agricultural residues used by 2022 to meet the EISA cellulosic biofuel standard (approximately 83 million dry tons used to produce 7.8 billion gallons of cellulosic ethanol).[145] Smaller contributions were expected to come from bagasse, which is a by-product from the production of sugarcane, (1.2 bgal ethanol) and sweet sorghum pulp (0.1 bgal ethanol). At the time of the proposal, FASOM was able to model agricultural residues but not forestry biomass as potential feedstocks. As a result, we had relied on the U.S. Forest Service for information on the forestry sector for our plant siting analysis.

Using the assumptions from FASOM on residue and ethanol yields, we determined if it is possible to site potential cellulosic plants based on the acres currently harvested. We identified that there are enough harvested acres to produce 7.8 Bgal of ethanol from corn stover by 2022 without having to rely on new lands. Therefore, the siting of many of the cellulosic facilities will likely be located where corn is typically grown today. See Table 1.8-18 for a summary of the

[144] Assuming approximately 90 gal/dry ton ethanol conversion yield; Note that this is slightly different from the 2.3 billion gallons of ethanol assumed in other analyses in this package.
[145] Assuming 94 gal/dry ton ethanol conversion yield for corn stover in 2022

states producing corn stover, and their projected volume contribution to meeting the EISA cellulosic requirement by 2022.

Table 1.8-18.
Projected Ethanol Produced to Meet EISA in 2022 from Corn Stover (NPRM version for AQ Modeling)[146]

State	Total Harvested Acres (in 2022)	Total Residue Yield (tons/acre)	Total Residue Available (Million tons)	Residue Used (Million tons)	Percent Residue Used	Ethanol Produced (Million gallons)
Illinois	12,994,100	5.43	71	15	21%	1444
Indiana	6,209,463	5.58	35	10	29%	922
Iowa	14,482,313	5.47	79	17	21%	1557
Kansas	3,026,615	5.33	16	3	19%	261
Kentucky	1,473,023	5.08	7	1	13%	63
Michigan	2,238,321	4.30	10	3	31%	246
Minnesota	7,509,658	5.37	40	8	20%	750
Missouri	2,732,875	4.73	13	5	39%	434
Nebraska	10,135,162	5.88	60	9	15%	840
Ohio	3,712,612	4.91	18	5	27%	453
South Dakota	4,268,425	4.01	17	4	23%	350
Wisconsin	3,001,454	4.74	14	5	35%	432
Total	71,784,020	n/a	380	82	22%	7752

Sugarcane, on the other hand, is grown mainly in Florida, Louisiana, and Texas, although plans are underway to also grow sugarcane in California as well. See Section 1.1.1.2 of the RIA for more discussion on sugarcane ethanol produced in the U.S. If all the sugarcane acres harvested in the U.S. in 2007 were used to produce ethanol from the bagasse, using the assumptions from FASOM on residue and ethanol yields, only approximately 700 million gallons could be produced, see Table 1.8-19. FASOM, however, predicted that the production of 1.2 billion gallons of ethanol could be economically feasible from sugarcane bagasse. This means that between now and 2022, more sugarcane may be grown, allowing for more availability of bagasse in the future.

[146] Corn stover is given in dry tons/acre and assumes an ethanol yield of 94 gal/dry ton (this was updated in the final rule to 92.3 gal/dry ton based on NREL estimates); This table gives approximate averages by state based on our April 2008 version of the agricultural modeling, actual yields will vary greatly depending on specific soil type, slope, etc. The values above are calculated using the FASOM data outputs from April 2008 and thus are different from those found in other sections of this package which use more updated runs from 2009.

Table 1.8-19.
Projected Ethanol Produced to Meet EISA in 2022 from Sugarcane Bagasse

State	Total Harvested Acres (in 2007)	Total Bagasse Yield (tons/acre)	Residue Used (Million tons)	Ethanol Produced (Million gallons)
Total	810,800	n/a	10	707
Florida	382,000	14.71	6	389
Louisiana	389,600	10.25	4	277
Texas	39,200	15.23	1	41

Using FASOM, we analyzed the types of land likely to be supplanted by additional sugarcane acres in 2022 in the states of Florida, Louisiana, and Texas. In Florida, sugarcane crops appear to replace mainly corn, soy, and hay acres. In Louisiana, sugarcane crops appear to have replaced mainly corn, soy, wheat, sorghum, and hay acres. In Texas, sugarcane crops appear to have replaced mainly soy and sorghum crops. For these three states we gathered available data on corn, soy, wheat, and sorghum acres currently harvested by county (data on hay acres were unavailable and appeared to show small changes compared to corn and soy).[485] We then identified the top counties (in terms of acres available) in close proximity to each other that could potentially be converted from corn to sugarcane crops, soy to sugarcane, wheat to sugarcane, etc. in order to produce enough ethanol for half a billion gallons.

Sweet sorghum pulp is predicted to be used to produce approximately 0.1 billion gallons of ethanol. According to the National Agriculture and Statistics Service (NASS) of the Department of Agriculture, there is not current available data on sweet sorghum acres grown in the United States. Therefore, we used FASOM to predict the type of crops that sweet sorghum is mainly replacing, which is corn and soybeans. Similar to the analysis done for sugarcane, we identified the top counties (in terms of acres available) in close proximity to each other that could potentially be converted from corn to sweet sorghum crops and soy to sweet sorghum crops in order to produce enough ethanol for 0.1 billion gallons.

For forestry biomass, we utilized data provided by the U.S. Forest Service (biomass supply curves for various sources i.e., logging residues, other removal residues, thinnings from timberland, etc.). This information suggested that a large portion of forest material could be available for producing biofuels (excluding forest biomass material contained in national forests as required under the Act). See Section 1.1.2.3 for more information on forest residue feedstock availability. However, much of the forest material is in small pockets of forest which because of its regional low density, could not help to justify the establishment of a cellulosic ethanol plant. After conducting our availability analysis, we estimated that approximately 44 million dry tons of forest material could be used, which would make up approximately one fourth, or 3.8 billion gallons, of the 16 billion gallons of cellulosic biofuel required to meet EISA.

The April 2008 version of the FASOM results projected that 0.9 billion gallons of cellulosic ethanol from switchgrass is economically feasible by 2022. The majority of switchgrass is projected to likely be grown in Oklahoma, where the majority of acres are replacing wheat and hay. A smaller portion is expected to come from West Virginia and New Hampshire where hay is mainly replaced. Similar to the analysis done for sugarcane and sweet sorghum, we identified the top counties (in terms of acres available) in close proximity to each other that could potentially be converted from wheat to switchgrass or hay to switchgrass in order to produce enough ethanol for 0.9 billion gallons.

1.8.1.4 Ethanol Usage Assumptions

To understand the impacts of increased ethanol use on air quality, we estimated where the ethanol might be used in the future under the RFS2 program. For this analysis, discussed in more detail in Chapter 3 of the RIA, we measured the impacts of 34.1 billion gallons of ethanol use in 2022, the total volume of ethanol assumed to be produced and consumed in the NPRM. For this analysis, we also applied NPRM assumptions with respect to FFV and E85 availability, described in more detail below.

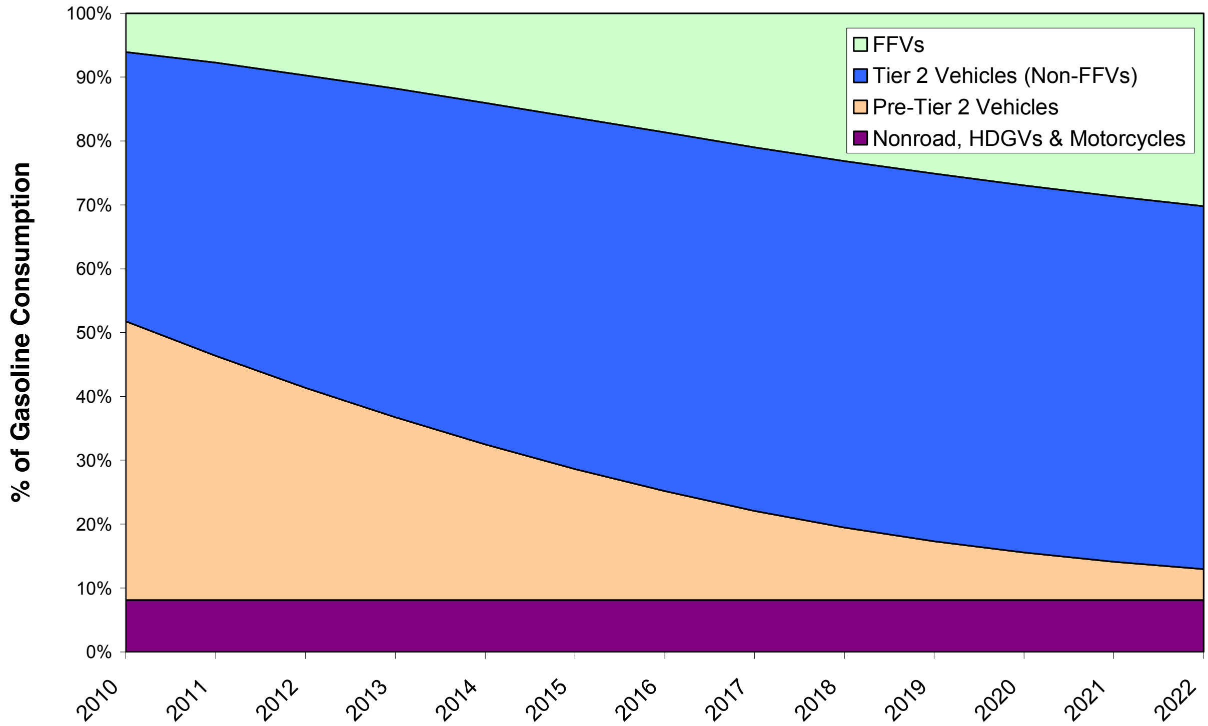
With respect to FFVs, we assumed that the Detroit 3 would follow through with their 50% by 2012 FFV commitment and the non-domestic automakers would follow suit and produce 25% FFVs by 2017. This corresponded to the primary Optimistic FFV Production Scenario outlined in the NPRM. The annual FFV sales by vehicle type are summarized in Table 1.8-20 below. For analysis purposes, we made the simplifying assumption that all FFVs would be distributed homogeneously and total vehicle sales would remain constant around 16 million units per year. This differs from vehicle assumptions made for the final rule, outlined in Section 1.7.1.2.

Table 1.8-20.
Optimistic FFV Production Scenario – FFV Production Assumptions

	GM, Chrysler & Ford			Non-Domestic Automakers		
Year	Tot FFVs	FFV-Cars	FFV-Trucks	Tot FFVs	FFV-Cars	FFV-Trucks
2002	1,000,000	200,000	800,000	0	0	0
2003	1,000,000	200,000	800,000	0	0	0
2004	1,000,000	200,000	800,000	0	0	0
2005	1,000,000	200,000	800,000	0	0	0
2006	1,000,000	200,000	800,000	0	0	0
2007	1,000,000	200,000	800,000	0	0	0
2008	1,600,000	320,000	1,280,000	80,000	0	80,000
2009	2,200,000	440,000	1,760,000	160,000	0	160,000
2010	2,800,000	560,000	2,240,000	240,000	0	240,000
2011	3,400,000	680,000	2,720,000	320,000	0	320,000
2012	4,000,000	800,000	3,200,000	400,000	0	400,000
2013	4,000,000	800,000	3,200,000	720,000	0	720,000
2014	4,000,000	800,000	3,200,000	1,040,000	0	1,040,000
2015	4,000,000	800,000	3,200,000	1,360,000	0	1,360,000
2016	4,000,000	800,000	3,200,000	1,680,000	0	1,680,000
2017	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000
2018	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000
2019	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000
2020	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000
2021	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000
2022	4,000,000	800,000	3,200,000	2,000,000	0	2,000,000

Based on these FFV production assumptions and forecasted vehicle phase-out, VMT, and fuel economy estimates provided by an earlier version of EPA's MOVES Model, we calculated that the maximum percentage of fuel (gasoline/ethanol mix) that could feasibly be consumed by FFVs in 2022 would be about 30%. The resulting gasoline energy consumption by vehicle type under the Optimistic FFV Production Scenario is shown below in Figure 1.8-5. For analysis purposes, we assumed that the percentage of gasoline energy consumed by nonroad, heavy-duty gasoline vehicles (HDGVs), and motorcycles would be about 8% based on historical information provided by DOE.[486]

Figure 1.8-5.
Optimistic FFV Production Scenario - Gasoline Consumption by Vehicle Type

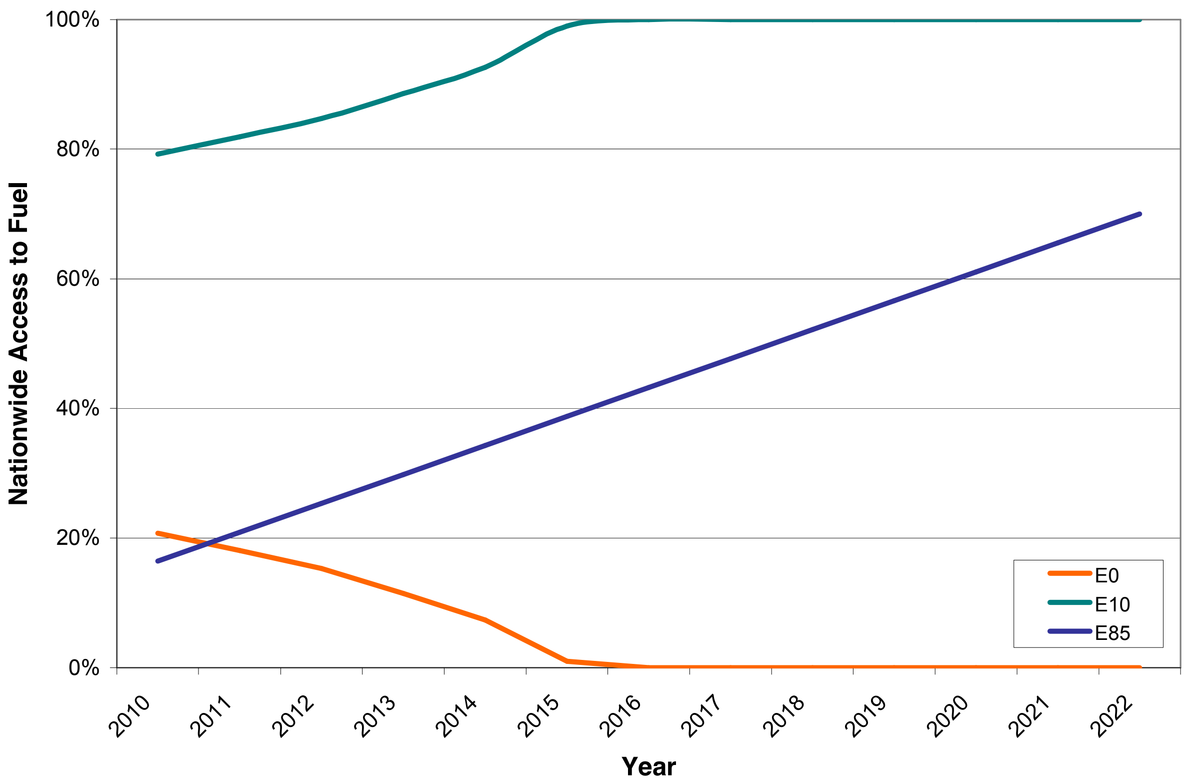


For the primary ethanol usage scenario analyzed in the NPRM and used for the AQ modeling work, we assumed practical, yet aggressive growth in E85 access. We considered the possibility that 70% of the nation could have reasonable one-in-four-station access to E85 by 2022. This is roughly equivalent to all urban areas in the United States offering E85 as explained in Section 1.7.3 of the RIA.

We are not concluding that E85 would only be offered in urban areas in the future. In fact, most E85 stations are currently located in the Midwest. However, we believe that this would be one possible way to provide 70% of the population with reasonable access to E85. From a fuel price standpoint, it makes sense that E85 might be offered in areas of the country with relatively high gasoline prices (e.g., RFG and low-RVP areas). Additionally, from an infrastructure cost standpoint, it makes sense that E85 might be offered in more populated metropolitan areas with high gasoline throughput. For more on fuel distribution logistics and costs, refer to Sections 1.6 and 4.2 of the RIA.

Assuming that reasonable E85 access grows linearly to 70% by 2022, we iteratively computed the corresponding nationwide E0 and E10 access assuming that a) each fuel retailer only carries one type of conventional gasoline (E0 or E10) and b) the nation does not exceed the RFS2 ethanol volume requirements analyzed for the NPRM. Under a very aggressive FFV production scenario, we estimate that E0 could theoretically remain in existence until 2016 as shown below in Figure 1.8-6. However, we anticipate that E10 will likely replace E0 sooner based on current market trends.

Figure 1.8-6.
Assumed Phase-Out of E0 and Phase-In of E10 & E85



To comply with the proposed RFS2 program and consume 34.1 billion gallons of ethanol by 2022, not only would we need more FFVs and more E85 retailers, we'll need to see a significant increase in FFV E85 refueling. Under the Optimistic FFV Production Scenario (assuming practical growth in E85 access), our analysis suggests that FFV owners with reasonable one-in-four access to E85 would need to fill up on it 74% of the time in 2022 - a significant increase from today's refueling frequency.

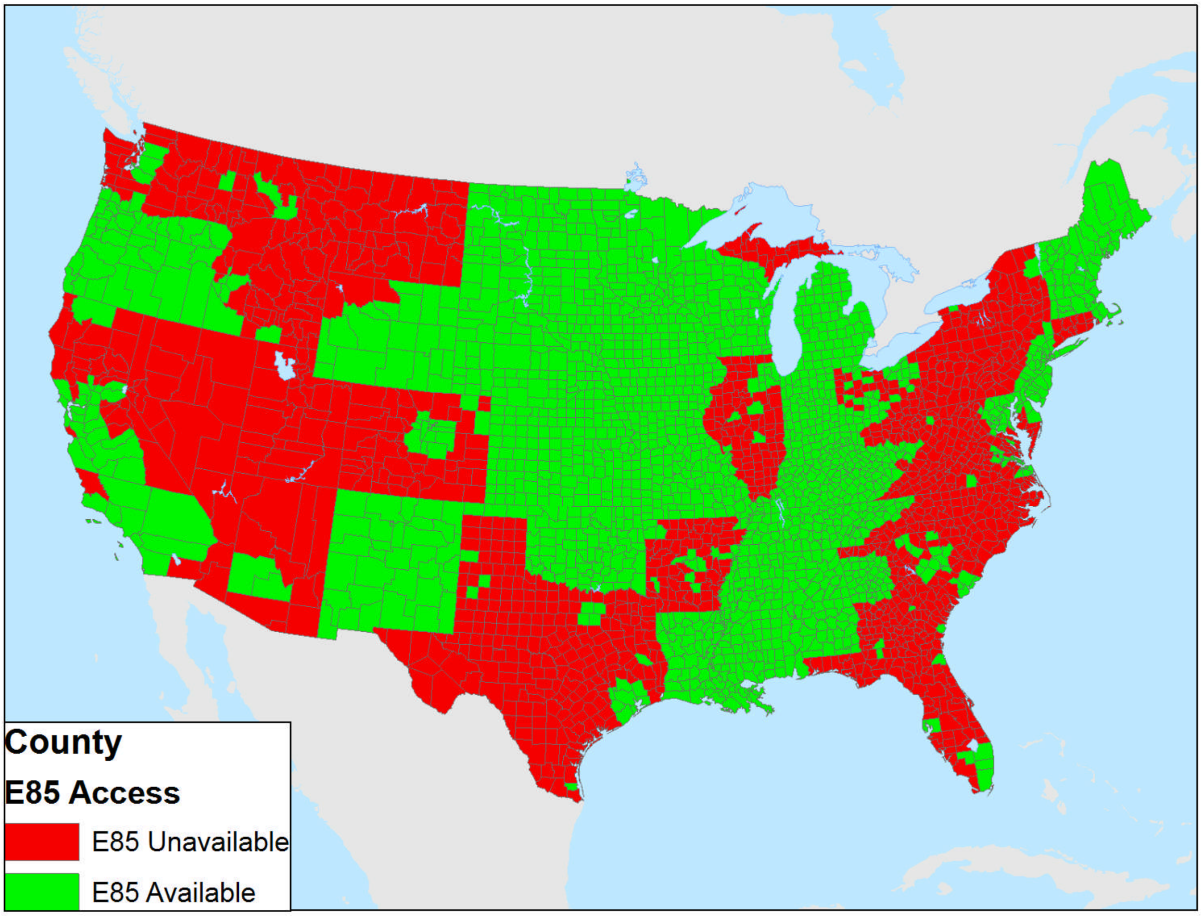
To estimate where E85 might be consumed under the proposed RFS2 program in 2022, we conducted a cost effectiveness study. For each area of the county, we began by looking at gasoline delivered prices. We started with state-level gasoline prices (excluding taxes) provided by EIA's Petroleum Marketing Annual 2006.[487] We relied on Table 31 for average gasoline prices, looked to Table 34 for RFG prices and back-calculated CG prices by applying the respective gasoline fuel volumes provided in Table 48. For states requiring 7 or 7.8-lb gasoline in the summertime, we applied PADD-average low-RVP gasoline production costs derived from the Mobile Source Air Toxics (MSAT) rule[488] to come up with the respective low-RVP and 9-lb conventional gasoline prices in these states. From there, we added in the corresponding gasoline taxes (state plus federal) according to the American Petroleum Institute (API).[489] This gave us the average retail cost of gasoline by state and fuel type.

Next we converted the gasoline prices into competitive retail E85 prices by adjusting for the reduced energy density of E85, the increased refueling time, and E85's presumed limited availability in 2022. For a more on this general methodology, refer to Section 1.7.1.2.5 of the RIA. From there, we deducted fuel taxes (assumed to be the same as gasoline), backed out marketing costs and retail profits (assumed to be $0.10 per gallon) and subtracted the terminal-to-retail transportation costs (assumed to be $0.03) to arrive at the estimated retail value of E85, and ultimately, the retail value of ethanol.[147] Once we computed the retail value of ethanol, we compared it to the estimated ethanol delivered price (based on transportation costs presented in Section 4.2 of the proposal) to come up with the respective E85 profit margin.

To conclude, we assigned E85 to the areas of the county with the highest E85 profit margins, or in some cases, the least negative E85 profit margins until we arrived at approximately 34 billion gallons of ethanol in 2022. For a graphical representation of the areas of the country we assumed would receive/consume E85, refer to Figure 1.8-7.

[147] For analysis purposes we assumed that E85 was taxed at the same rate as gasoline. We acknowledge that a number of states currently have reduced excise taxes or excise tax exemptions for E85. However, the extent of the tax breaks is somewhat unknown and the potential that these tax breaks will exist in the future is uncertain.

Figure 1.8-7
Projected E85 Availability in 2022 Under RFS2



1.8.2 Biodiesel & Renewable Diesel Inputs

1.8.2.1 Upstream Production Inputs

In order to generate county-level emissions inputs for the control case, we needed projected locations of biodiesel production facilities. This task was complicated by the fact that the current aggregate industry production capacity is significantly larger than the volume of biodiesel projected to be consumed in our primary control case, a fact which suggests the industry may downsize in the long term.

We developed a method to determine where biodiesel producers were most likely to remain based on state incentives to biodiesel producers and for biodiesel sales or use. Data on state incentives was taken from an online database maintained by the Department of Energy Office of Energy Efficiency and Renewable Energy.[490] Two other criteria we considered were the BQ-9000 status of individual plants and their ability to process multiple feedstock types, as listed by the National Biodiesel Board.[491] Based the volume of the primary control case, assuming a capacity utilization factor of approximately 80%, a list of plants for the 2022 scenarios was generated choosing first from those plants with most favorable status of the four criteria and working downward. We projected that a number of very small plants processing waste greases/fats would continue to operate based on local market niches regardless of these criteria. In an effort to be realistic in this forecast, other practical considerations were made, such as avoiding siting several plants in the same state (except in the Midwest).

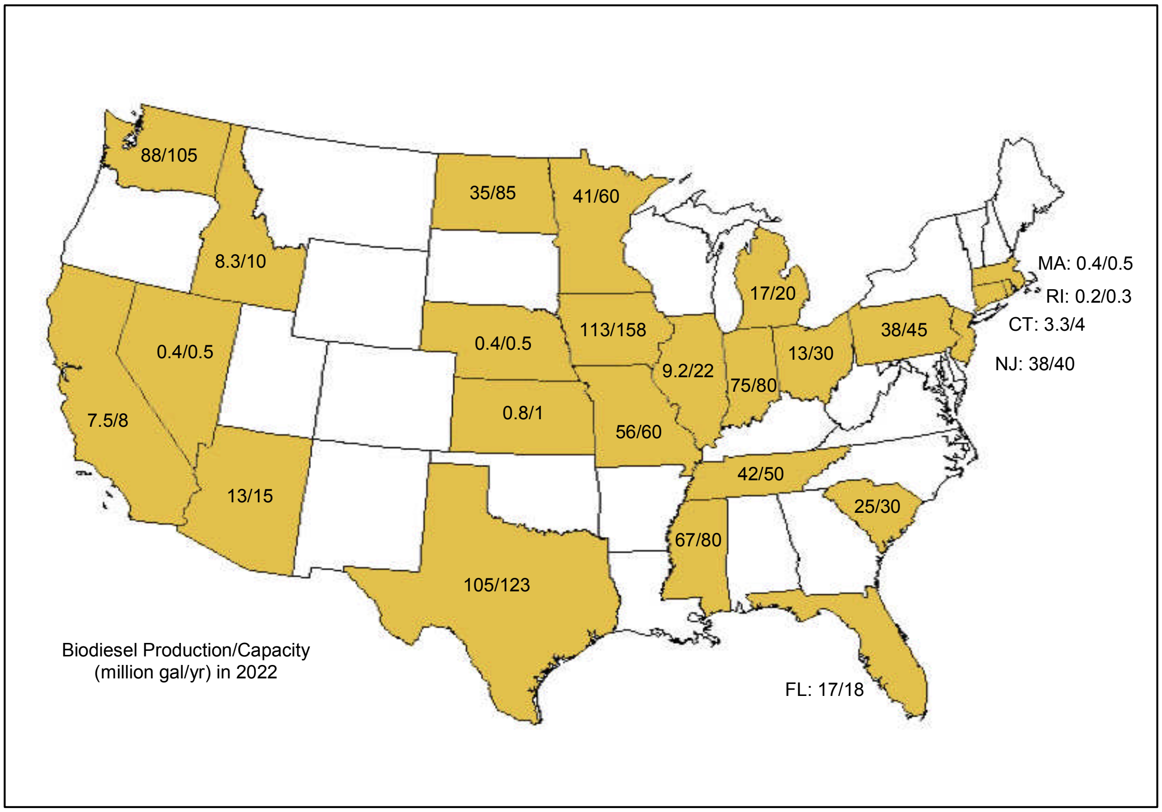
We project that between now and 2022 plants will continue to compete and consolidate to make fewer plants of larger size. During this period most plants will have added the pre-treatment and feedstock segregation capacity to process any mix of feedstock types available in their area.

From the projected list of plant locations, emission quantities were generated for each county based on each plant's biodiesel production rate. Spreadsheets showing lists of the representative plants and their emission factors as input in the inventory and air quality models can be found in the docket. This information is summarized here in Table 1.8-21 and Figure 1.8-9.

Table 1.8-50. Summary of biodiesel industry and forecast used for AQM.[492]

	2008	2022
Total production capacity on-line (million gal/yr)	2,610	1,050
Number of operating plants	176	35
Median plant size (million gal/yr)	5	30
Total biodiesel production (million gal)	700	810
Average capacity factor	0.27	0.77

Figure 1.5-18. Biodiesel industry forecast for 2022



1.8.2.2 Downstream Consumption Inputs

Biodiesel, like ethanol, is generally blended at the end of the distribution chain, just before delivery to retail outlets. Because of its chemical properties, it is not currently considered fungible with diesel fuel, and thus its blend level in fuels offered for sale is typically deliberate and explicit. Renewable diesel, on the other hand, is a fuel or hydrocarbon blendstock which can be blended into fungible fuel at any point in the distribution system, such that the blend level at the final point of use is not typically of concern and, in fact, would probably be difficult to determine. Because of its nature, and the relatively small volumes we are projecting (less than 0.5 billion gallons per year), we have not analyzed distribution or use impacts for renewable diesel. The remainder of this section addresses biodiesel use.

Vehicle and engine manufacturers recognize biodiesel as a lubricity improver at low levels, something that is useful with ultra-low sulfur diesel fuel now phasing in across the country. Therefore, most state that their products are compatible with blends up to 5%, and a few suggest blends up to 20% can be used without problems. Therefore, our analysis assumes blends up to 5% can find widespread use.

In order to conduct our distribution and emissions analyses, we needed to forecast approximate volumes of biodiesel to be used in each state. We considered transportation diesel fuel and home heating oil as the primary uses for biodiesel. For transportation fuel estimates, we assumed that biodiesel would be preferentially used in states that have blend mandates or significant per-gallon incentives. Table 1.8-21 shows the states with such mandates and incentives on record as of summer 2008, as well as the associated potential biodiesel volumes based on 2005 diesel fuel use.[493] State-level forecasts were not available for transportation fuel use, thus the reliance on historical data for this estimate.

Table 1.8-21.
State biodiesel incentives as of summer 2008 and potential volumes based on 2005 data.[494]

State	Incentive or mandate	Diesel fuel use (million gal/yr)	2% biodiesel (million gal/yr)	5% biodiesel (million gal/yr)
IL	per-gallon tax incentive(s) for B11+, state fleet requirement	1,660	33.2	
KS	per-gallon tax incentive(s) for B2+	816	16.3	
LA	B2 mandate with some conditions	1,734	34.7	
MA	B2 mandate, increasing to B15 with some conditions	491		24.5
MI	per-gallon tax incentive(s) for B5+	1,071		53.5
MN	B2 mandate; state fleet requirement	999	20.0	
NC	per-gallon tax incentive(s), B2 school bus requirement	1,234	24.7	
ND	per-gallon tax incentive(s)	358	7.2	
NE	per-gallon tax incentive(s)	547	10.9	
NM	B5 mandate with some conditions	475		23.7
OH	per-gallon tax incentive(s)	1,556	31.1	
OR	B2 mandate, increasing to B5 with some conditions	738		36.9
SC	per-gallon tax incentive(s)	764	15.3	
SD	per-gallon tax incentive(s)	263	5.3	
TX	per-gallon tax incentive(s)	5,339	106.8	
WA	B2 mandate, increasing to B5 with some conditions	1,230	24.6	
			Total biodiesel	**468.7**

Table 1.8-22 shows home heating oil use in 2005. We estimate potential biodiesel use in heating oil at 89 million gallons per year based on a 2% blend in all heating oil north of the Washington, DC, area (i.e., PADD 1A and 1B). This area was chosen because it is where the majority of heating oil is used, and should have adequate biodiesel access from New Jersey, Pennsylvania, and Connecticut in our forecasted production scenarios. To the extent that heating oil use declines over time, the blend levels may increase in some areas or in the shoulder seasons, such that the total biodiesel volume used in this market would not decline drastically.

Table 1.8-22.
Potential biodiesel use in heating oil based on 2005 data.[495]

Area	Heating oil (million gal/yr)	2% biodiesel (million gal/yr)	Volume Used (million gal/yr)
U.S.	5,565,489	111.3	
PADD 1	4,759,198	95.2	
PADD 1A	1,923,405	38.5	38.5
CT	545,910	10.9	
ME	308,464	6.2	
MA	674,324	13.5	
NH	175,484	3.5	
RI	136,618	2.7	
VT	82,604	1.7	
PADD 1B	2,529,106	50.6	50.6
DE	33,221	0.7	
DC	12,832	0.3	
MD	149,919	3.0	
NJ	322,088	6.4	
NY	1,282,899	25.7	
PA	728,147	14.6	
PADD 1C	306,687	6.1	
FL	3,608	0.1	
GA	1,520	0.0	
NC	81,528	1.6	
SC	8,810	0.2	
VA	197,255	3.9	
WV	13,966	0.3	
	Total used for biodiesel in heating oil		**89.1**

Combining these volumes gives 558 million gallons per year potential biodiesel consumption, leaving approximately 250 million gallons to be sold in blends above the projected levels shown here, or in states not included here. For more on biodiesel-related distribution issues and costs, refer to Section 4.2.2.2.

Chapter 2: Lifecycle GHG Analysis

2.1 Chapter Overview

This chapter describes each component of the analysis undertaken by EPA as part of the RFS2 rulemaking to determine lifecycle GHG emissions impacts for renewable and petroleum-based transportation fuels. The chapter is organized as follows:

- Section 2.2 provides background about lifecycle analysis for RFS2 and key modeling updates EPA has made since the proposed rule.
- Section 2.3 lays out the goals and scope of our analysis.
- Section 2.4 provides a detailed explanation of each component in EPA's lifecycle analysis of renewable fuels.
    - Section 2.4.1 summarizes the Agency's overall biofuel modeling approach.
    - Section 2.4.2 focuses on domestic agricultural sector GHG emissions impacts, including our evaluation of changes in agricultural inputs and livestock production.
    - Section 2.4.3 discusses international agricultural impacts.
    - Section 2.4.4 explains EPA's assessment of GHG emissions impacts from biofuel-induced domestic and international land conversions, including our quantification of uncertainty in international land conversion GHG emissions impacts.
    - Section 2.4.5 describes our accounting for lifecycle GHG emissions over time.
    - Section 2.4.6 explains EPA's analysis of biofuel feedstock transport.
    - Section 2.4.7 discusses energy use and GHG emissions from biofuel processing.
    - Section 2.4.8 includes our updated analysis of fuel transport and distribution.
    - Section 2.4.9 covers renewable fuel tailpipe emissions.
    - Section 2.4.10 discusses other potential indirect impacts from biofuel production.
    - Section 2.4.11 describes other modeling approaches that EPA considered for lifecycle GHG analysis.
- Section 2.5 presents EPA's analysis of baseline gasoline and diesel lifecycle GHG emissions for comparison with biofuels.
- Section 2.6 discusses the fuel-specific lifecycle GHG emissions results, including sensitivity analyses.
- Section 2.7 includes our analysis of the overall GHG impacts of the rulemaking volumes.
- Section 2.8 concludes the chapter with a discussion of the effects of the RFS2 on global temperature and sea level.

2.2 Background for Estimating Fuel Lifecycle Greenhouse Gas Emissions

2.2.1 Lifecycle Analysis for the RFS2 Proposal

Lifecycle modeling of transportation fuels, often referred to as fuel cycle or well-to-wheel analysis, assesses the net impacts of a fuel throughout each stage of its production and use including production / extraction of the feedstock, feedstock transportation, fuel production, fuel transportation and distribution, and tailpipe emissions. Use of a lifecycle approach to analyze different transportation fuels requires modeling and evaluation of many different input factors.

Lifecycle assessments can be divided into two major methodological categories: attributional and consequential.[496]

An attributional approach to GHG emissions accounting in products provides information about the GHG emitted directly by a product and its life cycle. The product system includes processes that are directly linked to the product by material, energy flows or services following a supply-chain logic.

A consequential approach to GHG emissions accounting in products provides information about the GHG emitted, directly or indirectly, as a consequence of changes in demand for the product. This approach typically describes changes in GHG emissions levels from affected processes, which are identified by linking causes with effects.

The definition of lifecycle greenhouse gas emissions established by Congress states that:

> *The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.*[497]

This definition and specifically the clause *"(including direct emissions and significant indirect emissions such as significant emissions from land use changes)"* requires the Agency to consider a consequential lifecycle analyses and to develop a methodology that accounts for all of the important factors that may significantly influence this assessment, including the secondary or indirect impacts of expanded biofuels use.

Furthermore, independent of the statutory language the Agency believes it is important to include secondary, indirect, or consequential impacts of biofuel use, specifically:

- Capturing secondary market driven agricultural sector impacts, such as changes in other crop patterns and livestock production as a response to changing prices in biofuel feedstocks.

- Production of co-products from biofuel production requires some type of allocation, either splitting emissions of fuel production between fuel and co-products or examining the use of co-products in other markets. For example in the case of corn ethanol, the co-product of ethanol production is a feed product that is assumed to replace the use of corn and soybean meal. Therefore, the emissions of producing an equivalent amount of corn and soybean meal to these co-products are subtracted from the lifecycle assessment. This requires modeling of the co-product economic markets.

- To the extent that they are included in attributional lifecycle analyses, land use impacts are typically confined to direct impacts, e.g., land converted to produce corn directly used for ethanol production. This does not capture effects of land converted to produce crops that are indirectly impacted by increased biofuel production. One specific example of this is increased corn ethanol production in the U.S. could lead to decreased crop exports resulting in increased crop production and land use impacts internationally. Another example is corn production increases resulting in less rice production and lower CH_4 emissions.

- Consideration of specific policies and interaction between different fuel volumes could have very distinct impacts especially in the agricultural sector.

The lifecycle methodology developed for the RFS2 rulemaking analysis included the use of economic models to perform a consequential type of lifecycle analysis.

The consequential approach of incorporating economic models into a lifecycle assessment is not a new concept. Most notably the Economic Input-Output Lifecycle Assessment (EIO-LCA) method has been employed in the past. The EIO-LCA method estimates the materials and energy resources required for, and the environmental emissions resulting from, activities in the overall economy. The EIO-LCA method was theorized and developed by economist Wassily Leontief in the 1970s based on his earlier input-output work from the 1930s for which he received the Nobel Prize in Economics. Researchers at the Green Design Institute of Carnegie Mellon University operationalized this method in the mid-1990s, once sufficient computing power was widely available to perform the large-scale matrix manipulations required in real-time. This work relies on static input-output tables of the U.S. economy to determine the full economy wide impacts of producing a product or service.

Mark Delucchi at the Institute of Transportation Studies of the University of California Davis has developed the Lifecycle Emissions Model (LEM) that looks at transportation fuels. He has also highlighted the need to look at market impacts when considering biofuel production and specifically to consider land use changes.[498] There have also been several studies examining the consequential or economic-based life cycle assessment including several focusing on the agricultural sector.

Currently, no single model captures all of the complex interactions associated with estimating lifecycle GHG emissions for biofuels, taking into account the "significant indirect emissions such as significant emissions from land use change" required by EISA. For example, some lifecycle analysis tools typically used in the past focused on process modeling—the energy and resultant emissions associated with the direct production of a fuel at a petroleum refinery or biofuel production facility. But this is only one component in the production of the fuel. Clearly in the case of biofuels, impacts from and on the agricultural sector are important, because this sector produces feedstock for biofuel production. Commercial agricultural operations make many of their decisions based on an economic assessment of profit maximization. Assessment of the interactions throughout the agricultural sector requires an analysis of the commodity markets using economic models. However, existing economy wide general equilibrium economic models are not detailed enough, on their own, to capture the specific agricultural sector interactions critical to our analysis (e.g., changes in acres by crop type) and would not provide the types of outputs needed for a thorough GHG analysis. As a result, EPA has used a set of tools that are best suited for each specific component of the analysis to create a more comprehensive estimate of GHG emissions. Where no direct links between the different models exist, specific components and outputs of each are used and combined to provide an analytical framework and the composite lifecycle assessment results.

To estimate the changes in the domestic agricultural sector (e.g., changes in crop acres resulting from increased demand for biofuel feedstock or changes in the number of livestock due to higher corn prices) and their associated emissions, we used the Forestry and Agricultural Sector Optimization Model (FASOM), developed by Texas A&M University and others. FASOM is a partial equilibrium economic model of the U.S. forest and agricultural sectors. EPA selected the FASOM model for this analysis for several reasons. FASOM is a comprehensive forestry and agricultural sector model that tracks over 2,000 production possibilities for field crops, livestock, and biofuels for private lands in the contiguous United States. It accounts for changes in CO_2, methane, and N_2O from most agricultural activities and tracks carbon sequestration and carbon losses over time. Another advantage of FASOM is that it captures the impacts of all crop production, not just biofuel feedstock. Thus, as compared to some earlier assessments of lifecycle emission, using FASOM allows us to determine secondary agricultural sector impacts, such as crop shifting and reduced demand due to higher prices. It also captures changes in the livestock market (e.g., smaller herd sizes that result from higher feed costs) and U.S. export changes. FASOM also has been used by EPA to consider U.S. forest and agricultural sector GHG mitigation options.[499]

The output of the FASOM analysis includes changes in total domestic agricultural sector fertilizer and energy use. These are calculated based on the inputs required for all the different crops modeled and changes in the amounts of the different crops produced due to increased biofuel production. FASOM output also includes changes in the number and type of livestock produced. These changes are due to the changes in animal feed prices and make-up due to the increase in biofuel production. The FASOM output changes in fertilizer, energy use, and livestock are combined with GHG emission factors from those sources to generate biofuel lifecycle impacts. The GHG emission factors for fuel and fertilizer production come from the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) spreadsheet analysis tool developed by Argonne National Laboratories, and livestock GHG emission factors are from IPCC guidance.

GREET includes the GHG emissions associated with the production and combustion of fossil fuels (diesel fuel, gasoline, natural gas, coal, etc.). GREET also estimates the GHG emissions associated with electricity production required for agriculture and biofuel production. For the agricultural sector, we also relied upon GREET to provide GHG emissions associated with the production and transport of agricultural inputs such as fertilizer, herbicides, pesticides, etc. GREET has been under development for several years and has undergone extensive peer review through multiple updates. Of the available data sources of information on lifecycle GHG emissions of fossil energy and agricultural sector inputs consumed, we believe that GREET offers the most comprehensive treatment of emissions from the covered sources. GREET version 1.8c was the primary version used in this analysis.

To estimate the domestic impacts of N_2O emissions from fertilizer application, we used the CENTURY and DAYCENT models, developed by Colorado State University. The DAYCENT model simulates plant-soil systems and is capable of simulating detailed daily soil water and temperature dynamics and trace gas fluxes (CH_4, N_2O, NOx and N_2). The CENTURY model is a generalized plant-soil ecosystem model that simulates plant production, soil carbon dynamics, soil nutrient dynamics, and soil water and temperature. Model results for N_2O emissions from different crop and land use changes were combined with FASOM output to generate overall domestic N_2O emissions.

FASOM output also provides changes in total land use required for agriculture and land use shifting between crops, and interactions with pasture, and forestry. This output is combined with emission factors from land use change to generate domestic land use change GHG emissions from increased biofuel production.

To estimate the impacts of biofuels feedstock production on international agricultural and livestock production, we used the integrated Food and Agricultural Policy and Research Institute international models, as maintained by the Center for Agricultural and Rural Development (FAPRI-CARD) at Iowa State University. These models capture the biological, technical, and economic relationships among key variables within a particular commodity and across commodities. FAPRI-CARD is a worldwide agricultural sector economic model that was run by the Center for Agricultural and Rural Development (CARD) at Iowa State University on behalf of EPA. The FAPRI models have been previously employed to examine the impacts of World Trade Organization proposals, changes in the European Union's Common Agricultural Policy, analyze farm bill proposals since 1984, and evaluate the impact of biofuel development in the United States. In addition, the FAPRI models have been used by the USDA Office of Chief Economist, Congress, and the World Bank to examine agricultural impacts from government policy changes, market developments, and land use shifts.

The output of the FAPRI-CARD model included changes in crop acres and livestock production by type and by country globally. Unlike FASOM, the FAPRI-CARD output did not include changes in fertilizer or energy use or have land type interactions built in. These were developed outside the FAPRI-CARD model and combined with the FAPRI-CARD output to generate GHG emission impacts.

Crop input data by crop and country were developed and combined with the FAPRI-CARD output crop acreage change data to generate overall changes in fertilizer and energy use. These fertilizer and energy changes along with the FAPRI-CARD output livestock changes were then converted to GHG emissions based on the same basic approach used for domestic sources, which involves combining with emission factors from GREET and IPCC.

The FAPRI-CARD model does predict how much crop land will change in other countries but does not predict what type of land such as forest or pasture will be affected. We used data analyses provided by Winrock International to estimate what land types will be converted into crop land in each country and the GHG emissions associated with the land conversions. Working with Winrock, we used recent satellite data to analyze recent land use changes around the world that have resulted from the social, economic, and political forces that drive land use. In our assessment, we are assuming that these recent drivers of land use change will remain in relative affect through our 2022 modeling time frame such that the recent trends in land use change are indicative of land use changes likely to result in 2022 due to biofuel production. We combined the recent land use change patterns with various estimates of carbon stocks associated with different types of land at the state level. This international land use assessment is an important consideration in our lifecycle GHG assessment and is explained in more detail later in Section 2.4.4 in this chapter.

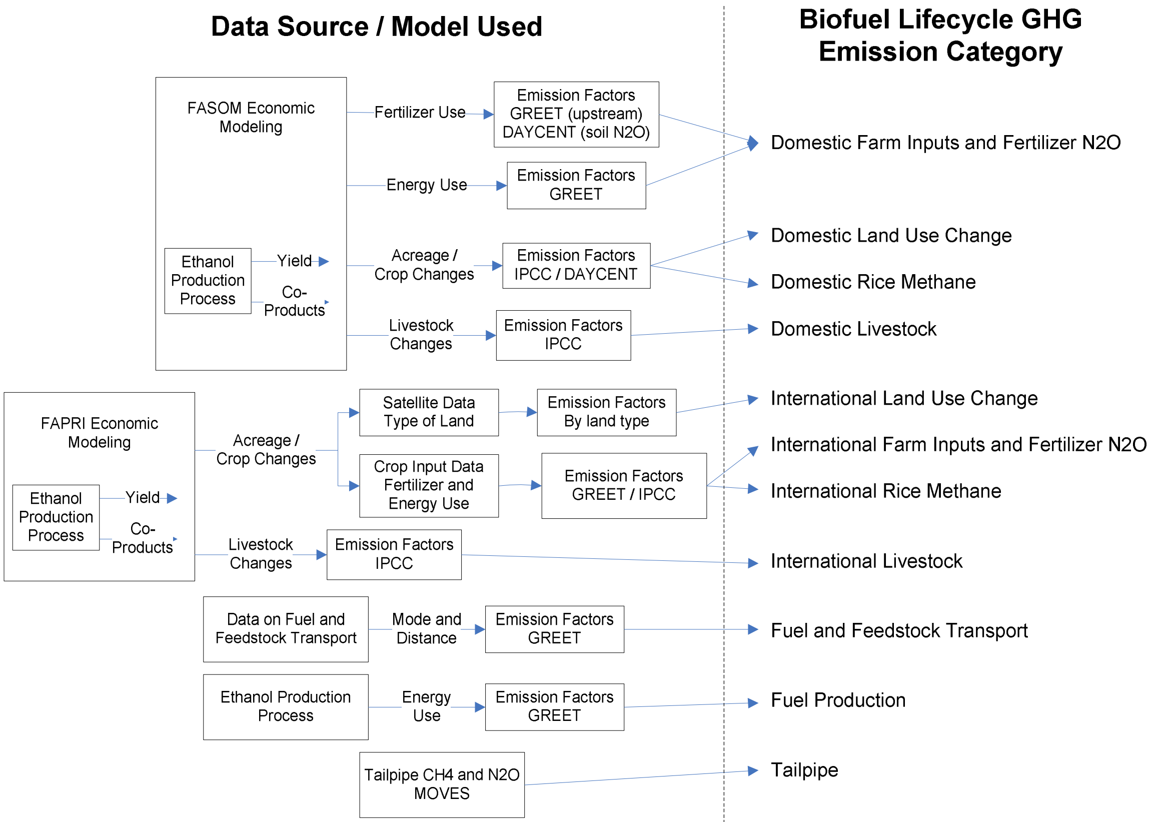
Additional modeling and data sources used to determine the GHG emissions of other stages in the biofuel lifecycle include studies and data on the distance and modes of transport needed to ship feedstocks from the field to the biofuel processing facility and the finished biofuel from the facility to end use. These distances and modes are used to develop the amount and type of energy used for transport which are combined with GREET factors to generate GHG emissions.

We also calculate energy use needed in the biofuel processing facility from industry sources, reports, and process modeling. This energy use is combined with emissions factors from GREET to develop GHG impacts of the biofuel production process

To test the robustness of the FASOM, FAPRI-CARD and Winrock results, we also examined biofuel land use change impacts with the Global Trade Analysis Project (GTAP) model, a multi-region, multi-sector, computable general equilibrium model that estimates changes in world agricultural production. Maintained through Purdue University, GTAP projects international land use change based on the economics of land conversion, rather than using the historical data approach applied by FAPRI-CARD/Winrock. GTAP is designed to project changes in international land use as a result of the change in U.S. biofuel policies, based on the relative land use values of cropland, forest, and pastureland. The GTAP design has the advantage of explicitly modeling the competition between different land types due to a change in policy. As further discussed in Section 2.4.11, the GTAP model results were generally consistent with our FAPRI-CARD/satellite data analysis, in particular supporting the significant impact on international land use.

Figure 2.2-1 graphically shows the different models used and what parts of the lifecycle they are used to represent.

Figure 2.2-1 System Boundaries and Models Used



2.2.2 Updates for this Final Rulemaking

Throughout the development of EPA's lifecycle analysis, the Agency has employed a collaborative, transparent, and science-based approach. EPA's lifecycle methodology, as developed for the RFS2 proposal, required breaking new scientific ground and using analytical tools in new ways. The work was generally recognized as state of the art and an advance in lifecycle modeling, specifically regarding the indirect impacts of biofuels.

However, the complexity and uncertainty inherent in this work made it extremely important that we seek the advice and input of a broad group of experts and stakeholders. In order to maximize stakeholder outreach opportunities, the comment period for the proposed rule was extended to 120 days. In addition to this formal comment period, EPA made multiple efforts to solicit public and expert feedback on our approach. Beginning early in the NPRM process and continuing throughout the development of this final rule, EPA held hundreds of meetings with stakeholders, including government, academia, industry, and non-profit organizations, to gather expert technical input. Our work was also informed heavily by consultation with other federal agencies. For example, we have relied on the expert advice of USDA and DOE, as well as incorporating the most recent inputs and models provided by these Agencies. Dialogue with the State of California and the European Union on their parallel, on-going efforts in GHG lifecycle analysis also helped inform EPA's methodology. As described below, formal technical exchanges and an independent, formal peer review of the methodology were also significant components of the Agency's outreach. A key result of our outreach effort has been awareness of new studies and data that have been incorporated into our final rule analysis.

Technology Exchanges: Immediately following publication of the proposed rule, EPA held a two-day public workshop focused specifically on lifecycle analysis to assure full understanding of the analyses conducted, the issues addressed, and the options discussed. The workshop featured EPA presentations on each component of the methodology as well as presentations and discussions by stakeholders from the renewable fuel community, federal agencies, universities, and environmental groups. The Agency also took advantage of opportunities to meet in the field with key, affected stakeholders. For example, the Agency was able to twice participate in meetings and tours in Iowa hosted by the local renewable fuel and agricultural community. As described in this section, one of the many outcomes of these meetings was an improved understanding of agricultural and biofuel production practices.

As indicated in the proposal, our lifecycle results were particularly impacted by assumptions about land use patterns and emissions in Brazil. During the public comment process we were able to update and refine these assumptions, including the incorporation of new, improved sources of data based on Brazil-specific data and programs. In addition, the Agency received more recent trends on Brazilian crop productivity, areas of crop expansion, and regional differences in costs of crop production and land availability. Lastly, we received new information on the effectiveness of current efforts to curb deforestation allowing the Agency to better predict this impact through 2022.

Peer Review: To ensure the Agency made its decisions for this final rule on the best science available, EPA conducted a formal, independent peer review of key components of the analysis. The reviews were conducted following the Office of Management and Budget's peer review guidance that ensures consistent, independent government-wide implementation of peer review, and according to EPA's longstanding and rigorous peer review policies. In accordance with these guidelines, EPA used independent, third-party contractors to select highly qualified peer reviewers. The reviewers selected are leading experts in their respective fields, including lifecycle assessment, economic modeling, remote sensing imagery, biofuel technologies, soil science, agricultural economics, and climate science. They were asked to evaluate four key components of EPA's methodology: (1) land use modeling, specifically the use of satellite data and EPA's proposed land conversion GHG emission factors; (2) methods to account for the variable timing of GHG emissions; (3) GHG emissions from foreign crop production (both the modeling and data used); and (4) how the models EPA relied upon are used together to provide overall lifecycle estimates. The full peer review records, including all of the charge questions and peer reviewer responses, are available in the public docket for this rulemaking.

The advice and information received through this peer review are reflected throughout this chapter. The reviewers also provided recommendations that have helped to inform the larger methodological decisions presented in this final rule. For example, the reviewers in general supported the importance of assessing indirect land use change and determined that in general EPA used the best available tools and approaches for this work. However, the review also recognized that no existing model comprehensively simulates the direct and indirect effects of biofuel production both domestically and internationally, and therefore model development is still evolving. The uncertainty associated with estimating indirect impacts and the difficulty in developing precise results also were reflected in the comments. In the long term, this peer review will help focus EPA's ongoing lifecycle analysis work as well as our future interactions with the National Academy of Science and other experts.

Altogether, the many and extensive public comments we received to the rule docket, the numerous meetings, workshops and technical exchanges, and the scientific peer review have all been instrumental to EPA's ability to advance our analysis between proposal and final and to develop the methodological and regulatory approach described in this section.

Based on peer review results as well as other comments received we have made several updates to our modeling since the NPRM analysis as shown in Table 2.2-1.

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Table 2.2-1. Key Lifecycle Modeling Updates

Update	Source
Updates to Domestic Agricultural Sector Modeling*:*	
• Incorporated the FASOM forestry module	• Updated FASOM Forestry component
• Added new land classifications: cropland, cropland-pasture, rangeland, forest-pasture, forest, CRP, developed land	• U.S. land cover databases
• Reflected new data on projected switchgrass yields	• New data from PNNL on switchgrass yields
• Updated N_2O / soil carbon emissions factors	• DAYCENT/CENTURY model updates by Colorado State University
• Updated emission factors for farm input production	• New version of GREET (version 1.8c)
Updates to International Agricultural Sector Modeling:	
• Incorporated a Brazil module into the international model framework o Regional crop and pasture modeling	• FAPRI-CARD Brazil Module[148]
• Added price induced yield changes (e.g., long term elasticity for the Corn Belt in the U.S. 0.07)	• FAPRI-CARD 2010 U.S. And World Agricultural Outlook
• Updated international agricultural GHG emission estimates	• International Fertilizer Industry Assoc. (2009)[500] and pesticide consumption from FAOStat[501]
• Updated Brazil sugarcane production based on recent studies	• Macedo (2008)[502]
Updates to Biofuel Processing in Both Domestic and International Agricultural Sector Modeling:	
• Built in corn fractionation pathways (with co-product markets, etc.)	• USDA
• Adjusted DGS co-product replacement rates o Reflected studies that indicate more efficient use of co-product	• Empirical studies by Argonne Laboratory and University of Minnesota: Arora, Wu and Wang (2008)[503] and Shurson (2009)[504]
• Added biodiesel glycerin co-product credit	• Based on data from NBB and GREET
• Updated process energy use	• New studies by USDA[505], NREL[506,507,508] and Energy Resources Center[509]
Updates to Land Use Change Modeling:	
• Used more recent / longer time coverage / higher resolution satellite data - 2001-2007	• MODIS V5 (2009)[510]
• Augmented satellite data with region specific data where available (e.g., data from Brazil on pasture intensification)	• FAPRI-CARD Brazil module
• New soil carbon data	• Harmonized World Soil Database (2009)[511]
• New studies monitoring long-term forest growth rates	• Lewis et al. (2009)[512] and Phillips et al. (2008)[513]
Petroleum Baseline Updates:	
• Updated 2005 petroleum baseline	• DOE/NETL (2009)[514]

[148] Iowa State University working with Brazilian experts developed this module which has been incorporated into the FAPRI-CARD 2010 U.S. And World Agricultural Outlook, released date early 2010

Furthermore, in the proposal, we asked for comment on whether and how to conduct an uncertainty analysis to help quantify the magnitude of this uncertainty and its relative impact on the resulting lifecycle emissions estimates. The results of the peer review, and the feedback we have received from the comment process, supported the value of conducting such an analysis. Therefore, working closely with other government agencies as well as incorporating feedback from experts who commented on the rule, one of the main changes we made since the proposal was that we have quantified the uncertainty associated with specifically the international indirect land use change emissions associated with increased biofuel production. More discussion of treatment of uncertainty is found in Section 2.4.4.2.8.

2.3 Goals and Scope of This Analysis

Lifecycle analysis is used in several ways for this rulemaking. Fuel-specific GHG reductions are used to develop threshold determinations for specific fuels. Lifecycle analysis is also used to determine the overall impact of the rulemaking on GHG emissions worldwide. The first step was to establish the goals and scope for this analysis, as summarized below.

2.3.1 Goal

The RFS2 rulemaking involves determining lifecycle GHG impacts of specific fuels and fuel pathways for comparison with thresholds as defined in the legislation. Obligated parties will be required to use mandated quantities of renewable fuels, but only fuels that meet the GHG thresholds can qualify under the program. (Fuels produced at grandfathered facilities are exempt from these GHG threshold requirements.) The lifecycle GHG reductions represent the GHG differences between renewable fuels relative to the petroleum-based gasoline and diesel that they displace. The lifecycle methodology described here is used to determine the GHG displacement values for different renewable fuels to be compared to the thresholds. Therefore this analysis will provide:

- Amount of GHG emissions (on a mass basis) per amount of fuel produced (on an energy content basis) for both conventional petroleum based fuels and renewable fuels.
- Results are combined to quantify the emission change per energy unit (i.e., per BTU) of renewable fuel compared to that for the conventional fuel replaced.

2.3.2 Scope

2.3.2.1 Scenario Analysis

To quantify the lifecycle GHG emissions associated with the increase in renewable fuel mandated by EISA, we needed to compare the impacts of renewable fuels with EISA to a reference case without EISA. Since it is not practical or workable to conduct such an analysis and come up with factors for every year, to carry out this analysis we chose to look at the final year of the RFS2 standards when they are fully phased in. For our reference case we assumed a "business as usual" volume of a particular renewable fuel based on what would likely be in the fuel pool in 2022 without EISA as predicted by the Energy Information Agency's Annual Energy Outlook (AEO) for 2007 (which took into account the economic and policy factors in existence in 2007 before EISA). For our control case we assumed the higher volumes of renewable fuels as mandated by EISA for 2022. For each individual biofuel, we analyzed the incremental impact of increasing the volume of that fuel to the total mix of biofuels needed to meet the EISA requirements while holding volumes of other fuels constant. Any changes between now and 2022 in factors such as crop yields, energy costs, or production plant efficiencies, both domestically and internationally, are reflected in both scenarios. Rather than focus on the impacts associated with a specific gallon of fuel and tracking inputs and outputs across different lifecycle stages, we determined the overall aggregate impacts across sections of the economy in response to a given volume change in the amount of biofuel produced. We then normalize those impacts to a gallon of fuel by dividing total impacts over the given volume change. In the case of overall rule impacts, we analyze the change in reference vs. control case volumes for all fuels together and take the absolute GHG results (e.g., do not normalize the overall rule impacts).

We did not calculate the emission impacts for each gallon of fuel based upon its unique production characteristics which could vary widely across the nation (e.g., a gallon of ethanol produced using corn grown in Iowa may have different direct lifecycle emissions impacts than a gallon of ethanol produced at an identical facility in Nebraska using corn grown in Nebraska due to regional differences in agricultural practices. However, on a lifecycle basis, considering the indirect impacts in the context of the entire corn market they are not different). Rather, we determined the overall aggregate impacts across sections of the economy in response to a given volume change in the amount of biofuel produced. In the case of agricultural impacts, we assessed the impact on the entire U.S. agricultural system that would result from expanded demand for biofuel feedstock. We then normalized those impacts to a gallon of fuel by dividing total impacts over the renewable fuel volume change between our business as usual case and the EISA volumes. Similarly, we estimated the typical emissions impact of a type of biofuel production facility (e.g., a plant that uses the dry mill process to turn corn starch into ethanol). The emissions assessment from a typical facility was then ascribed to all biofuel produced across facilities using that same basic technology.

We focus our final rule analyses on 2022 results for two main reasons. First, it would require an extremely complex assessment and administratively difficult implementation program to track how biofuel production might continuously change from month to month or year to year. Instead, it seems appropriate that each biofuel be assessed a level of GHG performance that is constant over the implementation of this rule, allowing fuel providers to anticipate how these GHG performance assessments should affect their production plans. Second, it is appropriate to focus on 2022, the final year of ramp up in the required volumes of renewable fuel as this year. Assessment in this year allows the complete fuel volumes specified in EISA to be incorporated. This also allows for the complete implementation of technology changes and updates that were made to improve or modeling efforts. For example, the inclusion of price induced yield increases and the efficiency gains of DDGS replacement are phased in over time. Furthermore, these changes are in part driven by the changes in earlier years of increased biofuel use.

Several of the lifecycle emission impacts for one fuel are interrelated with those of another fuel, in particular the land-use changes. For our analysis of the overall GHG impacts of the program (discussed in Section 2.7), we modeled all of the fuel changes simultaneously to determine the land-use impact. However, from that analysis it is not possible to differentiate the contribution of the land-use change to one fuel vs. another. As a result, for this analysis we had to model the impacts of just one fuel change at a time. In doing this we have held the other fuel volumes constant at their mandated levels in order to best approximate the impacts a single fuel change would have in the context of the full RFS2 standard volumes.

We used the same approach to determine the lifecycle GHG emissions for corn ethanol, cellulosic ethanol, biodiesel produced from soybean (and other vegetable) oils, and biodiesel produced using waste oils as feedstock. For waste oils, we note that no land use changes are included in the FASOM assessment, because any land use impacts are attributed to the original purpose of the feedstock (e.g.., the use of the vegetable oil for cooking or the production of animals for their meat), rather than the biofuel produced from the recovered waste material.

FASOM does not model feedstocks for fuels produced outside the U.S. We addressed imported ethanol by analyzing the difference in total GHG emissions based on two 2022 scenarios using only the results from FAPRI-CARD modeling runs: (1) the business as usual reference case volume of 0.6 Bgal and (2) an RFS2 projected volume of 2.2 Bgal of imported sugarcane ethanol.

Current models present some challenges in estimating GHG lifecycle emissions for cellulosic biofuels. For example, the FAPRI-CARD model used for this analysis did not include switchgrass or similar energy crops, and could only use corn stover or other food crop residues as feedstock in predicting cellulosic biofuel impacts. To overcome this limitation we ran the FASOM model with a switchgrass scenario to generate domestic land use and crop change results. We then applied these domestic crop changes by region to the FAPRI-CARD model to generate the international land use change and crop shifting due to the domestic impacts predicted by the FASOM switchgrass scenario.

For biofuels made from wastes and byproducts (e.g., MSW, rendered fats and waste oils and corn stover feedstock), we assumed no land use changes, because these biofuel feedstocks do not compete for domestic crop acreage. For corn stover, we analyzed only the change in domestic GHG emission resulting from an increase in fertilizer replacement application rates to compensate for the removal of stover from the land. Table 2.3-1 shows the different fuel scenarios considered.

Table 2.3-1. Fuel Volume Scenarios Considered in This Analysis (Billions of Gallons)

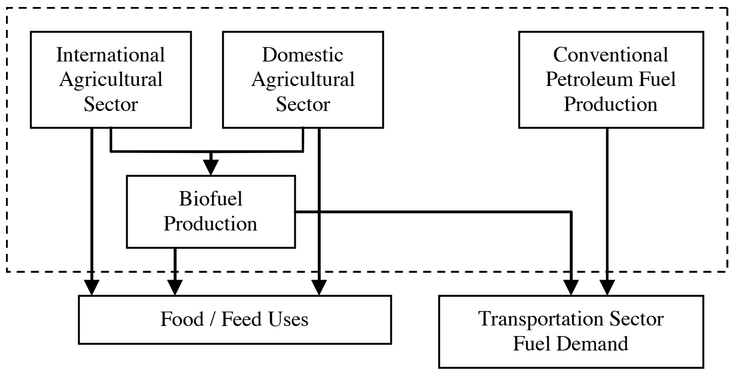
Biofuel	Reference Case – Low Volume	Control Case – High Volume	Change
Corn Ethanol	12.3	15.0	2.7
Switchgrass Cellulosic Ethanol	0	7.9	7.9
Corn Residue Cellulosic Ethanol	0	4.9	4.9
Imported Sugarcane Ethanol	0.6	2.2	1.6
Soybean Oil Biodiesel	0.1	0.6	0.5

2.3.2.2 System Boundaries

It is important to establish clear system boundaries in lifecycle analysis. By determining a common set of system boundaries, different fuel types can then be validly compared. As described in the previous section, we have assessed the direct and indirect GHG impacts in each stage of the full fuel lifecycle for biofuels and petroleum fuels.

Figure 2.3-1 Figure 2.3-1provides a simplified diagram describing the system studied.

Figure 2.3-1. Simplified Lifecycle System Diagram



The different fuel volume scenarios were compared based on delivery of the same functions, in this case providing for both the agricultural sector market and transportation fuels markets. Within the overall system shown in

Figure 2.3-1 the unit process listed in Table 2.3-2 will be considered.

Table 2.3-2. Unit Processes Considered

Biofuel	Petroleum-Based Fuel
Feedstock Agriculture	Crude Oil Extraction
Feedstock Transport	Crude Oil Transport
Feedstock Processing & Biofuel Production	Refining
Biofuel Transport and Distribution	Fuel Transport and Distribution
Biofuel Tailpipe Emissions	Fuel Tailpipe Emissions

Included in each unit process shown in **Table 2.3-2** are the emissions and energy use associated with each operation as well as upstream components that feed into them. For example, the feedstock agriculture stage includes emissions from fuel used in tractors as well as from producing and transporting the fertilizer used in the field. Electricity production emissions are included in almost all of the stages shown. For direct impacts, as was the case in the proposal analysis, this results in system boundaries that include operation-related activities, but not infrastructure-related activities. As such, while we do include the emissions associated with the operation of farm equipment and trucks used for feedstock / fuel transportation we do not include the emissions associated with the production of the equipment or vehicles. Furthermore, we include the emissions from the operations of biofuel production plants and petroleum refineries but we do not include emissions from producing the material used to construct the facilities.

In determining what indirect impacts to include in the system boundaries of this analysis we focus on the goal and scope of the analysis as specified by the statutory language in EISA.

The Act specifies different categories of renewable fuels, conventional renewable fuel, advanced biofuel, cellulosic biofuel, and biomass-based diesel. The categories of fuel are defined in part based on their GHG emissions. For example for cellulosic biofuel:

> *The term 'cellulosic biofuel' means renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions, as determined by the Administrator, that are at least 60 percent less than the baseline lifecycle greenhouse gas emissions.*

So, the main goal of this analysis is to determine the lifecycle GHG emissions of different biofuel feedstock and fuel pathways for determination of compliance against the GHG thresholds as defined and mandated in the Act. More specifically the language stipulates that the analysis compares biofuel "lifecycle greenhouse gas emissions" against the "baseline lifecycle greenhouse gas emissions".

Biofuel lifecycle greenhouse gas emissions are further defined as:

> *The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.*[149]

This definition forms the basis of defining the system boundaries for the biofuels lifecycle analysis. As the language specifically mandates that lifecycle GHG emissions include "*direct emissions and significant indirect emissions such as significant emissions from land use changes*" the system boundaries modeled include indirect impacts as determined through our economic modeling discussed in Section 2.4.

EISA defines baseline lifecycle greenhouse gas emissions as:

> *The term 'baseline lifecycle greenhouse gas emissions' means the average lifecycle greenhouse gas emissions, as determined by the Administrator, after notice and*

[149] Clean Air Act Section 211(o)(1).

opportunity for comment, for gasoline or diesel (whichever is being replaced by the renewable fuel) sold or distributed as transportation fuel in 2005.

Therefore, the petroleum production component of the system boundaries is specifically mandated by EISA to be based on the 2005 average for crude oil used to make gasoline or diesel sold or distributed as transportation fuel, and not the marginal crude oil that will be displaced by renewable fuel. Furthermore, as the EISA language specifies that the baseline emissions are to be only "average" lifecycle emissions for this single specified year and volume, it does not allow for a comparison of alternative scenarios. Indirect effects can only be determined using such an analysis; therefore, there are no indirect emissions to include in the baseline lifecycle greenhouse gas emissions. More discussion on the petroleum fuel baseline and potential impact of considering indirect impacts on the petroleum baseline are discussed in Section 2.5.

2.3.2.3 Environmental Flows Considered

The lifecycle analysis discussed here evaluates the impacts of increased renewable fuel use on greenhouse gas emissions. EISA specifies a definition of greenhouse gases to include in the analysis:

The term 'greenhouse gas' means carbon dioxide, hydrofluorocarbons, methane, nitrous oxide, perfluorocarbons, sulfur hexafluoride. The Administrator may include any other anthropogenically emitted gas that is determined by the Administrator, after notice and comment, to contribute to global warming.

EISA also specifies that the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

The relative global warming contribution of emissions of various greenhouse gases is dependant on their radiative forcing, atmospheric lifetime, and other considerations. For example, on a mass basis, the radiative forcing of CH_4 is much higher than that of CO_2, but its effective atmospheric residence time is much lower. The relative warming impacts of various greenhouse gases, taking into account factors such as atmospheric lifetime and direct warming effects, are reported on a 'CO_2-equivalent' basis as global warming potentials (GWPs). The GWPs used in this analysis were developed by the UN Intergovernmental Panel on Climate Change (IPCC) as listed in their Second Assessment Report, and are shown in Table 2.3-3. Second assessment report values are used to be consistent with current standards for international reporting of GHG emissions.

Table 2.3-3. 100 Year Global Warming Potentials for Greenhouse Gases

Greenhouse Gas	GWP
CO_2	1
CH_4	21
N_2O	310

Greenhouse gases are measured in terms of CO_2-equivalent emissions (CO_2e), which result from multiplying the GWP for each of the three pollutants shown in the above table by the mass of emissions for each pollutant. The sum of impacts for CH_4, N_2O, and CO_2, yields the total effective GHG impact. Other GHGs like HFCs, PFCs and SF6 are not released in significant amounts over the lifecycle of renewable or petroleum fuels, and are therefore not tracked in this analysis. Other non-GHG climate impacts like albedo (light reflectance), land surface roughness, hydrologic and energy flux, and loss of forest aerosols, while potentially an important aspect of climate impacts associated with land use change, are currently outside the scope of this analysis.

Other environmental flows besides GHG emissions are also considered in our analysis for this rulemaking. Criteria and toxic air pollutants are modeled and results are described in Chapter 3 of the RIA. Water use and impacts are also considered and are described in Chapter 6 of the RIA.

2.3.2.4 Data Quality

Lifecycle analysis is a data intensive process and the results are affected by data quality. Data quality may be defined by specific characteristics that describe both quantitative and qualitative aspects of data, as well as the methods used to collect and integrate those data into the analysis. The quality of data used can be characterized by how well the geographic, technical and temporal aspects of the data match the goals and scope of the analysis in question.

The quality of the data used in this analysis was classified based on its geographic, technical and temporal relevance to the goals of the study as follows:

Geographic coverage – this analysis was conducted without any regard to the geographic attributes of where emissions or energy use occurs. The benefits of this proposed rule represent global reductions in GHG emissions and energy use, not just those occurring in the U.S. For example, the savings associated with reducing overseas crude oil extraction and refining are included here, as are the international emissions associated with producing imported ethanol. Data for agricultural sector impacts include both U.S. and international defaults. Agricultural commodity production in other countries was based on data specific to those areas (e.g., fertilizer production in other countries). Land use change was specifically modeled in different countries; impacts of land use change were based on factors representing sub-country level land characteristics, and for areas where data was not available averages were used.

Technology coverage – this analysis models industries that do not exist yet – cellulosic ethanol and renewable diesel for example. Therefore assumptions based on existing information and modeling were made to represent these industries rather than relying on existing facility data. Even for industries that currently exist there is expected to be a range of technology development over time. For this analysis we have made our best projections for what the industry may look like by 2022. There is expected to be considerable variation in the technologies used, for example combined heat and power and corn oil fractionation in a dry mill ethanol plant. To account for this we have looked at different fuel technology pathways as discussed in Section 2.4.7.

Temporal coverage – this analysis considered impacts in 2022. Therefore we modeled future data; we projected ethanol production in 2022 based on process models – consistent with cost analysis used in this rulemaking. For example, this assumed that future plants will be more energy efficient then current plants. Agricultural sector models also represented 2022 values including improvements in yields and cropping patterns.

2.3.2.5 Addressing Uncertainty

The peer review, the public comments we have received, and the analysis conducted for the proposal and updated here for the final rule, indicate that it is important to take into account indirect emissions when looking at lifecycle emissions from biofuels. It is clear that, especially when considering commodity feedstocks, including the market interactions of biofuel demand on feedstock and agricultural markets is a more accurate representation of the impacts of an increase in biofuels production on GHG emissions than if these market interactions are not considered.

However, it is also clear that there are significant uncertainties associated with these estimates, particularly with regard to indirect land use change and the use of economic models to project future market interactions. Reviewers highlighted the uncertainty associated with our lifecycle GHG analysis and pointed to the inherent uncertainty of the economic modeling.

Therefore, working closely with other government agencies as well as incorporating feedback from experts who commented on the rule, we have quantified the uncertainty associated with specifically the international indirect land use change emissions associated with increased biofuel production. There are four main areas of uncertainty in our modeling approach:

- Economic Modeling Inputs
- Types of Land Converted and GHG Emission Factors
- Methodology Choices
- Other GHG Factors and Input Data

Although there is uncertainty in all portions of the lifecycle modeling, we focused our uncertainty analysis on the factors that are the most uncertain and have the biggest impact on the results. For example, the energy and GHG emissions used by a natural gas-fired ethanol plant to produce one gallon of ethanol can be calculated through direct observations, though this will vary somewhat between individual facilities. The indirect domestic emissions are also fairly well understood, however these results are sensitive to a number of key assumptions (e.g., current and future corn yields). The indirect, international emissions are the component of our analysis with the highest level of uncertainty and have particularly significant impact on our overall assessment results. For example, identifying what type of land is converted internationally and the emissions associated with this land conversion are critical issues that have a large impact on the GHG emissions estimates.

Therefore, we focused our efforts on the international indirect land use change emissions and worked to manage the uncertainty around those impacts in three ways: (1) getting the best information possible and updating our analysis to narrow the uncertainty, (2) performing sensitivity analysis around key factors to test the impact on the results, and (3) establishing reasonable ranges of uncertainty and using probability distributions within these ranges in threshold assessment. The following sections outline how we have incorporated these three approaches into our analysis.

Economic Modeling Inputs: The use of economic models and the uncertainty of those models to accurately predict future agricultural sector scenarios was one of the main comments we received on our analysis. While the comments and specifically the peer review supported our need to use economic models to incorporate and measure indirect impacts of biofuel production they also highlighted the uncertainty with that modeling approach, especially in projecting out to the future.

However, it is important to note that while many factors impact the certainty in predicting total land used for crop production, making accurate predictions of many of these factors are not relevant to our analysis. For example different assumptions about economic growth rates, weather, and exchange rates will all impact future agricultural projections including amount of land use for crops. However, we are interested only in the difference between two biofuel scenarios holding all other changes constant. So the absolute values and projections for crops, etc. in the model projections are not as important as the difference the model is projecting due to an increase in biofuels production. This limits the uncertainty of using the economic models for our analysis.

The main factors impacting the economic modeling and land use results due to biofuels are overall crop / commodity demand and yields (and the responsiveness of these parameters to price changes). To examine the impact of changes in yield on the overall biofuel lifecycle GHG results, we have made two main changes in the economic modeling used for the proposal. In order to update our analysis and reduce uncertainty we have included a price induced yield impact, as discussed in RIA Chapter 5. Furthermore we also include a sensitivity analysis of a high yield scenario to test the impact of higher yields on the results, as discussed in Section 2.6.2.

Types of Land Converted and Land Conversion GHG Emissions Factors: The international indirect land use change impacts of biofuels were determined based on the results of the economic models that provide the total amount of new land needed. The results of the economic models were combined with recent satellite data to predict the types of land converted to meet the increased land demand. GHG emissions factors were then applied to the type of land to calculate GHG emissions from land use change. As this is one of the areas of greatest uncertainty we specifically incorporated an approach to quantify the uncertainty in our satellite data and GHG emissions estimates and incorporated these results into our analysis.

Methodology Choices: A main underlying methodological decision that impacts the overall lifecycle GHG results is how to deal with the timing of emissions. This is manifested in two main ways, the first is how to deal with short term land use change emissions versus ongoing benefits of the use of biofuels, and the second is what timeframe to consider the analysis for. The main approach for addressing this uncertainty was to conduct sensitivity analysis with various methodology choices, as presented in Section 2.6.2.1. For example, we used a 30-year time period for our lifecycle analysis, but we also present results with different time periods, as well as the payback periods for each fuel, which is a metric that does not require the analyst to choose a specific time period.

Other GHG Factors and Input Data: Non-economic modeling inputs and assumptions impact overall GHG results, for example crop production inputs (energy use for tractors, etc.), and agricultural sector GHG emissions (livestock, soil N_2O, etc.). These factors are applied on top of economic modeling to determine mainly the non-land use GHG impacts of agriculture. While there is some uncertainty inherent in the factors, most of them do not have a significant impact on the overall results.

For the final rule analysis, instead of developing uncertainty profiles and ranges around these other input factors, we focused on reducing the uncertainty through updates to improve our data and modeling. For example, N_2O emissions from soil as part of crop production is a key component of agricultural sector GHG emissions so we focused on updating our analysis to include the most up to date information on this source of emissions. We also had our analysis of international agricultural sector GHG emissions peer reviewed and have updated our analysis in response to the peer review comments.

2.4 Biofuels Analysis

2.4.1 Modeling Approach

As mentioned in Section 2.2, our methodology includes the use of agricultural sector economic models. Our methodology involves the use of the FASOM model to determine domestic agriculture sector-wide impacts of increased biofuel production, and the FAPRI-CARD model to determine international changes in crop production and total crop. Agricultural sector GHG emissions are estimated by FASOM, and FAPRI-CARD results were converted to GHG emissions based on GREET defaults and IPCC emission factors. Biofuel process energy use and associated GHG emissions were based on process models for the different pathways considered. Feedstock and co-product transportation GHG emissions were based on GREET defaults.

The agricultural sector models were used to determine the impacts associated with biofuels production by comparing two similar scenarios in both models. Both agricultural sector models were run with two similar volumes of the specific fuel in question, while other fuel volumes were held constant to isolate the fuel-specific impacts. Table **2.4-1** shows the 2022 fuel volumes modeled in FASOM in order to isolate the incremental impacts of each type of renewable fuel. Section 2.3 includes more discussion of the fuel volume scenarios.

Table 2.4-1. 2022 Fuel Volumes Modeled with FASOM (Billions of Gallons)

	Control Case	Biodiesel Only Case	Corn Ethanol Only Case	Corn Stover Ethanol Only Case	Switchgrass Ethanol Only Case
Soybean Biodiesel	0.6	0.1	0.6	0.6	0.6
Corn Ethanol	15.0	15.0	12. 3	15.0	15.0
Corn Stover Ethanol	4.9	4.9	4.9	0.0	4.9
Switchgrass Ethanol	7.9	7.9	7.9	7.9	0.0

The total impacts from changes in biofuel production were calculated by taking the difference in total GHG emissions from the two scenarios considered. Per gallon or per million British Thermal Units (mmBTU) impacts were calculated by dividing the total GHG emission changes by the increase in volume of fuel represented in the scenarios. Therefore, the results presented in this proposed rulemaking represent the per mmBTU "average marginal" impact of the change in fuel volumes considered. In other words, the GHG impacts were estimated for a marginal increase in fuel production, and the average impact of a marginal gallon was calculated.

2.4.2 Domestic Agriculture

GHG emissions from the domestic agricultural sector were estimated with the FASOM model, a partial equilibrium economic model of the U.S. forest and agricultural sectors. As discussed in Section 2.2, FASOM accounts for changes in GHG emissions from most agricultural activities, including the total amount of fertilizer, chemicals, gasoline, diesel and electricity used on farms for the entire domestic agricultural sector. It also captures changes in the soil management, livestock production and U.S. agricultural exports. More detail on the FASOM model can be found in Chapter 5 of the RIA. For all figures and tables in Section 2.4.2, we report results for the biochemical pathway under the "Corn Stover Ethanol" and "Switchgrass Ethanol" scenarios.

Figure 2.4-1 shows the total harvested crop acres in the different fuel-specific pathway scenarios. The projected changes in total harvested acres are modest, because we modeled the incremental difference in renewable fuel volumes between the scenarios.

Figure 2.4-1. FASOM Projected Domestic Harvested Acres, 2022

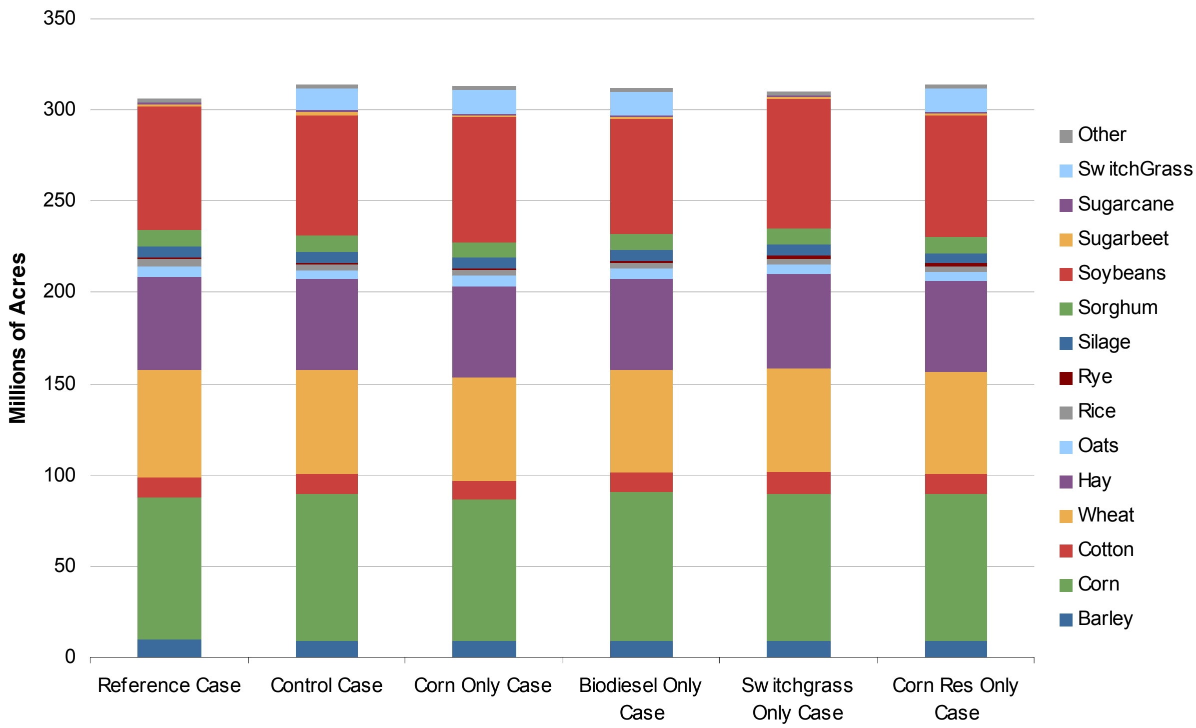
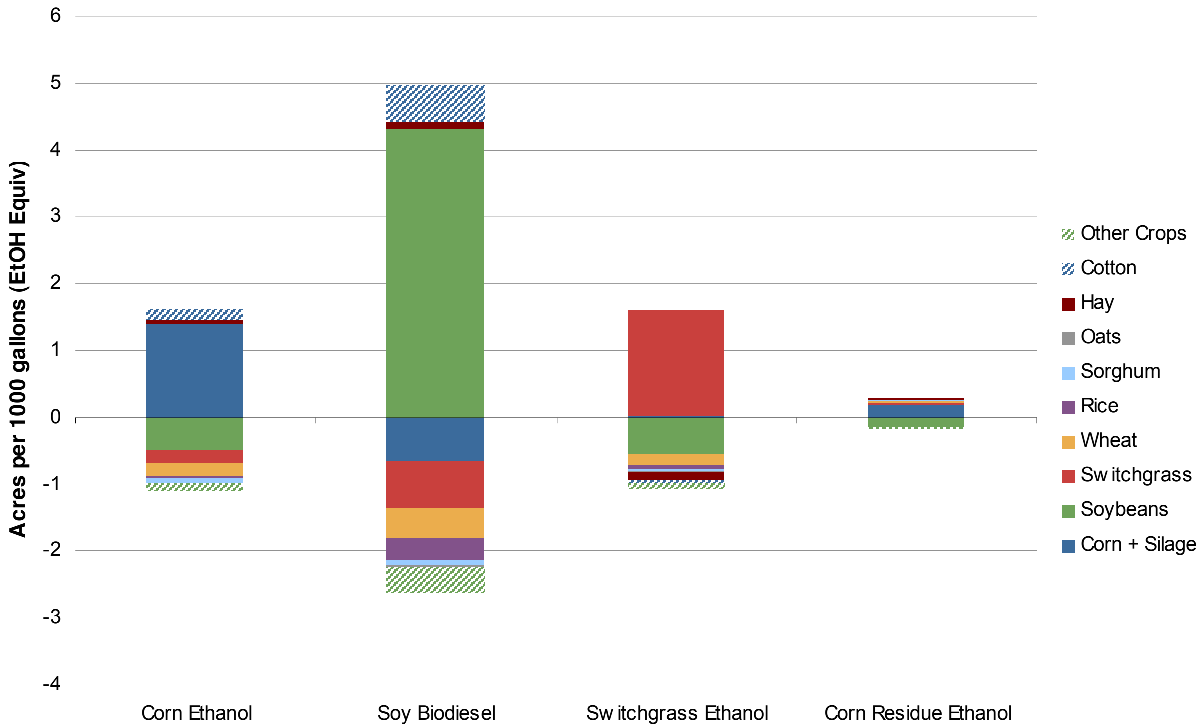


Figure 2.4-2 includes the projected changes in harvested crop acres by field crop for the fuel volume cases considered (acreage changes are normalized per thousand gallons of renewable fuel production). In the corn ethanol scenario, corn acreage increased; area planted with soybeans, wheat, switchgrass, sorghum and rice decreased; and harvested acres of other crops were practically unchanged. As anticipated, soybean acreage decreased the most when corn ethanol production increased, because corn and soybeans are often in direct competition for fertile land.

Figure 2.4-2.
Normalized Changes in Domestic Cropland by Crop, 2022
(acres per thousand gallons of renewable fuel)



Soy-based biodiesel production induced a large increase in harvested soybean acres, largely due to the low yield of soy-based biodiesel in terms of gallons produced per acre. Cotton was the only other crop that increased substantially along with biodiesel production. The competition between corn and soybeans was evident again, as corn acreage saw a steep decline. However, switchgrass acres declined by nearly the same amount as corn, showing the relative competition between switchgrass and soybeans. Wheat, rice, barley, sorghum and rye also declined when biodiesel volumes increased.

In the scenario where switchgrass ethanol production increased, switchgrass was the only field crop to gain acreage, with the exception of a small increase in corn and sugarbeet acres. New switchgrass plantings displaced a wide variety of other crops (

Figure 2.4-2). As discussed more in RIA Chapter 5, the FASOM runs for the proposed rule project that switchgrass will primarily be grown in Kansas, Missouri, Texas, Oklahoma, and Arkansas

Production of ethanol from corn residue had a very small effect on the acreage of other crops. This was expected because corn stover production does not displace other crop production, as corn stover is a residual product of corn cultivation. FASOM did project minor amounts of crop shifting in the corn stover scenario, because using corn stover for ethanol can increase the profitability of corn production in certain regions, with subsequent impacts. The effects of corn stover harvesting on agricultural inputs, such as the need to use more fertilizer after stover removal, are discussed below.

2.4.2.1 Domestic Crop Inputs

FASOM utilizes data about crop inputs to build crop budgets for field crops across 11 market regions and 63 sub-regions. FASOM crop budgets include data on yields, fertilizer, chemicals, and energy use needed to grow crops in each of the different regions. The crop budgets are based on USDA historic data and are also projected into the future. The crop budgets represent an average for each region, and do not specifically calculate input or yield changes that could result from the use of marginal croplands or altered crop rotation patterns (e.g., continuous corn production).[150] Table **2.4-2** defines the 11 market regions in FASOM. RIA Chapter 5 includes a detailed discussion of the FASOM crop budgets, including assumptions about crop yields and yield growth rates. Below we provide a summary of some of the key FASOM assumptions that were used to estimate domestic agricultural GHG emissions.

[150] FASOM does not explicitly model the selection of alternative crop rotations. Because the model operates in 5-year time steps, it has not generally been applied to shorter-term decisions such as changes in rotation patterns. Rather, the model data implicitly reflect average conditions for crop production (e.g., yields, input use, etc.) associated with historical rotation patterns on a regional level.

Table 2.4-2. Definitions of 11 Market Regions in FASOM

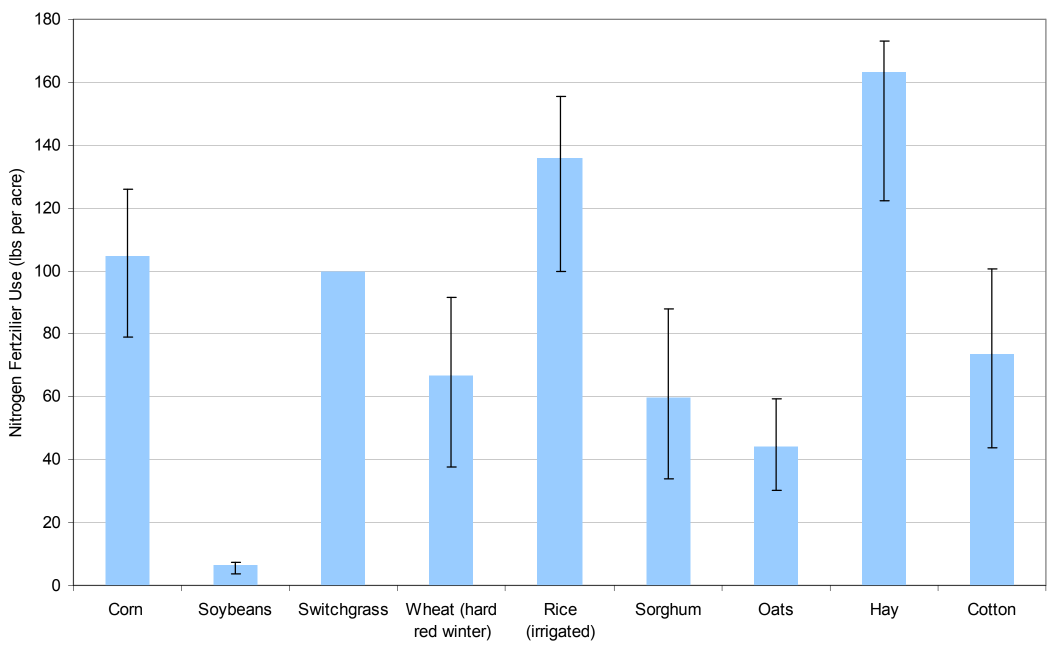
Key	Market Region	Production Region (States/Subregions)
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
LS	Lake States	Michigan, Minnesota, Wisconsin
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (IllinoisN, IllinoisS, IndianaN, IndianaS, IowaW, IowaCent, IowaNE, IowaS, OhioNW, OhioS, OhioNE)
GP	Great Plains	Kansas, Nebraska, North Dakota, South Dakota
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
SW	Southwest (agriculture only)	Oklahoma, All of Texas but the Eastern Part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
PSW	Pacific Southwest	All regions in California (CaliforniaN, CaliforniaS)
PNWE	Pacific Northwest—East side (agriculture only)	Oregon and Washington, east of the Cascade mountain range
PNWW	Pacific Northwest—West side (forestry only)	Oregon and Washington, west of the Cascade mountain range

The crop budgets included in the FASOM model include data on input use that varies by crop, management practices, and region. There is often considerable regional variation in the inputs used per acre, which suggests that total input use (and the associated GHG emissions and other environmental impacts) will be affected as biofuel production causes crop shifting and alters crop management practices. For example, nitrogen fertilizer use is an important factor for lifecycle GHG analysis because of GHG emissions from fertilizer production and use.

Figure 2.4-3 includes FASOM assumptions about average nitrogen fertilizer use by crop in 2022 for non-irrigated production without residue harvesting. Regions that have a zero nitrogen fertilizer use rate are not included in the averages.

Figure 2.4-3 illustrates the relative fertilizer intensity of major crops. Corn, hay and silage are relatively fertilizer-intense crops; whereas soybeans require less than 10 pounds of nitrogen per acre (soybeans naturally fix nitrogen in the soil as they grow).

Figure 2.4-3.
FASOM Average Nitrogen Fertilizer Use by Crop, 2022
Non-Irrigated, No Residue Harvesting
(lbs per acre)

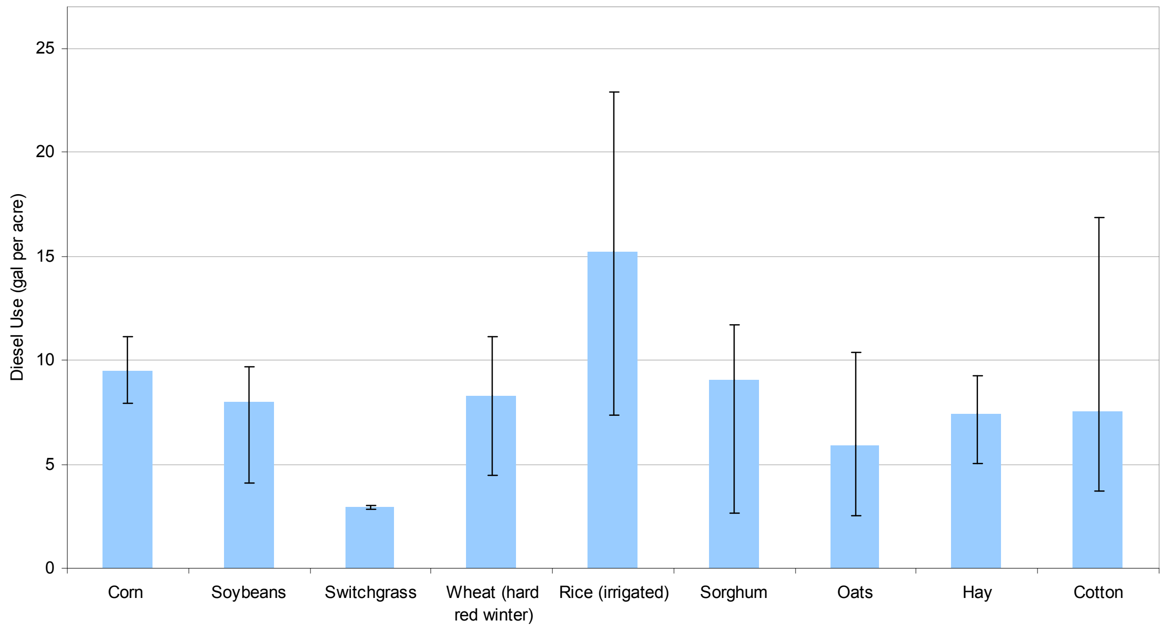


Note: The range indicates the regions with the highest and lowest average nitrogen fertilizer use rates.

Mechanized agriculture requires many forms of energy including diesel, gasoline, natural gas and electricity. The FASOM crop budgets include detailed energy use information by crop and region.

Figure 2.4-4 includes FASOM assumptions for average diesel use by crop in 2022, for non-irrigated production without residue harvesting.

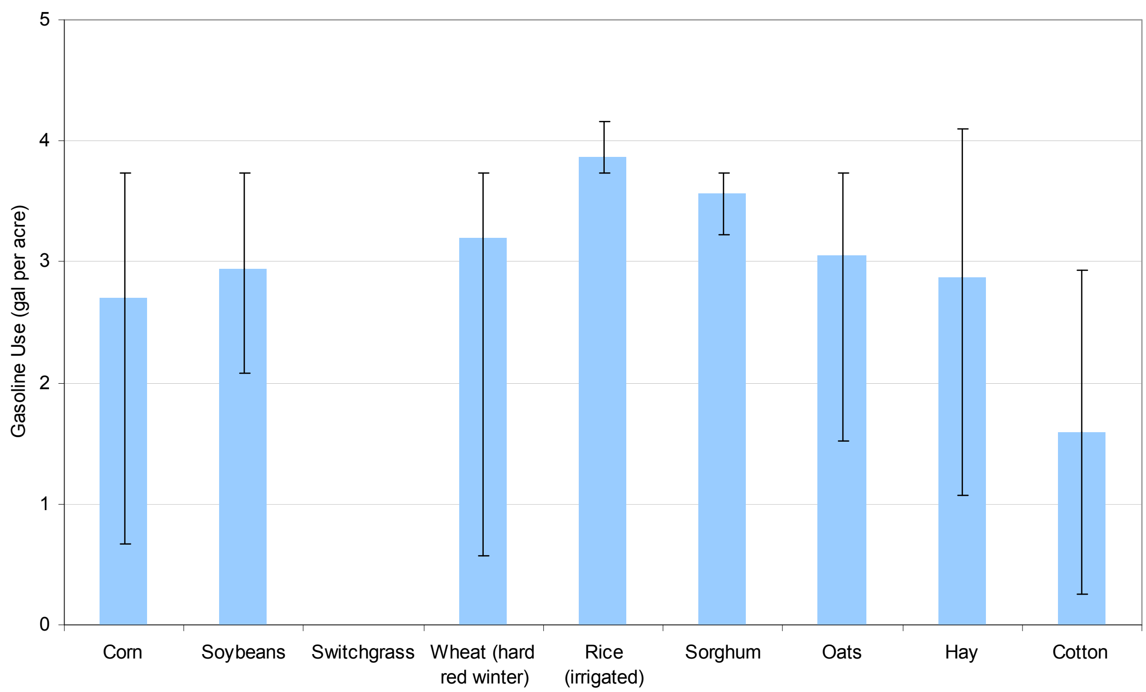
Figure 2.4-4.
FASOM Average Diesel Use by Crop, 2022
Non-Irrigated, No Residue Harvesting
(gallons per acre)



Note: The range indicates the regions with the highest and lowest average diesel use rates.

Figure 2.4-5 shows FASOM assumptions for average gasoline use by crop in 2022, for non-irrigated production without residue harvesting. The FASOM crop budgets do not include gasoline use for switchgrass production.

Figure 2.4-5
FASOM Average Gasoline Use by Crop, 2022
Non-Irrigated, No Residue Harvesting
(gallons per acre)



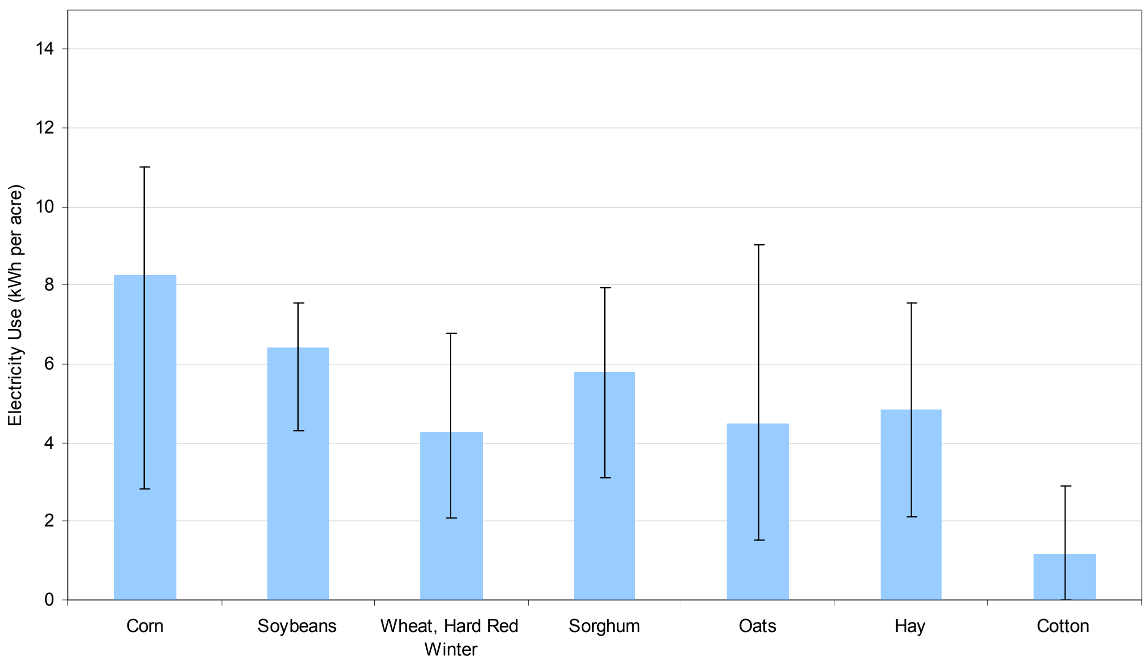
Note: The range indicates the regions with the highest and lowest average gasoline use rates.

FASOM crop budgets include electricity and natural gas use for irrigation water pumping. Rice and sugarbeets are the only crops assumed to use natural gas for water pumping (See **Table 2.4-3.**). Therefore, overall natural gas use in each scenario is dependent on changes in these crops. For the rest of the irrigated crops that have private energy use for water pumping, electricity is the assumed energy source, with the largest electricity consumption in the Great Plains region (See Figure **2.4-6**).

Table 2.4-3.
Natural Gas Usage for Irrigated Crop by Region, 2022
(1000 cu ft/acre)

Crop	CB	GP	LS	NE	PNWE	PSW	RM	SC	SE	SW
Rice	23.3	NA	NA	NA	NA	0.0	NA	20.1	NA	0.0
Sugarbeet	26.1	9.7	26.1	NA	3.8	0.0	0.0	NA	NA	0.0

Figure 2.4-6.
FASOM Electricity Use by Crop, 2022
Irrigated, No Residue Harvesting
(kWh per acre)



Note: The range indicates the regions with the highest and lowest average gasoline use rates.

Energy use for grain drying is calculated in FASOM based on assumptions that removing 10 percentage points of moisture from 100 bushels of grain requires 17.5 gallons of propane and 9 kWh of electricity. Thus, energy use per acre is calculated as the number of percentage points of moisture to be removed multiplied by the yield per acre and the energy use per percentage point and yield unit for each crop that is dried. Emissions are then calculated based on assumed emissions factors per unit of energy use by energy type. **Table 2.4-4** shows the average emissions associated with grain drying that are used in FASOM. Drying rice is a relatively energy intensive process, as reflected in the grain drying GHG emissions per acre. Emissions from grain drying are included in the overall domestic agricultural GHG emissions estimates.

Table 2.4-4. FASOM Average Carbon Dioxide Emissions from Grain Drying by Region (kgCO2e / acre)

Crop	CB	GP	LS	NE	PNWE	PSW	RM	SC	SE	SW
Dryland										
Corn	161.4	135.9	202.2	160.5	NA	NA	66.1	24.5	43.8	15.2
Sorghum	99.4	22.3	NA	54.3	NA	17.7	NA	NA	NA	NA
Soybeans	26.0	7.0	24.1	14.3	NA	NA	NA	NA	NA	NA
Wheat, Durham	NA	5.1	23.4	NA	NA	NA	NA	NA	NA	NA
Wheat, Hard Red Spring	NA	6.7	25.4	NA	9.1	NA	NA	NA	NA	NA
Wheat, Hard Red Winter	51.3	11.1	51.6	34.5	NA	11.6	NA	NA	NA	NA
Wheat, Soft White	NA	NA	NA	NA	NA	NA	11.6	NA	NA	NA
Irrigated										
Corn	NA	185.1	NA	NA	132.6	121.6	103.2	21.0	NA	30.7
Rice	1,216.6	NA	NA	NA	NA	1,667.3	NA	1,254.8	NA	1,400.8
Sorghum	NA	33.0	NA	NA	NA	NA	NA	NA	NA	NA
Soybeans	NA	10.3	NA	NA	NA	NA	NA	NA	NA	NA
Wheat, Durham	NA	11.3	NA	NA	NA	21.0	NA	NA	NA	NA
Wheat, Hard Red Spring	NA	10.2	NA	NA	NA	NA	17.6	NA	NA	NA
Wheat, Hard Red Winter	NA	15.4	NA	NA	NA	22.6	NA	NA	NA	NA
Wheat, Soft White	NA	NA	NA	NA	NA	NA	18.3	NA	NA	NA

Based on input data for each individual crop and the associated costs of production and projected prices, the model predicts how the total U.S. agricultural sector will change with increased feedstocks used for biofuel production. The results for total agricultural sector inputs of the different fuel scenarios considered are shown in Table 2.4-5 through Table 2.4-8.

Table 2.4-5. Change in Domestic Agricultural Inputs under Corn Ethanol Scenario, 2022

	Units per mmBTU	Corn Ethanol Only Scenario	Control Scenario	Difference	Percent Change
Total N use	Pounds	136.6	138.8	2.1	1.5%
Total P2O5 use	Pounds	31.2	31.7	0.5	1.5%
Total K2O use	Pounds	38.8	39.5	0.7	1.9%
Total Lime Use	Pounds	104.2	104.7	0.5	0.5%
Herbicide Use	Pounds	1.9	2.0	0.0	2.2%
Pesticide Use	Pounds	0.4	0.4	0.0	2.8%
Total Diesel Fuel use	Gal	14.3	14.2	-0.1	-0.5%
Total Gasoline use	Gal	1.7	1.7	0.0	-0.9%
Total Electricity Use	kWh	1.0	1.0	0.0	0.3%
Total Natural Gas Use	BTU	248,002	234,746	-13,257	-5.6%

Table 2.4-6. Change in Domestic Agricultural Inputs in the Soy Biodiesel Scenario, 2022

	Units Per mmBTU	Soy Biodiesel Only Scenario	Control Scenario	Difference	Percent Change
Total N use	Pounds	437.1	435.3	-1.8	-0.4%
Total P2O5 use	Pounds	99.2	99.4	0.2	0.2%
Total K2O use	Pounds	123.3	124.0	0.7	0.6%
Total Lime Use	Pounds	325.6	328.5	2.9	0.9%
Herbicide Use	Pounds	6.2	6.2	0.0	0.3%
Pesticide Use	Pounds	1.4	1.4	0.0	1.5%
Total Diesel Fuel use	Gal	45.0	44.7	-0.4	-0.9%
Total Gasoline use	Gal	5.3	5.4	0.1	1.6%
Total Electricity Use	kWh	3.2	3.2	0.0	1.4%
Total Natural Gas Use	BTU	833,308	736,362	-96,946	-13.2%

Table 2.4-7.
Change in Domestic Agricultural Inputs in the Corn Stover Ethanol Scenario, 2022

	Units per mmBTU	Corn Stover Only Ethanol Scenario	Control Scenario	Difference	Percent Change

	Units per mmBTU	Corn Stover Only Ethanol Scenario	Control Scenario	Difference	Percent Change
Total N use	Pounds	74.6	75.8	1.2	1.5%
Total P2O5 use	Pounds	16.8	17.3	0.5	3.1%
Total K2O use	Pounds	19.3	21.6	2.3	10.8%
Total Lime Use	Pounds	57.3	57.2	-0.1	-0.2%
Herbicide Use	Pounds	1.1	1.1	0.0	0.6%
Pesticide Use	Pounds	0.2	0.2	0.0	0.4%
Total Diesel Fuel use	Gal	7.8	7.8	-0.1	-0.8%
Total Gasoline use	Gal	0.9	0.9	0.0	0.0%
Total Electricity Use	kWh	0.6	0.6	0.0	0.0%
Total Natural Gas Use	BTU	133,037	128,201	-4,836	-3.8%

Table 2.4-8.
Change in Domestic Agricultural Inputs in the Switchgrass Ethanol Scenario, 2022

	Units per mmBTU	Switchgrass Ethanol Only Scenario	Control Scenario	Difference	Percent Change
Total N use	Pounds	44.5	45.9	1.4	3.1%
Total P2O5 use	Pounds	9.8	10.5	0.7	6.2%
Total K2O use	Pounds	12.5	13.1	0.6	4.3%
Total Lime Use	Pounds	34.7	34.7	0.0	-0.1%
Herbicide Use	Pounds	0.7	0.7	0.0	-1.1%
Pesticide Use	Pounds	0.1	0.1	0.0	-3.0%
Total Diesel Fuel use	Gal	4.8	4.7	-0.1	-1.1%
Total Gasoline use	Gal	0.6	0.6	0.0	-4.2%
Total Electricity Use	kWh	0.3	0.3	0.0	-0.2%
Total Natural Gas Use	BTU	90,890	77,690	-13,200	-17.0%

The amounts shown in Table 2.4-5 through Table 2.4-8 were combined with GREET defaults for GHG emissions from production of fertilizer and chemicals to calculate GHG emissions changes. Fuel use emissions included both the upstream emissions associated with production of the fuel as well as combustion emissions, also from GREET. Emissions from electricity production represented average U.S. grid electricity production.

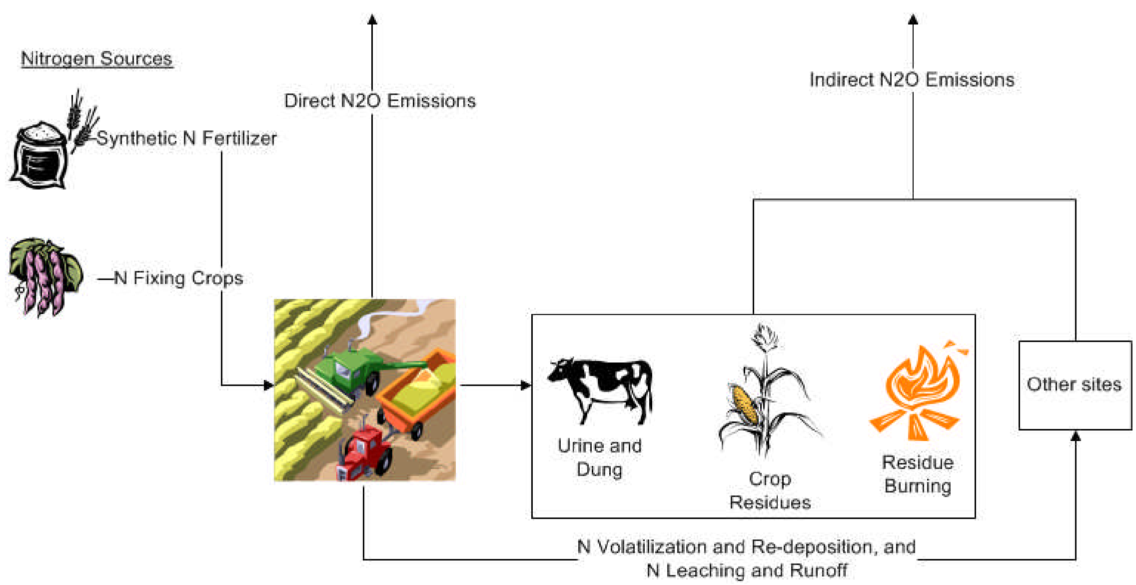
In addition to the GHG emissions associated with fertilizer and chemical production, and fuel production and use, there are several other non-fossil fuel combustion related GHG sources of emissions from the agricultural sector that would be impacted by the increased use of corn for ethanol and associated changes to the agricultural sector. FASOM provides directly the GHG emissions from these additional sources.

2.4.2.2 Domestic Nitrous Oxide Emissions

An important GHG impact from the agricultural sector is releases of nitrous oxide (N_2O) emissions. N_2O can be released from a number of different N-input sources including inorganic fertilizer, nitrogen fixing crops (e.g., soybeans), crop residues, and manure management. N_2O can be released either directly or indirectly through N leaching offsite.

Figure 2.4-7Figure 2.4-7 highlights some of the major sources of agricultural N_2O emissions.

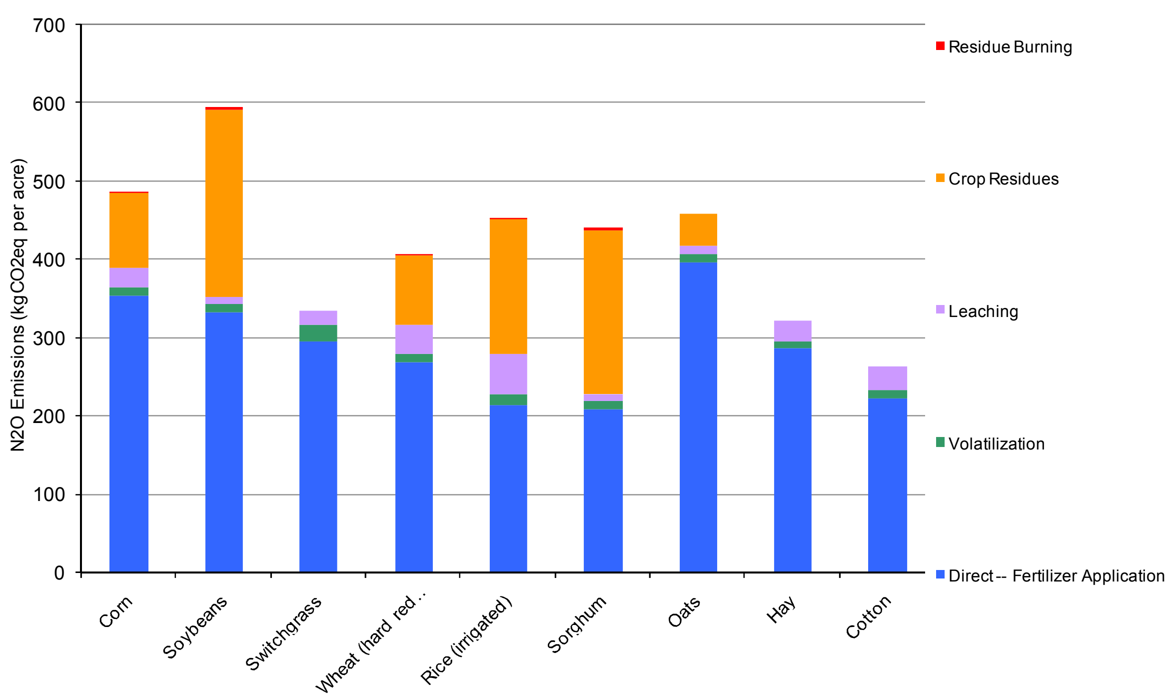
Figure 2.4-7. Agricultural Sources of N2O Emissions



Crutzen et al. show that, as long as it includes both direct and indirect emissions, top-down accounting for N_2O emissions are not inconsistent with the IPCC bottom –up approach to N_2O accounting.[515] Since the publication of the NPRM, the N_2O emission factors in FASOM have been updated with the DAYCENT/CENTURY model by Colorado State University (CSU) to more accurately estimate direct and indirect N_2O emissions in cropland. The FASOM modeling captures both direct N_2O emissions from fertilizer application and N-fixing crops and indirect emissions from leaching, volatilization well as from crop residue emissions and residue burning, capturing all sources of N_2O emissions and reflecting the most recent available science. This section discusses the changes made using the CSU DAYCENT/CENTURY work. It details the direct and indirect emissions from synthetic fertilizer, N fixing crops, and crop residue.

Figure 2.4-8 summarizes FASOM average direct and indirect N2O emissions per acre by crop. Livestock N_2O emissions and N_2O emissions associated with international agriculture are discussed in more detail in Section 2.4.2.3 and 2.4.3, respectively.

Figure 2.4-8.
FASOM Average N2O Emissions by Crop (Non-Irrigated, No Residue Harvesting) (kgCO2e per acre)



EPA worked with CSU to use the DAYCENT/CENTURY model to refine FASOM accounting of direct N_2O emissions from fertilizer application and indirect emissions associated with nitrogen leaching, volitization, and surface runoff. Specifically, DAYCENT simulations account for all N inputs to agricultural soils, including mineral N fertilizer, organic amendments, symbiotic N fixation, asymbiotic N fixation, crop residue N, and mineralization of soil organic matter.

CSU used the DAYCENT/CENTURY model to simulate a suite of domestic U.S. land use and crop management in the 11 FASOM market regions (Table 2.4-2). The DAYCENT/CENTURY simulations provided regression equations with coefficients for N_2O estimation that vary by region, crop type, irrigation status, and crop residue treatment. Each of the 63 FASOM regions was assigned the coefficients for its respective super-region. The regression equations were incorporated into FASOM to calculate N_2O emissions per acre according to region, crop, irrigation status, and crop residue treatment.

FASOM estimates N_2O emissions from crop residues and residue burning using IPCC guidelines, taking into account variation across regions in

- N content by crop based on yield,
- residue-to-crop ratio,
- percent dry matter,
- percentage of rice area burned in each state,
- burn and combustion efficiency,
- percent of residue burned by crop.

For crop residue emissions, FASOM assumes that 1% of N residing in crop residues that remain on the field is emitted as N_2O emissions, following IPCC guidelines.

Field burning of crop residues is not considered a net source of CO_2, because the carbon released to the atmosphere as CO_2 during burning is assumed to be reabsorbed during the next growing season. Field burning of crop residues, however, does emit N_2O and CH_4, which are released during combustion. Field burning is not a common method of agricultural residue disposal in the United States. The primary crop types whose residues are typically burned in the United States are wheat, rice, sugarcane, corn, barley, soybeans, and peanuts.

FASOM assumes that a certain fraction of fields are burned each year, which results in N_2O emissions as well as CH_4 emissions. Using the IPCC default value for burned residue, FASOM assumes that, on average, 0.7% of N contained in the burned residue is emitted as N_2O. FASOM predicts minor reductions in GHG emissions from residue burning under the full RFS2 policy due to reductions in crop production with residues that are typically burned. In addition, CH_4 emissions are calculated based on the average methane emissions per acre; however, CH_4 emissions are typically quite small relative to the other emissions tracked in FASOM.

2.4.2.3 Domestic Rice Production Emissions

Methane (CH_4) emissions associated with rice production are also a source of non-combustion GHG emissions from the domestic agricultural sector. When rice fields are flooded, aerobic decomposition of organic material gradually depletes most of the oxygen present in the soil, causing anaerobic soil conditions. Once the environment becomes anaerobic, CH_4 is produced through anaerobic decomposition of soil organic matter by methanogenic bacteria. Some of this CH_4 is transported from the soil to the atmosphere through the rice plants via diffusive transport. Minor amounts of CH_4 also escape from the soil via diffusion and bubbling through floodwaters.

FASOM assumes that all rice produced in the United States is grown in flooded fields and emits CH_4. Although there are potentially changes in water and soil management practices that could be implemented to reduce methane emissions, FASOM assumes that reduction of rice acreage is the only available method for reducing CH_4 emissions from rice cultivation. Thus, changes in CH_4 emissions from rice cultivation result only from changes in the acreage planted to rice in the model.

Methane emissions per acre are calculated based on regional emissions factors per acre calculated for each region based on 2001 data from the EPA GHG inventory for 1990–2003 (see Table **2.4-9**).[516] The model then calculates emissions from rice production based on emissions factors for each region and the distribution of rice acreage in the model solution.

Table 2.4-9. FASOM Average Methane Emissions from Irrigated Rice Cultivation by Region (kg CO2e / acre)

Crop	CB	GP	LS	NE	PNWE	PSW	RM	SC	SE	SW
Rice	1,826.1	NA	NA	NA	NA	1,783.4	NA	2,249.2	NA	4,375.0

Note: NA indicates not applicable, i.e., those crops were not cultivated under that irrigation status in that FASOM region. In addition, there is no dryland rice or sugarcane production or irrigated hybrid poplar, switchgrass, or willow production in FASOM.

As with other sources of emissions different management methods and other factors (such as soil type and amounts of fertilization) will impact CH_4 emissions from rice production. With the exception of corn stover ethanol, FASOM projects that rice methane emissions will decrease for all fuel pathways analyzed due to decreased domestic rice acreage (**Table 2.4-10**).

Table 2.4-10.
Change in Domestic Rice Emissions by Scenario, 2022

	Corn Ethanol	Soybean Biodiesel	Corn Stover Ethanol	Switchgrass Ethanol
Rice Methane Emissions (‘000 tons CO2e)	-42	-506	159	-938

2.4.2.4 Domestic Livestock Emissions

Livestock production and management also contribute significant non-combustion GHG emissions from the agricultural sector. GHG emissions from livestock come from two main sources: enteric fermentation and manure management. Enteric fermentation produces CH_4

emissions as a by-product of normal digestive processes in animals. During digestion, microbes resident in an animal's digestive system ferment food consumed by the animal. The amount of CH_4 produced and excreted by an individual animal depends primarily upon the animal's digestive system, and the amount and type of feed it consumes. Ruminant animals (e.g., cattle, buffalo, sheep, goats, and camels) are the major emitters of CH_4 because of their unique digestive system.

FASOM projects changes in CH_4 emissions associated livestock enteric fermentation due to change in livestock herd number. Changes in production of crops used for feeds, such as corn or soybeans, can impact feed prices which, in turn, drive livestock production and demand. Enteric fermentation emissions from livestock are calculated based on the number of each livestock type and on the average emissions per head. Average emissions per head are based on 2001 emissions values by livestock type and the number of livestock in each livestock category reported in the EPA GHG inventory report for 1990–2003.[517] There are emissions mitigation options included within the FASOM model, but these options do not enter the market in the absence of incentives for reducing CH_4 emissions. Thus, enteric fermentation emissions are affected only by the number of animals in each livestock category in this model. The FASOM model generally predicts reductions in livestock herds as shown in **Table 2.4-11**.

Table 2.4-11. Change in Domestic Livestock Herd Size by Scenario, 2022

Livestock Type	Corn Ethanol		Soy-based Biodiesel		Corn Stover Ethanol		Switchgrass Ethanol	
	mmHead	% change	mmHead	% change	mmHead	% change	mmHead	% change
Dairy	-0.02	-0.31%	-0.01	-0.17%	0.00	-0.01%	-0.02	-0.36%
Beef	0.09	0.14%	-0.11	-0.18%	0.95	1.56%	0.21	0.34%
Poultry	-58.84	-0.79%	-58.84	-0.79%	-58.84	-0.79%	-58.84	-0.79%
Swine	-0.22	-0.17%	0.24	0.19%	9.15	7.27%	7.80	6.20%

Enteric fermentation emissions increase across fuel pathway scenarios with the exception of the soybean biodiesel scenario. Cattle numbers increase under the corn ethanol, corn stover ethanol, and switchgrass ethanol scenarios. Cattle are ruminants, and therefore, increase in cattle number results in increased CH_4 emissions (**Table 2.4-12**). Cattle number decreases under the soy-based biodiesel scenario, resulting in decreased methane emissions due to enteric fermentation.

Table 2.4-12. Change in Domestic Livestock Emissions by Scenario, 2022

	Corn Ethanol	Soybean Biodiesel	Corn Stover Ethanol	Switchgrass Ethanol
Enteric CH_4 Emissions ('000 tons CO_2e)	21	-128	1,129	338
Manure CH_4 and N_2O Emissions ('000 tons CO_2e)	-94	-5	2,194	1,751
Total Livestock Emissions ('000 tons CO_2e)	*-73*	*-133*	*3,322*	*2,089*

Use of DGS has been shown to decrease methane produced from enteric fermentation if replacing corn as animal feed. This is due to the fact that the DGS are a more efficient feed source. Consistent with our assumptions regarding the efficiency of DGS as an animal feed in our agricultural sector modeling, we have also included the enteric fermentation methane reductions of DGS use in our final rule analysis. Based on default factors in GREET, the model assumed a decrease in CH_4 (-3,381 g CO_2e/mmBTU ethanol) per head of cattle and cows that were fed with DGS. The reduction in CH_4 is based on the same Argonne report used to determine DGS feed replacement efficiency (discussed in RIA Chapter 5). This assumption resulted in a reduction in the lifecycle GHG emissions for corn ethanol compared to the proposal assumptions.

The management of livestock manure can also produce anthropogenic CH_4 and N_2O emissions. CH_4 is produced by the anaerobic decomposition of manure. N_2O is produced through the nitrification and denitrification of the organic nitrogen in livestock manure and urine. The type of manure management methods impacts the quantity of GHG emissions emitted. FASOM bases manure management emissions calculations on emissions factors for livestock types and livestock management methods as reported in the EPA GHG inventory report for 1990–2003.[518] Manure management emissions are projected to decrease as a result of lower livestock herd values.

Under the corn ethanol and soybean biodiesel scenario, manure-associated GHG emissions slightly decrease. Under the corn stover and switchgrass scenarios, swine production markedly increases leading to an increase in total livestock emissions (**Table 2.4-12**).

2.4.2.5 Domestic Agriculture Sector Results (Excluding Land Use Change)

Table 2.4-13 provides a summary of FASOM projections for total GHG emissions impacts for the domestic agricultural sector for each fuel pathway scenario analyzed. Land use change impacts are discussed in Section 2.4.4.

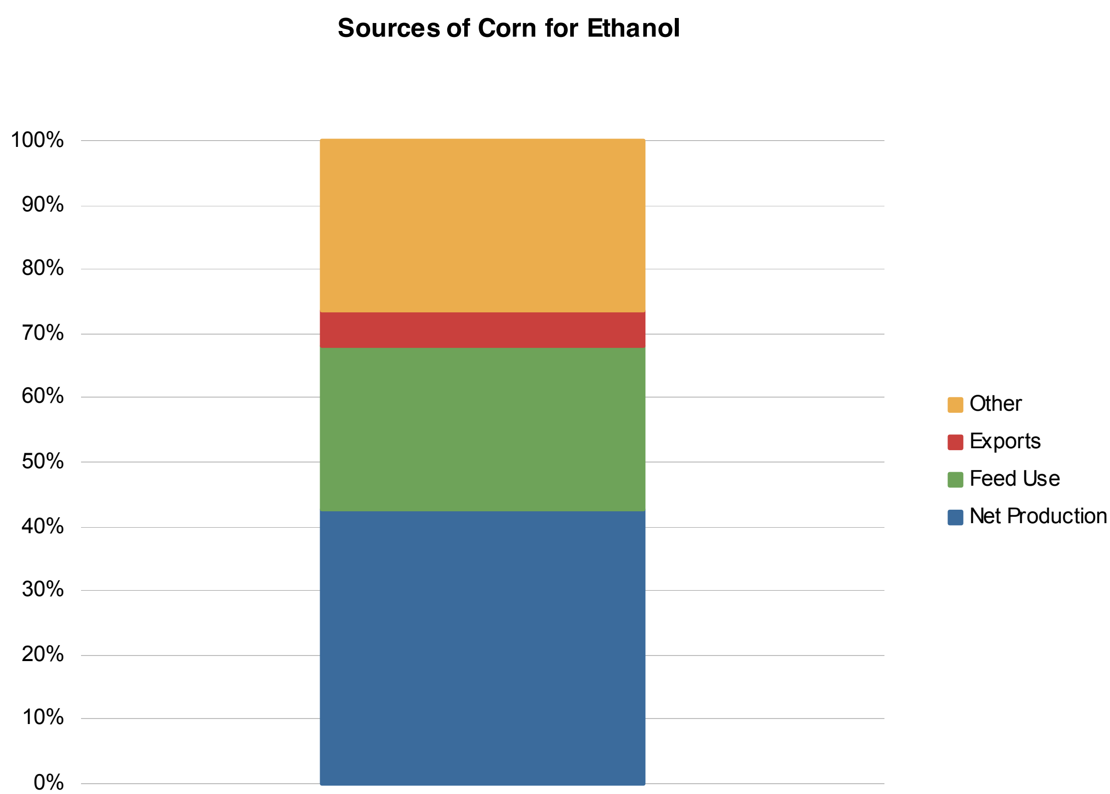
Table 2.4-13.
Domestic Agriculture GHG Emission Changes by Scenario, 2022
(g CO2e/mmBTU)

Emission Source	Corn Ethanol	Soybean Biodiesel	Corn Stover Ethanol	Switchgrass Ethanol
Fuel and Feedstock Transport	4,265	3,461	2,418	2,808
Farm Inputs	10,313	6,482	2,770	4,890
Livestock (Manure and Enteric Fermentation)	-3,746	-2,100	9,086	3,462
Rice Methane	-209	-7,950	434	-1,555
Total Domestic Agriculture	**10,623**	**-107**	**14,708**	**9,605**

With the exception of soybean biodiesel, FASOM projects that increased biofuel production in 2022 in the scenarios analyzed will lead to increased GHG emissions in the domestic agricultural sector, excluding land use change. With increased volumes of each biofuel, fuel and feed transport and farm inputs increase and thereby increase GHG emissions. No one domestic agricultural sector emission source (excluding land use change) emerges as the specific driver of GHG emissions across all fuel pathway scenarios. Rather, emission sources act with varying degrees of importance in each scenario.

Overall the small impact in the domestic agricultural sector is due to the indirect effects and demand changes, specifically demand changes in U.S. exports. For example, the sources of corn used in ethanol production in the FASOM model are shown in. Some of the additional corn comes from increased corn production; however, the increase in corn acres is mostly offset by reductions in other crop acres as shown in **Figure 2.4-10**. Some of the corn used for ethanol comes from decreased corn used for feed. During the corn ethanol production process, one of the byproducts produced are distillers grains with solubles (DGS). DGS can be used as a feed source for beef cattle, dairy cows, swine and poultry, and partially offsets the use of corn directly as feed.

Figure 2.4-9.



However, as seen from Figure 2.4-9, one of the sources of corn for ethanol production is projected to come from reductions in corn exports. Therefore, the domestic agricultural sector impacts are only a portion of the total impacts due to increased ethanol production in the U.S. The change in corn and other crop exports will have impacts on the international agricultural sector that need to be accounted for when determining lifecycle GHG impacts of biofuel production in the U.S.

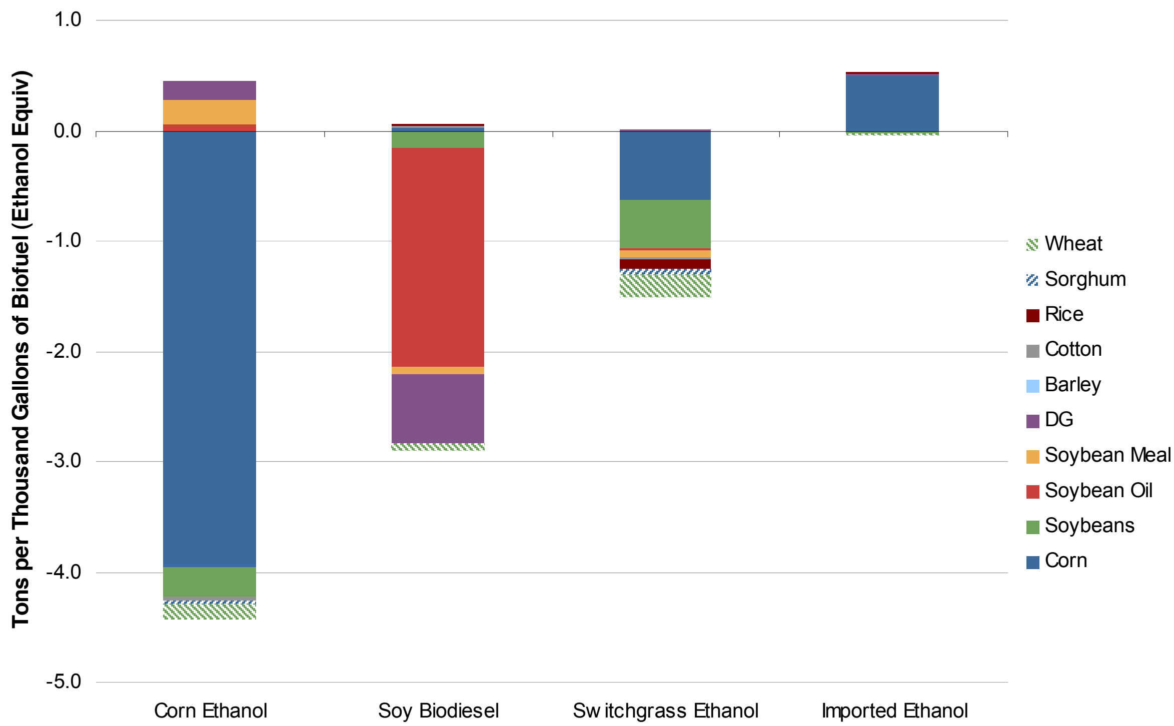
2.4.2.5 Translation of Domestic Impacts into International Impacts

In order to estimate the impact on international agricultural sector GHG emissions, the FAPRI-CARD model was run with the same domestic biofuel volume scenarios, with the exception of cellulosic ethanol, as was run in the FASOM model for the domestic agriculture sector analysis. In the FAPRI-CARD models, links between the U.S. and international models are made through commodity prices and net trade equations. In general, for each commodity sector, the economic relationship that quantity supplied equals quantity demanded is achieved through a market-clearing price for the commodity. In each country domestic prices are modeled as a function of the world price using a price transmission equation. Since econometric models for each sector can be linked, changes in one commodity sector will impact the other sectors.

The model for each commodity consists of a number of countries/regions, including a rest-of-the-world aggregate to close the model. The models specify behavioral equations for production, use, stocks, and trade between countries/regions. The models solve for representative world prices by equating excess supply and demand across countries. Using price transmission equations, the domestic price for each country is linked with the representative world price through exchange rates. It is through changes in world prices that change in worldwide commodity production and trade is determined.

When analyzing the impact of the RFS2 biofuel requirements in the U.S., there are two primary domestic effects that directly affect a commodity's worldwide use and trade: change in exports, and changes in domestic U.S. prices. For example, as discussed above, the corn ethanol biofuel requirement places an additional demand for corn used for ethanol, and this corn comes not just from additional production, but also from decreases in other uses including exports. In addition, as corn production expands, it places pressure in terms of relative demand on other crops in a particular region in the U.S., which in turn affects their prices and use (including exports). As the level of exports from the U.S. of a particular commodity decreases, other countries will adjust their production and trade to satisfy the demand for that commodity. **Figure 2.4-10** shows the change in U.S. exports per by major commodity per thousand gallons of biofuel, as projected by FASOM.

Figure 2.4-10. Normalized Changes in U.S. Exports by Crop, 2022
(tons per thousand gallons of renewable fuel)



As expected, an increase of a particular biofuel will have the greatest impact on U.S. exports of that biofuel's feedstock. For instance, with an increase of one thousand gallons of corn ethanol, corn exports decrease by four tons, and with an increase of one thousand gallons of soy biodiesel, soybean oil exports decrease by two tons. Increases in corn ethanol and soy biodiesel will not only affect the crop area and export levels of its primary feedstock (corn and soybean oil, respectively), but it will also affect other crops as increased demand for these commodities change the relative demand, and therefore production and use, between different commodities.

Although switchgrass and other cellulosic ethanol sources are not explicitly modeled in FAPRI-CARD, the changes in acres for various crops as a result from an increase in switchgrass ethanol as modeled by FASOM were applied to FAPRI-CARD on a regional basis in the U.S. This provides a reasonable approximation of the effects of an increase of switchgrass acres in the FAPRI-CARD model, and the affect it has on other crop area, production, prices and trade for other crops.

In addition, we have modeled the impact of increased production of Brazilian sugarcane ethanol for use in the U.S. market. The FAPRI-CARD model has been used to determine the international impacts of Brazilian sugarcane ethanol production. The increase in Brazilian sugarcane ethanol production is assumed to have no impacts on domestic U.S. agriculture emissions.

As well as the change in U.S. exports, the FAPRI-CARD model relies on price transmission equations, therefore changes in the U.S. price for a commodity will have a direct impact on the world price for that commodity. This, in turn, will have an impact on the demand for that commodity worldwide, and affect production and trade levels in other countries. Additional information on the changes in the world price for commodities and the coordination of assumptions between the FASOM and FAPRI-CARD models can be found in Chapter 5 of the RIA.

2.4.3 Evaluation of International Agricultural GHG Emissions Impacts

For this analysis we used the FAPRI-CARD model to estimate the impacts on international crop production due to changes in biofuel production. These results were used to generate GHG emissions from the international agricultural sector, similar to what was done to determine domestic agricultural GHG emission changes.

2.4.3.1 International Agricultural Inputs

The FAPRI-CARD model does not directly provide an assessment of the GHG impacts of changes in international agricultural practices (e.g., changes in fertilizer load and energy use). However, it does predict changes in crop area and production by crop type and country. We, therefore, determined international fertilizer and energy use based on data collected by the Food and Agriculture Organization (FAO) of the United Nations and the International Energy Agency (IEA). For the final rule, we have also incorporated more up-to-date fertilizer consumption statistics provided by a recent International Fertilizer Industry Association (IFA) report, Assessment of Fertilizer Use by Crop at the Global Level, 2006/07 – 2007/08.[519] For more details refer to the memorandum to EPA from ICF International.[520] Where country and crop specific energy use data was available (in the case of Brazilian sugarcane), we used that data as further discussed in Section 2.4.3.3.

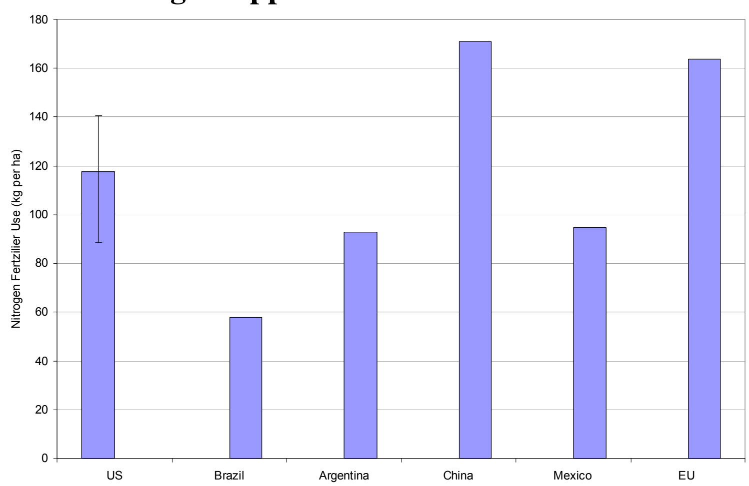
We took the FAPRI-CARD provided activity data on changes in crop acres, by crop and country, and multiplied by regional fertilizer use rate factors (kg per ha) to determine the global impacts of biofuel production on fertilizer application. Historical fertilizer application rates for nitrogen, phosphorus, and potassium were updated using more recent data available from the IFA report as recommended by expert reviewers during our peer review.[521] IFA data are preferred over FAO's Feristat data because estimates are more current and years of available data are consistent across all countries. Also, FAO has altered its survey methodology since 2004.[522]

The IFA dataset covers 23 countries (considering the European Union-27 as one country) and 11 crop groups including: wheat, rice, corn, other coarse grains, soybean, palm oil, other oilseeds, cotton, sugar crops, fruits and vegetables, and other crops. IFA consumption data were averaged over the two reported time periods: 2006 or 2006/07, and 2007 or 2007/08 to account for seasonal variations in crop production. Fertilizer application rates were calculated by dividing IFA total consumption values by FAOStat agricultural area harvested data from the FAOStat database.[523]

The FAO Feristat dataset was also updated to the most recent version since the proposal. Feristat data are used for country/crop and region/crop combinations not covered by the IFA dataset. In addition, Feristat data is preferred to calculate fertilizer consumption for "rest of the world" regions since the dataset provides for a greater number of countries and greater detail for a variety of crops. Feristat fertilizer application rates (kg per ha) are calculated by dividing total Feristat fertilizer consumption by Feristat agricultural area fertilized.

Figure 2.4-11 compares the nitrogen fertilizer application rates for major corn produces around the word as determined with IFA and FAO data, with the U.S. as a reference for comparison.

Figure 2.4-11. Nitrogen Application Rates for Corn in Select Regions



Herbicide and pesticide use data have been updated using the most current data available from FAO's FAOStat dataset for pesticide consumption.[524] FAO's pesticide consumption dataset did not provide values for China, and thus data was used from the U.S. Department of Agriculture's (USDA) Economic Research Service (ERS).[525]

We acknowledge that there may be other country and crop specific sources of fertilizer data available for example for Brazilian sugarcane in addition to the IFA data, however, it was not available in time for incorporation in the final rule analyses and furthermore the data used provides a consistent dataset for all crops and countries.[526] This is an area for future research for any future analysis.

IFA does not collect data on lime use, however for the final rule we include lime use for sugarcane based on data from Macedo (2008), estimated at 333.3 kg/ha.

We then used GREET factors for emissions from production of agricultural chemicals to estimate the upstream GHG impacts of fertilizer and chemical production to calculate total impacts for each fuel scenario with the exception of lime where we used data from Macedo to represent lime production in Brazil. **Table 2.4-14** provides the total change in fertilizer and chemical use for the different fuel scenarios, per mmBTU renewable fuel.

Table 2.4-14.
International Change in Fertilizer and Chemical Use by Scenario, 2022
(kg/mmBTU)

Input	Corn Ethanol	Soy-Based Biodiesel	Switchgrass Biochemical Ethanol	Sugarcane Ethanol
N Application	0.3683	0.0526	0.0774	0.4451
P Application	0.1780	0.6216	0.1302	0.1520
K Application	0.1245	0.6288	0.1179	0.5735
Herbicide Application	0.0006	0.0021	0.0006	0.0006
Pesticide Application	0.0009	0.0024	0.0008	0.0008

2.4.3.2 International N_2O Emissions

For international N_2O emissions we considered both direct and indirect emissions from synthetic fertilizer application, crop residue N, and manure management. Manure management emissions are discussed in the following section. Direct and indirect emissions from synthetic fertilizer application and crop residues were calculated based on IPCC guidance as shown in Table 2.4-15.[527]

Table 2.4-15. Calculations of N2O Emissions from Synthetic Fertilizer and Crop Residues

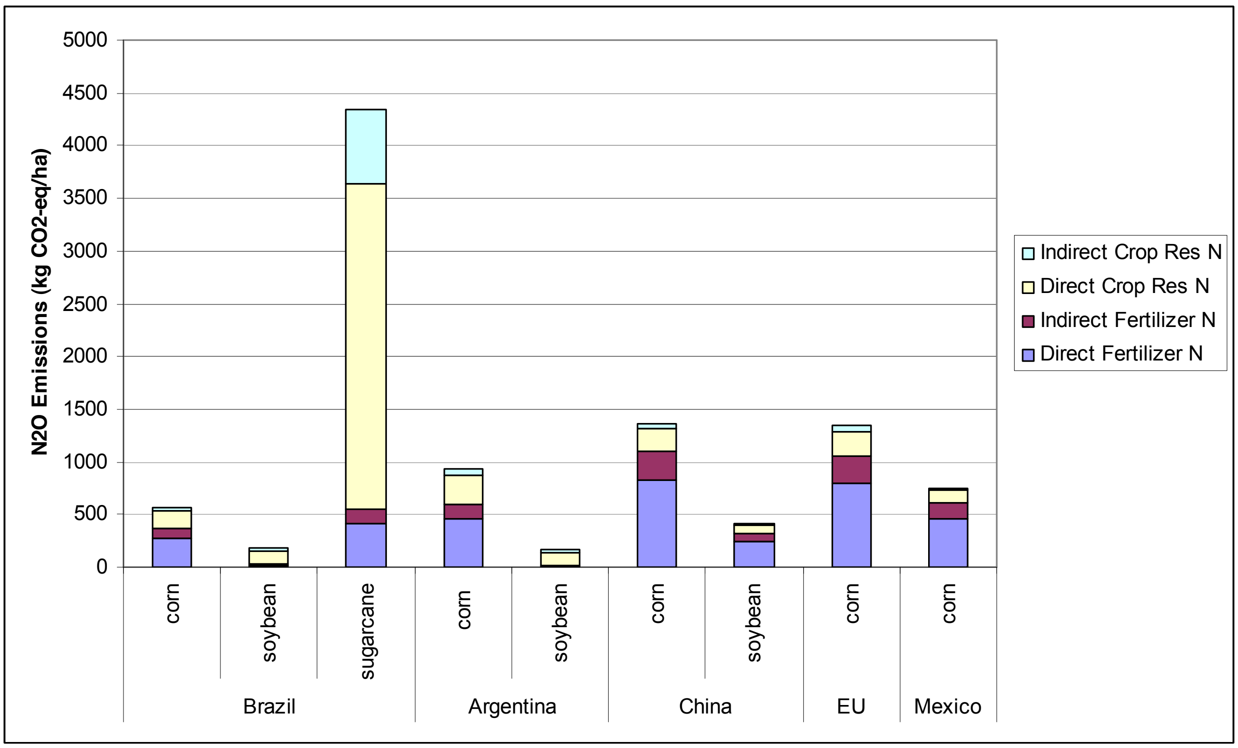
Direct N_2O Emissions		
Direct Emissions (Overall Equation)		**Equation**
Emissions	=	(N additions to soils from mineral fertilizer + N additions to soils from crop residues) × EF
EF for N additions from mineral fertilizer and crop residues	=	0.01 kg N_2O-N / kg N added
N Additions from Mineral Fertilizers		
N additions to soils from mineral fertilizers	=	Kg fertilizer N applied to soils (i.e., change in fertilizer N applications from Table 2.4-14)
N Additions from Crop Residues		
N additions to soils from crop residues	=	above-ground residue dry matter × Crop Area × [N content of aboveground residues + ratio of belowground residues to aboveground biomass × N content of belowground residues]
where,		
Above-ground residue dry matter and N additions to soils from crop residues	=	Taken from IPCC default values by crop
Indirect N_2O Emissions		
Note that for indirect emissions, the calculation of N applied to soils from fertilizers or crop residues is the same as for direct emissions		
Indirect Emissions from Volatilization		**Equation**
Emissions	=	N additions to soils from mineral fertilizers × N lost through volatilization × EF
N lost (from synthetic fertilizer additions) through volatilization	=	0.1 (kg NH_3–N + NOx–N) / kg N applied
EF for N lost through volatilization	=	0.010 kg N_2O–N / (kg NH_3–N + NO_X–N volatilised)
Indirect Emissions from Leaching/Runoff		**Equation**
Emissions	=	(N additions to soils from mineral fertilizers + N additions to soils from crop residues) × N lost through leaching or runoff × EF
N lost through leaching/runoff (from all N sources)	=	0.3 N losses by leaching or runoff / kg N addition
EF for N lost through leaching/runoff	=	0.0075 kg N20-N / kg N leaching or runoff

The proposal did not include N_2O emissions from the Direct and Indirect Emissions from Crop Residues for cotton, palm oil, rapeseed, sugar beet, sugarcane, or sunflower. These were not included for these crops because default crop-specific IPCC factors used in the calculation were not available.

Comments from our peer review process suggested that we include proxy emissions from these crops based on similar crop types that do have default factors. Therefore, for our final rule analysis we have included crop residue N_2O emissions from sugarcane production based on perennial grass as a proxy. Perennial grass is chosen as a proxy based on input from N_2O modeling experts. Emissions for cotton, palm oil, rapeseed, sugar beet, and sunflower were also included based on root crops, other as a proxy.

Figure 2.4-12 summarizes N_2O emissions by crop for a sample of crops and countries by the four categories of N_2O emissions.

Figure 2.4-12. Sources of N2O Emissions by Crop for Select Regions



Based on the equations in Table 2.4-15

Table 2.4-15and the crop production changes projected by FAPRI-CARD, we estimated the total change in N_2O emissions for each fuel scenarios, as shown in Table 2.4-16.

Table 2.4-16.
International Crop Change in N2O Emissions in 2022 from Different Fuel Scenarios (kg CO2e/mmBTU)

	Corn Ethanol	Soybean Biodiesel	Switchgrass Ethanol	Brazilian Sugarcane Etanol
Direct and Indirect N_2O Emissions	3.38	2.09	0.95	29.25

2.4.3.3 International Fuel Combustion Emissions

In terms of evaluating international agriculture energy use data, we continued to use IEA data as these are the best available for this purpose (providing data by end use and fuel type for over 130 countries representing the major energy users of the world). We collected data from IEA on total CO_2 emissions from agricultural fuel combustion by country.[528] We also collected IEA data on agricultural electricity and fuel use by country, which was combined with emissions factors to estimate country-level GHG emissions from agricultural electricity and fuel use. Historical trends were used to project chemical and energy use in 2022. These total GHG emissions were only combustion related, so we scaled them to represent full lifecycle GHG emissions from fuel production, based on the ratio of combustion to full lifecycle GHG emissions from U.S. fuel and electricity use. Country-level GHG emissions from agricultural energy use were then divided by the area of agricultural land in each country, from the FAOSTAT land area database to derive a per acre GHG emissions factor from agricultural energy use by country. Our estimates use average energy consumption and GHG emissions per acre for all crops in each foreign country. We multiplied these agricultural energy consumption emissions factors by the country-level crop acreage changes projected by FAPRI-CARD to determine the change in GHG emissions from foreign agricultural energy use for each fuel scenario.

In the case of Brazilian sugarcane, we had country and crop specific data available to estimate agricultural energy use.[529] For sugarcane farming, energy use includes the diesel fuel used to power farming equipment and energy use for sugarcane preparation. The energy used to perform other activities and small services during productive operation was also included. Energy embedded in farming equipment was not included in this calculation, as consistent with other renewable fuel pathways. **Table 2.4-17** shows how diesel consumption is expected to increase in the future mainly due to increased use of diesel consumption with the growth of mechanical harvesting and trash recovery.

Table 2.4-17. Energy Use (BTU/MT sugarcane)[151]

Activity	2002	2005/2006	2020
Ag Operations	15544	12606	14028
Harvesting	20568	31562	44453
Other Activities		36491	42462
Seeds	5592	5592	6256
Total	41704	86251	107198

For the final rule we assumed the energy use estimated in 2020 for agricultural operations, harvesting, other activities and seed production would be similar to that in 2022, and have adopted these estimates for our GHG calculations for the case where 40% of the trash (sugarcane leaves and tops) are assumed to be collected as predicted in literature. When trash is not assumed to be collected, we used 2005/2006 energy use data to account for the fact that less energy use would be required as the collection of trash is not needed. We assume the energy use is from 100% diesel.

Table 2.4-18 provides the total change in agricultural energy use GHG emissions for the different fuel scenarios.

Table 2.4-18.
International Change in Agricultural Energy Use GHG Emissions by Scenario, 2022 (kg CO2e / mmBTU)

	Corn Ethanol	Soybean Biodiesel	Switchgrass Ethanol	Brazilian Sugarcane Ethanol
Agricultural Sector Energy Use GHG Emissions	1.7	1.88	-0.16	5.14

2.4.3.4 International Rice Methane Emissions

To estimate rice emission impacts internationally, we used the FAPRI-CARD model to predict changes in international rice production as a result of the increase in biofuels demand in the U.S. Since FAPRI-CARD does not have GHG emissions factors built into the model, we applied IPCC default factors by country.

Calculating emissions from rice cultivation, per the IPCC 2006 guidelines, requires the following data: area of rice harvested, an emissions factor, and planting to harvesting season length. Area of rice harvested by country was provided by the FAPRI-CARD results. The default IPCC emission factors were used scaled for each cropping regime: irrigated, rainfed lowland, upland and deepwater by country. Rice cultivation season lengths were available from the International Rice Research Institute (IRRI).[530]

[151] Converted from Macedo (2008) Table 9.

2.4.3.5 International Crop Residue Burning Emissions

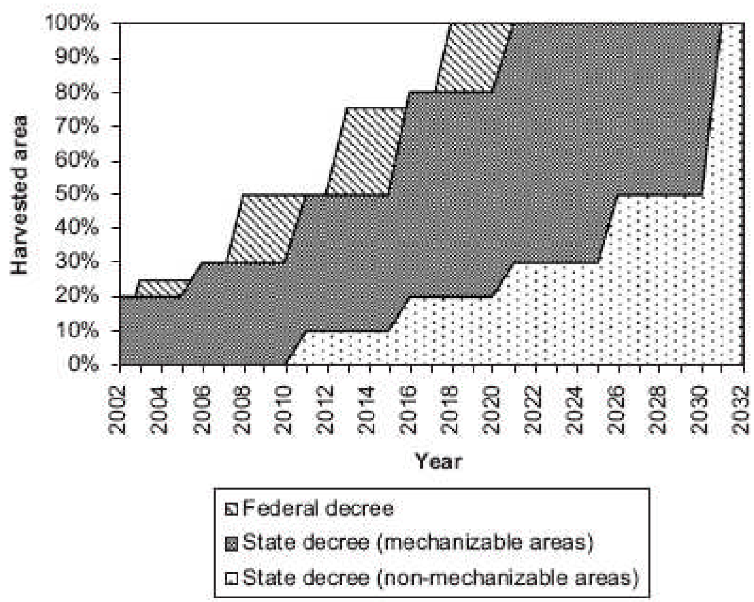
International crop residue burning on the field, and specifically changes in residue burning emissions could occur due to changes in U.S. biofuel policy. We specifically included for the final rule analysis an estimate of sugarcane field burning and mechanical harvesting emissions. We also incorporate emissions from land clearing for crop production as discussed in Section 2.4.4.

Sugarcane leaves and tops are typically burned in the field before and after harvest. Per metric ton of sugarcane, there is 280 kg of leaves and tops (with 50% moisture content) or 140 kg of dry leaves and tops, which we assume for modeling purposes. In the case where trash is collected, it was assumed that 40% (i.e. 56 kg dry leaves and tops per metric ton of cane would be recovered to be used as fuel at the mill).

Current trends in Brazil are moving from burned cane with manual harvesting to unburned cane with mechanical harvesting. This change is related to the gradual reduction of cane trash pre-burning at both Federal and State levels in Brazil. See

Figure 2.4-13 for the phase out schedule for trash burning practices.

Figure 2.4-13. Phase Out Schedule for Trash Burning Practices



According to Brazil's Sugarcane Research Center (CTC), about 47.5% of all sugarcane in Brazil is already mechanically harvested, and 35.3% of all sugarcane in Brazil is mechanically harvested without being burned in the field.[531] These percentages have increased since 2002, see **Table 2.4-19**.

Table 2.4-19. Sugarcane Harvest –2002 Situation

Type of harvest	Sao Paulo (%)	Center-South (%)
Manual	63.8	65.2
Mechanical	36.2	34.8
Burned sugarcane	75.0	79.1
Unburned sugarcane	25.0	20.9

UNICA states that in 2008 about half of the sugarcane fields in Sao Paulo were mechanically harvested, up from 36.2% in 2002. In the future, Sao Paulo state law requires that sugarcane field burning be phased-out by 2021 for areas where mechanical areas are possible with existing technologies (over 85% of existing sugarcane fields) and where mechanical harvesting may not be possible, 30% will be required to phase-out burning. This implies that by 2022 considering all areas in Sao Paulo about 90% of sugarcane fields could be unburned.

Sao Paulo currently accounts for 60% of all national production of sugarcane, with the Center-South producing about 89% of all sugarcane. Considering that 89% of Brazilian Production occurs in the Center-South, and Sao Paulo consists of a considerable portion of that production, the following situation in **Table 2.4-20** as assumed for Brazil in 2022.

Table 2.4-20. Sugarcane Harvest – Projected for 2022

Type of harvest	Brazil (%)
Manual	0
Mechanical	100
Burned sugarcane	10
Unburned sugarcane	90

We took into account emissions from open-field burning from two pollutants, methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide (CO_2) emissions were not taken into account because the CO_2 is considered to be taken from the air during sugarcane growth.

Table 2.4-21. Emission Factors of Open-Field Burning of Sugarcane Leaves and Tops[532]

Pollutant	g/kg of dry leaves and tops burned
CH_4	2.7
CO	92
N_2O	0.07
NO_x	2.5
PM_{10}	7.8
$PM_{2.5}$	3.9
SO_x	0.4
VOC	7.0

2.4.3.6 International Livestock GHG Emissions

Similar to domestic livestock impacts associated with an increase in biofuel production, internationally the FAPRI-CARD model predicts changes in livestock production due to changes in feed prices. The GHG impacts of these livestock changes, enteric fermentation and manure management GHG emissions, were included in our analysis. Unlike FASOM, the FAPRI-CARD model does not have GHG emissions built in and, therefore, livestock GHG impacts were based on activity data provided by the FAPRI-CARD model (e.g., number and type of livestock by country) multiplied by IPCC default factors for GHG emissions.

Table 2.4-22

Table 2.4-22 shows the changes in livestock predicted by the FAPRI-CARD model in 2022 for each of the fuel scenarios considered.

Table 2.4-22.
Foreign Livestock Changes by Region and Renewable Fuel, 2022
(head / billion BTU)

Corn Ethanol	Dairy	Beef	Swine	Sheep	Poultry
Canada	0.00	0.05	-0.17	0.00	1.37
Western Europe	0.00	-0.07	0.12	0.02	1.58
Eastern Europe	0.00	-0.83	0.01	0.00	17.72
Oceania	-0.02	0.11	0.01	0.07	3.53
Latin America	-0.15	3.44	0.48	0.00	-0.46
Asia	-0.09	0.17	-0.04	-1.19	-1.53
Africa and Middle East	-0.03	-0.45	0.32	0.00	-3.01
Indian Subcontinent	0.00	0.12	0.02	0.00	-3.66
Soy-Based Biodiesel	Dairy	Beef	Swine	Sheep	Poultry
Canada	0.02	0.27	1.62	0.00	-8.07
Western Europe	-0.01	0.57	-1.16	-0.45	29.30
Eastern Europe	0.00	-0.59	-0.44	0.00	-114.88
Oceania	0.05	0.03	0.11	-0.20	-30.92
Latin America	0.45	-8.38	0.18	0.00	-0.06
Asia	0.33	0.92	0.60	6.67	-55.37
Africa and Middle East	0.01	2.11	0.82	0.00	2.65
Indian Subcontinent	0.00	0.27	0.06	0.00	-34.31
Sugarcane Ethanol	Dairy	Beef	Swine	Sheep	Poultry
Canada	0.00	0.00	-0.10	0.00	0.47
Western Europe	0.00	-0.01	0.07	0.01	-0.32
Eastern Europe	0.00	-0.12	0.02	0.00	4.56
Oceania	0.00	0.01	-0.01	0.00	0.96
Latin America	-0.03	0.22	-0.08	0.00	-0.09
Asia	-0.01	-0.01	-0.14	-0.32	0.13
Africa and Middle East	-0.01	0.00	-0.06	0.00	-0.58
Indian Subcontinent	0.00	-0.01	0.00	0.00	-0.43
Switchgrass Ethanol (Biochemical)	Dairy	Beef	Swine	Sheep	Poultry
Canada	0.00	0.00	-0.11	0.00	0.72
Western Europe	0.00	-0.01	0.06	0.02	-0.34
Eastern Europe	0.00	-0.12	0.05	0.00	6.36
Oceania	0.00	0.02	0.00	0.00	1.10
Latin America	-0.03	0.04	0.07	0.00	-0.11
Asia	-0.02	0.00	0.13	-0.47	0.48
Africa and Middle East	-0.01	0.05	0.03	0.00	-0.77
Indian Subcontinent	0.00	-0.01	0.00	0.00	-0.44

The enteric fermentation GHG impacts of livestock changes were calculated by applying regional default factors for enteric fermentation CH_4 emissions by livestock type. These factors are shown in Table 2.4-23.

Table 2.4-23. Enteric Fermentation Emission Factors

Enteric Fermentation (kg CH_4/head/year)	Dairy	Cattle	Swine	Sheep
North America	121	53	1.5	8
Western Europe	109	57	1.5	8
Eastern Europe	89	58	1.5	8
Oceania	81	60	1	5
Latin America	63	56	1	5
Asia	61	47	1	5
Africa and Middle East	40	31	1	5
Indian Subcontinent	51	27	1	5

Manure management GHG impacts of livestock changes for each fuel scenario were calculated by applying regional default factors for manure management CH_4 and N_2O emissions by livestock type. Manure management CH_4 emission factors are shown in **Table 2.4-24**. Manure management N_2O values were based on default IPCC nitrogen produced per livestock type and IPCC default manure management practices by region.

Table 2.4-24. Manure Management Methane Emission Factors

Manure Management (kg CH_4/head - year)	Dairy	Cattle	Swine	Sheep	Poultry
North America	78	2	23.5	0.28	0.02
Western Europe	51	15	15.5	0.28	0.02
Eastern Europe	27	13	6.5	0.28	0.02
Oceania	29	2	18	0.15	0.02
Latin America	1	1	1	0.15	0.02
Asia	18	1	4	0.15	0.02
Africa and Middle East	1.5	1	2	0.15	0.02
Indian Subcontinent	5	2	4	0.15	0.02

Based on the peer review of the methodology used for the proposal it was determined that the calculations for manure management did not include emissions from soil application. These emissions were included for our final rule analysis but do not cause a significant change in the livestock GHG emission results.

2.4.3.7 International Agriculture Sector Results (Excluding Land Use Change)

Table 2.4-25 provides an overview of the total GHG emissions impacts from the international agricultural sector based on the results of the FAPRI-CARD modeling. As discussed above, emissions from farm inputs include the production, transport and fate of agricultural inputs including pesticide, fertilizer and other chemicals. The farm inputs category also includes energy used in crop production processes. Land use change impacts are discussed in Section 2.4.4.

Table 2.4-25.
Foreign Agriculture GHG Emission Changes in 2022 from Different Fuel Scenarios (g CO2e/mmBTU)

	Corn Ethanol	Soy Biodiesel	Sugarcane Ethanol	Switchgrass Ethanol
Farm Inputs	6,601	5,402	37,884	1,310
Livestock Production	3,458	-6,436	-128	-245
Rice Methane	2,089	2,180	485	-920

2.4.4 Land Conversion GHG Emissions Impacts

Our lifecycle GHG estimates include emissions from domestic and international land use conversions induced by increased renewable fuels consumption in the United States. To estimate land conversions GHG emissions we answered six key questions:

1. How much land is converted?
2. Where does land conversion occur?
3. What types of land are converted?
4. What are the GHG emissions impacts from that land conversion?
5. How do we account for the variable timing of land conversion GHG releases?
6. What is the level of uncertainty in our land conversions GHG emissions estimates?

This section describes our approach for answering these questions about land use change. We used the FASOM model to project land conversions in the United States. FASOM was designed to simulate domestic land use interactions and land use change GHG impacts. We used the FAPRI-CARD model to project international cropland expansion in response to increased United States biofuel consumption. We used the FAPRI-CARD international models to project changes in the area of land used for crop production and pasture. FAPRI-CARD does not, however, project which types of land would be cleared to make room for additional agricultural land uses, or where within in each country or region agricultural expansion would likely take place. To fill this information gap we used MODIS satellite data provided by Winrock International, Inc. (from now on referred to as Winrock), that shows recent land use change patterns from 2001 to 2007. To determine the GHG impacts of the projected land conversions we applied GHG emissions factors prepared by Winrock following IPCC guidelines. To account for the variable timing of land use change GHG impacts, we annualized land use change GHG impacts over 30 years (with a 0% discount rate).

To quantify the uncertainty in our quantification of GHG emissions from international land conversions, we focused on two areas: uncertainty in the MODIS satellite data used to determine the types of land affected (e.g., forest or grassland), and uncertainty in the our land conversion GHG emissions factors (i.e., the GHG emissions per unit area of land conversion). To reduce and quantify the uncertainty in the MODIS satellite data we utilized extensive data validation efforts by NASA, which we used to correct systematic errors in the MODIS data set and to quantify the remaining uncertainty. To quantify the uncertainty in land conversion GHG emissions factors, we evaluated the uncertainty in every data input based on the quality, quantity, resolution and variability in the underlying data sources. Correlation groups were assigned based on the sources of underlying data. Finally, the total uncertainty in international land use change GHG emissions was quantified a Monte Carlo analysis following Tier 2 IPCC guidelines.

This section describes the data sources and methods used for the analysis summarized above, with key results illustrated throughout.

2.4.4.1 Evaluation of Domestic Land Conversion GHG Emissions Impacts

We used FASOM to project U.S. land use change under each fuel-specific pathway scenario due to the increase in respective renewable fuels and then the change in GHG emissions that result from the changes in land use. FASOM was designed to simulate land use interactions to predict the types of land converted in the U.S. (See RIA Chapter 5 for more details). In this section we discuss FASOM modeling of land conversion and related GHG emissions as well as final calculations for GHG emissions on a per mmBTU basis for each fuel-specific pathway scenario.

2.4.4.1.1 Area and Location of Domestic Land Conversions

How land is used in FASOM is determined through the relative profits from various activities. This varies not only between crops, but also between different land uses, such as pasture for livestock production. A number of updates have been made to the FASOM model since the analysis for the Proposal in order to have a more complete assessment of land use in the U.S. One of these updates includes the incorporation of the forestry component of the FASOM model. Running both the forestry and agriculture components of the model for the final rulemaking analysis shows the interaction between these two sectors as they compete for land in various regions, as well as the effect on products and prices in each respective sector.

In addition, FASOM also includes a representation of seven major land use categories, including cropland, cropland pasture, forestland, forest pasture, rangeland, developed land, and acres enrolled in the Conservation Reserve Program (CRP). These categories are based on the USDA National Agriculture Statistics Service (NASS), and enable the FASOM model to explicitly link the interaction between livestock, pasture land, cropland, and forest land, as well as have a detailed accounting of acres in the U.S. across different land uses. Cropland is actively managed cropland, used for both traditional crops (e.g., corn and soybeans) and dedicated energy crops (e.g., switchgrass). Cropland pasture is managed pasture land used for livestock production, but which can also be converted to cropland production. Forestland contains a number of sub-categories, tracking the number of acres both newly and continually harvested (reforested), the number of acres harvested and converted from other land uses (afforested), as well as the amount of forest acres on public land. Forest pasture is unmanaged pasture land with varying amounts of tree cover that can be used to raise livestock. A portion of this land may be used for timber harvest. Rangeland is unmanaged land that can be used for livestock grazing production. While the amount of rangeland idled or used for production may vary, rangeland may not be used for any other purpose than for animal grazing. For each of these categories, FASOM accounts for how much is actively used in production, and how much idled, in a particular time period.

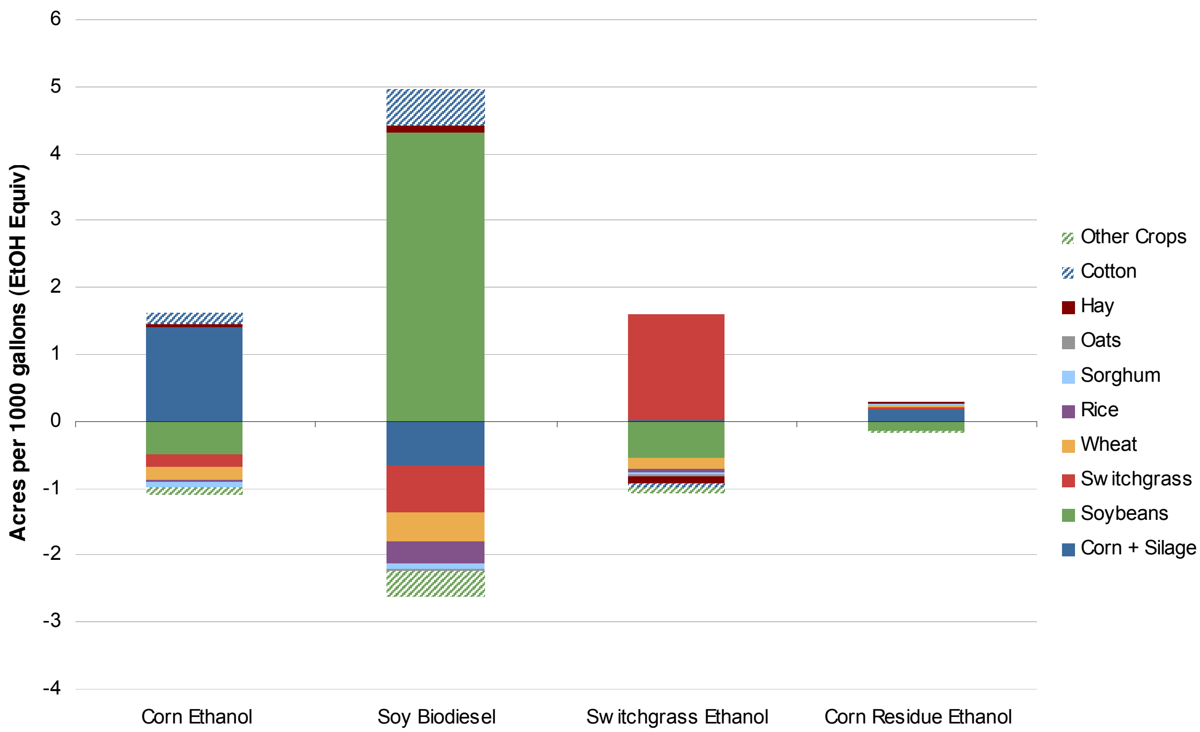
Another update to the FASOM model is the distillers grains and solubles (DGS) replacement rates for corn and soybean meal in animal feed. These replacement rates are based on recent research published by Argonne National Laboratory[533] that demonstrate higher replacement rates than what was used in the analysis for the Proposal. This means that DGS, as a byproduct of corn ethanol production, are relatively more efficient compared to the Proposal's analysis, and results in less corn and soybean meal needed for animal feed. This, in turn, results in less corn and soybean production needed for use in animal feed relative to the Proposal. Further discussion of changes made to the FASOM model can be found in Chapter 5.

For the corn ethanol scenario, the FASOM model estimates that total cropland area used for production increases by 1.4 million acres in 2022. This is a result of an increase of 3.7 million acres of corn, a decrease of 1.3 million acres in soybeans, as well as changes in other crop acres. Similarly, total cropland area increases by 1.9 million acres in the soybean biodiesel scenario, which consists of an increase of 3.5 million acres of soybeans, decreases of 0.6 million acres each of corn and switchgrass, as well as a variety of other changes. In the switchgrass ethanol scenario, total cropland acres increases by 4.2 million acres, including an increase of 12.5 million acres of switchgrass, a decrease of 4.3 million acres of soybeans, a 1.4 million acre decrease of wheat acres, a decrease of 1 million acres of hay, as well as decreases in a variety of other crops. Table 2.4-26 summarizes the change in total cropland acres used in production, both total and normalized by changes in biofuel volume, and Figure 2.4-14 shows the changes for each crop in each fuel-specific volume scenario.

Table 2.4-26.
Change in total area of domestic cropland used for production by scenario, in 2022

Scenario	Total Cropland Increase (million acres)	Normalized Cropland Increase (acres per thousand gallons, ethanol equivalent)
Corn Ethanol	1.4	0.12
Soybean Biodiesel	1.9	0.39
Switchgrass Ethanol	4.2	0.04
Corn Stover Ethanol	0.6	0.06

Figure 2.4-14. Normalized Domestic Crop Acreage Changes by Scenario, 2022 (acres per thousand gallons, ethanol equivalent)



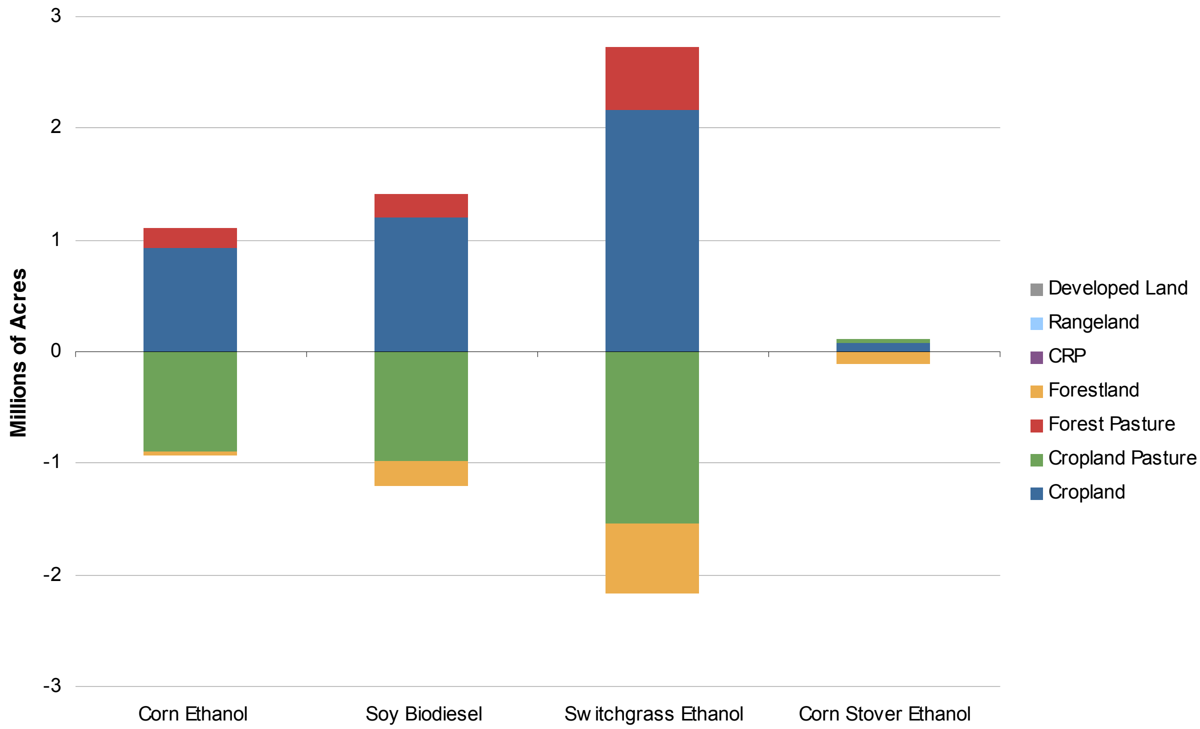
2.4.4.1.2 Types of Domestic Land Conversions

Based on relative demand for crop and livestock production changes that result from increased demand for biofuels, there are direct effects on land used for crop and livestock production, as well as indirect effects on other land types in the U.S. For instance, in 2022, as demand for corn ethanol increases in the corn ethanol scenario, total cropland (used for production and idled) increases by 0.9 million acres, total cropland pasture decreases by 0.9 million acres, total forest pasture increases by 0.2 million acres, forestland decreases by 0.03 million acres. As soybean biodiesel increases (in the biodiesel scenario), total cropland increases by 1.2 million acres, cropland pasture decreases by 1.0 million acres, forest pasture increases by 0.2 million acres, and forestland decreases by 0.2 million acres. With an increase in switchgrass ethanol, cropland increases by 2.2 million acres, cropland pasture decreases by 1.5 million acres, forest pasture increases by 0.6 million acres, and forestland decreases by 0.6 million acres.

In the corn stover scenario, an increase in ethanol from corn stover does not directly result in crop acre changes, merely an increase in the harvesting of residue from existing corn acres. However, an increased demand for ethanol from corn stover does inherently give more value per acre of corn with residue removal. Based on corn residue removal possibilities by region, there are relatively small changes to land uses with an increase in corn stover ethanol production. Specifically, cropland increases by 0.07 million acres, cropland pasture increases by 0.05 million acres, forest pasture acres do not change, and forestland acres decrease by 0.2 million acres.

The number of acres enrolled in CRP does not vary between volume scenarios because in each scenario, the maximum amount is taken from the program and converted to cropland for production, all leaving the assumed minimum limit of 32 million acres, in accordance with the 2008 Farm Bill. The number of acres in rangeland does not vary because rangeland acres are not suitable for any other use than unmanaged land for livestock production. The only change in rangeland is whether or not a certain number of acres are actively used for production, or whether they remain idle. Lastly, developed land is assumed to be of higher value than all other land categories, and FASOM assumes that the amount of developed land increases at a steady rate over time, and does not vary with changes in demand for biofuel.

Figure 2.4-15. Change in Domestic Land Use by Type, 2022



Note: Some of these land use categories are not used in GHG emission calculations

2.4.4.1.3 Quantification of GHG Emissions from Domestic Land Conversions

Domestic land use change GHG emissions are based on outputs of the FASOM model. FASOM models the changes in GHG emissions and sequestration due to changes in land management. FASOM explicitly models change in soil carbon due to change in crop production acres and in crop type. In addition, FASOM's forestry module models the change in above-ground biomass and below-ground biomass carbon stock and soil carbon in the forestry sector due to land conversion. With the addition of the forestry module for the final rulemaking, we have used FASOM to model changes in soil carbon and biomass carbon due to land use conversion between cropland, pasture, forestland, and developed land.

In addition to quantifying GHG emissions and sinks, FASOM distinguishes the unique time dynamics and accounting issues of carbon sequestration options. These include issues such as saturation of carbon sequestration over time (i.e., carbon sequestration in a particular sink reaches an equilibrium such that carbon storage is maintained, but is no longer increasing), potential reversibility of carbon benefits (e.g., due to changes in tillage, forest harvests, wildfires), and fate of carbon stored in products after forest harvest.

GHGs, generally in the form of carbon, can be sequestered in soils, standing trees, other vegetation, and wood products. Sequestration refers to storage of the GHGs for more than one year. As a consequence, the sequestration definition used in the model for standing vegetation is limited to carbon storage in trees, understory, and litter within both forests and plantations of woody biofuel feedstocks (poplar and willow) but excludes, for instance, carbon stored in annually cultivated crops. Carbon sequestration is also modeled within cropland soils, pastureland soils, soils in idled lands, timberland soils, and harvested wood products. In addition, changes in sequestration for lands that move out of forestry and agricultural production into some form of developed usage such as housing, shopping centers, and roads are tracked in the model.

In the subsections below, we detail FASOM accounting of carbon stock changes from agricultural land and forestry land. We also describe EPA's use of FASOM GHG accounting to project the changes in GHG emissions associated with domestic land use change for each renewable fuel-specific pathways for the year 2022.

2.4.4.1.4 Domestic Agricultural Soil GHG Accounting

FASOM models the change in agricultural soil carbon due to land conversion and changes in crop patterns. The FASOM GHG factors for agricultural land conversion are based on factors for different crops, management practices, and land conversion effects (e.g., converting pasture to crop production). As EPA committed in the NPRM, the FASOM agricultural land GHG emission factors were updated with new DAYCENT/CENTURY model runs to reflect the most recent science available.

Agricultural soil carbon sequestration depends on management activities that influence carbon storage per acre. Baseline carbon storage is estimated from the baseline distribution of land across tillage practices, irrigation status, land use, and cropping patterns, assuming carbon sequestration rates are equal to those at equilibrium.

- Intensity of agricultural tillage. Agricultural soils have traditionally been tilled; however, tillage breaks up soil aggregates and increases the exposure of soil organic matter to oxygen, which speeds oxidation and results in reduced soil carbon with an associated release of CO_2 into the atmosphere. The use of tillage alternatives that reduce soil disturbance and therefore reduce oxidation of soil organic matter will increase soil carbon sequestration. Reduced tillage practices also leave crop residues on the soil, thereby potentially increasing carbon inputs.

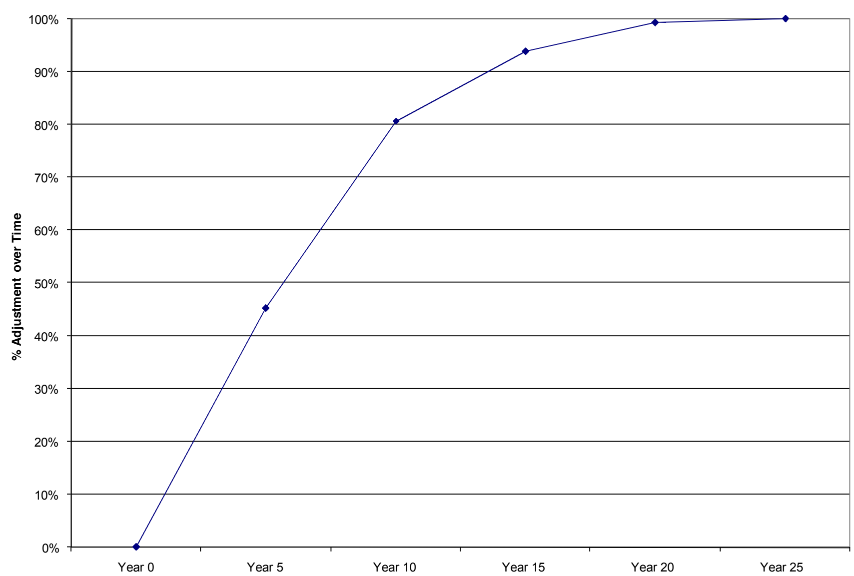
Irrigation status. The DAYCENT/CENTURY model shows differences in soil carbon sequestration per acre for a given region between irrigated and dryland cropland systems.[152] For irrigated sites, the increased yields are expected to increase biological activity and therefore increase soil carbon sequestration compared to dryland cropland.

Relative abundance of grasslands. Generally, pastureland and CRP land experience less soil disturbance than actively tilled croplands and store more carbon per acre. Thus, changes in the distribution of land between pastureland, cropland, and land in the CRP will affect agricultural soil carbon sequestration.

Mix of annuals versus perennials. Perennial crops are not tilled on an annual basis typically show a reduction in soil disturbance relative to actively tilled annual crops. By definition in FASOM, perennial crops such as switchgrass, hybrid poplar, and willow are produced under zero tillage.

Changes in agricultural soil carbon due to changes in tillage, irrigation status, or land use are generally assumed to take place over a number of years as the soil carbon levels adjust to a new equilibrium. In FASOM, soil carbon levels are assumed to reach a new equilibrium after 25 years, although almost 94% of the adjustment takes place within 15 years (see **Figure 2.4-16**).[153]

Figure 2.4-16. Percentage Adjustment over Time to New Soil Carbon Equilibrium Following Change in Land Use or Management



Because movement of soil carbon sequestration towards equilibrium levels is not constant over time, FASOM yields non-uniform changes in soil carbon consistent with the

[152] All pastureland and CRP land in FASOM are assumed to be produced in dryland systems.
[153] There is an immediate jump in carbon storage in year 0 due to changing tillage, irrigation, and/or land use that depends on the initial state and the new state. The dynamics discussed and shown in Figure A-5 refer to the change over time from the initial state under new management/land use conditions to the equilibrium for that state.

generally accepted scientific finding that carbon sequestered in an ecosystem approaches steady-state equilibrium under any management alternative. The rate of change in carbon storage decreases over time and eventually reaches zero at the new equilibrium (saturation). See Figure 2.4-16.[534] Soil carbon per acre may increase or decrease depending on the land use change or change in land management taking place.

FASOM also estimates N_2O emissions from cropland and pastureland due to land use change based on Colorado State University DAYCENT/CENTURY models. See Section 2.4.2.2 for a full discussion.

2.4.4.1.5 Evaluation of GHG Emissions Impacts from Domestic Forests

One of the largest carbon pools is carbon sequestered in forests. Carbon is stored not just in the live and standing dead trees, but also in understory, forest floor and coarse woody debris, and forest soil. Harvesting timber causes a reduction in carbon sequestration, although some of the carbon that was in the harvested trees will continue to be stored in forest products for some time afterward. If harvested stands are replanted, then there is little loss in forest soil carbon, and carbon sequestration in trees planted in that stand will increase over time.

The FASOM model estimates change in carbon stock of above-ground and below-ground biomass in continuous and afforesting forestland. It accounts for carbon storage in forest products and emission streams from these products over time. It also takes into account changing management practices (e.g., harvest cycles). Land converted from forestry to agricultural or other uses, however, will have a much greater permanent reduction in carbon sequestration. We summarize the forest carbon accounting procedures used in FASOM below.[535]

Forest carbon accounting in FASOM follows the FORCARB model developed by the U.S. Forest Service and used in the periodic aggregate assessments of forest carbon sequestration. Tree carbon is the largest forest carbon pool and is modeled as a function of three factors: (1) merchantable volume, (2) the ratio of growing stock volume to merchantable volume, and (3) and parameters of a forest volume-to-biomass model developed by U.S. Forest Service researchers.[536] Harvest age is allowed to vary; thus, the growth of existing and regenerated/afforested stands must be modeled. Timber growth and yield data are included for existing stands, reforested stands, and afforested lands that track the volume of wood in each unharvested stand, which, in turn, is used in computing forest carbon sequestration. These data indicate the wood volume per acre in unharvested timber stands for each timber stand strata (e.g., a stand giving location, forest type, management intensity class) by age cohort. The data used are derived largely from the U.S. Forest Service RPA modeling system.[537] Merchantable volume, by age, on each representative stand is obtained from the timber growth and yield tables included in FASOM. The volume factors and biomass model parameters vary by species and region and are obtained from[538,539] and Smith et al. (2003).[540]

Carbon in live and standing dead trees is calculated using the parameters of the forest volume-to-biomass model equations for live and dead tree mass densities (above- and belowground) in Smith et al.,[541] weighted for the FASOM region/forest type designations. Forest land area data reported by the RPA assessment[542] are used to calculate the appropriate weights. Birdsey's assumption that the mass of wood is approximately 50% carbon is used to derive the associated levels of carbon.[543]

Soil carbon is the second-largest pool of carbon. Treatment of soil carbon follows Birdsey[544,545] and recent work by Heath, Birdsey, and Williams.[546] FASOM computes soil carbon profiles using soil carbon data over time from Birdsey.[547,548] As Heath, Birdsey, and Williams noted, little change in soil carbon occurs if forests are regenerated immediately after harvest.[549] As a result, FASOM assumes soil carbon on a reforested stand remains at a steady-state value. Currently, the age that this value is reached is assumed to be the minimum harvest age for FASOM region/forest type. This assumption is generally consistent with the ages at which steady-state levels of soil carbon are achieved in Birdsey.[550,551] Afforested land coming from crop or pasture use start with the initial soil carbon value for that land/region combination reported by the Century Model, which was developed by Colorado State University.[154] The land then accumulates carbon until reaching the steady-state value for forests of the type planted in the region afforestation takes place (where steady state is assumed to be reached at the minimum harvest age in FASOM for that region/forest type).

Forest floor carbon constitutes the third largest carbon storage pool, but is much smaller than tree or soil carbon pools. FASOM bases its forest floor carbon estimates on the model developed by Smith and Heath[552] to estimate forest floor carbon mass. The model's definition of forest floor excludes coarse woody debris materials; that is, pieces of down dead wood with a diameter of at least 7.5 cm that are not attached to trees.[553] In order to account for this material, coarse woody debris is assumed to be a fixed fraction of live tree carbon based on ratios of coarse woody debris carbon to live tree carbon.[554] This value is then added to the forest floor carbon values generated by Smith and Heath's forest floor model. The model for net accumulation of forest floor carbon is a continuous and increasing function of age, although the rate of accumulation eventually approaches zero (i.e., forest floor carbon reaches a steady state).

Understory vegetation comprises the smallest component of total carbon stock and includes all live vegetation except trees larger than seedlings. FASOM makes the assumption that understory carbon is a fixed fraction of live tree carbon and uses published ratios reported in U.S. EPA Inventory of U.S. GHG Emissions and Sinks[555] as the basis for these calculations. When timber is harvested, FASOM tracks the fate of the carbon that had been sequestered on the harvested land.

[154] The current version of the CENTURY agroecosystem model simulates carbon, nitrogen, phosphorus, and sulfur dynamics through an annual cycle over time scales and centuries and millennia. CENTURY is capable of modeling a wide range of cropping system rotations and tillage practices for analysis of the effects of management and climate on agroecosystem productivity and sustainability. The model has undergone numerous enhancements since the original version developed in Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal 51:1173-1179.

Figure 2.4-17 Figure 2.4-17 summarizes the disposition of carbon following harvest. To calculate carbon in harvested logs, cubic feet of roundwood (the units in which timber is quantified in the model) is converted into metric tons of carbon using factors reported in Skog and Nicholson.[556] These factors vary by region and are reported for logs coming from an aggregate softwood and hardwood stand. They exclude carbon in logging residue left onsite. Logging residue is tracked separately in the forest floor carbon pool described above.

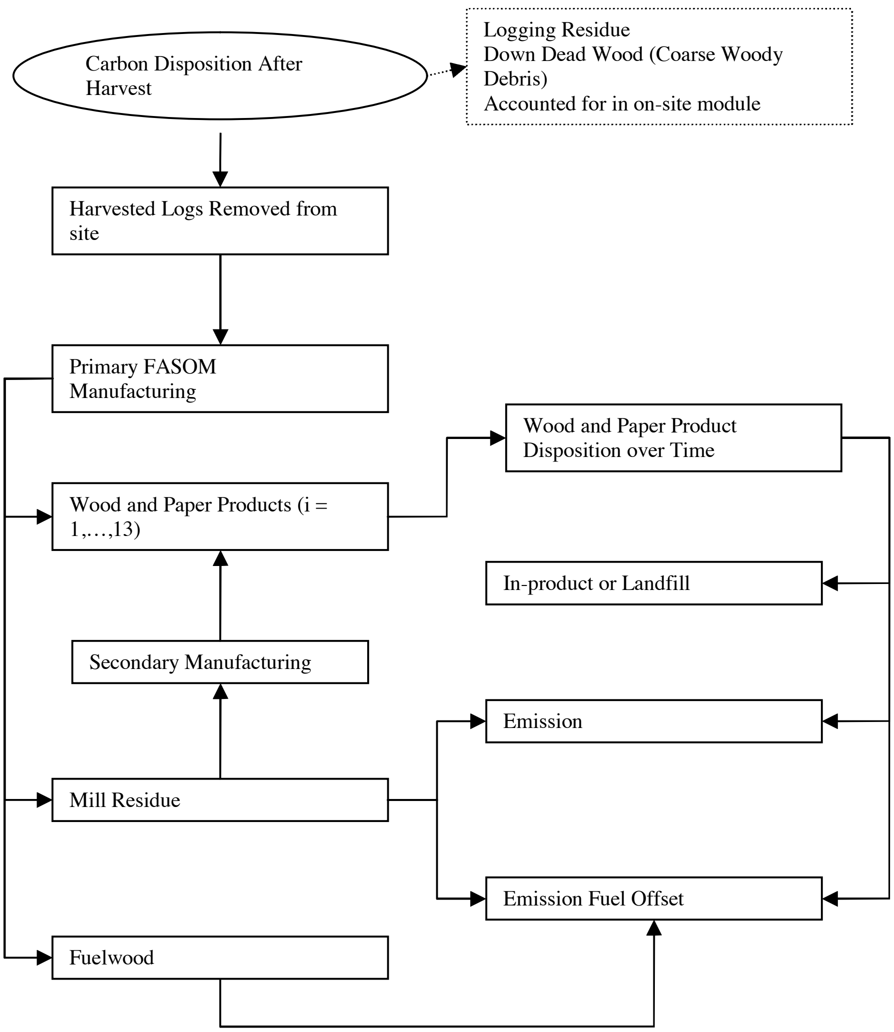
Harvested logs removed from site are converted into three types of outputs through primary manufacturing processes: wood and paper products, mill residues, and fuel wood (See Table 2.4-27 for a list of products tracked by FASOM). The fate of each of these outputs is discussed below.

Table 2.4-27. Wood and paper products tracked by FASOM

Product
softwood sawlogs for export
hardwood sawlogs for export
softwood lumber
softwood plywood
oriented strand board
hardwood lumber
hardwood plywood
softwood miscellaneous products
hardwood miscellaneous products
softwood used in non-OSB reconstituted panel
hardwood used in non-OSB reconstituted panel
softwood pulpwood
hardwood pulpwood

The distribution of product carbon changes over time. FASOM tracks the fate of product carbon with two carbon pools: carbon remaining in-product and carbon leaving the product (Figure 2.4-17). Carbon that leaves the product ultimately is emitted or permanently sequestered in landfills.

Figure 2.4-17. Carbon Disposition after Timber Harvest[557]



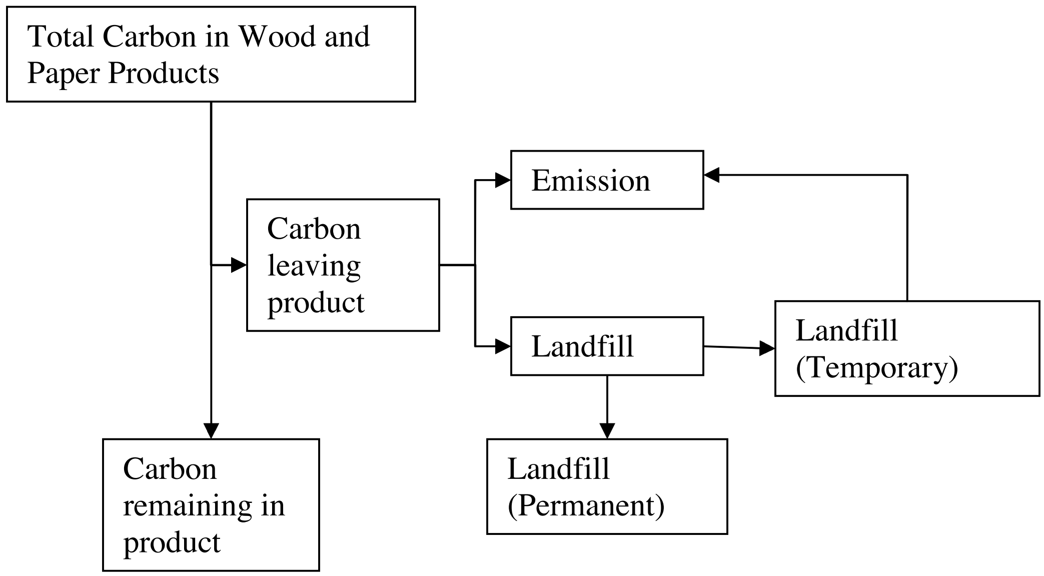
FASOM determines the fraction of carbon that remains in products using specified half-life values for a set of end-use categories (Table 2.4-28).[558] The half-life represents the time it takes for approximately half of the product to decompose. Skog and Nicholson[559] assumed that

67% of carbon leaving the wood product pool and 34% of carbon leaving the paper product pool goes to landfills (Figure 2.4-18). The remainder of the carbon leaving the wood and paper product pools is emitted as CO_2 into the atmosphere.

Table 2.4-28. Half-life for Forest Products in End Uses[560]

End Use or Product	Half-Life in Years
Paper	2
New residential construction	
Single family	100
Multifamily	70
Mobile homes	12
Residential upkeep & improvement	30
New nonresidential construction	
All ex. railroads	67
Railroad ties	12
Railcar repair	12
Manufacturing	
Household furniture	30
Commercial furniture	30
Other products	12
Shipping	
Wooden containers	6
Pallets	6
Dunnage etc.	6
Other uses for lumber and panels	12
Uses for other industrial timber products	12
Exports	12

Figure 2.4-18. Wood and Paper Product Carbon Disposition[561]



FASOM tracks the fate of mill residue using two different pools. The first is for mill residue that is used as an intermediate input in the production of wood and paper products. This carbon is tracked using the appropriate product category as described above. The second pool is for carbon in mill residue that is burned for fuel. The fraction burned in each region based on Smith et al.[562] It was assumed that one-third of mill residue burned is used to offset fossil fuels. Harvested fuel logs and the associated carbon are used as to produce energy at mills. For fuel wood, FASOM assumes that 100% of fuel wood burned in the sawtimber and pulpwood production process is used to offset fossil fuels.

In FASOM, land used in forestry can move to agriculture or developed use, resulting in a dynamic change in carbon storage levels on the previously forested land. When land moves from forestry to agricultural use or developed use, FASOM tracks carbon in residual forest floor carbon and in soil carbon. FASOM's model of forest floor decay is based on the average forest floor of mature forests and regional averages for decay rates, as described in Smith and Heath.[563] When forested land is converted to agricultural use, soil carbon levels are consistent with DAYCENT/CENTRUY model data on agricultural soil carbon for the appropriate category of agricultural land and do not vary over time. When forest is converted to developed land uses, FASOM assumes that soil carbon levels are consistent with the steady-state value of the minimum harvest age.

2.4.4.1.6 Aggregate GHG Emissions Impacts from Domestic Land Conversions in 2022

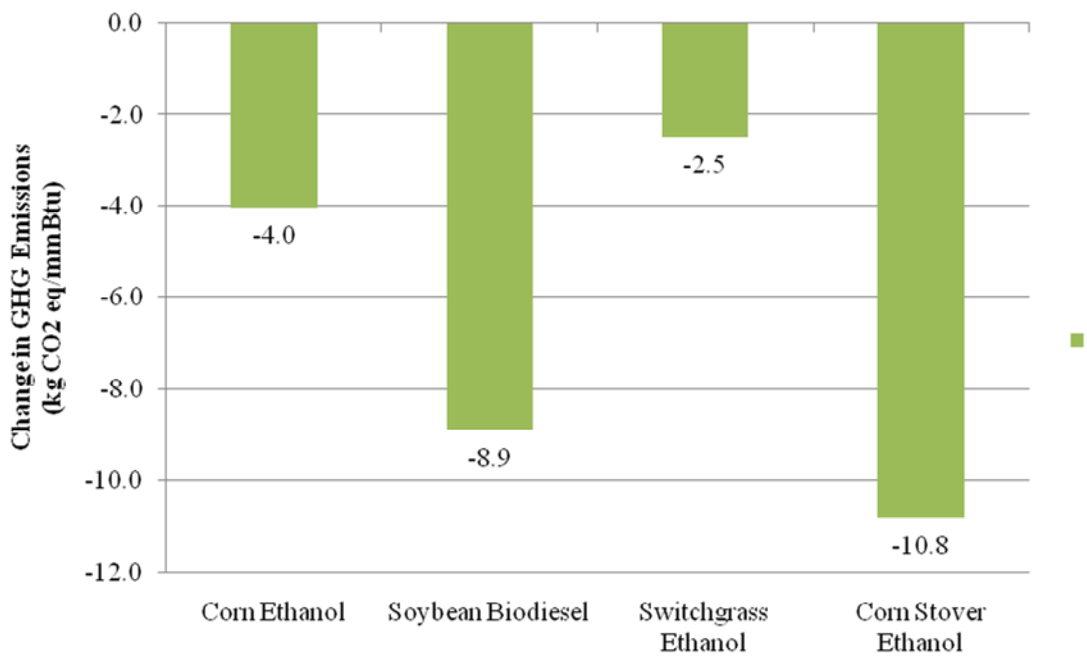
In the FASOM model the difference in GHG emissions and sequestrations from agricultural and forest lands related to land use changes are not only a function of the difference between the land use change and management practices in 2022 under two scenarios, but are also dependent on previous changes in land use and practices under the two scenarios. For instance, different land use patterns under two scenarios may result in differing harvesting cycles.

Ideally, an emissions comparison of land use patterns in two scenarios would capture the changes and associated emissions that lead to the 2022 land use status in both scenarios. Because FASOM generates GHG emissions estimates associated with land use change for every five year period over the time horizon of the model run, EPA was able to calculate the cumulative GHG emissions change for each fuel-specific pathway and for the RFS2 policy. We then annualized the cumulative change.

To calculate the annualized cumulative GHG emissions due to land use change for a specific fuel, we first summed all emissions associated with agricultural land (CO_2 and N_2O from cropland, pastureland, CRP land) and forestland (CO_2 from biomass, soil, and forest products) between the years 2000 and 2022 for the control and fuel-specific scenarios. Emissions from soil, decaying biomass, and forest products can occur over several years or decades. FASOM tracks such emission streams over time. We included in the cumulative GHG emissions from land use change all emission streams due to changes that occurred between 2000 and 2022 for the thirty year time horizon (See Section 2.4.5) after 2022.

We report these results as CO_2 equivalent mass and then normalize the results on an mmBtu basis (**Figure 2.4-19**).

Figure 2.4-19. Change in GHG Emissions Due to Domestic Land Use Change by Scenario, 2022, Annualized Over 30 Years



2.4.4.2 International Land Conversion GHG Emissions Impacts

2.4.4.2.1 Area and Location of International Land Conversions

We used the FAPRI-CARD international agricultural models to determine the amount of international land use change resulting from the renewable fuel volumes mandated by RFS2. The FAPRI-CARD model provides a dynamic projection of how policy or economic shocks will affect international agricultural commodity markets, and the resulting area of land used to produce agricultural goods. FAPRI-CARD accounts for several key factors that affect the amount/area of international land use change: crop yield growth rates over time, price-induced crop yield changes, crop yields on marginal/new land, the efficiency of renewable fuel co-products over time, supply and demand in the livestock sector, and many other significant variables. More details about the FAPRI-CARD model and our assumptions are provided in RIA Chapter 5.

2.4.4.2.2 Area and Location of International Cropland Conversions

To determine the area of land use change caused by increased consumption of each of the renewable fuels analyzed (i.e., corn ethanol, soy-based biodiesel, sugarcane ethanol and switchgrass ethanol) we used the FAPRI-CARD model to simulate the scenarios outlined in Table **2.3-1**2.4-1. By varying only one type of renewable fuel in each scenario we isolated the impacts for each fuel type. The land use change results are the difference between each scenario and the control case, and are normalized by dividing by the incremental increase in renewable fuel production in a given scenario and year, on an energy-content basis. Table 2.4-29 shows foreign (i.e. not including the United States) crop area changes in thousands of harvested hectares (000s ha), and the normalized changes in hectares per billion British Thermal Units (ha/ billion BTU), for each of the scenarios considered.[155] Note that we focus on the change in land use between scenarios in 2022.[156]

Table 2.4-29. Changes in International Crop Area Harvested by Renewable Fuel, 2022

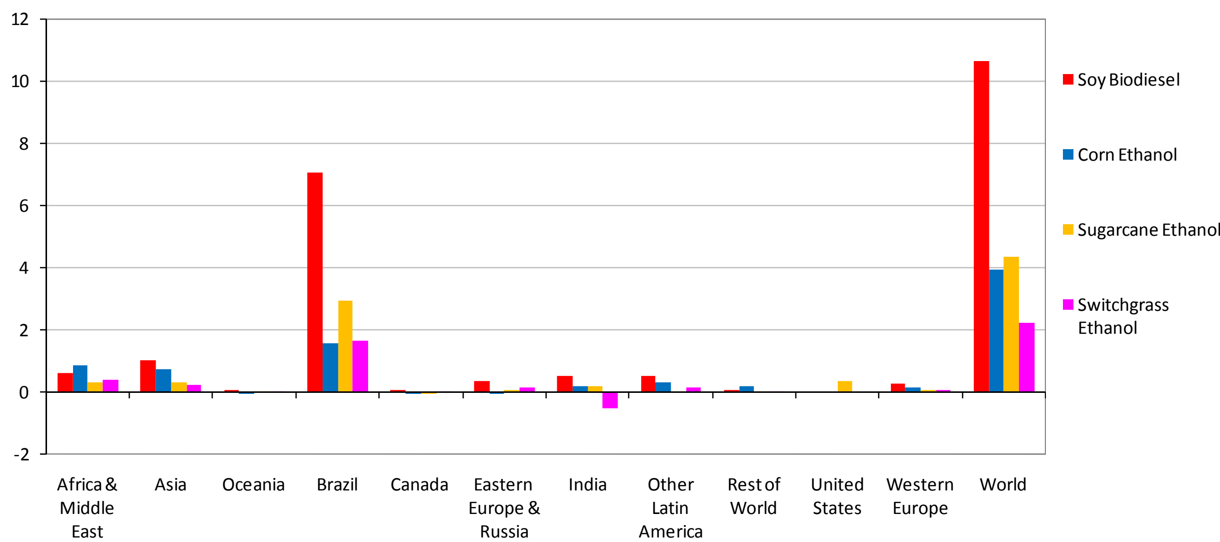
Scenario	International Crop Area Change (000s ha)	Normalized Crop Area Change (ha / billion BTU)
Corn Ethanol	789	3.94
Soy-Based Biodiesel	678	10.65
Sugarcane Ethanol	430	4.38
Switchgrass Ethanol	1,358	2.25

The location of land use changes is a critical factor in the determination of land use change GHG impacts, because the GHG impacts of land conversions varies substantially by region. For example, deforestation in the tropics releases substantially more carbon than deforestation in drier regions. The FAPRI-CARD model allocates crop area changes across 54 regions based on a number of factors, including existing trade patterns, regional costs of production, and the potential for agricultural expansion in each region. Normalized crop area changes by region and renewable fuel are shown in

Figure 2.4-20, with 12 aggregated regions for purposes of illustration. Once again, land use changes in the United States are excluded from the figure, except for the case of sugarcane ethanol.

[155] The sugarcane ethanol scenario includes land use changes in the United States as projected by FAPRI-CARD. For all of the other renewable fuels, domestic land use changes were determined with FASOM as described in the previous section.
[156] We assumed 76,000 BTU/gallon of ethanol; 115,000 BTU/gallon of biodiesel and 2.471 acres/hectare.

Figure 2.4-20. Normalized Harvested Crop Area Changes by Renewable Fuel, 2022 (ha / billion BTU)



The projected net changes in crop area are the result of many factors, including shifting among different types of crops in each region. For example, for scenarios where corn ethanol production increases in the United States, we project a domestic shift from soybean production to corn production, and a shift toward oilseeds production in other countries to fill the gap in lost U.S. output. The following figures illustrate projected changes in harvested area by crop type and region for each renewable fuel scenario. All results are from the FAPRI-CARD model, with changes in the United States are included for illustrative purposes.

Figure 2.4-21. Harvested Crop Area Changes by Crop and Region Corn Ethanol Scenario, 2022 (000s ha)

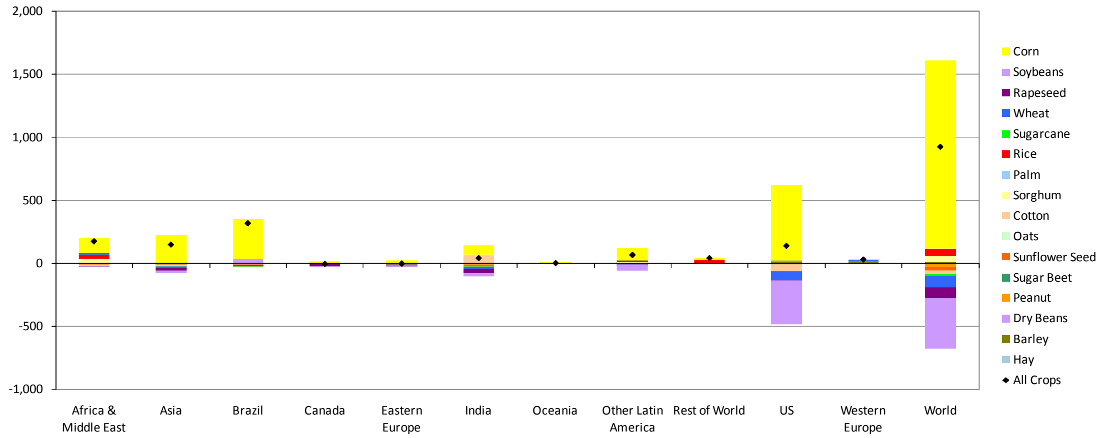


Figure 2.4-22. Harvested Crop Area Changes by Crop and Region Soy-Based Biodiesel Scenario, 2022 (000s ha)

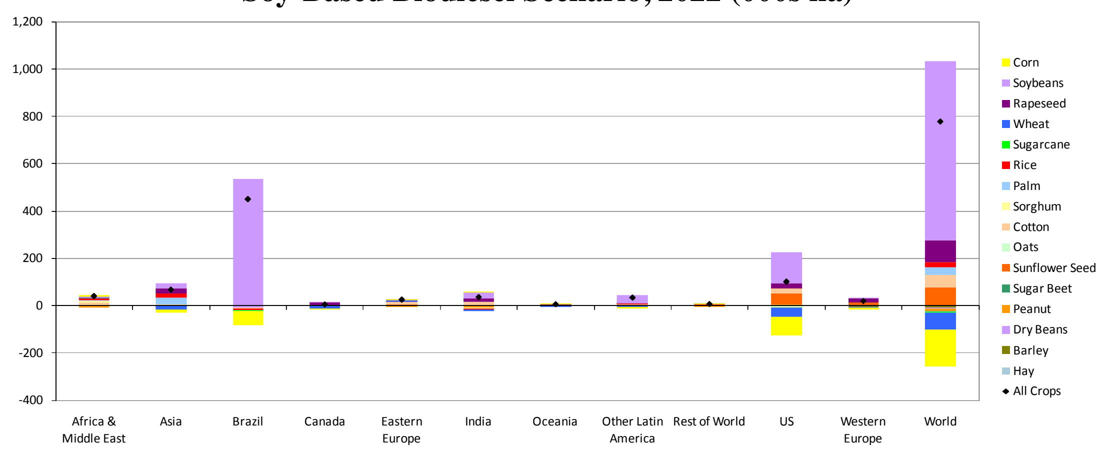


Figure 2.4-23. Harvested Crop Area Changes by Crop and Region Sugarcane Ethanol Scenario, 2022 (000s ha)

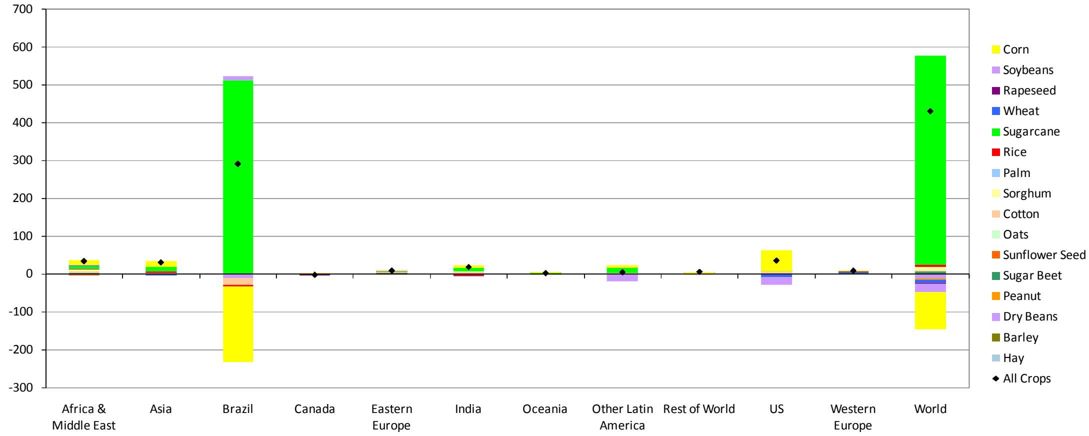
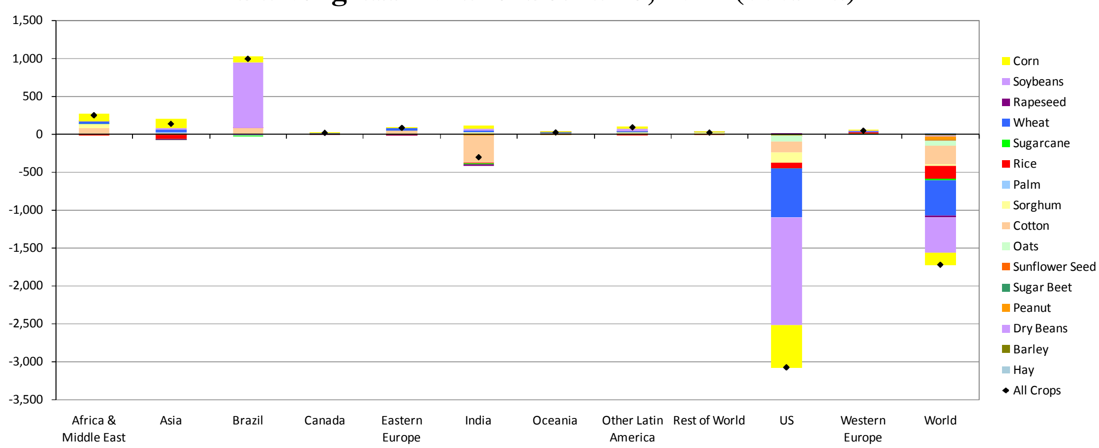


Figure 2.4-24. Harvested Crop Area Changes by Crop and Region Switchgrass Ethanol Scenario, 2022 (000s ha)



Note: Switchgrass harvested area is not included in the figure.

2.4.4.2.3 Area and Location of International Pasture Land Conversions

In addition to considering international changes in crop area, our analysis also accounts for changes in pasture area, i.e., land used for livestock grazing. Accounting for pasture area is essential to understand the land use change impacts of renewable fuels, because renewable fuel production can affect the livestock sector which uses pasture. Furthermore, more land is used globally for pasture than for crop production.[564] The new, more detailed, representation of Brazil in the FAPRI-CARD model (see RIA Chapter 5 for more details) explicitly accounts for changes in pasture area, therefore, accounting for the competition between crop and pasture land uses. Furthermore, the FAPRI-CARD Brazil module allows for livestock intensification, i.e., the increasing the heads of cattle per unit area of land in response to higher commodity prices, increased demand for land, or other reasons. In addition to modifying how pasture is treated in Brazil, we also improved the methodology for calculating pasture area changes in other countries.

In the proposed rule, we made a broad assumption that the total land area used for pasture would stay constant in each country or region. Thus, in the proposed rule, we assumed that any crop expansion onto pasture would necessarily require an equal amount of pasture to be replaced on forest or shrubland. For the final rule we relaxed this assumption, and we now account for changes in pasture area resulting from livestock fluctuations and therefore capture the link between livestock and land used for grazing. Based on regional pasture stocking rates (i.e., livestock per hectare), we now calculate the amount of land used for livestock grazing. As a result of this analytical improvement, in countries where we project decreased livestock numbers we also project less land needed for pasture. Therefore, unneeded pasture areas are available for cropland or allowed to revert to their natural state. In countries where livestock numbers increase, more land is needed for pasture, which can be added on abandoned cropland or unused grassland, or it can result in deforestation. This new methodology provides a more realistic assessment of land use changes, especially in regions where livestock populations are changing significantly.

A multi-step process was used to translate the FAPRI-CARD livestock projections to pasture area changes. First, the FAPRI-CARD projections for dairy cattle and beef cattle (i.e., all non-dairy cattle) and sheep were converted to animal unit equivalents (AUE) using IPCC data (see Table 2.4-30).[565] Next, average stocking rates for each of the 54 FAPRI-CARD regions were determined with data on livestock populations from the UN Food and Agricultural Organization (FAO)[566] and data on pasture area measured with agricultural inventory and satellite-derived land cover data.[567] The FAO data set provides a globally consistent estimate of livestock units per country. The estimated stocking rates are listed in Table 2.4-31. Expert judgment was used to adjust unusually low regional stocking rates. For example, we removed serious outliers from the "CIS, Other" FAPRI-CARD region.[157] Specifically Kazakhstan and Turkmenistan were removed from this calculation because these countries include vast stretches of desert pasture used for rotational sheep grazing. Removing these outliers provided a more realistic estimate of how cattle population changes would affect land use in this region. For

[157] CIS, Other includes the following countries in the Commonwealth of Independent States: Armenia, Azerbajian, Belarus, Georgia, Kazakhstanm, Krygyzstan, Moldova, Tajikistan, Turkmenistan, Uzbekistan

other regions that had unreasonably low stocking rate factors, we set the stocking rates equal to a neighboring country with a more reasonable factor. [158]

Based on the data sources considered, some regions had very high stocking rates due in part to the use of intensive livestock operations, such as feedlots. We did not adjust these stocking rates because we would not expect livestock population changes to have a large impact on pasture area in these regions.

Table 2.4-30. Animal Unit Equivalents (Livestock Units per Head)

Region	Dairy	Beef	Sheep
Canada	1.33	0.86	0.18
Western Europe	1.32	0.93	0.18
Eastern Europe	1.21	0.86	0.18
Oceania	1.10	0.73	0.10
Brazil	0.88	0.67	0.10
Other Latin America	0.88	0.67	0.10
Asia	0.77	0.70	0.10
Africa & Middle East	0.61	0.38	0.10
India	0.61	0.24	0.10
US	1.33	0.86	0.18
Rest of World	1.00	0.69	0.13

Source: IPCC Vol. 4, Ch.10

[158] These adjustments were made after consulting experts at Iowa State University and USDA who suggested that, although the best available data was used, the calculated stocking rates in many regions were unreasonably low. One reason for this, and part of the justification for adjusting the stocking rates upward, is that the data used considered all pasture land globally, including areas (e.g., Kazakhstan) with extraordinarily low stocking rates. The adjustments help to account for the fact that we would expect biofuel-induced livestock changes to affect globally integrated livestock regions, and these regions would likely not exhibit very low stocking rates.

Table 2.4-31. Pasture Stocking Rates by FAPRI-CARD Region (Livestock Units / Ha)

FAPRI-CARD Regions	Stocking Rate	Notes/Adjustments
Algeria	0.50	equals Tunisia
Argentina	0.41	
Australia	0.41	equals world average
Bangladesh	25.25	
Brazil: Amazon Biome	0.95	from FAPRI-CARD Control Case, 2022
Brazil: Central-West Cerrados	1.00	
Brazil: Northeast Coast	0.87	
Brazil: North-Northeast Cerrados	0.90	
Brazil: South	1.62	
Brazil: Southeast	0.94	
Canada	0.64	
China	0.41	
New Zealand	1.14	
Colombia	0.60	
Cuba	1.02	
Egypt	0.44	equals Iraq
EU	1.45	
Guatemala	0.74	
India	9.22	
Indonesia	4.11	
Iran	0.22	
Iraq	0.44	
Ivory Coast	0.45	equals Guinea
Japan	9.63	
Malaysia	1.99	
Mexico	0.45	
Morocco	0.50	equals Tunisia
Myanmar (Burma)	11.41	
Nigeria	0.74	
Africa, Other	0.33	Zambia, Chad and Botswana removed
Asia, Other	0.34	Mongolia & Singapore removed
CIS, Other	0.45	Kazakhstan & Turkmenistan removed
Eastern Europe, Other	0.37	
Latin America, Other	0.52	Bolivia removed
Middle East, Other	0.30	
Pakistan	3.64	
Paraguay	0.35	
Peru	0.37	
Philippines	17.16	
Rest of World	0.41	equals world average
Russia	0.41	equals China
South Africa	0.33	equals Africa, Other
South Korea	35.14	
Taiwan	0.41	equals China
Thailand	17.01	
Tunisia	0.50	
Turkey	0.61	
Ukraine	0.49	
Uruguay	0.67	
United States	0.46	
Uzbekistan	0.45	equals CIS, Other
Venezuela	0.63	
Vietnam	8.95	
Western Africa	1.89	
World	0.41	

As described above, pasture intensification was modeled endogenously in Brazil by the FAPRI-CARD model. In the FAPRI-CARD model, pasture intensification was a function of many factors, including livestock and crop prices, and competition for land between grazing and crop production uses. In general, the FAPRI-CARD results produced pasture intensification elasticities of 5-10% (i.e., the % change in pasture intensification resulting from a % change in livestock population). For regions outside of Brazil we used a simple pasture intensification factor of 10% in regions where livestock populations increased.

Table 2.4-32 shows total and normalized international pasture area changes for each of the scenarios considered.[159] The pasture area results are largely driven by the relative changes in the livestock markets. In scenarios where beef and dairy production (which require pasture) declined more than swine and poultry production (which do not require pasture), the pasture area changes were larger. Section 2.4.3.6 includes international livestock production results for each scenario, and RIA Chapter 5 discusses the determining factors for these changes, such as co-product and livestock feed ration efficiencies.

Table 2.4-32. Changes in International Pasture Area by Renewable Fuel, 2022

Scenario	International Pasture Area Change (000s ha)	Normalized Pasture Area Change (ha / billion BTU)
Corn Ethanol	-446	-2.23
Soy-Based Biodiesel	-268	-4.20
Sugarcane Ethanol	-164	-1.67
Switchgrass Ethanol	-580	-0.96

Note: Only the Sugarcane ethanol scenario results include United States land use changes.

The location of pasture area changes is very important when analyzing these results. As the above table shows, we projected that global pasture area would decrease in all of our renewable fuel scenarios. However, pasture area changes resulted in positive net GHG emissions in some cases because of the location of the resulting land conversions. For example, in the corn ethanol scenario we projected a significant increase in pasture area in the Brazilian Amazon, which causes large GHG emissions. Figure 2.4-25 illustrates pasture area changes by region. Figure 2.4-26 includes pasture area changes by region in Brazil.

[159] The sugarcane ethanol scenario includes land use changes in the United States as projected by FAPRI-CARD. For all of the other renewable fuels, domestic land use changes were determined with FASOM as described in the previous section. Thus, in Table 2.4-32 only the sugarcane ethanol scenario includes United States land use change results.

Figure 2.4-25. Normalized Pasture Area Changes by Renewable Fuel, 2022 (ha / billion BTU)

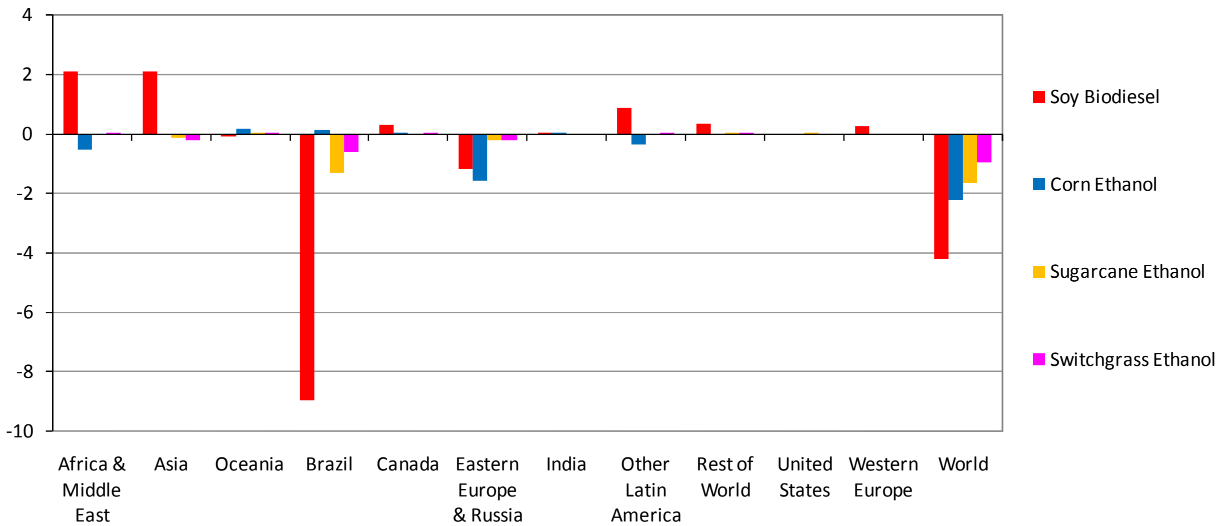
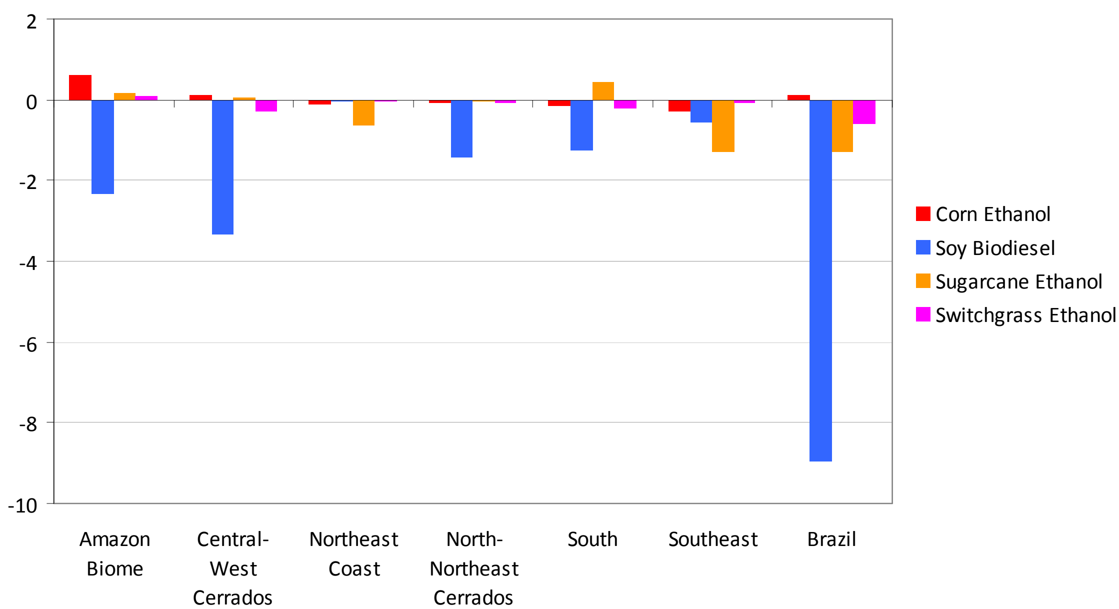


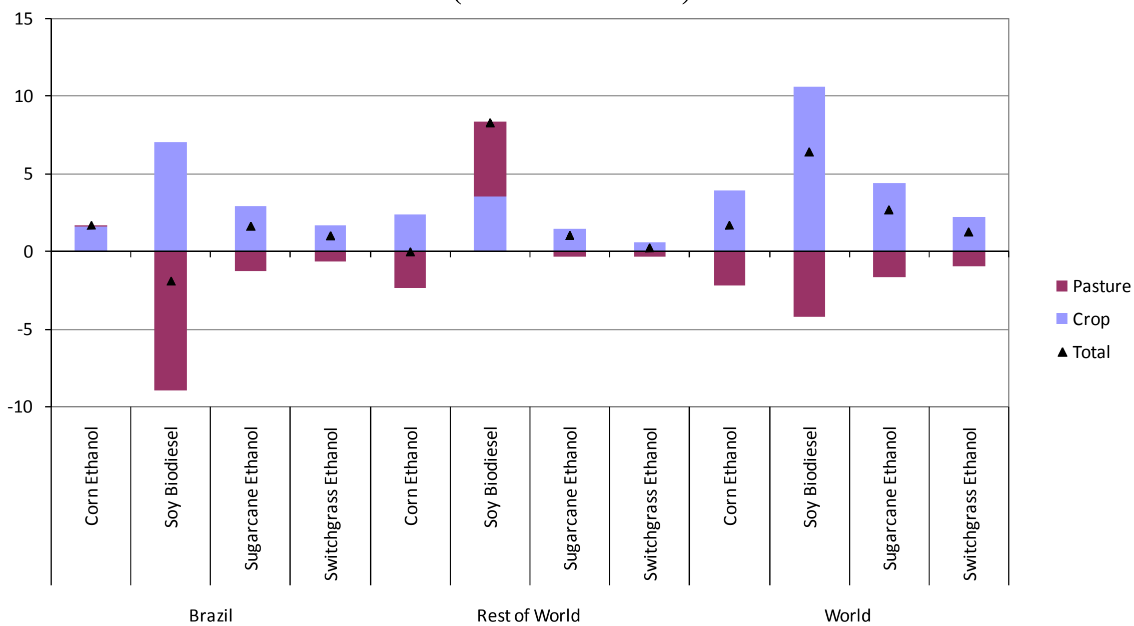
Figure 2.4-26. Normalized Pasture Area Changes in Brazil by Renewable Fuel, 2022 (ha / billion BTU)



2.4.4.2.4 Area and Location of International Cropland and Pasture Land Conversions

As discussed above, in the proposed rule we made a broad assumption that the total land area used for pasture would stay constant in each country or region. Thus, in the proposed rule, we assumed pasture area could not decrease in regions where crop area increased. In the final rule analysis we used a more sophisticated approach that captures a wider range of potential interactions between crop and pasture areas. For example, in regions were pasture decreases, this land is available for crop expansion. Therefore, it is important to look at both the crop and pasture area changes together to understand the land use change GHG emissions impacts. **Figure 2.4-27** shows the crop and pasture area changes for each scenario. Brazil is broken out as a separate region because, as the figure shows, it is the most important country in terms of its response in livestock production and pasture area.

Figure 2.4-27. Normalized International Land Use Change by Renewable Fuel (ha / billion BTU)



Finally, the following figures compare the proposed rule land use change projections to the land use change results in the final rule. Notice that in the final rule pasture area decreases in many regions, whereas in the proposed rule we assumed that pasture area could not decline. As discussed in the next sections, this had a large impact on the types of land conversions projected, and on the resulting GHG emissions impacts.

Figure 2.4-28. Proposed Rule and Final Rule Comparison Normalized International Land Use Changes Corn Ethanol, 2022 (ha / billion BTU)

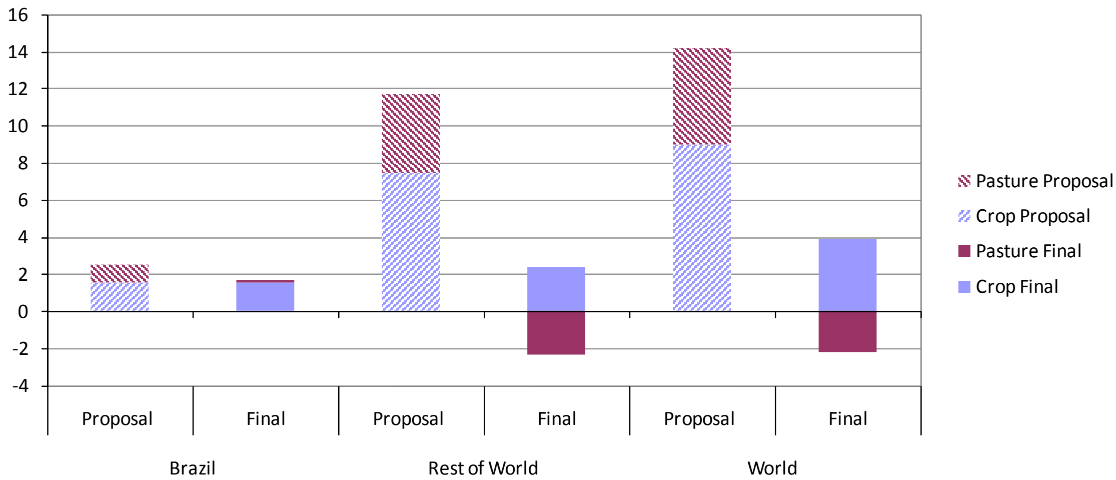


Figure 2.4-29. Proposed Rule and Final Rule Comparison Normalized International Land Use Changes Soy-Based Biodiesel, 2022 (ha / billion BTU)

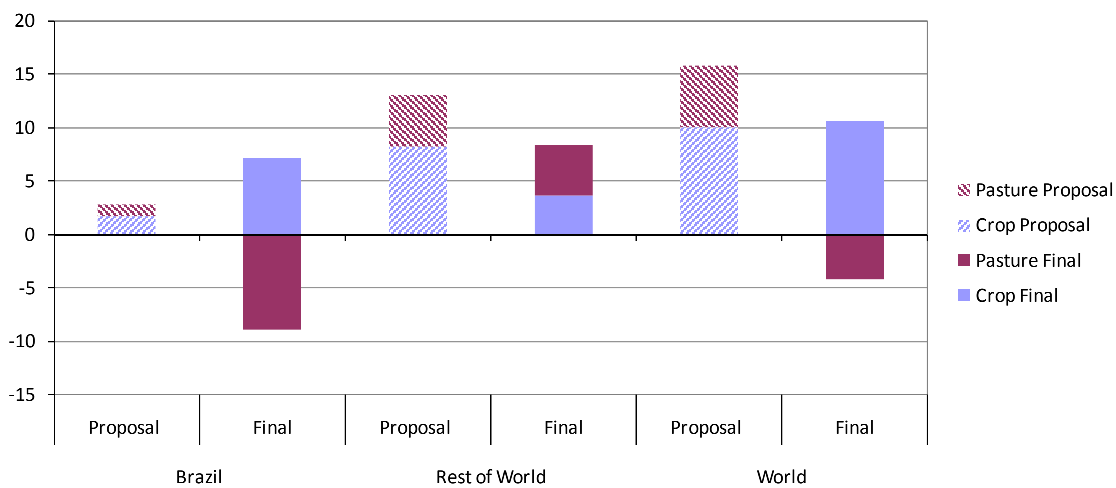


Figure 2.4-30. Proposed Rule and Final Rule Comparison Normalized International Land Use Changes Sugarcane Ethanol, 2022 (ha / billion BTU)

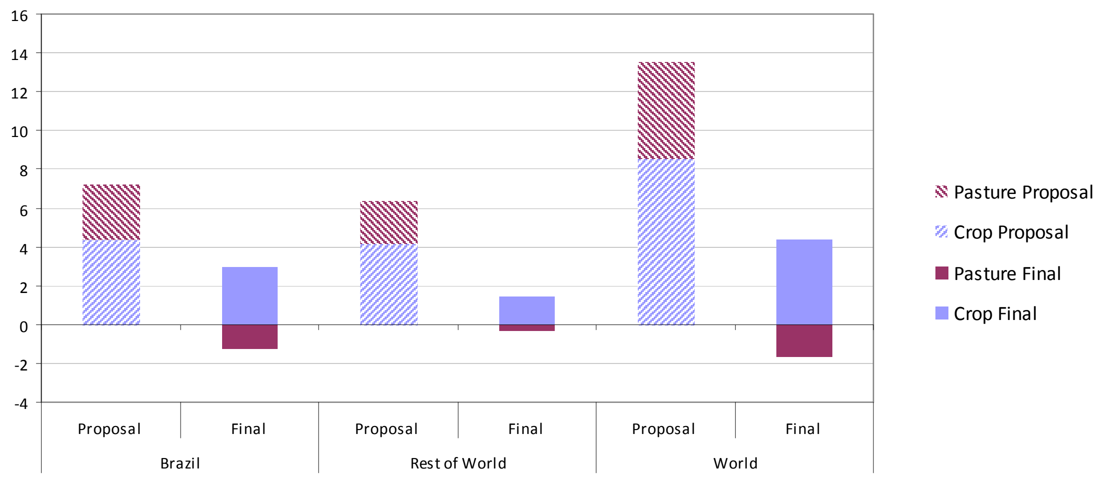
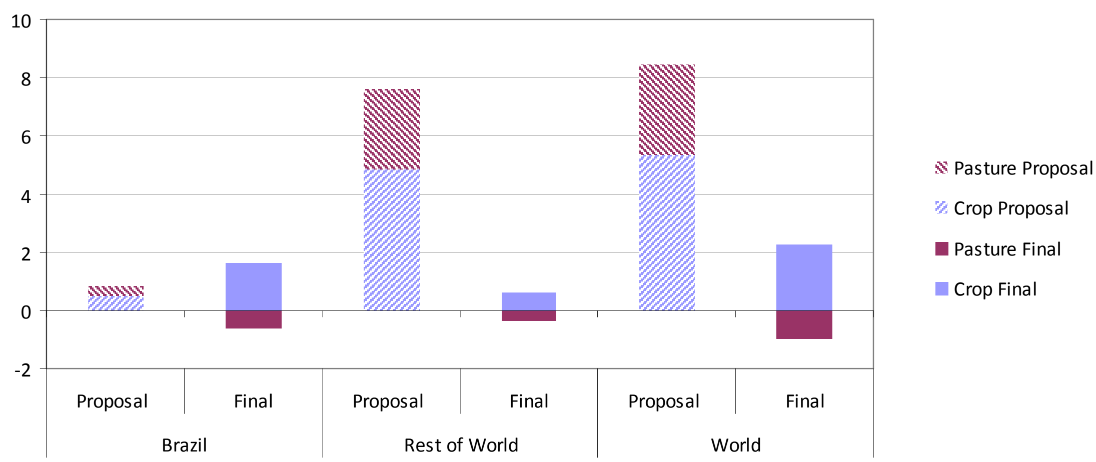


Figure 2.4-31. Proposed Rule and Final Rule Comparison Normalized International Land Use Changes Switchgrass Ethanol, 2022 (ha / billion BTU)



2.4.4.2.5 Evaluation of the Types of International Land Conversions

As explained in the previous section, the FAPRI-CARD international models were used to project changes in the area of land used for cropland and pasture in 54 regions. In this section we describe the two-step procedure that was used to determine in more detail the types and locations of land conversions:

1. The FAPRI-CARD output was disaggregated into 12 land conversion categories.
2. The land cover types affected (e.g., forest or grassland) and the location of land conversions (i.e., by Administrative Unit) were evaluated with MODIS Version 5 satellite data from 2001-2007.

2.4.4.2.5.1 Determination of International Land Conversion Categories

Based on the FAPRI-CARD model results, we determined the conversions between annual crops, perennial crops, pasture land, and natural ecosystems in each of the 54 FAPRI-CARD regions. First, the FAPRI-CARD land use change projections (both positive and negative changes in area) were broken into three categories for each region: annual crops, perennial crops and pasture.[160] We used a rule-based approach to determine the interaction of these three agricultural land uses with natural eco-systems in each region. These rules are summarized below in order of priority:

1. Annual and perennial crop areas interact with each other, e.g., where annual crop area increases and perennial crop area decreases, annual crops expand onto the land previously used for perennial crops.
2. Pasture and crop area interact with each other, e.g., where pasture area decreases and crop area increases, crops expand onto the land previously used for pasture.
3. Changes in the total area of land used for agriculture affect previously non-agricultural areas.

Following the 3 rules listed above, the FAPRI-CARD projections were disaggregated into 12 land conversion categories, where natural eco-systems include forests, grasslands, savannas, shrublands, wetlands and barren land:

- Annual Crops to/from Perennial Crops
- Pasture to/from Perennial Crops
- Pasture to/from Annual Crops
- Natural Ecosystems to/from Annual Crops
- Natural Ecosystems to/from Perennial Crops
- Natural Ecosystems to/from Pasture

Table 2.4-33 illustrates the results of this process with the results in Argentina for each scenario.[161] The FAPRI-CARD Results columns show the projected change in area for annual crops (Annl), perennial crops (Prnnl) and pasture (Pstr). Positive numbers indicate expansion and negative numbers indicate contraction. These results were translated into the 6 Land Conversion columns, where positive numbers indicate conversion in the direction shown in the header row, and negative numbers indicate a conversion in the opposite direction. For example, in the Ntrl to Annl (i.e., Natural Ecosystems to Annual Crops) column, a positive number

[160] The perennial crops included in the FAPRI-CARD model are sugarcane and palm oil.
[161] The results for all 54 FAPRI-CARD regions are included in the public docket.

indicates conversion of natural ecosystems to annual crop production. A negative number in the Ntrl to Annl column indicates reversion of annual crops back to natural ecosystems.

Table 2.4-33. Argentina Land Conversion Categories by Renewable Fuel, 2022 (Ha / billion BTU)

	FAPRI-CARD Results			*Land Conversions*					
Scenario	**Annl Crops**	**Prnnl Crops**	**Pstr**	Annl to Prnnl	Pstr to Prnnl	Pstr to Annl	Ntrl to Annl	Ntrl to Prrnl	Ntrl to Pstr
Corn Ethanol	**0.01**	**0.00**	**0.00**	0.00	0.00	0.00	0.01	0.00	0.00
Soy Biodiesel	**0.26**	**0.00**	**-0.48**	0.00	0.00	0.26	0.00	0.00	-0.22
Sugarcane Ethanol	**-0.18**	**0.01**	**0.00**	0.01	0.00	0.00	-0.17	0.00	0.00
Switchgrass Ethanol	**0.52**	**0.00**	**0.06**	0.00	0.00	0.00	0.51	0.00	0.06

2.4.4.2.5.2 Evaluation of International Land Conversion Patterns with Satellite Data

In the proposed rule analysis land use change patterns were estimated at the national scale (and sub-national scale for key countries) using 1-km resolution MODIS products for the years 2001-2004.[568] MODIS land cover products were chosen originally due to their global, multi-year coverage, low cost and homogenous classification scheme. For the final rule analysis we used the higher resolution, and more recent, MODIS Version 5 (MODIS V5) land cover dataset which covers the years 2001-2007 with 500-meter resolution.

To assess the accuracy/uncertainty in our use of MODIS satellite data we performed a Monte Carlo analysis based on the underlying uncertainty in the satellite data as quantified by NASA. The MODIS data set is routinely validated by NASA's MODIS land validation team.[162] NASA uses several validation techniques for quality assurance and to develop uncertainty information for its products. NASA's primary validation technique includes comparing the satellite classifications to data collected through field and aircraft surveys, and other satellite data sensors. The accuracy of the MODIS V5 land cover product was assessed over a significant set of international locations, including roughly 1,900 sample site clusters covering close to 150 million square kilometers. The results of these validation efforts are summarized in a "confusion matrix" which compares the satellite's land classifications with the actual land types observed on the ground.[569] We used this information to assess and correct the accuracy and systematic biases in the published MODIS data. Our analytical procedures are summarized below and discussed in more detail in a technical report by ICF International, Inc., available on the public docket.[570] The full Monte Carlo model, with all data inputs and results, is also publicly available.

The key data source that allows us to understand the accuracy of the MODIS V5 product is a confusion matrix published by researchers that work as part of the MODIS land validation team. As explained by Dr. Mark Friedl:

> *The confusion matrix is a commonly used tool for assessment of accuracy for land cover classifications. The matrix scores how the classification process has*

[162] More information about the MODIS Land Validation procedures is available from the NASA Goddard Space Flight Center website, http://landval.gsfc.nasa.gov/

labelled a series of test sites or test pixels at which the correct land cover label is known. Typically, the true class label is displayed across rows, while the actual mapped class is displayed in columns. The diagonal of the confusion matrix displays the number of sites or pixels for which the true class and the mapped class agree. The overall accuracy of the entire sample is then the sum of the diagonal elements divided by the total of all sites or pixels. For individual classes, the marginal totals of the matrix can easily be used to estimate the producer's accuracy and user's accuracy from the sample. The producer's accuracy is the probability that a pixel truly belonging to class i is also mapped as class i, while the user's accuracy is the probability that a pixel mapped as class i is truly of class i.[571]

The MODIS V5 confusion matrix includes 17 land use/ land cover categories developed by the International Geosphere-Biosphere Programme (IGBP). As shown in Table 2.4-34, we aggregated the confusion matrix data to match the 10 land categories used in our analysis. The resulting aggregate confusion matrix is shown below in Table 2.4-36.

Table 2.4-35 Table 2.4-35 is a number key for the land cover classes presented in confusion matrix.

Table 2.4-34. Aggregation of IGBP land cover classes into EPA land cover classes

IGBP Land Cover Class	EPA Land Cover Classes	
	Proposed Rule	Final Rule
Evergreen Needleleaf	Forest	Forest
Evergreen Broadleaf	Forest	Forest
Deciduous Needleleaf	Forest	Forest
Deciduous Broadleaf	Forest	Forest
Mixed Forest	Forest	Forest
Closed Shrubland	Shrubland	Shrubland
Open Shrubland	Shrubland	Shrubland
Woody Savanna	Savanna	Savanna
Savanna	Savanna	Savanna
Grasslands	Grassland	Grassland
Permanent Wetlands	Excluded	Wetland
Cropland	Cropland	Cropland
Cropland/Nat Veg Mosaic	Excluded	Mixed
Barren/Sparse	Excluded	Barren
Snow and Ice	Excluded	Excluded
Water	Excluded	Excluded

Table 2.4-35. EPA land cover class number key

Number Key	EPA Land Cover Class
1	Annual Crops
2	Forest
3	Grassland
4	Mixed
5	Savanna
6	Shrubland
7	Wetland
8	Barren
9	Perennial Crops
10	Excluded

Table 2.4-36. MODIS Version 5 confusion matrix with aggregated EPA land cover classes

Training Site Label	*Satellite Classification Label* 1	2	3	4	5	6	7	8	10	*Training Total*
1	6,963	0	118	84	77	73	60	2	127	*7,504*
2	25	7,763	5	42	564	52	482	1	5	*8,939*
3	414	3	1,938	26	279	570	40	77	111	*3,458*
4	498	103	22	402	264	69	105	0	0	*1,463*
5	300	422	172	102	2,331	275	233	16	0	*3,851*
6	148	34	341	10	279	3,135	71	111	8	*4,137*
7	19	59	5	0	6	0	2,406	0	0	*2,495*
8	4	0	14	0	27	334	0	4,802	1	*5,182*
10	0	0	13	0	0	1	12	4	2,411	*2,441*
Satellite Total	*8,371*	*8,384*	*2,628*	*666*	*3,827*	*4,509*	*3,409*	*5,013*	*2,663*	*39,470*

Note: values for perennial crops (land class 9) were assigned with a procedure described in the ICF report.[572]

The confusion matrix contains information about the accuracy of the satellite data which can be used statistically to correct systematic biases. The matrix includes data from 39,470 training sites where the MODIS land team validated the satellite classification labels with on-the-ground training site surveys. For example, if we look at forest (land class 2) in the matrix, we see that of the 8,384 sites that were classified by the satellite as forest (see the satellite total row) 7,763 of these sites (see the diagonal in row 2) were correctly classified. The quotient of these figures (i.e. 7,763/8,384 = 92.6%) gives us what it is known as the producer's accuracy for forest. The user's accuracy for forest, 86.8%, can also be calculated by using the training site total for forest in the denominator (i.e., 7,763/8,939 = 86.8%).

Furthermore, we can determine which land classes forestlands tended to be misclassified as (i.e., confused with), which classes tended to be misclassified as forests, and the probability of each specific misclassification. Table 4 presents the producer's accuracy matrix for MODIS Version 5 using EPA's aggregated land classes. Each value in Table 2.4-37 gives the probability that a pixel reported as land cover R is actually land cover A, where R is the reported land class listed in the columns and A is the actual land cover listed in the rows. For example, the intersection of column 2 and row 5 shows that there was a 5.0% probability that a pixel reported as forest (land class 2) was actually savanna (land class 5).

Table 2.4-37.
MODIS Version 5 producer's accuracy matrix with aggregated EPA land cover classes

Actual \ *Reported*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*10*
1	83.2%	0.0%	4.5%	12.6%	2.0%	1.6%	1.8%	0.0%	4.8%
2	0.3%	92.6%	0.2%	6.3%	14.7%	1.2%	14.1%	0.0%	0.2%
3	4.9%	0.0%	73.7%	3.9%	7.3%	12.6%	1.2%	1.5%	4.2%
4	5.9%	1.2%	0.8%	60.4%	6.9%	1.5%	3.1%	0.0%	0.0%
5	3.6%	5.0%	6.5%	15.3%	60.9%	6.1%	6.8%	0.3%	0.0%
6	1.8%	0.4%	13.0%	1.5%	7.3%	69.5%	2.1%	2.2%	0.3%
7	0.2%	0.7%	0.2%	0.0%	0.2%	0.0%	70.6%	0.0%	0.0%
8	0.0%	0.0%	0.5%	0.0%	0.7%	7.4%	0.0%	95.8%	0.0%
10	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.4%	0.1%	90.5%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Using the information in Table 2.4-37, it is fairly straight-forward to adjust/correct the reported land use data to provide a much better estimate of the actual land use during this time period. The MODIS data was corrected with the following multi-step process:

- First, the confusion matrix for each country and administrative unit is scaled for each year so that the share of reported land use of total land use matches the adjusted MODIS estimates share.
  - $ACM_{cup} = CM_{up} / CM_{xp}$, where CM_{up} are the values in the input aggregated confusion matrix and $CM_{xp} = \sum_u CM_{up}$ where *u* is the user's land use and *p* is the producer's land use[163]
  - The coefficients from the resulting matrix sum to 1.0
- Next, the number of producer sites is scaled similarly to the approach above and the producer's estimate is recalculated[164]
- The actual land use in 2001 and 2007 is then given by the following equations[165]
  - $ALU_{ci} = \sum_p BCM_{cyip} * AM_{cpx}$ for $y = 2001$ and where *i* is the initial land use
  - $ALU_{cf} = \sum_p BCM_{cyfp} * AM_{cxp}$ for $y = 2007$ and where *f* is the final land use
- The reported land use change is then calculated first for 2001

[163] *x* is a placeholder that indicates that the matrix presents total land use.
[164] In fact, the producer's estimate does not change.
[165] *x* is a placeholder that indicates that the matrix presents total land use.

- We find a land use category where the total land use for 2001 decreased (ALU_{ci} < AM_{cix})
- We scale the land use change to all land uses down from that land use category based on the percentage decrease in total land use
- We allocate the remaining land use change to the remaining land uses in 2001 based on the share of the increase in land use that increased

- We then use a similar process to adjust the 2007 land use

As an example of the 2nd to last step, let's assume that, based on the confusion matrix adjustment procedure described above, the adjusted land use for savanna has decreased in 2001 from the producer values by 30%, from 21 to 14 million hectares and that the adjusted land use for cropland and forestland, and grassland increase by 5, 3, and 2 million hectares respectively and all other land uses decrease or do not change. The adjusted land use change from Savanna to all 10 land uses is then scaled to be 70% of the original land use change from Savanna. The remaining 30% of the land use change is then allocated as coming from cropland, forestland, and grassland with the shares equal to 5/(5+3+2) = 5/10 for cropland,3/10 for forestland, and 2/10 for grassland respectively. This means that 3.5, 2.1, and 1.4 million hectares of increased cropland, forestland, and grassland have been accounted for and the ratios to apply to the land use change from Savanna is 0.5*0.3, 0.3*0.3, and 0.2*0.3 respectively. If the Savanna to Cropland land use change was 1 million hectares originally, it is now 0.7 million hectares. If the Cropland, Forestland, and Grassland to Cropland land use change was 2, 0.1, 0.4 million hectares originally, they are 2.0 + 1.0 * 0.5 * 0.3, 0.1 + 1.0*0.3*0.3, and 0.4 + 1.0*0.2 or 2.15, .19, and .6 respectively. We then go to the next land use with reductions in the adjusted land use for 2001 and repeat this process but in the allocation, we use (5-3.5), (3-2.1), and (2-1.4) million hectares for the allocation for cropland, forestland, and grassland respectively.

The approach for the adjustments in land use for 2007 is similar, but it scales and adds using (i) the change in land use in 2007, instead of change in land use in 2001, and (ii) the land use change from the 10 land uses to Savanna, instead of the change from Savanna to the 10 land uses.

The corrected satellite data was used to evaluate the types of land affected by the projected land conversions in each scenario. For agricultural expansions, the types of land affected were evaluated with the corrected land use change data from 2001-2007. We also used this approach to determine, within each country/region, the location of land use changes, i.e. the Administrative Units where conversions would occur. For example, in each region we looked at the types of land converted to cropland during this time period.

To determine the types of land converted to pasture, we applied the land use change data for cropland. This was done primarily because the MODIS data set does not classify land used for pasture. MODIS does classify grasslands and savanna, which we know are used for livestock grazing, but it provides no information about the share of grassland and savanna used as pasture in each region. Thus, looking only at land types that were replaced by grassland or savanna would ignore the fact that pasture can expand onto grassland and savanna areas. By applying the cropland change data for pasture we included/approximated these important land conversion possibilities. The justification for this approach was based, in part, on the assumption that pasture expansion is likely to affect similar land types as cropland.[166]

For land reversions, land cover in 2007 was used to estimate the land types that would likely grow back on abandoned agricultural lands in each region. For example, in a region that was 80% forest, we assume that 80% of abandoned agricultural land would grow back as forest. For land reversions this approach was preferable to using change data, because the time period covered by the MODIS satellite imagery was not long enough to determine the final land category following reversion, i.e., 30 years later. We also used this approach to determine, within each country/region, the location of land reversions, i.e. the Administrative Units where reversions would occur.

The contributing land use change categories and the bases of their weighting factors for each agricultural land use change are presented in **Table 2.4-38.**. The first column lists the 12 land conversion categories modeled. The middle column indicates the satellite data weighting approach used. The last column includes the resulting land conversions, which were weighted with the approach listed in the middle column. More details about the application of satellite data to weight land conversions is provided in a technical report by ICF International available on the public docket.[573]

[166] This assumption is supported to some degree by Cardille and Foley (2003) who found that cropland and pasture expansion affected similar land types in the Brazilian Amazonia between 1980 and 1995.

Table 2.4-38.
Contributing Land Use Change Categories and Bases of Weighting Factors for Agricultural Land Use Change Categories

Agricultural Land Use Change Category	Land Use Change or Land Use Used to Estimate Weighted Emission Factors	Land Use Change Category or Land Use Type
Annual Crops to Perennial Crops	2007 Land Use	Cropland
Perennial Crops to Annual Crops	2007 Land Use	Cropland
Pasture to Perennial Crops	Land Use Change - 2001 to 2007	Grasslands to Perennial
		Savanna to Perennial
Perennial Crops to Pasture	Land Use Change - 2001 to 2007	Perennial to Grasslands
		Perennial to Savanna
Pasture to Annual Crops	Land Use Change - 2001 to 2007	Grasslands to Croplands
		Savanna to Croplands
Annual Crops to Pasture	Land Use Change - 2001 to 2007	Croplands to Grasslands
		Croplands to Savanna
Natural Ecosystems to Annual Crops	Land Use Change - 2001 to 2007	Forestland to Croplands
		Grasslands to Croplands
		Mixed to Croplands
		Savanna to Croplands
		Shrubland to Croplands
		Wetland to Croplands
		Barren to Croplands
Annual Crops to Natural Ecosystems	2007 Land Use	Forestland
		Grasslands
		Mixed
		Savanna
		Shrubland
Natural Ecosystems to Perennial Crops	Land Use Change - 2001 to 2007	Forestland to Perennial
		Grasslands to Perennial
		Mixed to Perennial
		Savanna to Perennial
		Shrubland to Perennial
		Wetland to Perennial
		Barren to Perennial
Perennial Crops to Natural Ecosystems	2007 Land Use	Forestland
		Grasslands
		Mixed
		Savanna

Agricultural Land Use Change Category	Land Use Change or Land Use Used to Estimate Weighted Emission Factors	Land Use Change Category or Land Use Type
		Shrubland
Natural Ecosystems to Pasture	Land Use Change - 2001 to 2007	Forestland to Grasslands
		Shrubland to Grasslands
		Mixed to Grasslands
		Wetland to Grasslands
		Barren to Grasslands
		Forestland to Savanna
		Shrubland to Savanna
		Mixed to Savanna
		Wetland to Savanna
		Barren to Savanna
Pasture to Natural Ecosystems	2007 Land Use[167]	Forestland
		Mixed
		Shrubland

[167] The model actually uses the three land uses twice, once to represent the replacement of grasslands and the other to represent the replacement of Savanna

Table 2.4-39 includes the regional shares of land types converted to cropland and pasture based on the original Version 5 MODIS data.

Table 2.4-40 shows the same data after it was corrected using the confusion matrix data and the procedure described above. In many regions, the corrections significantly reduced the share of grassland, savanna and/or mixed land converted to cropland. This was due, in part, to the tendency of MODIS to confuse these land types with each other and with cropland. As a result, the share of forest affected by agricultural expansion increased for most of the regions analyzed. Table 2.4-41 shows the land type shares for agricultural reversion with the corrected data. Our estimates of satellite data uncertainty are presented in below in Table 2.4-49.

Table 2.4-39. Types of Land Converted to Cropland/Pasture by Region Original Version 5 MODIS Data, 2001-2007

FAPRI-CARD Region	Forest	Grassland	Mixed	Savanna	Shrubland	Wetland	Barren
Algeria	0%	12%	7%	8%	72%	0%	0%
Argentina	11%	37%	20%	17%	13%	1%	0%
Australia	1%	54%	2%	16%	27%	0%	0%
Bangladesh	21%	6%	24%	24%	11%	13%	1%
Brazil: Amazon Biome	15%	33%	12%	36%	4%	0%	0%
Brazil: Central-West Cerrados	3%	30%	17%	49%	1%	0%	0%
Brazil: Northeast Coast	0%	22%	15%	54%	9%	0%	0%
Brazil: North-Northeast Cerrados	1%	32%	7%	53%	7%	0%	0%
Brazil: South	5%	52%	22%	20%	0%	0%	0%
Brazil: Southeast	1%	20%	43%	35%	1%	0%	0%
Canada	2%	52%	5%	5%	32%	0%	3%
China	1%	67%	6%	3%	15%	0%	7%
New Zealand	30%	37%	6%	2%	24%	0%	0%
Colombia	3%	74%	5%	14%	4%	0%	0%
Cuba	2%	6%	74%	15%	2%	1%	0%
Egypt	2%	4%	50%	4%	27%	0%	13%
EU	4%	37%	36%	8%	14%	0%	1%
Guatemala	17%	3%	60%	18%	1%	0%	0%
India	2%	12%	41%	23%	22%	0%	1%
Indonesia	27%	5%	43%	22%	2%	2%	0%
Iran	0%	77%	1%	1%	16%	0%	4%
Iraq	0%	53%	4%	2%	39%	0%	2%
Ivory Coast	26%	6%	30%	30%	6%	2%	1%
Japan	8%	9%	58%	15%	10%	0%	0%
Malaysia	35%	4%	50%	5%	3%	3%	0%
Mexico	2%	36%	17%	16%	29%	0%	0%
Morocco	0%	18%	4%	4%	72%	0%	2%
Myanmar	7%	9%	46%	27%	10%	2%	0%
Nigeria	2%	73%	12%	11%	2%	0%	0%
Other Africa	0%	59%	8%	18%	11%	0%	3%
Other Asia	0%	79%	2%	1%	6%	0%	11%
Other CIS	0%	87%	2%	1%	4%	0%	5%
Other Eastern Europe	1%	48%	38%	9%	4%	0%	0%
Other Latin America	7%	40%	13%	19%	20%	0%	1%
Other Middle East	0%	13%	13%	8%	54%	0%	11%
Pakistan	0%	13%	29%	3%	51%	0%	4%
Paraguay	8%	31%	22%	39%	0%	0%	0%
Peru	1%	78%	2%	3%	15%	0%	0%
Philippines	12%	2%	78%	4%	1%	3%	0%
Rest of World	1%	54%	9%	22%	12%	0%	1%
Russia	3%	50%	25%	6%	16%	0%	0%
South Africa	1%	52%	12%	18%	17%	0%	0%
South Korea	5%	5%	82%	6%	3%	0%	0%
Taiwan	25%	6%	36%	15%	16%	1%	1%
Thailand	5%	10%	64%	15%	4%	1%	0%
Tunisia	0%	8%	10%	3%	79%	0%	1%
Turkey	0%	81%	3%	6%	9%	0%	0%
Ukraine	2%	26%	59%	7%	6%	0%	0%
Uruguay	2%	82%	13%	3%	0%	0%	0%
US	0%	84%	5%	4%	7%	0%	0%
Uzbekistan	0%	56%	3%	3%	20%	0%	18%
Venezuela	1%	38%	8%	36%	16%	0%	0%
Vietnam	16%	5%	55%	11%	4%	7%	1%
Western Africa	2%	15%	34%	46%	3%	0%	0%

Table 2.4-40. Types of Land Converted to Cropland/Pasture by Region Corrected Version 5 MODIS Data, 2001-2007

FAPRI-CARD Region	Forest	Grassland	Mixed	Savanna	Shrubland	Wetland	Barren
Algeria	1%	16%	8%	10%	64%	0%	0%
Argentina	12%	26%	27%	17%	14%	1%	3%
Australia	6%	32%	11%	22%	25%	0%	4%
Bangladesh	19%	21%	24%	20%	11%	5%	1%
Brazil: Amazon Biome	54%	8%	15%	20%	2%	1%	0%
Brazil: Central-West Cerrados	11%	26%	20%	36%	6%	0%	0%
Brazil: Northeast Coast	11%	19%	19%	41%	8%	0%	1%
Brazil: North-Northeast Cerrados	15%	16%	10%	49%	9%	0%	1%
Brazil: South	13%	23%	28%	29%	6%	0%	0%
Brazil: Southeast	10%	18%	30%	36%	6%	0%	0%
Canada	8%	28%	13%	14%	31%	2%	4%
China	6%	30%	23%	20%	17%	1%	3%
New Zealand	28%	33%	15%	7%	15%	1%	1%
Colombia	33%	9%	31%	18%	8%	1%	1%
Cuba	9%	12%	49%	23%	7%	0%	0%
Egypt	2%	20%	30%	8%	33%	0%	7%
EU	6%	25%	32%	21%	14%	1%	1%
Guatemala	21%	7%	42%	24%	5%	1%	0%
India	10%	21%	30%	19%	17%	1%	2%
Indonesia	39%	5%	29%	22%	3%	2%	0%
Iran	2%	43%	5%	8%	33%	0%	9%
Iraq	1%	37%	8%	8%	43%	0%	3%
Ivory Coast	22%	8%	15%	46%	8%	0%	1%
Japan	8%	9%	47%	23%	11%	1%	1%
Malaysia	52%	3%	27%	13%	2%	2%	0%
Mexico	10%	18%	27%	21%	21%	1%	2%
Morocco	2%	28%	7%	9%	50%	0%	4%
Myanmar	14%	10%	34%	30%	9%	2%	1%
Nigeria	11%	36%	19%	25%	9%	0%	1%
Other Africa	10%	19%	14%	37%	13%	0%	6%
Other Asia	4%	42%	15%	11%	19%	0%	9%
Other CIS	1%	49%	17%	11%	18%	0%	3%
Other Eastern Europe	6%	37%	31%	16%	8%	1%	1%
Other Latin America	18%	13%	27%	26%	13%	1%	2%
Other Middle East	2%	21%	11%	11%	32%	0%	23%
Pakistan	3%	23%	28%	13%	31%	0%	2%
Paraguay	17%	20%	22%	36%	5%	1%	0%
Peru	45%	30%	4%	9%	10%	1%	1%
Philippines	16%	5%	54%	19%	2%	3%	0%
Rest of World	18%	13%	25%	27%	12%	1%	3%
Russia	8%	20%	27%	20%	22%	1%	2%
South Africa	5%	35%	19%	18%	20%	0%	3%
South Korea	5%	11%	58%	20%	5%	1%	0%
Taiwan	25%	8%	27%	21%	17%	1%	1%
Thailand	12%	10%	48%	23%	5%	1%	0%
Tunisia	3%	29%	12%	12%	43%	0%	1%
Turkey	5%	45%	15%	10%	23%	0%	3%
Ukraine	3%	31%	20%	32%	13%	2%	1%
Uruguay	3%	57%	17%	11%	12%	0%	0%
US	6%	36%	24%	18%	14%	1%	1%
Uzbekistan	2%	34%	16%	15%	32%	0%	1%
Venezuela	7%	13%	27%	43%	9%	0%	1%
Vietnam	21%	8%	39%	20%	6%	5%	1%
Western Africa	14%	12%	14%	50%	8%	0%	1%

Table 2.4-41. Types of Land That Replace Abandoned Cropland/Pasture by Region
***Corrected* Version 5 MODIS Data, 2001-2007**

FAPRI-CARD Region	Forest	Grassland	Mixed	Savanna	Shrubland
Algeria	3%	21%	3%	10%	64%
Argentina	14%	21%	6%	13%	45%
Australia	7%	20%	3%	19%	51%
Bangladesh	32%	14%	20%	24%	9%
Brazil: Amazon Biome	83%	1%	5%	10%	1%
Brazil: Central-West Cerrados	24%	9%	11%	49%	6%
Brazil: Northeast Coast	14%	10%	15%	54%	7%
Brazil: North-Northeast Cerrados	20%	9%	11%	53%	7%
Brazil: South	32%	17%	23%	23%	5%
Brazil: Southeast	21%	7%	22%	44%	6%
Canada	43%	11%	4%	15%	26%
China	27%	34%	10%	16%	14%
New Zealand	64%	14%	2%	6%	13%
Colombia	64%	8%	11%	14%	4%
Cuba	36%	7%	33%	21%	4%
Egypt	2%	30%	8%	10%	50%
EU	45%	11%	15%	17%	11%
Guatemala	54%	3%	17%	23%	3%
India	22%	12%	24%	29%	13%
Indonesia	77%	1%	12%	9%	1%
Iran	3%	36%	3%	8%	51%
Iraq	2%	25%	3%	8%	62%
Ivory Coast	32%	5%	20%	38%	4%
Japan	77%	2%	8%	11%	2%
Malaysia	82%	1%	10%	7%	1%
Mexico	19%	17%	8%	24%	32%
Morocco	2%	18%	4%	10%	66%
Myanmar	59%	4%	12%	22%	3%
Nigeria	17%	18%	25%	33%	7%
Other Africa	24%	17%	8%	36%	15%
Other Asia	13%	52%	5%	9%	22%
Other CIS	5%	64%	4%	8%	19%
Other Eastern Europe	42%	8%	29%	17%	4%
Other Latin America	56%	7%	8%	15%	14%
Other Middle East	1%	20%	2%	8%	68%
Pakistan	5%	17%	8%	10%	60%
Paraguay	41%	8%	14%	33%	5%
Peru	62%	17%	2%	7%	12%
Philippines	54%	3%	30%	12%	1%
Rest of World	44%	11%	9%	20%	16%
Russia	43%	10%	6%	14%	27%
South Africa	8%	22%	6%	23%	42%
South Korea	67%	3%	13%	13%	3%
Taiwan	75%	3%	9%	10%	3%
Thailand	32%	5%	34%	25%	3%
Tunisia	3%	17%	5%	10%	65%
Turkey	12%	47%	7%	16%	18%
Ukraine	34%	14%	32%	16%	5%
Uruguay	4%	67%	5%	11%	13%
US	27%	31%	14%	12%	16%
Uzbekistan	2%	40%	3%	9%	46%
Venezuela	55%	8%	11%	21%	4%
Vietnam	48%	5%	21%	22%	4%
Western Africa	14%	8%	17%	54%	7%

2.4.4.2.6 Quantification of International Land Conversion GHG Emissions Impacts

Land use change emissions factors were calculated by the non-profit organization Winrock International following 2006 IPCC Agriculture Forestry and Other Land Use (AFOLU) Guidelines.[574] Winrock's staff is highly regarded for their years of experience and accomplishments in this field, including their work with the IPCC to develop the AFOLU Guidelines. Following publication of the proposed rule, we sponsored an expert peer review on this part of our lifecycle analysis. Based on the reviewers recommendations a number of important improvements were made, including incorporation of more recent and higher resolution data sets. Our analysis of land use change emissions factors has also been expanded to provide global coverage. For the proposed rule, emissions factors were estimated for 5 land categories in 314 regions across 35 of the most important countries, with a weighted average applied to the rest of the world. Our analysis now includes 9 land categories in over 750 distinct regions across 160 countries covering all significant agricultural producers. This section describes the methods used to estimate GHG emissions from international land use change, with a focus on updates since the proposed rule. More details are available in a technical document by Winrock available on the public docket.[575]

2.4.4.2.6.1 Data Sources and Methods for International Land Conversion GHG Emissions Factors

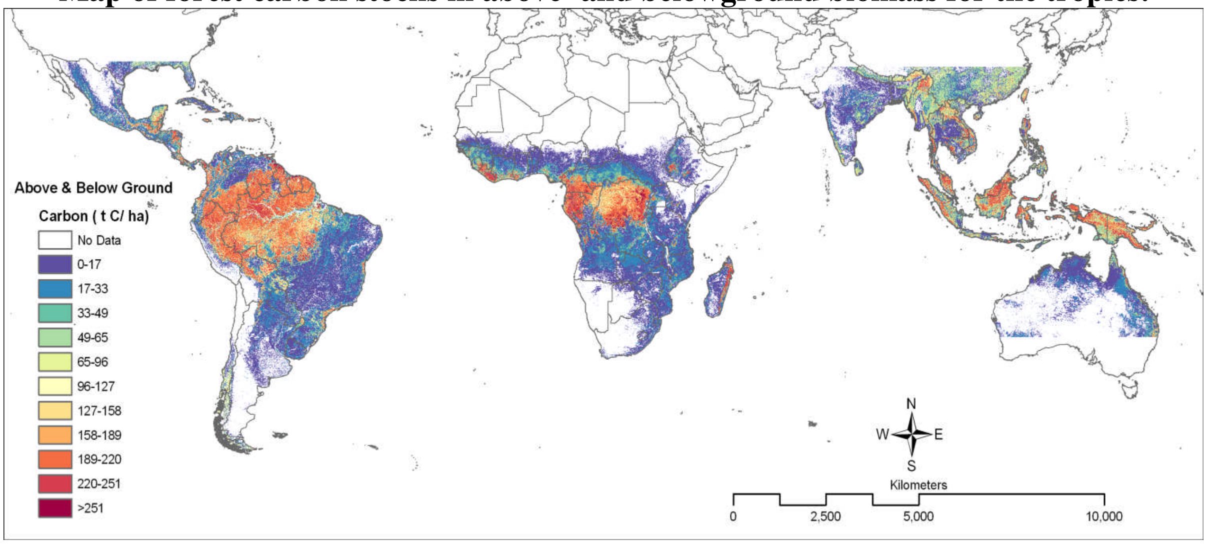
Emission factors were calculated using the IPCC equations explained in DRIA Chapter 2.[576] The emissions factors include the sum of changes in above- and belowground biomass carbon stocks, changes in soil carbon stocks on mineral soils, emissions from peat drainage on peat soils cleared for agriculture, foregone forest sequestration, and non-CO_2 emissions (CH_4, N_2O) resulting from land clearing with fire where applicable. Methane emissions from rice cultivation were excluded from the updated emission factors, as these emissions are accounted for elsewhere in EPA's lifecycle analysis. Updates to various components of the final emission factor are described below.

2.4.4.2.6.1.1 Data Sources and Methods for International Forest Carbon Stock Estimates

Our emission factor analysis incorporated spatial maps of forest carbon stocks from several data sources. The region-specific maps were preferred due to the use of country-specific data (i.e., IPCC Tier 2 vs. Tier 1), and also because the only globally consistent carbon stock map available was derived using adjusted biome-level Tier 1 default values from IPCC rather than from country specific data sources (Ruesch and Gibbs 2008). We used regional and/or country-level maps where available, and the global Ruesch and Gibbs (2008) data product was used only to fill in gaps where no other information on forest carbon stocks was available.[577]

Our analysis of forest carbon stocks was improved by incorporating several new data sources. Most notable is the inclusion of a new spatially explicit map of tropical forest carbon stocks. Winrock is working with Dr. Sassan Saatchi from NASA's Jet Propulsion Laboratory to create a pantropical benchmark map of above- and belowground forest carbon stocks for the year 2000 at 1-km resolution.[578] The methodology uses about 4,000 ground inventory plots of forest biomass, 150,000 biomass values estimated from heights measured by spaceborne lidar, and a suite of satellite imagery products to derive a spatially refined map of aboveground forest carbon at a 1-km grid cell resolution. Belowground carbon is added to aboveground carbon using an equation from Mokany et al. (2006).[579] The estimates are directly comparable across countries and regions due to the consistency in the methodological approach (see **Figure 2.4-32**).

Figure 2.4-32.
Map of forest carbon stocks in above- and belowground biomass for the tropics.

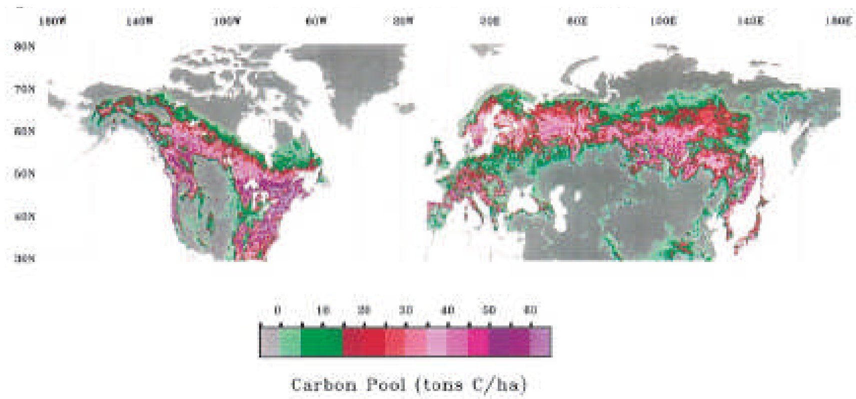


Note: from Saatchi et al. (in prep)

Preliminary results of Saatchi et al. for forest carbon stocks in Latin America and Africa were incorporated into the updated EPA analysis by clipping the map to MODIS forest cover in 2001 and calculating the area-weighted average forest carbon stock per country (and per administrative unit in key countries). Preliminary results for Asia are now complete, but were not included in the updated EPA analysis due to timing considerations. Therefore, the original Brown et al. (2001) map was retained for forest carbon stock estimates in Asia.[580] The Saatchi et al. results represent a significant improvement over previous estimates; the maps were evaluated for accuracy using cross validation with approximately 50% of the ground and lidar biomass data and resulted in an overall accuracy of 76% across the three regions (Latin America: 81%, Africa: 86%, Southeast Asia: 69%).

Myneni et al. (2001) also produced a spatially-explicit map of woody biomass for Northern (i.e., boreal and temperate) forests (Figure 2.4-33).[581] Although we used carbon stock values from other data sources for the United States, Russia and many countries of the European Union (Blackard et al. 2007, Houghton et al. 2007, Nabuurs et al. 2003, see Figure 2.4-34), the Myneni et al. (2001) dataset filled in the data gap for Canada and many Eastern European countries.[582,583,584,585]

Figure 2.4-33. Aboveground biomass carbon stocks in Northern forests.

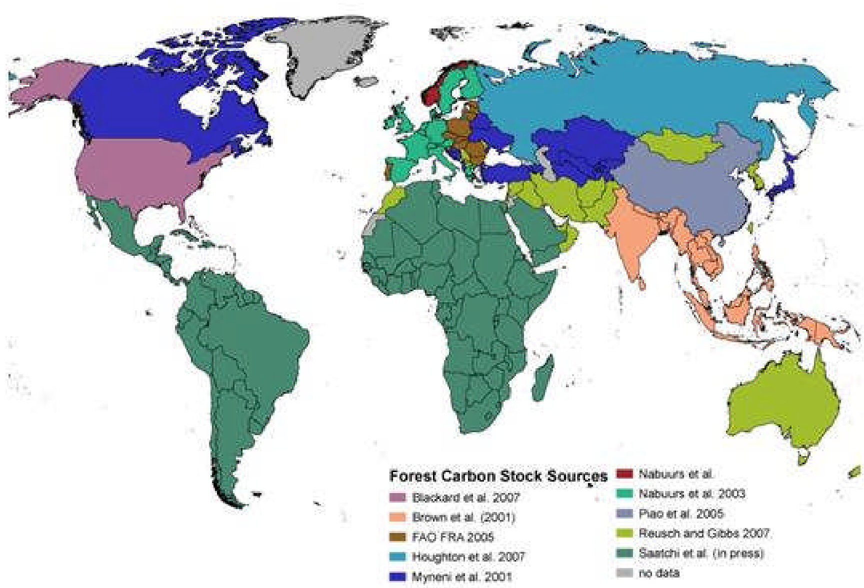


Note: reproduced from Figure 2 of Myneni et al. (2001).

Apart from the new data sources described above, the data sources used to estimate forest carbon stocks in other regions remained unchanged in the updated analysis.[586] A summary of data sources used is shown in Figure 2.4-34.

Figure 2.4-34

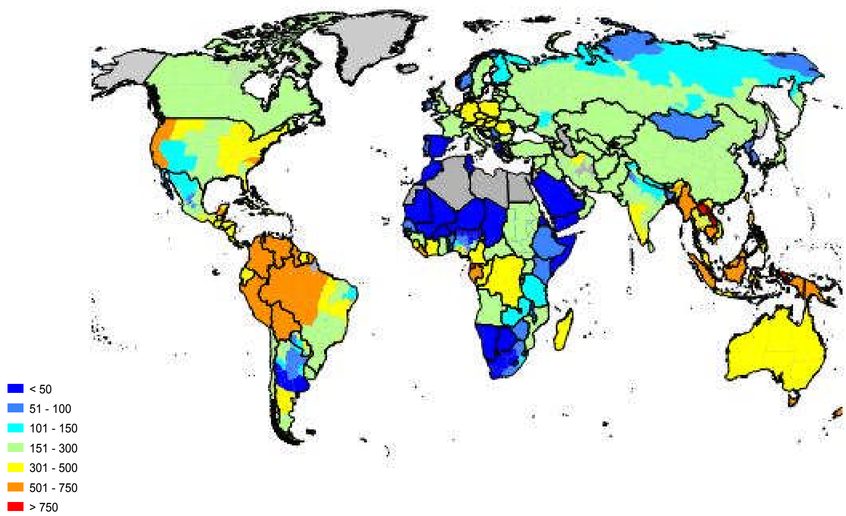
Figure 2.4-34.
Data sources used for estimating forest carbon stocks in updated emission factor analysis



Note: Nabuurs et al. and Nabuurs et al. 2003 are the same data source.

In all cases where belowground biomass was not estimated, belowground biomass was added to aboveground biomass estimates using an equation from Mokany et al. (2006).[587] (This equation represents an update to the default belowground biomass values given in the IPCC Guidelines.) Forest carbon stock values per country or administrative unit (for key countries) are shown in **Figure 2.4-35**.

Figure 2.4-35. Spatially averaged forest carbon stocks in above- and belowground biomass (tCO2e/ha)



2.4.4.2.6.1.2 Data Sources and Methods for International Cropland Carbon Stock Estimates

In the proposed rule emission factor analysis, all cropland conversion was assumed to be conversion to annual cropland. In the updated analysis, emission factors were estimated separately for conversion to annual cropland and conversion to perennial cropland. Perennial cropland in Indonesia and Malaysia was assumed to be oil palm, while perennial cropland in all other countries was sugarcane. Carbon stocks in oil palm plantations after one year of growth were estimated as 15 t CO_2e/ha. Table 5.3 of the 2006 IPCC Guidelines for AFOLU gives biomass stocks on oil palm plantation as 136 t/ha (68 t C/ha), and if this value is divided by an assumed 15-year growth period, a linear growth rate of 4 t C/ha/yr (15 t CO_2e/ha/yr) was assumed. This value is also nearly identical to the average carbon stock in biomass after one year of growth averaged across all tropical climate regions and all perennial crop types, as given in Table 5.9 of the 2006 IPCC Guidelines.

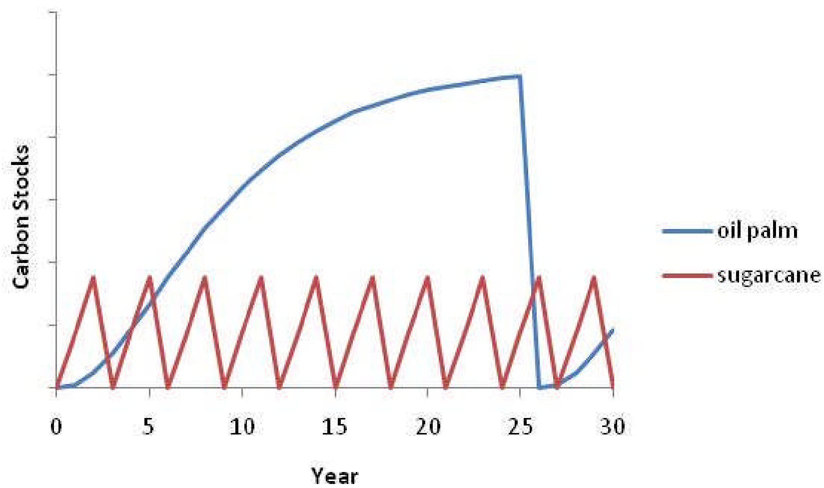
Carbon stocks in sugarcane after one year of growth were assumed to be 44 t CO_2e/ha. (Carbon stocks for long-lived tree species such as oil palm accumulate carbon more slowly in the early phases of growth.) The value for sugarcane was derived from estimates of carbon stocks in sugarcane in aboveground biomass (17 t C ha^{-1} or 62 t CO_2, Amaral et al. 2008)[588] and in belowground biomass (7 t C/ha or 26 t CO_2/ha, Smith et al. 2005)[589] for a total of 88 t CO_2e/ha. We assumed a growth period of two years to achieve full carbon stocks, therefore the carbon stock in sugarcane after one year of growth was assumed to be 44 t CO_2/ha.

All biomass accumulated after Year 1 would have been harvested over the course of 30 years in the case of both sugarcane and oil palm, leading to little net sequestration during the time period for which emission factors were estimated (30 years). Over the long term (e.g., 100 years), oil palm plantations may have a long-term average carbon stock higher than that at Year

1, but the land use after 30 years is highly uncertain and there is no guarantee of future rotations. Therefore, the average carbon sequestration at any given time over 30 years was assumed to be the carbon stock in vegetation after one year of growth.

Figure 2.4-36 illustrates this concept by showing an example of carbon stock growth for perennial crops with different rotation lengths.

Figure 2.4-36. Perennial Crop Carbon Stocks Over Time



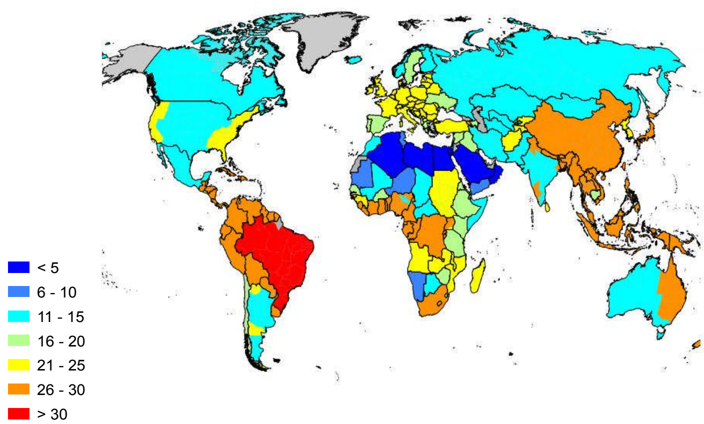
2.4.4.2.6.1.3 Data Sources and Methods for International Grassland, Savanna and Shrubland Carbon Stock Estimates

The approach for estimating carbon stocks in grassland, savanna and shrubland land cover categories was unchanged from the proposed rule, as there were no significant comments on this aspect of our analysis from the peer reviewers. Above- and belowground carbon stocks of grassland, savanna and shrublands in Brazil were estimated using values from de Castro and Kauffman (1998)[590] who report biomass along a vegetation gradient from campo limpo (pure grassland), campo sujo (a savanna with a sparse presence of shrubs), campo cerrado (a dominance of shrubs with scattered trees and a grass understory), cerrado *sensu stricto* (a dominance of trees with scattered shrubs and a grass understory) and cerradão (a closed canopy forest) (Coutinho 1978, Eiten 1972, Goodland & Pollard 1973).[591,592,593] Shrubland carbon stocks in Brazil were estimated as the average of biomass values reported for cerrado aberto and cerrado denso. Savanna carbon stocks in Brazil were estimated as the average biomass value reported for campo sujo and grassland carbon stocks in Brazil were estimated as the average value reported for campo limpo.

To maintain a consistent approach, for all countries except Brazil (explained in the paragraph above), carbon stocks in grasslands were estimated based on default biomass values given in Table 6.4 of the IPCC AFOLU Guidelines. These default values are presented by ecological zone. Therefore, grassland C stocks within each country reflect the area-weighted value based on the proportions of each ecological zone present within each country. Carbon stocks of savanna and shrubland land cover types in all countries except Brazil were estimated using a proportional approach based on the Brazil dataset, which indicates an increasing trend in carbon stocks from grassland to savanna to shrubland in a ratio of 1 to 1.8 to 3.4. These ratios were applied to other countries for estimating carbon stocks in savanna and shrubland based on the estimated carbon stocks of grassland within each country.

Grassland carbon stock estimates for each country and administrative unit (for key countries) are shown in **Figure 2.4-37**.

Figure 2.4-37. Grassland carbon stock estimates for each country and administrative unit (t CO2e/ha)



2.4.4.2.6.1.4 Data Sources and Methods for International Wetland, Barren and Mixed Carbon Stock Estimates

In line with recommendations for the expert peer reviewers, the updated analysis included land cover change to/from the wetland and barren land cover categories, and therefore emission factors were estimated for these conversions. According to the IGBP land cover description, the permanent wetlands category can consist of herbaceous and/or woody vegetation. However, after confirming that Indonesian peat swamp forests (a type of permanent forested wetland) are classified as forest and not wetland in the MODIS land cover maps, the carbon stocks of permanent wetlands in a given country or administrative unit were calculated as the average of carbon stocks in shrubland and grassland land cover categories. Carbon stocks on barren lands were assumed to be zero. In accordance with the IGBP land cover definitions, mixed carbon stocks were calculated as the average of forest, shrubland, grassland and cropland carbon stocks.

2.4.4.2.6.2 Evaluation of Changes in Biomass Carbon Stocks from International Land Conversions

Initial changes in biomass carbon stocks on land converted to another land category (e.g., from forest to cropland) were calculated the same way as in the proposed rule analysis, i.e. based on Equation 2.16 in the IPCC AFOLU:

$$\Delta C_{CONVERSION} = \sum_i (B_{AFTER_i} - B_{BEFORE_i}) \bullet CF$$

where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C ha^{-1} yr^{-1}

B_{AFTER_i} = biomass stocks on land type i immediately after the conversion, tonnes d.m. ha^{-1}

B_{BEFORE_i} = biomass stocks on land type I before the conversion, tonnes d.m. ha^{-1}

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$

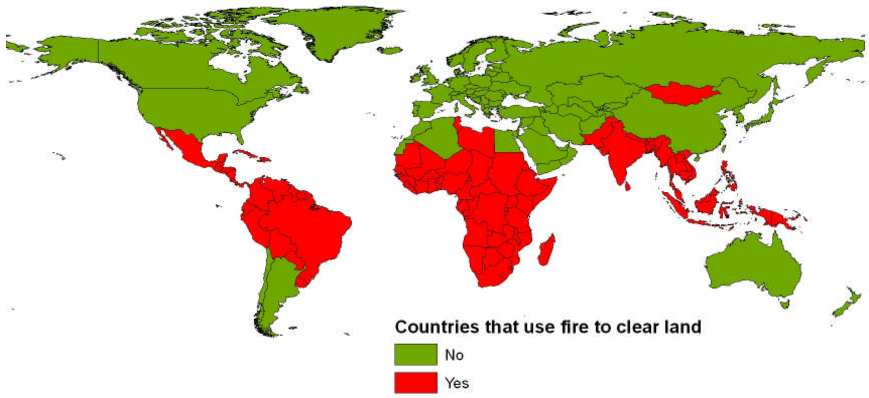
i = type of land use converted to another land-use category

2.4.4.2.6.3 Evaluation of GHG Emissions from International Land Clearing with Fire

In the proposed rule we used expert judgment to determine the regions where land is cleared with fire prior to conversion to crop production. In general, it was assumed that clearing with fire takes place in tropical regions. Several of the expert peer reviewers suggested the use of fire products, such as those derived from MODIS and AVHRR sensors, to determine which regions typically use fire to clear land for another land use. However, the use of these products in isolation would not allow a distinction between fire that occurs for land conversion versus fire that occurs due to wildfires, especially for temperate regions. Therefore, we considered an approach in which various fire maps could be overlain onto land cover change maps to determine fires that occurred on changed pixels (land conversion) versus fires that occurred on pixels that remained in the same land cover category (e.g., forest fire, annual burning of cropland residues, etc.). However, the time needed to do this analysis exceeded the time available. Therefore, we maintained the approach used in the proposed rule analysis, whereby expert judgment was used to determine the regions where fire is commonly used when land is cleared for agricultural production.

Figure 2.4-38 shows the countries where fire is assumed to occur as part of site preparation for crop production.

Figure 2.4-38. Countries that Clear with Fire in Preparation for Crop Production



As in the proposed rule analysis, in countries where fire is used commonly as a land clearing practice for conversion to agriculture, non-CO_2 emissions were estimated using emission factors in Table 2.5 and Equation 2.27 of the IPCC AFOLU. Fire for land clearing was assumed to occur in all countries included in the analysis except China and Argentina.

Non-CO_2 emissions from land clearing with fire were estimated as:

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, MT of each GHG (i.e., CH_4, N_2O)

A = area burnt, ha

M_B = mass of fuel available for combustion, MT ha^{-1}.

C_f = combustion factor, dimensionless

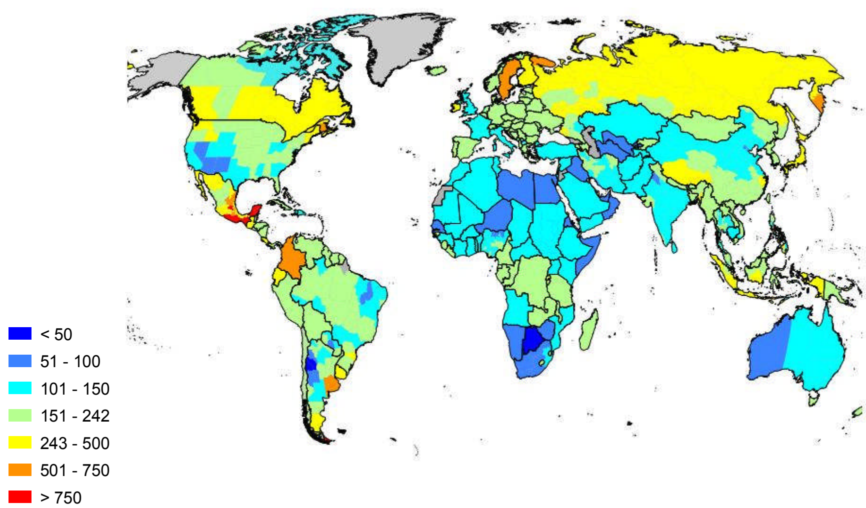
G_{ef} = emission factor, g kg^{-1} dry matter burnt

The mass of fuel available for combustion was conservatively assumed to be equal to the above- and belowground biomass only; dead wood and litter pools were not included in the fuel load estimates. IPCC defaults were used for the forest combustion factor. Values from de Castro and Kaufmann (1998) were used for clearing other land cover types (grassland, savanna, shrubland).

2.4.4.2.6.4 Evaluation of International Soil Carbon Stocks

For the initial analysis, soil carbon stocks were estimated using the FAO/UNESCO Soil Map of the World. In March 2009, a new soil database was released (Harmonized Soil Map of the World v.1.1) with 1-km resolution grid cells and therefore this improved dataset was used for the updated analysis.[594] Attribute values of the database did not include average soil carbon stocks, but values were included instead for bulk density (g cm^{-3}) and carbon content (%C) in both the top 30 cm and top meter of soil in each grid cell. Therefore, we calculated average soil carbon stocks in the top 30 cm of soil – assumed to be the depth to which soil carbon stocks would be affected when converted to agriculture – by multiplying the volume of soil in a given hectare (1 ha x 30 cm depth = 3,000 m^3) by the bulk density to calculate the mass of soil in a given hectare, then multiplied the soil mass by the carbon content to derive an average soil carbon stock value per hectare (t C ha^{-1}). Soil carbon stocks estimated per country (and per administrative unit in key countries) are shown in **Figure 2.4-39**. The soil carbon stocks for annual cropland (i.e., after conversion) are based on long-term cultivated annual cropland with full tillage and medium inputs.

Figure 2.4-39.
Soil carbon stocks in the top 30 cm of soil for each country and administrative unit (t CO2e/ha)



Note: estimates were derived from the Harmonized World Soil Database v. 1.1

2.4.4.2.6.4.1 Evaluation of Changes in Soil Carbon Stocks from International Land Conversions

Identical to the approach used in the proposed rule analysis, changes in soil carbon stocks on land converted to cropland were calculated based on Section 5.3.3.4 of the IPCC AFOLU. Soil carbon stocks after conversion to cropland were based on specific soil stock change factors for land use, management and inputs (F_{LU}, F_{MG}, F_I, respectively) listed in Table 5.10 of the IPCC AFOLU. Stock change factors were selected for each land cover type (before and after conversion) and multiplied by reference soil carbon stocks. Following the IPCC AFOLU guidelines, the total difference in carbon stocks before and after conversion was averaged over 20 years. Thus the average annual change in soil carbon stocks due to land use conversion was calculated as:

$$\Delta SOC = \frac{(SOC_{\mathrm{Re}f} \bullet F_{LU,before} \bullet F_{MG,before} \bullet F_{I,before}) - (SOC_{\mathrm{Re}f} \bullet F_{LU,after} \bullet F_{MG,after} \bullet F_{I,after})}{20}$$

where:

ΔSOC = average annual change in carbon stocks in top 30 cm of soil; t C ha^{-1} yr^{-1}

$SOC_{\mathrm{Re}f}$ = reference carbon stocks in top 30 cm of soil; t C ha^{-1}

F_{LU} = land use factor before or after conversion

F_{MG} = management factor before or after conversion

F_{I} = input factor before or after conversion

As default values for stock change factors (F_{LU}, F_{MG}, F_{I}) are all one for forest soils and non-degraded grassland soils, soil carbon stocks were assumed to remain unchanged for all conversion types (conversion to shrubland, savanna, perennial cropland) except conversion to cropland. Full tillage and medium inputs were assumed in all scenarios of cropland conversion. Consistent with IPPC default guidelines, soil carbon stock changes were spread equally over 20 years.

2.4.4.2.6.5 Accounting for International Harvested Wood Products

In the updated analysis, we addressed the potential significance of the harvested wood product pool and concluded that the amount of carbon stored in wood products long-term is immaterial for most regions of the world, especially when considering a timeframe of 30 years. Therefore, carbon storage in harvested wood products was not incorporated into our updated emission factors.

We reached this conclusion as follows: the proportion of extracted timber that ends up in long-lived (>5 yr) wood products was estimated using information presented in Winjum et al. (1998), who related harvesting and use of wood products to carbon impacts (Table 2).[595] The proportion of timber volume extracted ending up in long-lived wood products was calculated by dividing carbon in net production of industrial roundwood by the total carbon in commodity uses >5 yr. We did this for the developing and developed world and calculated percentages of 53% and 60%, respectively. The country-level percentages were generally lower than the aggregated values. Winjum et al. (1998) also estimates inherited emissions from the retirement of past wood products, so we also estimated the proportion of roundwood production that is re-emitted into the atmosphere through the retirement of past wood products. These values are reproduced in Table 2.4-42 below.

Table 2.4-42.
Calculation of the proportion of extracted timber that goes to long-lived wood products and the proportion of extracted timber as inherited emissions. (Tg C)
All units are in Tg C. From Winjum et al. (1998). SWD=sawnwood, WBP=woodbase panels, OIR=other industrial roundwood and P&P=paper and paperboard.

Category / Country	Industrial Roundwood Production*	Commodity use ≥ 5 yr[#] SWD	WBP	OIR	P&P	Total	Inherited emissions	% HWP	% Inherited Emissions
Developing									
Brazil	23	4	1	1	1	7	4	30	17
India	9	4	0.1	1	1	6	3	67	33
Indonesia	12	2	0.1	1	0.42	3	1	25	8
Ivory Coast	1	0.05	0.03	0.2	0.01	0.3	0.2	30	20
Developed									
Canada	39	3	1	1	2	7	1	18	3
Finland	9	0.6	0.2	0.1	0.4	1.2	0.3	13	3
New Zealand	2.7	0.3	0.1	0.1	0.2	0.6	0.3	22	11
U.S.A.	102	23	8	3	23	57	17	56	17
Worldwide									
Developing	128	26	6	22	14	68	42	53	33
Developed	308	70	27	29	58	184	71	60	23
Total	436	96	33	51	72	252	113	58	26

* From Table 4 in Winjum et al. (1998).
[#] From Table 5 in Winjum et al. (1998).

Next, we analyzed per-hectare extraction volumes from 111 developing countries using data reported to FAO for the 2005 Forest Resources Assessment. Of the countries analyzed, the country with the highest reported extraction rate was Indonesia (50 m^3/ha). This value was much higher compared to countries in Africa and Asia, which weren't much higher than about 20 m^3/ha and often less.

For the 50 m^3/ha Indonesia case, we converted volume to biomass using an average conversion factor of 0.55 (Table 1 in Winjum et al. 1998, tropical aggregate), then converted biomass to carbon using a conversion factor of 0.5. Therefore, 50 m^3/ha of extracted timber translates into 14 t C/ha. Assuming that 25% of this carbon ends up in long-lived (>5 yrs) wood products (i.e., the value calculated in Table 3 above for Indonesia), the emission factor estimated for forest conversion after taking into account carbon storage in wood products would be reduced only by 3 t C ha^{-1}, or 11 t CO_2 ha^{-1}, or approximately 1-2%.

This result of 11 t CO_2/ha stored in wood products from Indonesian harvests longer than five years is an overestimate. The calculation assumes that the carbon that ends up in these wood products is stored forever. After taking into account the inherited emissions that emanate from the oxidation (i.e., burning and decay) of wood products that were produced from harvests during previous years (retirement rate, see Table 3), the Indonesia value of carbon stored in wood products decreases even further to 2 t C/ha, or 7 t CO_2e/ha.

Finally, Winjum et al. (1998) states that for the oxidation fractions of 0.04, 0.08 and 0.10 (representing rates for woodbase panels, other industrial roundwood and paper/paperboard), the time period of oxidation would extend back 25, 12 and 10 yr from the base year, respectively, for tropical regions. Therefore, much of the timber harvested today and stored as wood products will be completely oxidized 25 years from now. Considering EPA is estimating 30-year emission factors, carbon storage in wood products is likely insignificant, even for temperate and boreal regions where oxidation rates are slower. The analysis outlined above is also representative of productive forestlands only, and it is unlikely that every hectare of forest that is cleared for another land use is stocked for timber production.

As discussed in preamble Section V, modeling the fate of international harvested wood products is an area for future work and consideration of more data. For example, Pingoud et al. (2001)[596] and Micales and Skog (1997)[597] estimate longer average lifetimes for wood products than the assumptions used in our analysis. However, based on our research discussed above, we believe it is very likely that carbon sequestration from harvested wood products is captured in our estimated uncertainty ranges.

2.4.4.2.6.6 Evaluation of International Foregone Forest Sequestration

Forest sequestration rates were estimated in the proposed rule analysis using IPCC Tier 1 default values for native forests. These values are listed by ecological zone, so final rates in the initial analysis were calculated by weighting the ecological zone-based sequestration rates by the proportion of forest area in each ecological zone within a country or administrative unit (for key countries). The expert peer reviewers pointed out a number of recent papers that summarize long-term monitoring plots in old growth tropical forests across the tropics and suggested the use of these more recent datasets for estimating annual rates of carbon sequestration in tropical forests.

Lewis et al. (2009) published long-term aboveground carbon sequestration rates of 0.63 t C/ha/yr for African “closed canopy mature forests” (assumed moist or rain forest) based on long-term monitoring plots.[598] This is similar to the IPCC default rate for >20 yr old African tropical moist deciduous forests (0.65 t C/ha/yr) but lower than for >20 yr old African tropical rain forests (1.55 t C/ha/yr). Baker et al. (2004) also report an annual Amazonian C sequestration rate of 0.61 t C ha^{-1} yr^{-1}, which is lower than the IPCC default of 1.0 t C ha/yr for >20 yr old tropical moist deciduous forests and 1.55 t C/ha/yr for >20 yr old tropical rain forests of South America. After combining all standardized inventory data from Africa, tropical America and Asia together, Lewis et al. (2009) estimate carbon sequestration across all tropical intact old growth forests as 0.49 t C/ha/yr. We have used this estimate for foregone sequestration across the tropics in our updated analysis.

Myneni et al. (2001) and Nabuurs et al. also estimated the carbon sink of temperate and boreal forests in various countries, and these values were generally higher than sequestration in tropical forests, with rates of approximately 3-4 t CO_2e/ha/yr on average but extending up to 7-8 t CO_2e/ha/yr in Norway and Switzerland. These data reflect the long-term carbon sink capacity of forests, which have long been understood to be the case in temperate forests and have more recently been illustrated for old-growth tropical forests as well.

2.4.4.2.6.7 Evaluation of International Land Reversion Carbon Uptake Factors

In addition to estimating emission factors, reversion factors were developed to estimate the carbon accumulation in biomass and soils that occurs when managed cropland and pasture land is abandoned. All reversion factors (except reversion to forest) were estimated as the reverse of emission factors, whereby all increases in biomass carbon stocks occur in Year 1 (analogous to the stock change approach used to estimate emission factors) while changes in soil carbon stocks on abandoned cropland recovers to pre-land use change levels in 20 years (analogous to the soil emission factors, which were assumed to emit over 20 years). The only reversion factor to include soil carbon accumulation was reversion from abandoned cropland.

While most reversion factors assumed that all biomass carbon stock changes occurred in Year 1 (i.e., IPCC stock change approach), forest reversion factors assumed that biomass accumulates every year over the entire 30-year time period. This was done to reflect forests' slow but continual carbon sink capacity. Despite the fact that young (<20 year old) forests accumulate biomass more quickly than older (>20 year old) forests, the annual rate of carbon accumulation on abandoned croplands that revert back to forests was conservatively assumed to be equal to the foregone forest sequestration rate (estimated for the emission factor analysis). If the forest biomass carbon stock (estimated for the emission factor analysis, see Figure 4 above) was less than 20 times the assumed annual foregone carbon sequestration value, then the annual carbon sequestration rate for reversion factors was assumed to be 1/20th of the initial forest carbon stock. Both of these assumptions provide a very conservative estimation of the carbon accumulation that occurs on abandoned land when it reverts to forest.

2.4.4.2.6.8 International Land Conversion GHG Emissions Factor Results

Our updated analysis includes land use change emissions factors for up to 42 different land conversions in over 750 regions across 160 countries, i.e. over 30,000 land conversion emissions factors. In this section we use the example of the Amazon region in Brazil to illustrate the emissions factors used in our analysis. The sample results shown below cover all of the types of land conversions considered, but they do not cover all of the 750+ regions. For all of the emissions factors used in our analysis, including the data inputs, refer to the results spreadsheets available on the public docket.

The FAPRI-CARD model simulates agricultural production in 6 regions in Brazil, including the Amazon Biome. The Amazon Biome region in FAPRI-CARD includes the following Administrative Units: Acre, Amapa, Amazonas, Para, Rondonia, Roraima, and the northern part of Mato Grosso which is characterized by forest biome land cover.

Figure 2.4-40 illustrates the segment of Mato Grosso included in the Amazon region). The carbon stock data inputs for the Amazon region are shown in **Table 2.4-43**.

Figure 2.4-40. Division of Mato Grosso into North and South regions

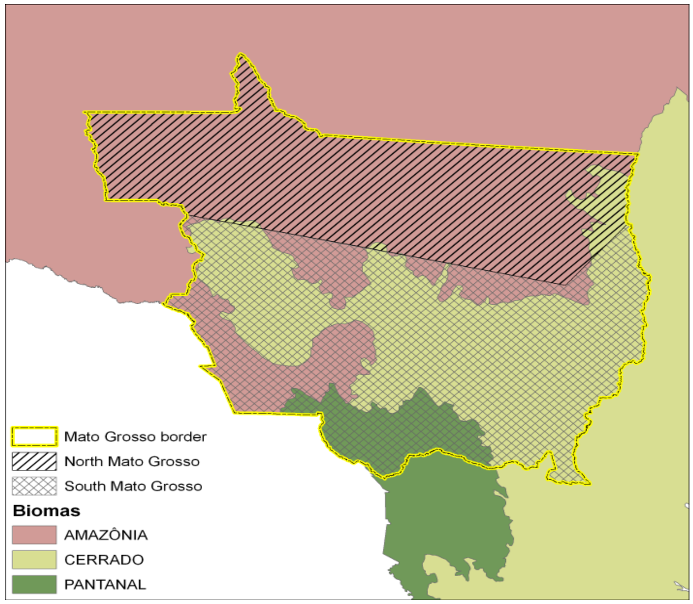


Table 2.4-43. Carbon stocks by land type and Administrative Unit in the Amazon Region ($t\ CO_2e/ha$)

	Administrative Units						
	Acre	Amapa	Amazonas	North Mato Grosso	Para	Rondonia	Roraima
Forest, Above Ground	585	425	477	453	457	481	487
Forest, Below Ground	150	112	125	119	120	125	127
Grassland	40	40	40	40	40	40	40
Savanna	72	72	72	72	72	72	72
Shrubland	137	137	137	137	137	137	137
Mixed	232	183	199	192	193	200	202
Wetland	88	88	88	88	88	88	88
Annual	18	18	18	18	18	18	18
Perennial	44	44	44	44	44	44	44
Soil	131	154	231	213	174	115	145
Soil, Annual	63	74	111	102	84	55	70

We assume that land converted to cropland in the Amazon will be cleared with fire. Therefore, to determine non-CO_2 emissions from fire in the Amazon we used the fire combustion data inputs in **Table 2.4-44** where the data inputs are the same for all of the Administrative Units.

Table 2.4-44. Data inputs for non-CO2 emissions in the Amazon by land type

Land Cover	Fire combustion factors (dimensionless)	Fire CH_4 emission factors (g/kg)	Fire N_2O emission factors (g/kg)
Forest	0.46	6.80	0.20
Grass	0.76	2.30	0.21
Shrub	0.72	2.30	0.21
Savanna	0.57	2.30	0.21
Wetland	0.70	2.30	0.21
Mixed	0.64	3.80	0.21

To show emissions estimates for all of the land conversions considered in our analysis, we will focus on the North Mato Grosso, i.e. the portion of Mato Grosso in the Amazon region. **Table 2.4-45.** shows land use change GHG emissions, broken out by emissions category, for crop and pasture expansion in this region. We show emissions for conversion of land cover to annual cropland and perennial cropland. We also show emissions for conversion to pasture, which can be in the form of grassland or savanna. The values are presented as total GHG emissions, or, where specified, as annual emissions (yr-1). Note that negative values signify carbon uptake, whereas positive values denote GHG releases.

We also present the emissions results over time. For accounting purposes, emissions are allocated to either year zero (i.e., the year when land clearing takes place), years 1-19 or to years 20-80. This procedure is not intended to be a precise accounting of the timing of emissions releases, but it is sufficient to determine total emissions over the first 30 years following land conversion. Carbon emissions from the changes in biomass resulting from land conversion (i.e., biomass combustion or decay) are assigned to year zero. Non-CO_2 emissions from fire combustion are also allocated to year zero. Lost forest sequestration continues indefinitely. The change in soil carbon is spread evenly over the first twenty years following conversion, i.e. ending in year 19. Thus, total emissions are presented for year zero, years 1 through 19, and years 20-80. We also present the total emissions over 30 years.

Table 2.4-45. Land use change emissions factors for North Mato Grosso, Brazil (t CO2e/ha)

Start	End	Change in biomass	Lost forest seques. yr-1	Change in soil yr-1	Total fire emis.	Yr 0 emis.	Yrs 1-19 emis. Yr-1	Yrs 20-80 emis. yr-1	30-yr emis.
Forest	Annual	553.78	1.80	5.53	53.31	614.42	7.33	1.80	771.62
Shrub	Annual	118.43	0.00	5.53	11.17	135.13	5.53	0.00	240.22
Savanna	Annual	53.90	0.00	5.53	4.67	64.10	5.53	0.00	169.19
Grass	Annual	21.63	0.00	5.53	3.42	30.59	5.53	0.00	135.68
Wetland	Annual	70.03	0.00	5.53	7.01	82.58	5.53	0.00	187.67
Mixed	Annual	173.46	0.00	5.53	17.88	196.87	5.53	0.00	301.96
Forest	Perennial	528.12	1.80	0.00	0.00	529.91	1.80	1.80	582.02
Shrub	Perennial	92.77	0.00	0.00	0.00	92.77	0.00	0.00	92.77
Savanna	Perennial	28.23	0.00	0.00	0.00	28.23	0.00	0.00	28.23
Grass	Perennial	-4.03	0.00	0.00	0.00	-4.03	0.00	0.00	-4.03
Wetland	Perennial	44.37	0.00	0.00	0.00	44.37	0.00	0.00	44.37
Mixed	Perennial Crop	147.80	0.00	0.00	0.00	147.80	0.00	0.00	147.80
Forest	Grass	532.15	1.80	0.00	0.00	533.95	1.80	1.80	586.05
Shrub	Grass	96.80	0.00	0.00	0.00	96.80	0.00	0.00	96.80
Mixed	Grass	151.83	0.00	0.00	0.00	151.83	0.00	0.00	151.83
Forest	Savanna	499.88	1.80	0.00	0.00	501.68	1.80	1.80	553.78
Shrub	Savanna	64.53	0.00	0.00	0.00	64.53	0.00	0.00	64.53
Mixed	Savanna	119.56	0.00	0.00	0.00	119.56	0.00	0.00	119.56

Note: "Annual" refers to annual crops, and "Perennial" refers to perennial crops, i.e., sugarcane.

Table 2.4-46. is similar to the preceding table, except that emissions factors are shown for crop and pasture abandonment, i.e. land reversion. For land reverting to forest, the change in biomass (i.e. plant growth) is an annual factor that continues for twenty years. After twenty years forests grow at the foregone sequestration rate, which is 1.80 tCO_2e /ha/yr in the Amazon region. For land reverting to any other land type, the change in biomass is a total uptake that is allocated fully to year zero. That is why year zero uptake in **Table 2.4-46.** is larger for reversion to shrubland than to forest, but the total forest uptake over thirty years is larger than reversion to shrubland. These time accounting procedures were designed to provide accurate estimates of emissions over 30 years. Soil carbon uptake is an annual factor that is constant for the first twenty years following conversion.

Table 2.4-46.
Land reversion factors for North Mato Grosso, Brazil (t CO2e/ha)

Start	End	Change in biomass	Soil seques. yr-1	Yr 0 uptake	Yr 1-19 uptake yr-1	Yr 20-80 uptake yr-1	30-yr uptake
Annual	Forest	-25.93	-5.53	-31.46	-31.46	-1.80	-647.18
Annual	Shrub	-118.43	-5.53	-123.96	-5.53	0.00	-229.05
Annual	Savanna	-53.90	-5.53	-59.43	-5.53	0.00	-164.52
Annual	Grass	-21.63	-5.53	-27.16	-5.53	0.00	-132.25
Annual	Mixed	-173.46	-5.53	-178.99	-5.53	0.00	-284.08
Perennial	Forest	-25.93	0.00	-25.93	-25.93	-1.80	-536.56
Perennial	Shrub	-92.77	0.00	-92.77	0.00	0.00	-92.77
Perennial	Savanna	-28.23	0.00	-28.23	0.00	0.00	-28.23
Perennial	Grass	4.03	0.00	4.03	0.00	0.00	4.03
Perennial	Mixed	-147.80	0.00	-147.80	0.00	0.00	-147.80
Grass	Forest	-25.93	0.00	-25.93	-25.93	-1.80	-536.56
Grass	Shrub	-96.80	0.00	-96.80	0.00	0.00	-96.80
Grass	Mixed	-151.83	0.00	-151.83	0.00	0.00	-151.83
Savanna	Forest	-25.93	0.00	-25.93	-25.93	-1.80	-536.56
Savanna	Shrub	-64.53	0.00	-64.53	0.00	0.00	-64.53
Savanna	Mixed	-119.56	0.00	-119.56	0.00	0.00	-119.56

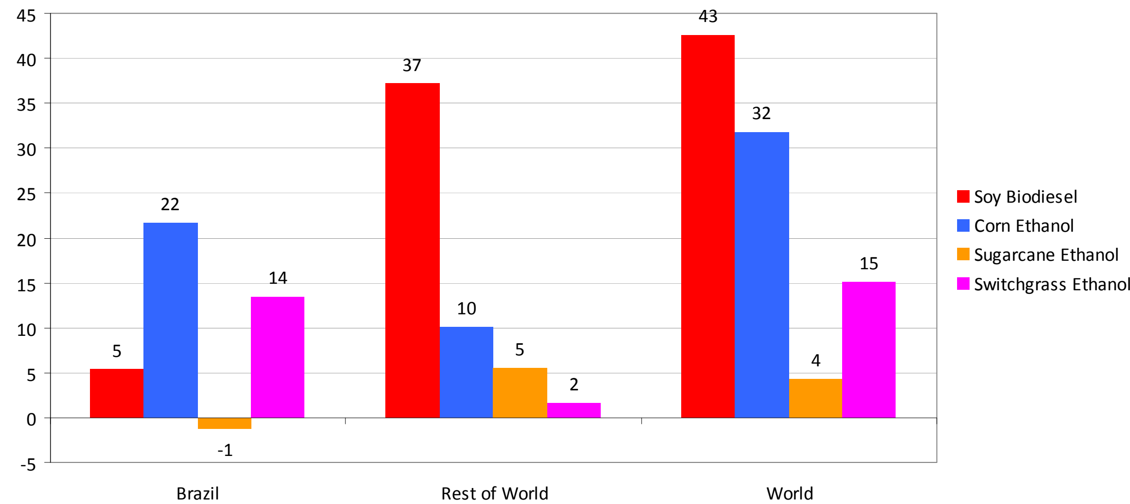
Note: "Annual" refers to annual crops, and "Perennial" refers to perennial crops, i.e., sugarcane.

All of the data and calculations for the results presented above for the Amazon region, and for all of the 750+ regions analyzed, are available in supporting material on the public docket for this rulemaking.

2.4.4.2.7 Aggregate International Land Conversion GHG Emissions Impact Results

Figure 2.4-41 presents the 2022 international land use change GHG emissions by renewable fuel, with land use change emissions normalized by the increment of additional biofuel produced in each scenario and annualized over 30 years. The figure shows that, based on our modeling, soy-based biodiesel causes the largest release of international land use change GHG emissions. The majority of international land use change emissions originate in Brazil in the corn ethanol and switchgrass ethanol scenarios. This is largely a consequence of projected pasture expansion in Brazil, and especially in the Amazon region where land clearing causes substantial GHG emissions. Of the renewable fuels analyzed, our modeling found that sugarcane ethanol causes the least amount of land use change emissions. This was due largely to our projection that sugarcane crops would expand onto grasslands in South and Southeast Brazil, which results in a net sequestration because sugarcane sequesters more biomass carbon than the grasslands it would replace.

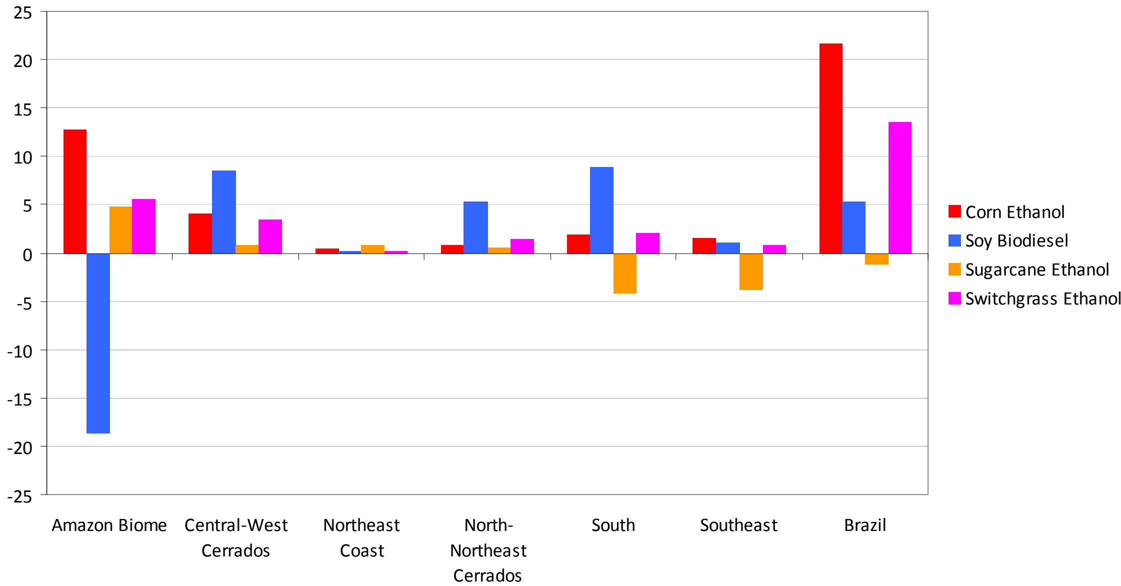
Figure 2.4-41. International land use change GHG emissions by renewable fuel, 2022 (kgCO2e/mmBTU)



Brazil is a very prominent region in our projections of where biofuel-induced land use changes would occur.

Figure 2.4-42 Figure 2.4-42 shows the land use change emissions across the 6 regions of Brazil included in the FAPRI-CARD model. All of the renewable fuels analyzed, except for soy-based biodiesel, cause land use change emissions in the Amazon region. In the soy biodiesel scenario we project net sequestration in the Amazon as a result of reduced pasture area in that region. As discussed above, sugarcane ethanol results in net sequestrations in South and Southeast Brazil.

Figure 2.4-42. Brazil land use change GHG emissions by renewable fuel, 2022 (kgCO2e/mmBTU)



Finally, for reference, Table 2.4-47 presents same results broken out by all 54 international regions in the FAPRI-CARD model.

Table 2.4-47.
International land use change GHG emissions by renewable fuel and by region, 2022 (kgCO2e/mmBTU)

FAPRI-CARD Region	Corn Ethanol	Soy Biodiesel	Sugarcane Ethanol	Switchgrass Ethanol
Algeria	0.02	0.02	0.01	0.01
Argentina	-0.31	0.11	-0.52	0.15

FAPRI-CARD Region	Corn Ethanol	Soy Biodiesel	Sugarcane Ethanol	Switchgrass Ethanol
Australia	0.52	0.00	0.00	0.18
Bangladesh	-0.43	-0.56	-0.12	0.10
Brazil: Amazon Biome	12.83	-18.63	4.79	5.57
Brazil: Central-West Cerrados	4.09	8.52	0.76	3.47
Brazil: Northeast Coast	0.41	0.14	0.77	0.14
Brazil: North-Northeast Cerrados	0.86	5.33	0.52	1.47
Brazil: South	1.93	8.95	-4.20	2.08
Brazil: Southeast	1.56	1.00	-3.81	0.80
Canada	-0.04	0.73	-0.11	0.08
China	0.56	4.54	-0.03	0.46
New Zealand	0.05	0.60	0.01	0.03
Colombia	0.25	1.98	0.25	0.15
Cuba	0.05	0.10	0.14	0.01
Egypt	-0.01	0.00	0.00	0.00
EU	0.47	1.68	0.30	0.29
Guatemala	0.22	0.17	0.11	0.06
India	0.84	2.30	0.47	-2.14
Indonesia	3.34	4.07	1.13	-0.13
Iran	0.09	0.22	0.05	0.06
Iraq	0.01	0.04	0.01	0.01
Ivory Coast	0.07	0.33	0.09	0.13
Japan	1.22	0.07	0.02	-0.74
Malaysia	-0.11	2.98	0.03	0.04
Mexico	1.01	2.25	0.11	0.06
Morocco	0.04	0.05	0.02	0.03
Myanmar (Burma)	-0.06	0.14	0.01	-0.01
Nigeria	0.76	0.58	0.19	0.32
Africa, Other	1.13	3.87	0.43	0.61
Asia, Other	0.12	0.34	0.00	-0.09
CIS, Other	-1.50	-0.70	-0.13	-0.05
Eastern Europe, Other	0.02	0.14	0.02	0.03
Latin America, Other	0.49	2.27	0.26	0.21
Middle East, Other	0.00	0.05	0.01	0.02
Pakistan	-0.07	0.39	0.06	0.14
Paraguay	0.03	-0.52	0.17	0.26
Peru	-0.56	1.88	0.08	0.09
Philippines	1.25	1.26	0.51	0.34
Rest of World	1.04	2.73	0.32	0.29
Russia	0.01	0.31	0.09	0.12
South Africa	0.04	0.58	0.05	0.05
South Korea	0.00	0.02	0.00	0.01
Taiwan	0.00	0.04	0.00	0.00
Thailand	0.22	0.40	0.15	0.16
Tunisia	0.02	0.05	0.01	0.02
Turkey	-0.10	0.11	0.03	0.02
Ukraine	-0.13	0.18	0.01	0.02
Uruguay	-0.03	0.37	0.03	0.05
United States*			1.05	
Uzbekistan	-0.47	-0.29	-0.06	-0.05
Venezuela	-0.21	1.14	0.05	0.02
Vietnam	0.23	0.15	0.11	0.07
Western Africa	0.03	0.09	0.04	0.08
TOTAL	**31.79**	**42.54**	**4.30**	**15.07**

Note: land use change emissions in the United States were calculated by the FASOM model (see discussion above about domestic land use change), except for in the sugarcane ethanol scenario.

2.4.4.2.8 Uncertainty Assessment for International Land Conversion GHG Emissions Impacts

For the proposed RFS rule, EPA estimated uncertainty around its lifecycle GHG emission estimates by sensitivity analyses by which, for example, the upper bound of the emissions from international land use change was estimated by assuming that all crop expansion came from forest and the lower bound was estimated by assuming that all expansion came from idle grassland (also by assuming that no pasture replacement is necessary). For its updated analysis, we took a more rigorous approach towards estimating uncertainty.

Uncertainty can be expressed as a percentage confidence interval relative to a mean value, with the confidence interval defined as a range that encloses the true value of an unknown parameter with a specified probability. For example, if the area of forest land converted to cropland (mean value) is 100 ha, with a 95% confidence interval ranging from 90 to 110 ha, we can say that the uncertainty around the estimate is ±10%.

The 95% confidence interval, which is the value typically used in the context of estimating GHG emissions and removals under the United Nations Framework Convention on Climate Change (UNFCCC), has a 95 percent probability of enclosing the true but unknown value of a given parameter.

The first step in our uncertainty analysis was to identify the potential sources of uncertainty. We focused on two key sources of uncertainty in international land use change GHG emissions:

(1) Classification errors that arise from interpretation of satellite imagery to derive land cover maps (i.e., the types of land affected by land use change);
(2) Errors in parameters used in emission factor estimates (i.e., the magnitude of GHG emissions per unit of land area converted).

When estimating the total uncertainty in land use change GHG emissions, the two sources of uncertainty listed above need to be considered together, which was done with a Monte Carlo simulation model that combined the total uncertainty in the satellite imagery and the emissions factor estimates. Each step of our uncertainty analysis is explained in this section.

2.4.4.2.8.1 Satellite Data Uncertainty Assessment

As discussed above, MODIS validation data was used to adjust/correct systematic errors in the MODIS land cover classifications from 2001 to 2007. These adjustments were based on the producer's accuracies for each land cover class derived from the aggregated confusion matrix (see **Table 2.4-37** above). To estimate the uncertainty in this procedure, we calculated the producer's accuracy standard errors for each land category based on the number of training sites that were used to validate the satellite classifications. For example, based on the number of training sites that validated forest land, we calculated a standard error of +/- 1.2% around the 92.6% producer's accuracy for forest. The most accurate approach to estimate the standard errors from the aggregated confusion matrix would be to reassign the detailed site and pixel data and then recalculate the standard error following Stehman (1997).[599] However, detailed data about the training site clusters were not available, so a simplification of this procedure was used where we assumed that the number of pixels per site (or cluster) was constant for each producer land use, essentially representing the random variable for the producer's accuracy estimate as a binomial distribution:[168]

- We assumed that the number of pixels per site for the reported land use is constant.
- The number of reported sites in each land category was then estimated by using the producer's accuracy estimate, sometimes referred to as the producer's estimate, and the producer's standard error using the following equation derived from the equation for the standard deviation for a binomial distribution:
    - $N = e * (1-e)/(s+a)^2$
    - where,
        - N is the number of sites
        - e is the producer's estimate
        - s is the producer's standard error reported as a percentage of the number of sites
        - a is an adjustment factor (-0.0007397) used to account for round off and so the total number of sites estimated approximates the total number of sites report by the input source[169]
    - This equation is derived by assuming that the assignment of sites to land categories is a binomial process (either assigned to the actual land category or not) which has a standard deviation of $(s+a)*N = (N *e*(1-e))^{0.5}$
- The number of sites for the 17 land categories were then aggregated to the 10 EPA land uses
- The standard error as a percentage of the total number of reported sites for the 10 EPA land uses was then calculated using the equations = (N*e*(1-e))^0.5/N

The producer's accuracy and standard errors were reduced significantly by aggregating the MODIS data from 17 land cover categories to 10 categories. As an example, the standard error for forest estimated with 17 land categories land was high because there were less training sites for each type of forest, and the producer estimate for each forest type was low because different types of forest were confused with each other. **Table 2.4-48**

Table 2.4-48 compares the producer's accuracy and standard errors for the 17 IGBP land categories to the producer's accuracies and standard errors for EPA's aggregated land cover classes.

[168] Our simplified procedures very closely reproduced the producer accuracy standard errors reported in Friedl et al. (2010).

[169] This equation is derived from the equation from the standard deviation for a binomial distribution.

Table 2.4-48. Producer accuracies and standard errors for MODIS Collection 5 classes and EPA classes based on cross-validation

IGBP Land Cover Class	Producer's accuracy (%)		EPA Land Cover Class	Producer's accuracy (%)	
	PA	Std. err.		PA	Std. err.
Evergreen Needleleaf	89.8	2.3	Forest	92.6	1.2
Evergreen Broadleaf	92.6	2.4			
Deciduous Needleleaf	67.3	10.9			
Deciduous Broadleaf	68.9	6.2			
Mixed Forest	76.2	5.7			
Closed Shrubland	63.4	5.9	Shrubland	69.5	4.0
Open Shrubland	48.3	6.2			
Woody Savanna	45.2	4.1	Savanna	60.9	3.1
Savanna	22.6	4.4			
Grasslands	73.6	4.1	Grasslands	73.7	4.0
Permanent Wetlands	70.6	4.2	Wetlands	70.6	4.1
			Annual Crops	83.2	2.7
Cropland	83.3	2.0	Perennial Crops	83.2	8.6
Cropland/Nat Veg Mosaic	60.5	5.7	Mixed	60.4	5.6
Barren/Sparse	95.8	1.4	Barren	95.8	1.3
Snow and Ice	75.6	10.9	Excluded	90.5	2.7
Water	96.6	1.9			

The MODIS data was adjusted/corrected based on the producer accuracies reported above, i.e., with the producer standard errors set to zero. To assess the uncertainty in our correction process, and thus the MODIS data, we simulated the uncertainty in the producer's accuracy by generating 10 pseudo random values each for 2001 and for 2007 (RV_{py}), for each of the land uses. The pseudo random values are distributed normally with a mean of zero and a standard deviation equal to the calculated producer standard error. The stochastic model uses these to adjust the reported land use in the confusion matrix and create an adjusted confusion matrix, BCM, with coefficients BCM_{cyup} as follows:

- $BCM_{cypp} = ACM_{cpp} * (1+RV_{py})$
- Scale the remaining coefficients in the column so that the total of the column does not change
  - $BCM_{cyup} = ACM_{cup} * \beta$
  - Where $\beta = (1\text{-}BCM_{cypp})/(1\text{-}ACM_{cpp})$ when $ACM_{cpp} < 1$ and 0 otherwise
- For every iteration, we repeated the steps listed above in Section 2.4.4.2.5.2 to calculate the land conversion shares in each region.

We repeated this stochastic procedure 300 times to generate the 95% confidence intervals for the share of land conversion types in each of the 54 FAPRI-CARD regions.

Table 2.4-49

30-Year Emissions Factor Satellite Data Uncertainty for Select Land Conversions (+/- 95% confidence intervals as percent of mean)

FAPRI-CARD Region	Natural to Annual	Annual to Natural	Natural to Pasture	Pasture to Natural
Algeria	12%	1%	16%	7%
Argentina	1%	1%	5%	4%
Australia	3%	1%	6%	3%
Bangladesh	2%	1%	9%	5%
Brazil: Amazon Biome	6%	1%	8%	1%
Brazil: Central-West Cerrados	2%	1%	5%	3%
Brazil: Northeast Coast	1%	1%	4%	5%
Brazil: North-Northeast Cerrados	2%	1%	5%	4%
Brazil: South	1%	1%	6%	3%
Brazil: Southeast	1%	1%	5%	3%
Canada	5%	1%	11%	2%
China	2%	1%	5%	3%
New Zealand	3%	1%	5%	1%
Colombia	7%	1%	17%	1%
Cuba	3%	1%	8%	2%
Egypt	25%	6%	19%	14%
EU	4%	1%	11%	2%
Guatemala	3%	1%	6%	2%
India	2%	2%	4%	4%
Indonesia	2%	1%	4%	2%
Iran	3%	1%	5%	2%
Iraq	2%	3%	3%	4%
Ivory Coast	3%	1%	5%	2%
Japan	10%	1%	29%	1%
Malaysia	2%	2%	3%	2%
Mexico	1%	1%	4%	2%
Morocco	3%	1%	8%	4%
Myanmar	3%	1%	6%	2%
Nigeria	2%	1%	5%	3%
Other Africa	2%	2%	7%	4%
Other Asia	3%	1%	6%	2%
Other CIS	6%	1%	10%	2%
Other Eastern Europe	3%	1%	9%	2%
Other Latin America	5%	1%	11%	2%
Other Middle East	12%	3%	13%	5%
Pakistan	3%	1%	5%	3%
Paraguay	2%	1%	6%	2%
Peru	9%	1%	13%	1%
Philippines	2%	1%	4%	2%
Rest of World	5%	3%	8%	4%
Russia	3%	1%	9%	2%
South Africa	2%	1%	6%	3%
South Korea	2%	1%	7%	2%
Taiwan	3%	1%	6%	2%
Thailand	2%	1%	4%	2%
Tunisia	3%	1%	8%	4%
Turkey	5%	1%	15%	4%
Ukraine	10%	2%	31%	4%
Uruguay	0%	1%	5%	6%
US	4%	1%	7%	2%
Uzbekistan	11%	2%	15%	4%
Venezuela	5%	1%	15%	2%
Vietnam	2%	1%	3%	2%
Western Africa	1%	1%	5%	5%

Table 2.4-49 reports relatively modest levels of uncertainty from the MODIS data. There are several potential explanations for this. First, by correcting for systematic errors in the MODIS data, based on NASA's extensive validation efforts, the uncertainty in the satellite data set is reduced substantially. Second, the aggregated land classes in our analysis reduced the uncertainty compared to the 17 MODIS land cover classes. Third, the greatest uncertainty in the satellite data is between land cover classes that sequester similar amounts of carbon (i.e., savanna, shrubland and mixed land). Finally, we assume that recent land use change patterns accurately predict future patterns, and our uncertainty assessment does not quantify the potential uncertainty from this assumption.

The overall uncertainty in our land use change GHG emissions estimates also includes the uncertainty in the emissions factors per unit area of land use change. Before the final uncertainty estimates are presented, our evaluation of emissions factor uncertainty is discussed in the next section.

2.4.4.2.8.2 International Land Conversions GHG Emissions Factor Uncertainty Assessment

We assessed the uncertainties in our estimates of carbon stocks, and consequently of carbon stock changes (i.e., the emission factors), for every land conversion included in our land use change modelling. The final emissions factors for each land conversion were derived from a combination of several different input parameters, each with its own uncertainty. In this section we describe the uncertainty estimates for each input parameter and the Monte Carlo analysis used to combine all of the individual input parameter uncertainties. At the end of this section we present the total emissions factor uncertainty, which considers spatial correlation across emissions factor errors. All of the uncertainty estimates, for each data input and region, are available on the public docket.

2.4.4.2.8.2.1 Evaluation of Input Parameter Uncertainty

The foundation of our emissions factor uncertainty analysis was a rigorous assessment, following IPCC guidelines, of the uncertainty in all of the input parameters used to calculate the land use change emissions factors. Winrock generated 95% confidence intervals for every data input based on the quality, quantity, resolution and variability in the underlying data sources. The estimation of uncertainty was difficult for some parameters due to the absence of quantitative error analyses in the source data. Therefore, where no uncertainty information was available for a given parameter, expert judgement was used to identify an uncertainty range, and the upper bound was assumed as the uncertainty value. This produced final emission factor uncertainty values that are likely overestimated and thus conservative.

2.4.4.2.8.2.1.1 Evaluation of Forest Carbon Stocks Input Parameter Uncertainty

Forest carbon stocks for countries in Latin America and Africa were estimated using the new pantropical carbon stock map of Saatchi et al. (in prep.). However, an accuracy assessment for this new map was not completed in time for our updated analysis. Therefore, although we used the new map to derive mean values, uncertainty around these mean values was estimated to be 19% using accuracy information reported for a prior forest biomass product for Latin America derived using a similar methodological approach (Saatchi et al. 2007). This represents a very conservative estimate (i.e., a high estimate) of uncertainty in our analysis because the Saatchi et al. estimates are very robust at the multi-state/regional scale. Because we used the same pantropical carbon stock map to derive estimates for Latin America and Africa, 19% uncertainty is also a conservative estimate for Africa.

Forest biomass carbon stocks for countries in South Asia were estimated using a map developed by Brown et al. (2001), but no formal accuracy assessment was performed as part of their analysis. Therefore, we consulted Table 4.7 in the IPCC 2006 Guidelines for AFOLU to see what the reported uncertainty was around Tier 1 aboveground biomass estimates. Biomass ranges are reported by continent and ecological zone, with extremely wide ranges in many cases (e.g., mean biomass of subtropical humid forests in Asia is 180 t ha^{-1}, with a range of 10 to 560 t ha^{-1}). Because the Brown et al. (2001) map was derived using some Tier 2 (country-level) information, we assumed the uncertainty of the Brown et al. (2001) product to be lower than uncertainty for Tier 1 IPCC values and therefore assigned Asia biomass carbon stocks an uncertainty value of 50%. This was done to reflect the somewhat better prediction of biomass over IPCC Tier 1 default values.

Some data sources provided accuracy information in the original documentation, and therefore this information was used to assign uncertainty values to the country-level estimates derived for our analysis. Uncertainty was estimated for biomass carbon estimates in Eastern Europe and Canada (33%; Myneni et al. 2001), China (36%, Piao et al. 2005), Russia (40%, Houghton et al. 2007), various EU countries (11%, Nabuurs et al. 2003), and the United States (7-31% depending on state, Blackard et al. 2007). For other EU countries in which biomass carbon stocks were estimated using FAO data, an uncertainty value of 50% was assumed. We assigned an uncertainty value of 80% to the global carbon stock map developed by Reusch and Gibbs (2008), as this was developed primarily from IPCC Tier 1 information. A summary of uncertainty values used for forest biomass carbon stocks is presented in Table 2.4-50.

In cases where data sources reported only aboveground biomass (or aboveground carbon) stocks only, we used regression equation information presented in Cairns et al. (1997) to add in the uncertainty related to estimating belowground biomass. The relationship in Cairns et al. (1997) relates belowground biomass to aboveground biomass, and the equation has an adjusted R^2 value of 0.83. Therefore, we assumed the uncertainty (the percent of variation in belowground biomass not explained by aboveground biomass to be 7%.

Table 2.4-50. Uncertainty values used for forest carbon stock estimates.

Data Source	Uncertainty Value	Justification
Saatchi et al. (2007)	19% (aboveground), 17% (belowground)	Accuracy assessment based on past product (Saatchi et al. 2007)
Brown et al. (2001)	50% (above- and belowground combined)	No formal accuracy assessment given; therefore expert opinion as 50% (some country-level data used therefore better than IPCC Tier 1)
Blackard et al. (2007)	7 – 31% (aboveground), 17% (belowground)	Pixel-level uncertainty values averaged per state
Houghton et al. (2007)	40% (above- and belowground combined)	Reported in original source
Myneni et al. (2001)	27% (aboveground), 33% (belowground)	Reported in original source
Nabuurs et al. (2003)	11% (above- and belowground combined)	Reported in original source
Piao et al. (2005)	36% (above- and belowground combined)	Reported in original source
Reusch and Gibbs (2008)	80% (above- and belowground combined)	IPCC Tier 1
FAO (2006)	50% (above- and belowground combined)	No formal accuracy assessment given; therefore expert opinion as 50% (some country-level data used therefore better than IPCC Tier 1)

2.4.4.2.8.2.1.2 Evaluation of Cropland, Grassland, Savanna, Shrubland and Wetland Carbon Stocks Input Parameter Uncertainty

Uncertainty around carbon stocks in annual croplands and grasslands was assumed to be 75%, based on default error margins reported in IPCC Table 5.9 and 6.4, respectively. In the absence of any uncertainty information for savanna, shrubland, perennial cropland and wetlands, uncertainty in carbon stock estimates for these other land cover categories was also estimated as 75% in keeping with the default uncertainty values presented in the IPCC Guidelines. The one exception to the 75% uncertainty assumption was Brazil, for which more precise information was available on the carbon stocks along a continuum of grasslands, savanna and shrublands. The uncertainty for these land cover types was estimated as 0.6%, 0.9% and 16%, respectively, derived from the standard errors reported in the original data source (de Castro and Kaufmann 1998). The higher uncertainty in shrubland carbon stocks is likely related to the comparatively large variation in tree cover (and therefore carbon stocks) in shrublands compared to grasslands and savannas. Uncertainty in the mixed land cover category was estimated as the average of the uncertainty in forest, crop, shrub and grass categories in keeping with the IGBP description of this land cover class.

2.4.4.2.8.2.1.3 Evaluation of Soil Carbon Input Parameter Uncertainty

The data source used to estimate initial (i.e., reference) soil carbon stocks was changed from FAO/UNESCO's Soil Map of the World to the newly released World Harmonized Soil Database for the updated analysis. This was done because the spatial resolution of the new data product is much improved compared to the FAO map. However, neither data source reports information on accuracy or uncertainty. In the absence of any reliable information about the uncertainty of the estimates, we assumed an uncertainty value of 90%, which is the default error estimate for Tier 1 default soil organic carbon stocks in all soil-climate types (derived from Table 2.3 of the IPCC 2006 Guidelines).

Carbon stocks after land use conversion to cropland were calculated using IPCC Equation 2.25 as the initial soil carbon stock modified by land use, management, and input factors that relate to how the soil is managed. Default soil factors presented in Table 5.5 of the 2006 IPCC Guidelines were used, assuming conversion to long-term cultivated annual cropland under full tillage and medium inputs. The error margin for the land use factor was estimated using default values presented in Table 5.5 of the 2006 IPCC Guidelines and ranged from 9 to 61% depending on temperature and moisture regime. After carbon stocks after land use conversion were estimated, changes in carbon stocks due to land conversion were calculated as the difference between initial and final carbon stocks divided by an assumed transition period of 20 years during which soil emissions take place.

2.4.4.2.8.2.1.4 Evaluation of Foregone Forest Sequestration Input Parameter Uncertainty

Uncertainty values for foregone forest carbon sequestration were derived from standard errors reported in the original data sources. Uncertainty in carbon sequestration rates ranged from 20% to 50%, with higher uncertainty in tropical regions.

2.4.4.2.8.2.1.5 Evaluation of Clearing with Fire Input Parameter Uncertainty

Fire emissions were calculated in the updated analysis when land is cleared for cropland in a region where fire is assumed to be used as a means of site preparation for the new land use. Fire emissions were calculated following IPCC Guidelines as the product of initial carbon stocks, a combustion factor (define) and a GHG emission factor (define). Combustion factors were estimated per land cover type using information on standard errors reported on combustion factors in de Castro and Kaufmann (1998). Uncertainties in combustion factors ranged from 42% to 69%. IPCC defaults were used to estimate uncertainty in the CH_4 and N_2O emission factors and ranged from 59% to 78% depending on land cover type burned.

2.4.4.2.8.2.2 Monte Carlo Analysis of Combined Emissions Factor Uncertainty

The uncertainties in individual parameters of an emission factor can be combined using either (1) simple error propagation (IPCC Tier 1) or (2) Monte Carlo simulation (IPCC Tier 2). We followed the Tier 2 approach.

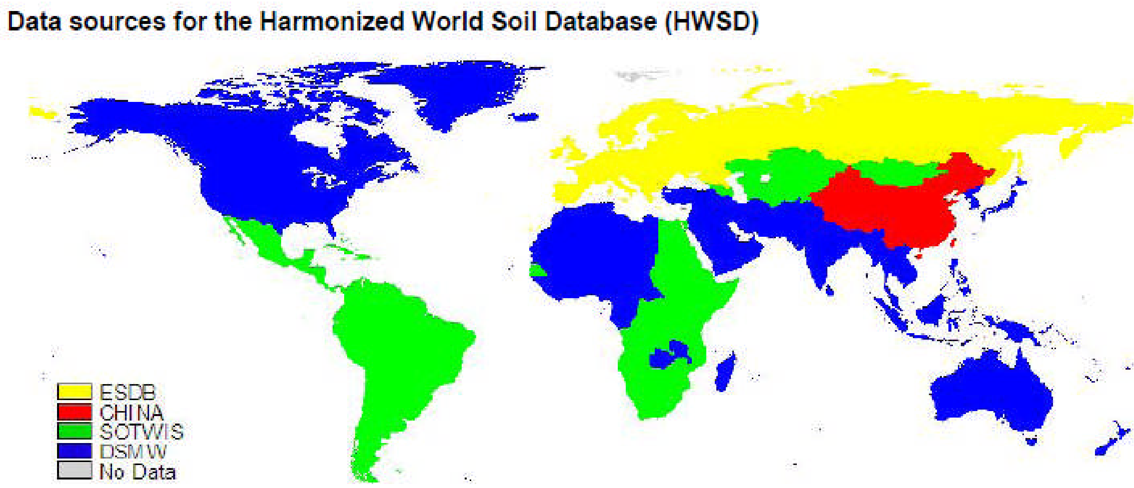
One of the inputs required for the Monte Carlo uncertainty model is an estimate of the degree of correlation among different variables – both the correlation of one variable across space as well as the correlation of one variable to any others used in the analysis. This is in contrast to the IPCC error propagation approach, which assumes no correlation. The assumed correlations among different data inputs used to calculate uncertainty in emission factors using the Monte Carlo approach are summarized below.

Forest carbon stocks were derived from various sources, and therefore estimates for certain countries are correlated, i.e. errors in estimates that came from the same data source are assumed to be correlated. The correlation groups for forest carbon stocks are shown in

Figure 2.4-34. Figure 2.4-34 above. All countries use the same equation that relates belowground biomass to aboveground biomass (Mokany et al. 2006), therefore we assumed that belowground biomass is perfectly correlated to aboveground biomass.

Although the World Harmonized Soil Database was used to estimate soil carbon stocks in the updated analysis, the dataset was developed by compiling different data sources together, and therefore soil carbon stocks are not correlated across all regions. The regional distribution of data sources is shown in **Figure 2.4-43** below.

Figure 2.4-43. Correlation groups for soil carbon stocks



Note: Different colors represent different correlation groups.

Grassland carbon stocks were estimated using IPCC default carbon stock values and weighting the carbon stock based on the proportion of each country falling within each ecological zone. Correlation groups for these land cover categories were determined by assuming that countries with the same dominant ecological zone were correlated (i.e., all use the same carbon stock value). In addition, carbon stocks of grassland, shrubland and savanna were all assumed to be correlated to each other because we used a simple proportional approach to estimate the carbon stocks of savanna and shrubland (based on the grassland value).

All annual croplands have an assumed carbon stock of 5 t C ha^{-1} and therefore all regions are correlated for this input parameter. Perennial croplands in Indonesia and Malaysia are assumed to be oil palm, and are therefore these regions are correlated, while perennial croplands in the rest of the world are assumed to be in a different correlation group than Indonesia and Malaysia (and have carbon stocks equivalent to that of sugarcane).

Correlation groups for lost forest sequestration are delineated by data sources, described above, such that lost forest sequestration across the tropics is correlated.

To estimate the uncertainty in each land conversion emissions factor, a Monte Carlo analysis was completed using the uncertainty estimates and correlation groups specified for each data input. For the Monte Carlo analysis we treated the data inputs as variables and assumed that each variable's uncertainty distribution is normal with a standard deviation equal to the uncertainty value times the mean divided by 100, converting the uncertainty range to a fraction then dividing by 2.[170]

To calculate emission factors, Monte Carlo model first generates pseudo random values for the variables above using the mean, calculated standard deviations, and pseudo random values for a Normal (0,1) distribution. Note that the resulting values after applying the mean and standard deviations are all constrained to be greater than 0.

The Monte Carlo model then used these pseudo random variables to calculate intermediate emissions variables for each country and administrative unit in each Monte Carlo iteration. 15,000 iterations were generated to calculate the mean and 95% confidence intervals for the land use change emissions factors. The uncertainty ranges from the emissions factor estimates, excluding the uncertainty from the MODIS data, are presented below for select land conversions and for all of the FAPRI-CARD regions.

Table 2.4-51 shows the contribution of uncertainty in our emissions factor estimates to total uncertainty by land conversion category and region. The uncertainty from emissions factors is generally larger than the uncertainty from our satellite data analysis (see Table 2.4-49 for uncertainty from the satellite data). The uncertainty ranges, as a percent of the mean, are very large in certain regions, such as Egypt, where the mean emissions factor estimates are very small.

[170] The uncertainty range is defined as the absolute value of the 97.5th percentile of the distribution minus the 2.5th percentile of the distribution, divided by the mean value of the distribution which is 2 standard deviations divided by the mean for a random variable with a normal distribution.

Table 2.4-51.
Contribution of Emissions Factor Estimates to Uncertainty in the 30-yr Weighted Land Conversion Emissions Factors
(+/- 95% confidence intervals as percent of mean)

FAPRI-CARD Region	Natural to Annual	Annual to Natural	Natural to Pasture	Pasture to Natural
Algeria	142%	143%	69%	69%
Argentina	74%	80%	18%	27%
Australia	59%	57%	43%	35%
Bangladesh	65%	64%	39%	49%
Brazil: Amazon Biome	23%	37%	19%	41%
Brazil: Central-West Cerrados	45%	41%	28%	34%
Brazil: Northeast Coast	48%	50%	28%	22%
Brazil: North-Northeast Cerrados	39%	38%	25%	22%
Brazil: South	56%	52%	33%	22%
Brazil: Southeast	47%	40%	38%	24%
Canada	58%	52%	32%	47%
China	57%	43%	33%	29%
New Zealand	60%	54%	75%	52%
Colombia	55%	54%	20%	43%
Cuba	53%	43%	34%	36%
Egypt	595%	401%	42%	50%
EU	56%	61%	38%	48%
Guatemala	53%	47%	24%	36%
India	57%	63%	38%	39%
Indonesia	42%	46%	47%	49%
Iran	81%	76%	70%	67%
Iraq	57%	57%	74%	72%
Ivory Coast	42%	53%	16%	49%
Japan	54%	34%	43%	32%
Malaysia	42%	44%	47%	50%
Mexico	61%	56%	29%	38%
Morocco	95%	92%	71%	74%
Myanmar	54%	47%	54%	50%
Nigeria	63%	68%	16%	37%
Other Africa	52%	57%	19%	40%
Other Asia	53%	48%	45%	38%
Other CIS	53%	49%	56%	55%
Other Eastern Europe	62%	48%	34%	39%
Other Latin America	47%	40%	21%	35%
Other Middle East	88%	87%	61%	63%
Pakistan	81%	90%	76%	70%
Paraguay	52%	50%	15%	28%
Peru	34%	45%	15%	43%
Philippines	54%	47%	53%	51%
Rest of World	37%	37%	34%	32%
Russia	60%	56%	40%	39%
South Africa	46%	43%	32%	39%
South Korea	56%	36%	23%	24%
Taiwan	59%	65%	73%	77%
Thailand	49%	48%	38%	37%
Tunisia	119%	116%	58%	66%
Turkey	72%	73%	51%	57%
Ukraine	62%	48%	51%	52%
Uruguay	83%	86%	47%	47%
US	45%	43%	28%	41%
Uzbekistan	50%	58%	59%	69%
Venezuela	57%	47%	34%	48%
Vietnam	44%	43%	42%	41%
Western Africa	62%	64%	7%	23%

2.4.4.2.8.3 Evaluation of Total Uncertainty in International Land Conversion GHG Emissions Impacts

Total uncertainty in land use change GHG emissions was estimated for every renewable fuel scenario by combining the satellite data and emissions factor uncertainty estimates. The Monte Carlo model generated 15,000 iterations by generating 300 cases where it varied the pseudo-random values for historic land used changes and, for each of these 300 cases, generated 50 iterations where it varied the pseudo-random values for the variables used to calculate the emissions factors.

Within each of the 300 land use cases, the model first took the reported land use change from MODIS and remapped it to the simulated land use change using the MODIS version 5 confusion matrix and the uncertainties derived from the confusion matrix. This provided land use in 2007 and land use change from 2001 to 2007 for up to 10x10=100 combinations of land use in 2001 and land use in 2007.

Next, the Monte Carlo model calculates emission factors for each of the 50 iterations within the land use case for each of the 42 land use change possibilities (e.g., forest to cropland) for each country and administrative unit. The model calculated annual land use change emissions for up to 80 years, and also 30-year aggregated emissions factors. The model then used the land use change to calculate weighted average emission factors for each of the 54 FAPRI-CARD regions and each of the 12 land conversion options (e.g., annual crops to natural eco-systems). Finally, the model reports mean emissions as well as 95% confidence ranges. It also produces the mean and uncertainty ranges for each of the FAPRI-CARD scenario results, i.e., for each renewable fuel type.

Figure 2.4-44 Figure 2.4-44 provides a graphical illustration of the total uncertainty ranges for international land use change emissions. Error bars are only presented for the global estimates because Brazil and Rest of World are aggregate regions and the uncertainty ranges are not the sum of the sub-regions. The error bars in the figure present the low and high ends of the 95% confidence range for international land use change GHG emissions. **Table 2.4-52** and **Table 2.4-53** include the low and high ends of the 95% confidence range for land conversion GHG emissions for each region and renewable fuel scenario. Taken together, the values in these tables form the 95% confidence intervals for land use change GHG impacts in each region. Note that given the nature of stochastic modeling, the total low and high ends of the range are not the sum of the regions.

Figure 2.4-44. International land use change GHG emissions by renewable fuel with 95% confidence intervals, 2022 (kgCO2e/mmBTU)

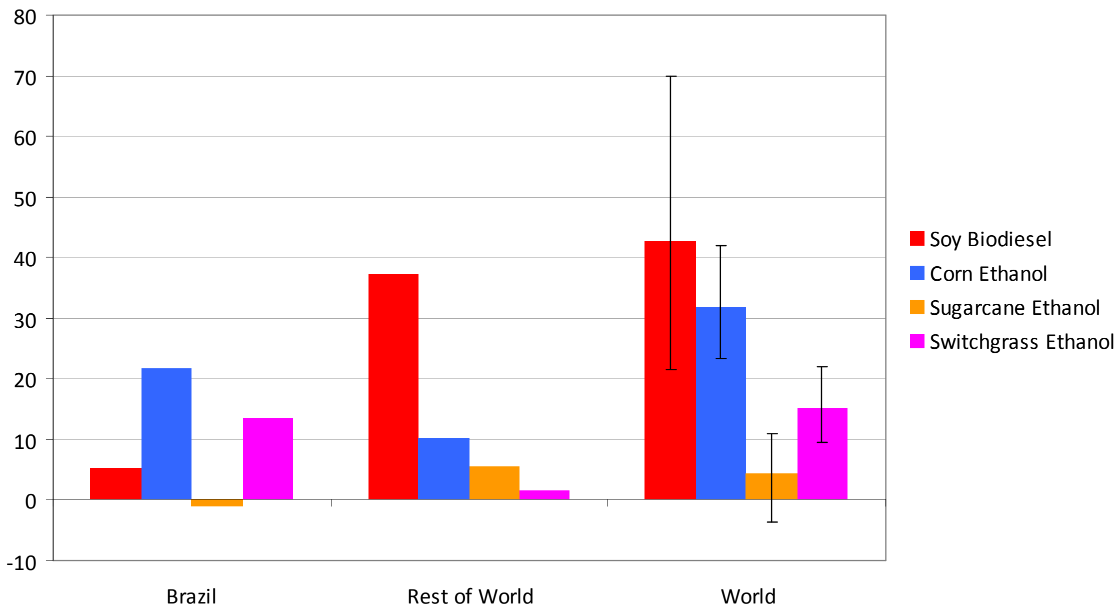


Table 2.4-52. Low end of the 95% confidence range for international land use change GHG emissions by renewable fuel, 2022 (kgCO2e/mmBTU)

FAPRI-CARD Region	Corn Ethanol	Soy Biodiesel	Sugarcane Ethanol	Switchgrass Ethanol
Algeria	0.00	0.00	0.00	0.00
Argentina	-0.46	-0.35	-0.94	0.05
Australia	0.28	-0.13	-0.02	0.10
Bangladesh	-0.72	-0.95	-0.21	0.04
Brazil: Amazon Biome	10.48	-27.56	3.94	4.45
Brazil: Central-West Cerrados	2.67	0.62	0.26	1.76
Brazil: Northeast Coast	0.18	0.07	0.27	0.07
Brazil: North-Northeast Cerrados	0.49	2.19	0.37	0.87
Brazil: South	0.73	3.26	-7.83	0.79
Brazil: Southeast	0.69	-0.02	-9.71	0.41
Canada	-0.11	0.50	-0.16	0.04
China	0.26	3.04	-0.17	0.11
New Zealand	0.01	0.16	0.00	0.01
Colombia	0.01	1.49	0.17	0.09
Cuba	0.02	0.06	0.09	0.00
Egypt	-0.02	-0.01	-0.01	-0.01
EU	0.19	0.99	0.14	0.13
Guatemala	0.11	0.12	0.08	0.03
India	0.42	1.16	0.27	-3.52
Indonesia	1.97	2.42	0.67	-0.19
Iran	0.02	0.10	0.01	0.02
Iraq	0.00	0.02	0.00	0.01
Ivory Coast	0.04	0.22	0.06	0.08
Japan	0.55	0.03	0.01	-1.00
Malaysia	-0.18	1.52	0.02	0.02
Mexico	0.36	1.55	0.01	-0.02
Morocco	0.01	0.01	0.00	0.01
Myanmar (Burma)	-0.09	0.07	0.00	-0.02
Nigeria	0.34	0.34	0.09	0.15
Africa, Other	0.52	3.05	0.24	0.36
Asia, Other	0.06	0.20	0.00	-0.15
CIS, Other	-2.43	-1.26	-0.24	-0.16
Eastern Europe, Other	0.00	0.09	0.01	0.02
Latin America, Other	0.23	1.71	0.18	0.13
Middle East, Other	0.00	0.02	0.00	0.01
Pakistan	-0.15	0.13	0.02	0.04
Paraguay	-0.03	-0.88	0.13	0.20
Peru	-0.84	1.55	0.05	0.05
Philippines	0.62	0.63	0.26	0.17
Rest of World	0.66	1.81	0.21	0.19
Russia	-0.01	0.13	0.04	0.05
South Africa	-0.04	0.39	0.03	0.03
South Korea	0.00	0.01	0.00	0.00
Taiwan	-0.01	0.01	0.00	0.00
Thailand	0.12	0.23	0.09	0.09
Tunisia	0.00	0.02	0.00	0.00
Turkey	-0.18	0.05	0.01	0.01
Ukraine	-0.21	0.04	0.01	0.01
Uruguay	-0.05	0.20	0.01	0.02
United States			0.62	
Uzbekistan	-0.80	-0.51	-0.10	-0.08
Venezuela	-0.38	0.73	0.02	0.01
Vietnam	0.13	0.09	0.07	0.04
Western Africa	0.01	0.04	0.02	0.04
TOTAL	**23.45**	**21.37**	**-3.66**	**9.58**

Note: given the nature of stochastic modeling, the total low and high 95% confidence ranges do not equal the sum of the regions.

Table 2.4-53. High end of the 95% confidence range for international land use change GHG emissions by renewable fuel, 2022 (kgCO2e/mmBTU)

FAPRI-CARD Region	Corn Ethanol	Soy Biodiesel	Sugarcane Ethanol	Switchgrass Ethanol
Algeria	0.06	0.05	0.02	0.04
Argentina	-0.18	0.64	-0.17	0.27
Australia	0.77	0.17	0.02	0.28
Bangladesh	-0.18	-0.23	-0.05	0.17
Brazil: Amazon Biome	15.27	-6.87	5.68	6.80
Brazil: Central-West Cerrados	5.82	18.14	1.20	5.54
Brazil: Northeast Coast	0.69	0.23	1.27	0.22
Brazil: North-Northeast Cerrados	1.31	9.18	0.71	2.19
Brazil: South	3.40	15.85	-1.24	3.65
Brazil: Southeast	2.61	2.25	1.20	1.27
Canada	0.02	0.97	-0.06	0.12
China	0.91	6.05	0.14	0.89
New Zealand	0.08	1.05	0.02	0.05
Colombia	0.53	2.46	0.33	0.21
Cuba	0.08	0.13	0.19	0.01
Egypt	0.01	0.01	0.00	0.01
EU	0.78	2.43	0.48	0.47
Guatemala	0.35	0.22	0.14	0.10
India	1.41	3.83	0.72	-1.11
Indonesia	4.81	5.79	1.63	-0.07
Iran	0.17	0.35	0.10	0.11
Iraq	0.01	0.06	0.01	0.02
Ivory Coast	0.10	0.45	0.14	0.19
Japan	1.97	0.12	0.03	-0.48
Malaysia	-0.05	4.49	0.05	0.06
Mexico	1.77	2.96	0.23	0.16
Morocco	0.09	0.10	0.05	0.07
Myanmar (Burma)	-0.04	0.22	0.02	-0.01
Nigeria	1.30	0.89	0.33	0.55
Africa, Other	1.96	4.73	0.67	0.93
Asia, Other	0.21	0.49	0.00	-0.04
CIS, Other	-0.58	-0.15	-0.01	0.06
Eastern Europe, Other	0.05	0.19	0.03	0.04
Latin America, Other	0.81	2.85	0.35	0.29
Middle East, Other	0.00	0.09	0.02	0.04
Pakistan	-0.02	0.71	0.11	0.27
Paraguay	0.08	-0.07	0.21	0.33
Peru	-0.23	2.21	0.12	0.13
Philippines	1.97	1.97	0.79	0.53
Rest of World	1.50	3.68	0.45	0.40
Russia	0.02	0.52	0.15	0.21
South Africa	0.13	0.78	0.07	0.07
South Korea	0.00	0.03	0.00	0.01
Taiwan	0.00	0.07	0.00	0.00
Thailand	0.34	0.59	0.22	0.24
Tunisia	0.06	0.08	0.02	0.04
Turkey	-0.04	0.17	0.06	0.04
Ukraine	-0.06	0.34	0.02	0.02
Uruguay	-0.01	0.58	0.07	0.10
United States		1.03		
Uzbekistan	-0.15	-0.09	-0.02	-0.01
Venezuela	-0.04	1.55	0.07	0.04
Vietnam	0.35	0.22	0.16	0.10
Western Africa	0.05	0.14	0.06	0.14
TOTAL	**41.89**	**69.80**	**10.99**	**21.86**

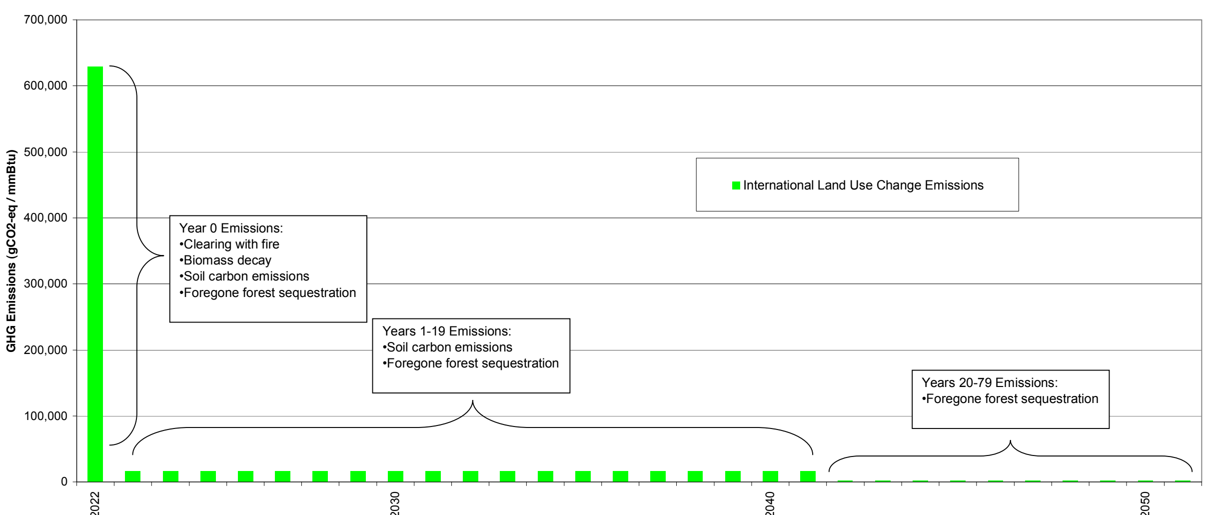
Note: given the nature of stochastic modeling, for the low and high 95% confidence ranges total emissions do not equal the sum of the regions.

2.4.5 Accounting for Lifecycle GHG Emissions Over Time

When comparing the lifecycle GHG emissions associated with biofuels to those associated with gasoline or diesel emissions, it is critical to take into consideration the time profile associated with each fuel's GHG's emissions stream. With gasoline, a majority of the GHG emissions associated with extraction, conversion, and combustion are likely to be released over a short period of time (i.e., annually) as crude oil is converted into gasoline or diesel fuel which quickly pass to market.

In contrast, the GHG emissions from the production of a typical biofuel (e.g., corn-based ethanol) may continue to occur over a long period of time. As with petroleum based fuels, GHG emissions are associated with the conversion and combustion of biofuels in every year they are produced. In addition, GHG emissions could be released through time if new acres are needed to produce corn or other crops for biofuels. The GHG emissions associated with converting land into crop production would accumulate over time with the largest release occurring in the first few years due to clearing with fire or biomass decay. After the land is converted, moderate amounts of soil carbon would continue to be released for approximately 20 years. Furthermore, there would be foregone sequestration associated with the fact that the forest would have continued to sequester carbon had it not been cleared for approximately 80 years (See **Figure 2.4-45.**).

Figure 2.4-45.
Timing of International Land Use Change Emissions in the Corn Ethanol Scenario (gCO2e / mmBTU)



While biomass feedstocks grown each year on new cropland can be converted to biofuels that offer an annual GHG benefit relative to the petroleum product they replace, these benefits may be small compared to the upfront release of GHG emission. Depending on the specific biofuel in question, it can take many years for the benefits of the biofuel to make up for the large initial releases of carbon that result from land conversion (e.g., the payback period).

As required by EISA, our analysis must demonstrate whether biofuels reduce GHG emissions by the required amount relative to the 2005 petroleum baseline. A payback period alone cannot answer that question. Since the payback period is not sufficient for our analysis, we have developed methods for capturing the stream of emissions and benefits over time. For our analytical purposes, it is important for us to determine how the time profiles of emission releases of different fuels compare. It is useful to have a unitary metric that allows for a direct comparison of biofuels compared to gasoline or diesel, which requires an accounting system for GHG emissions over time. When considering the time profile of GHG emissions, the two assumptions that have a significant impact on the determination of whether a biofuel meets the emissions reduction threshold include: 1) the time period considered and 2) the discount rate we apply to future emissions. The proposed rule presented results using a 100-year time horizon and a 2% discount rate, as well as results with a 30-year time horizon and a 0% discount rate.

Based on input from the expert peer review and public comments, EPA has chosen to analyze lifecycle GHG emissions using a 30 year time period, over which emissions are not discounted, i.e., a zero discount rate is applied to future emissions.

The main reasons for why a short time period is appropriate: this time frame is the average life of a typical biofuel production facility; future emissions are less certain and more difficult to value, so the analysis should be confined insofar as possible to the foreseeable future; and a near-term time horizon is consistent with the latest climate science that indicates that relatively deep reductions of heat-trapping gasses are needed to avoid catastrophic changes due to a warming climate.

EPA has decided not to discount (i.e., use a 0% discount rate) GHG emissions due to the many issues associated with applying an economic concept to a physical parameter. First, it is unclear whether EISA intended lifecycle GHG emissions to be converted into a metric whose underpinnings rest on principals of economic valuation. A more literal interpretation of EISA is that EPA should consider only physical GHG emissions. Second, even if the principle of tying GHG emissions to economic valuation approaches were to be accepted, there would still be the problem that there is a lack of consensus in the scientific community about the best way to translate GHG emissions into a proxy for economic damages. Also, there is a lack of consensus as to the appropriate discount rate to apply to GHG lifecycle emissions streams through time. Finally, since EPA has decided to base threshold assessments of lifecycle GHG emissions on a 30 year time frame, the issue of whether to discount GHG emissions is not as significant as if the EPA had chosen the 100 year time frame to assess GHG emissions impacts.

2.4.6 Feedstock Transport

The GHG impacts of transporting biofuel feedstock from the field to the biofuel facility and transporting co-products from the biofuel facility to the point of use were included in this analysis. The GREET default of truck transportation of 50 miles was used to represent corn and soybean transportation from farm to plant. This includes 10 miles from farm to stacks and 40 miles from stacks to plant. Transportation assumptions for DGS transport were 14% shipped by rail 800 miles, 2% shipped by barge 520 miles, and 86% shipped by truck 50 miles. The percent shipped by mode was from data provided by USDA and based on Association of American

Railroads, Army Corps of Engineers, Commodity Freight Statistics, and industry estimates. The distances DGS were shipped were based on GREET defaults for other commodities shipped by those transportation modes. Default GREET assumptions were also used for cellulosic ethanol feedstock transport. Crop residues, switchgrass and forest wastes were all assumed to be shipped by truck from point of production to plant. Crop residue distance shipped was 30 miles, switchgrass distance was 40 miles, and forest waste was 75 miles. The GHG emissions from transport of these feedstocks and co-products are based on GREET default emission factors for each type of vehicle including capacity, fuel economy, and type of fuel used.

GHG emissions from the transport of sugarcane from the field to the ethanol production facility also depend on distance and the type of truck used. The average one-way distance in 2002 was 20 km (12.4 mi)[600]. Over time, transport distance has increased to 23 km for 2005/2006, and is expected to be close to 30 km (18.6 mi) by 2020.[601] In terms of trends for logistics, there has been a replacement of single load trucks by trucks with lower specific fuel consumption and higher load capacities (3 to 4 wagons).

Table 2.4-54. Sugarcane Transportation Inputs

Parameter	**Units**	**GREET Default**	**GREET ISJ (2008)**[602]	**2002**	**2005/ 2006**	**Scenario 2020**
Transportation distance (one-way)	km	19.3	20	20	23	30
Truck diesel use efficiency	ml/(t*km)	27.7	14.8	20.4	19.1	16.1
Diesel consumption	ml/tonne cane	534	296	408	439	483

As we are projecting to a 2022 case, we used the projections available for the 2020 scenario given in **Table 2.4-54**, along with a revised truck payload assumption based on comments we received, to estimate GREET inputs for truck payload (tons), fuel economy of the truck (mpg), and the average one-way distance from field to the mill (miles). Specifically, we assumed a truck payload of 42 tons[603], fuel economy of 3.8 mpg, and an average distance of 19 miles. We incorporated these revised inputs into a recent release of the GREET model to estimate the GHG impacts of sugarcane transport.[604]

2.4.7 Biofuel Processing

GHG emissions from renewable fuel production were calculated by multiplying the BTUs of the different types of energy inputs at biofuel process plants by emissions factors for combustion of those fuel sources. The BTU of energy input was determined based on analysis of the industry and specific work done as part of the NPRM. The emission factors for the different fuel types are from GREET and were based on assumed carbon contents of the different process fuels. The emissions from producing electricity in the U.S. were also taken from GREET and represent average U.S. grid electricity production emissions. The emissions from combustion of biomass fuel source are not assumed to increase net atmospheric CO_2 levels. Therefore, CO_2 emissions from biomass combustion as a process fuel source are not included in the lifecycle GHG inventory of the biofuel production plant. The following sections outline the assumptions used to model biofuel production for different feedstocks and fuel pathways.

2.4.7.1 Corn Ethanol

One of the key sources of information on energy use for corn ethanol production was a study from the University of Illinois at Chicago Energy Resource Center. Between proposal and final rule, the study was updated to reflect more recent data, therefore, we incorporated the results of the updated study in our corn ethanol pathways process energy use for the final rule. We also updated corn ethanol production energy use for different technologies in the final rule based on feedback from industry technology providers as part of the public comment period. The main difference between proposal and final corn ethanol energy use values was a slight increase in energy use for the corn ethanol fractionation process, based on feedback from industry technology providers.

The two basic methods for producing ethanol from corn are dry milling and wet milling. In the dry milling process, the entire corn kernel is ground and fermented to produce ethanol. The remaining components of the corn are then either left wet if used in the near term or dried for longer term use as animal feed (dried distillers grains with solubles, or DGS). In the wet milling process, the corn is soaked to separate the starch, used to make ethanol, from the other components of the corn kernel. Wet milling is more complicated and expensive than dry milling, but it produces more valuable products (ethanol plus corn syrup, corn oil, and corn gluten meal and feeds). The majority of ethanol plants in the United States are dry mill plants, which produce ethanol more simply and efficiently.

For this analysis the amount of corn used for ethanol production as modeled by the FASOM and FAPRI-CARD models was based on yield assumptions built into those two models. Assumptions were ethanol yields of 2.71 gallons per bushel for dry mill plants and 2.5 gallons per bushel for wet mill plants (yields represents pure ethanol).

As mentioned above, in traditional lifecycle analyses, the energy consumed and emissions generated by a renewable fuel plant must be allocated not only to the renewable, but also to each of the by-products. However, for corn ethanol production, this analysis accounts for the DGS and other co-products use directly in the FASOM and FAPRI-CARD agricultural sector modeling described above. DGS are considered a partial replacement for corn and other animal feed and thus reduce the need to make up for the corn production that went into ethanol production. Since FASOM takes the production and use of DGS into account, no further allocation was needed at the ethanol plant and all plant emissions are accounted for here.

In terms of the energy used at renewable fuel facilities, there is a lot of variation between plants based on the process type (e.g., wet vs. dry milling) and the type of fuel used (e.g., coal vs. natural gas). There can also be variation between the same type of plants using the same fuel source based on the age of the plant and types of processes included, etc. For our analysis we considered different pathways for corn ethanol production. Our focus was to differentiate between facilities based on the key differences between plants, namely the type of plant and the type of fuel used. One other key difference we modeled between plants was the treatment of the co-products DGS. One of the main energy drivers of ethanol production is drying of the DGS. Plants that are co-located with feedlots have the ability to provide the co-product without drying. This has a big enough impact on overall results that we defined a specific category for wet vs.

dry co-product. One additional factor that appears to have a significant impact on GHG emissions is corn oil fractionation from DGS. Therefore, this category is also broken out as a separate category in the following section. See RIA Chapter 1.4 for a discussion of corn oil fractionation.

Furthermore, as our analysis was based on a future timeframe, we modeled future plant energy use to represent plants that would be built to meet requirements of increased ethanol production, as opposed to current or historic data on energy used in ethanol production. The energy use at dry mill plants was based on ASPEN models developed by USDA and updated to reflect changes in technology out to 2022 as described in RIA Chapter 1. The modeling provided energy use for the different types of dry mill ethanol plants as shown in **Table 2.4-55**.

Table 2.4-55. 2022 Energy Use at Ethanol Plants w/CHP (BTU/gal)

Type	Technology	NG Use	Coal Use	Biomass Use	Purchased Elec
Corn Ethanol – Dry Mill NG	Base Plant (dry DDGS)	28,660			2,251
	w/ CHP (dry DDGS)	30,898			512
	w/ CHP and Fractionation (dry DDGS)	25,854			1,512
	w/ CHP, Fractionation and Membrane Seperation (dry DDGS)	21,354			1,682
	w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (dry DDGS)	16,568			1,682
	Base Plant (wet DGS)	17,081			2,251
	w/ CHP (wet DGS)	19,320			512
	w/ CHP and Fractionation (wet DGS)	17,285			1,512
	w/ CHP, Fractionation and Membrane Seperation (wet DGS)	12,785			1,682
	w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (wet DGS)	9,932			1,682
Corn Ethanol – Dry Mill Coal	Base Plant (dry DGS)		35,824		2,694
	w/ CHP (dry DGS)		39,407		205
	w/ CHP and Fractionation (dry DGS)		33,102		986
	w/ CHP, Fractionation and Membrane Seperation (dry DGS)		27,477		1,191
	w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (dry DGS)		21,495		1,191
	Base Plant (wet DGS)		21,351		2,694
	w/ CHP (wet DGS)		24,934		205
	w/ CHP and Fractionation (wet DGS)		22,390		986
	w/ CHP, Fractionation and Membrane Seperation (wet DGS)		16,766		1,191
	w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (wet DGS)		13,200		1,191
Corn Ethanol – Dry Mill Biomass	2022 Base Plant (dry DGS)			35,824	2,694
	2022 Base Plant w/ CHP (dry DGS)			39,407	205
	2022 Base Plant w/ CHP and Fractionation (dry DGS)			33,102	986
	2022 Base Plant w/ CHP, Fractionation and Membrane Seperation (dry DGS)			27,477	1,191
	2022 Base Plant w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (dry DGS)			21,495	1,191
	2022 Base Plant (wet DGS)			21,351	2,694
	2022 Base Plant w/ CHP (wet DGS)			24,934	205
	2022 Base Plant w/ CHP and Fractionation (wet DGS)			22,390	986
	2022 Base Plant w/ CHP, Fractionation and Membrane Seperation (wet DGS)			16,766	1,191
	2022 Base Plant w/ CHP, Fractionation, Membrane Seperation, and Raw Starch Hydrolysis (wet DGS)			13,200	1,191
Corn Ethanol – Wet Mill	Plant with NG	45,950			
	Plant with coal		45,950		
	Plant with biomass			45,950	

In response to comments received, we included corn oil fractionation and extraction as a potential source of renewable fuels for this final rulemaking. Based on research of various corn ethanol plant technologies, corn oil as a co-product from dry mill corn ethanol plants can be used as an additional biodiesel feedstock source. Dry mill corn ethanol plants have two different technological methods to withdraw corn oil during the ethanol production process. The fractionation process withdraws corn oil before the production of the DGS co-product. The resulting product is food-grade corn oil. The extraction process withdraws corn oil after the production of the DGS co-product, resulting in corn oil that is only suitable for use as a biodiesel feedstock.

Based on cost projections outlined in Section 4, it is estimated that by 2022, 70% of dry mill ethanol plants will conduct extraction, 20% will conduct fractionation, and that 10% will choose to do neither. These parameters have been incorporated into the FASOM and FAPRI-CARD models for the final rulemaking analysis, allowing for corn oil from extraction as a major biodiesel feedstock.

2.4.7.2 Corn Butanol

For the final rule analysis we included a scenario of converting corn starch into butanol. The production of corn was assumed to be the same as for ethanol production and based on the agricultural sector modeling described in the previous sections. However, the results were scaled based on the yield of butanol produced. Corn ethanol was assumed to have a processing yield of 2.7 gal/bu and an energy content of 76,000 Btu/gal which results in an overall energy yield of 206,280 Btu/bu. Corn butanol has a slightly lower processing yield of 2.12 gal/bu but a higher energy content of 99,827 Btu/gal for an overall energy yield of 212,153 Btu/bu. Therefore, on a per Btu produced basis corn butanol has slightly lower emissions compared to corn ethanol.

For process energy use we assumed the same types of technology as used for corn ethanol production. To estimate GHG emissions we used the average 2022 mix of plants and technologies which includes fractionation and 63% dry DGS and 37% wet DGS using natural gas as an energy source. Average energy use was 26,496 Btu NG per gallon produced and 4,642 Btu purchased electricity per gallon.

2.4.7.3 Biodiesel (including Algae)

Three scenarios for biodiesel production were considered, one utilizing soybean oil as a feedstock, one using yellow grease, and the last using algae oil. All three were assumed to be converted to biodiesel through the Fatty Acid Methyl Ester (FAME) process. The emissions from soybean growing were estimated through the agricultural sector modeling described in the previous sections. This section discusses the modeling for the production of algal oil, producing soybean oil, and conversion of al oils into biodiesel.

2.4.7.3.1 Algae Oil Production

We developed our lifecycle analysis of the algae pathways primarily based on Aspen modeling provided by the National Renewable Energy Laboratory (NREL).[605] As the algae industry is still in its nascent stages and there are potentially many variations to the processing of algae, e.g. methods used for harvesting and lipid extraction, byproduct utilization, etc., it is challenging to say which set of technologies and configurations may be the most successful in the future. A recent publication summarized some of the potential algae-biofuel production pathways being considered.[606]

Two production pathways were evaluated at this time, one utilizing an open pond (op) system and the other a photobioreactor (PBR) system. More details on the assumptions used for those systems are described in the following sections as well as in the technical memorandum from NREL. We view this assessment as a starting point for evaluating algae-to-biofuel pathways and not as the only or preferred production configurations for algae. Nevertheless, we believe that the assumptions and scenarios chosen to represent the production of algae by 2022 are reasonable given the expert opinion solicited. Over time we plan to evaluate different variations of these pathways and to update the data and analyses as the algae industry grows and commercializes.

NREL evaluated three cases: a base case, an aggressive case, and a maximum case for each of the algae production pathways, i.e. op and PBR. A brief summary of the cases evaluated are given below:

Base case: algae yield = 25 g/m^2/day (op), 63 g/m^2/day (PBR); lipid content = 25% (corresponds to a reasonable but still challenging target for the near future)

Aggressive case: algae yield = 40 g/m^2/day (op), 100 g/m^2/day (PBR); lipid content = 50% (assumes identification of a strain with near optimal growth rates and lipid content)

Maximum case: algae yield = 60 g/m^2/day (op), 150 g/m^2/day (PBR); lipid content = 60% (represents the near theoretical maximum based on photosynthetic efficiencies)

For all cases: scale of facility = 10 MMgal/yr, 10% algae lost after production, 5% lipid lost in extraction

The production of algae-based biofuel consists of the following stages:

- Algae Cultivation
- Algae Harvesting
- Algae Oil Extraction and Recovery
- Algae Oil Transport to Biofuel Facility
- Algae Oil Conversion to Biofuel
- Biofuel Distribution

The modeling completed by NREL covered the first three production steps. We assumed that the biofuel facility would be co-located next to the algae oil production processes and thus transport emissions for the fourth step would be negligible. The last two steps were assumed to be similar to the conversion of soy oil to biodiesel and soy-based biodiesel distribution.

Algae require several inputs, including water, land, nutrients, and in most cases, light to sustain growth. The following **Table 2.4-56** summarizes these main inputs for the various open pond and photobioreactor scenarios:

Table 2.4-56. Inputs for Algae Cultivation

Input	Base Case		Aggressive Case		Max Case	
	op	PBR	op	PBR	op	PBR
Water Use:						
Net water demand [MMgal/yr]	9,740	720	3,830	320	2,710	250
Net water demand [gal/gal lipid]	974	72	383	32	271	25
Land Use [acre]:						
Pond/PBR land size	4,743	1,897	1,482	593	823	329
Total plant land required	7,079	3,795	2,212	1,186	1,229	659
Nutrient Use [ton/yr]:						
Fertilizer for algae	23,920	23,880	12,000	11,980	10,010	10,000
Nutrients for anaerobic digester	2,960	3,000	1,440	1,460	1,190	1,200
CO_2 Use:						
CO_2 consumed [lb/lb algae produced]	2	2	2	2	2	2
Net CO_2 used from offsite flue gas [ton/yr]	290,000	290,000	150,000	150,000	120,000	120,000

The scenarios assume water use is from low-value brackish or saline water pumped from an underground source rather than drawing from fresh water resources.[171] In areas where water is limited, fresh water may not be available at a reasonable cost and therefore may affect the feasibility of the system. One factor that could further limit water consumption is by cultivating algae in nutrient-rich eutrophic or mixed waters (e.g. animal litter, tertiary wastewater, and agricultural or industrial runoffs). This in turn could limit the amount of nutrients purchased for algae cultivation. An additional benefit to the use of wastewater is that an algae process that treats wastewater displaces carbon that would have been generated in conventional wastewater treatment processes.

[171] Some fresh makeup water is assumed to replace evaporative losses in the cooling system for the PBR system.

Algae cultivation is expected to be able to use non-arable lands. As such, the conversion of carbon-rich lands to agriculture can be avoided and thus emissions from land-use change. Due to higher cell densities, the use of photobioreactors can lower land use in comparison to open pond systems. The scenarios assume 330 operating days/year and a solar exposure of 12 hours/day which implies that a site location is chosen which receives high year-round solar exposure.

The nutrients used in the process include fertilizers purchased for the algae and those needed to operate the anaerobic digesters. The fertilizers for the algae purchased are approximately 64% urea and 36% di-ammonium phosphate (DAP). The nutrients required to aid anaerobic digestion are primarily caustic with some phosphoric acid, urea and micronutrients.

Algae also consume CO_2 during cultivation. The scenarios assume that part of the CO_2 is recycled within the process from anaerobic digestion of spent biomass and part of the CO_2 is delivered from offsite flue gas, e.g. from power plant. Scenarios assume that CO_2 is delivered from a distance of 1.5 miles from a power plant or other emissions source. For both the open pond and PBR "base case", pure CO_2 was chosen where instead of transporting the entire flue gas material, the CO_2 is scrubbed out and transported under pressure to the facility.

Harvesting is necessary to recover biomass from the cultivation system. Commonly used techniques include flocculation, dissolved air flotation (DAF), centrifugation, microfiltration, and decantation. Wet biomass may also be dewatered or dried. Dewatering decreases the moisture content by draining or mechanical means. Additional drying can follow using e.g. drum dryer, freeze dryer, spray dryer, rotary dryer, or by solar drying. Primary harvesting under our scenarios occurs using natural settling to concentrate the algae from 0.05% to 1%. Secondary harvesting concentrates the algae to 10% via DAF using chitosan as a flocculant.

Oil from algae can be extracted through chemical or mechanical processes to separate the algal oil from the cell membrane. The TAGs (Triacylglycerides) are typically the main product which goes to biodiesel production. The remainder consists of carbohydrates, proteins, nutrients, and ash), usually referred to as the algal residue or spent biomass.

The extraction step is commonly regarded as the most speculative in terms of large-scale feasibility.[607] Thus extraction is a critical area of research going forward to achieve practical algal lipid production. Some of the more common methods are solvent extraction, supercritical fluid extraction, and mechanical extraction. Algal extraction under both op and PBR cases was assumed here to be carried out using mechanical extraction via high-pressure homogenization to lyse algae cells. Homogenization was chosen because it is the closest to the necessary processing scale investigated given current technology. Other extraction techniques discussed include solvent extraction, supercritical fluid extraction, osmotic shock, and sonication.

The lipids are assumed to be recovered via phase separation in a clarifier tank which allows contents to settle into lipid, water and spent biomass.

The spent biomass is assumed to be used in anaerobic digestion and power generation via gas turbine which provides power to run the plant. The other method commonly discussed is its use as animal feed; however, this was not assumed under these scenarios. Table 2.4-57 summarizes the net annual electricity required (purchased from grid) for the cultivation, harvesting, oil extraction and recovery stages. We assumed that the average U.S. grid electricity is used.

Table 2.4-57. Net Annual Electricity Required (purchased from grid) [MM kwh/yr] for 10 MMgal/yr Lipid Production

Base Case		Aggressive Case		Max Case	
Op	PBR	Op	PBR	op	PBR
60.2	35.7	27.0	18.8	19.8	16.0

2.4.7.3.2 Soybean Oil Production

For the soybean oil scenario, the energy use and inputs for the biodiesel production process were based on a model developed by USDA and used by EPA in the cost modeling of soybean oil biodiesel including crushing, as discussed in Chapter 4. Soybean crushing was modeled assuming yields of 11.2 lbs soybean oil/bu soybeans and energy use of 14,532 BTU of natural gas and 2,843 BTU of purchased electricity per gallon of biodiesel produced.

Similar to the case with corn ethanol co-products, we analyze the aggregate GHG emissions from soybean crushing and transesterification that occur as a result of increased demand for a particular biofuel. Therefore, any increase in soybean meal or soybean oil produced as a result of larger biodiesel volumes would take into account GHG emissions reductions from a decrease in the production of other feed and vegetable oil substitutes from our FASOM modeling.

2.4.7.3.3 Conversion of Oil to Biofuel

For the proposal we based biodiesel processing energy on a process model developed by USDA-ARS to simulate biodiesel production from the Fatty Acid Methyl Ester (FAME) transesterification process. In this process vegetable oil (triglyceride) is reacted with an alcohol (e.g., methanol) and a catalyst (e.g., sodium hydroxide) to produce biodiesel and glycerin. During the comment period USDA updated their energy balance for biodiesel production to incorporate a different biodiesel dehydration process based on a system which has resulted in a decrease in energy requirements. Soybean biodiesel transesterification was modeled assuming yields of one kilogram of biodiesel from a kilogram of soybean oil and energy use of 4,381 BTU of natural gas and 361 BTU of electricity per gallon of biodiesel produced.[608]

We assumed that the algae oil produced would be similar in quality as soy oil. Although it is possible that the algae oil may require an upgrading step such as degumming to remove phospholipids, this step was not included as there is no information at this time regarding the process logistics specific to algal-derived oil. Algae oil is also assumed to be converted to biodiesel through the transesterification process with the same energy and material requirements of soybean oil.

For the yellow grease case, no soybean agriculture emissions or energy use was included. Soybean crushing natural gas use was included as a surrogate for yellow grease processing (purification, water removal, etc.). Also, due to additional processing requirements, the energy use associated with producing biodiesel from yellow grease is higher than for soybean oil biodiesel production. The energy use for yellow grease biodiesel production was assumed to be 1.7 times the energy used for soybean oil biodiesel and yields of 0.94 kilograms of biodiesel from a kilogram of yellow grease.

GHG emissions from other biodiesel production raw material inputs were also included in the analysis. HCl, methanol, NaOCH3 and sodium hydroxide are used in the production of biodiesel and GHG emissions from producing the raw material inputs were also added to the model. **Table 2.4-58** shows the values that were used to convert raw material inputs into GHG emissions used in the anlaysis.

Table 2.4-58.
Lifecycle Factors for Biodiesel Raw Material Production

Factor	Unit	Methanol	Sodium Methoxide	Sodium Hydroxide	HCl
CO_2	g/g	0.401	0.966	0.923	1.011
CH_4	g/g	0.003	0.002	0	0
N_2O	g/g	3.9E-06	2.5E-06	0	0
Total Energy	BTU/g	19.05	24.10	9.67	9.35

Glycerin is a co-product of biodiesel production. Our proposal analysis did not assume any credit for this glycerin product. We have included for the final rule analysis that glycerin would displace residual oil as a fuel source on an energy equivalent basis. This is based on the assumption that the glycerin market would be saturated in 2022 and that glycerin produced from biodiesel would not displace any additional petroleum glycerin production. However, the biodiesel glycerin would not be a waste and a low value use would be to use the glycerin as a fuel source. The fuel source assumed to be replaced by the glycerin is residual oil.

2.4.7.4 Cellulosic Biofuel

For the cellulosic biofuel pathways, we updated our final rule energy consumption assumptions on process modeling completed by NREL. For the NPRM, NREL estimated energy use for the biochemical enzymatic process to ethanol route in the near future (2010) and future (2015 and 2022).[609] As there are multiple processing pathways for cellulosic biofuel, we have expanded the analysis for the FRM to also include thermochemical processes (Mixed-Alcohols route and Fischer-Tropsch to diesel route) for plants which assume woody biomass as its feedstock.[610,611]

Cellulosic biofuel can be produced through two main types of production processes, either fermentation or gasification. The fermentation option may show preference towards using more homogeneous feedstock sources like farmed trees (hardwoods), switchgrass and corn stover whereas more heterogeneous sources like forestry waste (typically softwoods) may prefer the gasification option due to processing challenges. For more information on key biomass feedstock considerations and the potential impact they may have on yields and processability within the biorefinery refer to the technical document provided by NREL.[612]

As discussed, we have worked with NREL to generate models of cellulosic ethanol and diesel fuel production.

Table 2.4-59Table 2.4-59 shows the energy use required for the different cellulosic ethanol and F-T diesel production processes. For the biochemical pathway, process energy is assumed to be generated through the unfermentable portion (mainly lignin) of incoming biomass being burned for electricity production. The process is assumed to generate excess electricity per gallon of ethanol produced.

Table 2.4-59. 2022 Energy Use at Cellulosic Biofuel Plants (BTU/gal)

Type	Technology	Biomass Use	Diesel Fuel Use	Purchased Elec.	Sold Elec.
Cellulosic Ethanol – Enzymatic	Switchgrass feedstock & lignin used as fuel	61,001			-12,249
	Corn stover feedstock & lignin used as fuel	61,001			-12,249
	Forest waste feedstock & lignin used as fuel	64,220			-18,391
Cellulosic Ethanol – Thermochemical	Switchgrass feedstock	90,935	177		
	Corn stover feedstock	90,935	177		
	Forest waste feedstock	90,935	177		
	Farmed trees feedstock	90,935	177		
Cellulosic Diesel – F-T	Switchgrass feedstock	168,220	327	17	
	Corn stover feedstock	168,220	327	17	
	Forest waste feedstock	168,220	327	17	
	Farmed trees feedstock	168,220	327	17	

The benefit of electricity generation is the possibility of lowering greenhouse gas emissions by offsetting other forms of electricity production. This is captured in our analysis by assuming that the excess electricity produced by the ethanol plant will offset U.S. grid electricity production. Therefore, GHG emissions from U.S. grid electricity are calculated for the amount of excess electricity produced based on GREET defaults for electricity production and subtracted from the lifecycle results of cellulosic ethanol production.

2.4.7.5 Brazilian Sugarcane Ethanol

Under the imported sugarcane ethanol cases we updated process energy use assumptions to reflect anticipated increases in electricity production for 2022 based on recent literature and comments to the proposal. One major change was assuming the potential use of trash (tops and leaves of sugarcane) collection in future facilities to generate additional electricity. The NPRM had only assumed the use of bagasse for electricity generation. Based on comments received, we are also assuming marginal electricity production (i.e., natural gas) instead of average electricity mix in Brazil which is mainly hydroelectricity. This approach assumes surplus electricity will likely displace electricity which is normally dispatched last, in this case typically natural gas based electricity. The result of this change is a greater credit for displacing marginal grid electricity and thus a lower GHG emissions profile for imported sugarcane ethanol than that assumed in the NPRM. We also received public comment that there are differences in the types of process fuel e.g. used in the dehydration process for ethanol. While using heavier fuels such as diesel or bunker fuel tends to increase the imported sugarcane ethanol emissions profile, the overall impact was small enough that lifecycle results did not change dramatically. We describe these changes in further detail below.

In Brazil, the majority of mills are configured to produce both sugar and ethanol simultaneously. To simplify the lifecycle analysis, we assumed that a sugarcane ethanol mill is operated with 100% feed for ethanol production. In a sugarcane mill, sugarcane is cleaned, crushed, and the cane juice extracted. The juice is then treated to produce ethanol and/or sugar, depending on market demands. The stream for ethanol is fermented and distilled into hydrous ethanol. From there, there are two possibilities. Hydrous ethanol may be stored as the final product or dehydrated to anhydrous ethanol.

2.4.7.5.1 Sugarcane Ethanol Process Energy Consumption

In Brazil, the majority of energy used at the sugarcane ethanol facility is supplied by burning bagasse, the fiber material leftover after extracting cane juice. The bagasse is combusted in a boiler to produce steam and generate electricity to meet internal demands as well as export surplus electricity to the grid. A smaller portion of energy is required for chemical and lubricant use. We used a bagasse yield of 280 kg (with 50% moisture) per MT of sugarcane.

2.4.7.5.2 Bagasse Combustion Emissions

We used the IPCC guidelines (2006b) and average emission factors of CH_4 and N_2O from biomass combustion, as shown in Table 2.4-60.

Table 2.4-60. Emissions per mmBTU Bagasse Burned[613]

Pollutant	g/mmBTU bagasse burned
CH_4	31.65
N_2O	4.22

2.4.7.5.3 Chemical and Lubricant Use

We assumed that the chemicals and lubricants are similar to residual oil in terms of energy and emission profiles (see **Table 2.4-61**).

Table 2.4-61. Energy used for Chemicals and Lubricants[614]

	2005/2006	Scenario 2020
Energy Use (Btu/gal); 100% residual oil	798	766

We further assumed a 10% allocation of residual oil to ethanol to account for lubricating oil that is used not as a combustion source but is lost during operation of the machinery in the production of ethanol.

2.4.7.5.4 Ethanol yields

Table 2.4-62 shows a summary of ethanol yields from several studies.

Table 2.4-62. Ethanol yields in Sugarcane Mills

Year	L/MT	Source
1996-1997	79.5	Moreira & Goldemberg (1999)
2000	85.4	Assuncao (2000)
2001	78.58	UNICA-Carb Comments; 138.7 TRS/ton cane and 1.7651 kg TRS/L anhydrous
2005	85	OECD (2008)
Avg. 2006-2008	84.68	UNICA-Carb Comments; 149.47 TRS/ton cane and 1.7651 kg TRS/L anhydrous
Avg. in 2002 Best	86 91	Macedo et al. (2004) GREET default
2006 “2020”	86.3 92.3/129*	Macedo et al. (2008) *Includes cellulosic ethanol
2015 2025	100 109	Unicamp, as noted in OECD (2008)

2.4.7.5.5 Ethanol dehydration

Standard distillation leaves over 4% water in ethanol, requiring a second step in the process to remove water in order to obtain fuel grade anhydrous ethanol (>99.3 wt%).[615] The most important ethanol dehydration techniques used in the world industry include azeotropic distillation, dehydration on molecular sieves, and more recently, pervaporation or vapor permeation.[616] Azeotropic distillation uses a third component, typically benzene or cyclohexane, to remove the final water from ethanol. Molecular sieves use an adsorbent with a strong affinity for water and little affinity for ethanol. This allows for separation of water from the ethanol product. Most new ethanol plants today are built with molecular sieve dehydrators. Pervaporation is still a fairly new technology, however, there is potential for energy consumption savings, thus making the technology attractive for newly built facilities.[617]

Data was unavailable to determine the split of facilities using one type of dehydration process over the other for import into the United States. However, we collected data on the amount of energy required to dehydrate a gallon of hydrous ethanol into anhydrous ethanol using primarily molecular sieve technology, see **Table 2.4-63**.

Table 2.4-63. Energy Required for Dehydration

BTU/gallon of anhydrous	**Source/Details**
4,000	Swain
2,830-5665	Vane[618]
4,500	Kawaitkowski[619]
4186-5931	CBEPG[620]; Fuel Oil (primarily diesel)
5156-5210	CBEPG[621]; Natural Gas

As noted in Chapter 1, the majority of ethanol imported into the U.S. may preferentially come through the Caribbean Basin Initiative countries due to favorable economic conditions. As the public comments on our rule suggest, there are differences in the type of fuels burned to run the processes for dehydration. This depends on the location of the dehydration facility and the fuel choices available at those locations. Fuels used to run the dehydration process include bagasse, natural gas, #2 distillate (diesel fuel), and #6 oil (bunker fuel).[622]

For the final rule, we have assumed an average energy consumption for dehydration from fuel oil use of 5059 BTU/gallon anhydrous produced and 5183 BTU/gallon anhydrous produced if natural gas is used.

We received comment to include a pathway for the Caribbean Basin countries. We evaluated the pathway based on the type of fuel used for dehydration, either from fuel oil or from natural gas. For the NPRM we had already evaluated the Brazilian direct pathway assuming dehydration used bagasse as a fuel. We calculated 1) the additional emissions from burning fuel oil and natural gas instead of bagasse and 2) the emissions credit from not dehydrating in Brazil from bagasse (i.e. electricity is produced instead).

Assuming an electricity generation efficiency of 30% (the current Brazil industrial average) and the energy consumption for dehydration as 5059 BTU/gallon anhydrous and 5183 BTU/gallon anhydrous for fuel oil and natural gas, we calculated an electricity credit of 0.44 and 0.46 kWh/gallon anhydrous produced for fuel oil and natural gas, respectively. This electricity credit is assumed to displace electricity as it is produced in Brazil, i.e. marginal electricity produced from natural gas. See discussion of Brazilian electricity generation in the following section.

2.4.7.5.6 Electricity generation in Brazil

In Brazil, there has been an increasing use of bagasse to generate enough steam and electricity to supply the whole mill energy demand while still producing electricity surpluses. **Table 2.4-64** summarizes the current and anticipated electricity generated for Brazilian sugarcane facilities. As noted, this is highly dependent on the types of boilers used, and whether or not there is collection of sugarcane leaves and tops (trash). Average cogeneration surplus for all sugarcane mills in Brazil was 10.5 kwh/MT cane in 2008, and could increase above 100 kwh/MT cane with the utilization of trash.

For the final rule, we have chosen to model the low (40 kwh/MT cane) and high (135 kwh/MT cane) surplus electricity scenarios.

Table 2.4-64. Electricity Surplus in Brazil under Various Conditions

Year	Biomass Used	Kwh/MT cane	Source/Details
2006	Bagasse w/ surplus leftover	9.2	CTC (2006); 10% mills use high press boilers, 90% 21 bar/300 C
2007	Bagasse	22.5/23	UNICA/MME/COGEN-SP/GREET default
2008	Bagasse	10.5	Avg. for all UNICA members (124 mills)
2008	Bagasse	40	OECD (2008), one standard facility; 20% of 39 mills or 4% of all mills
2008	Bagasse	25.16	Avg. for 39 mills surveyed by UNICA
Current	Bagasse	0-10	Smeets (2008), Combustion, partial steam extraction turbine, 22 bar, -300C
Current	Bagasse	40-60	Smeets (2008), Combustion, partial steam extraction turbine, 80 bar, -480C
2012	Bagasse	65	COGEN-SP, Amounts contracted
Near-term	Bagasse	75	UNICA, Upgrading to high-pressure steam cycle generators, using all bagasse
2020+	Bagasse + 40% trash for cellulosic ethanol; Bagasse + 40 % trash for electricity	44 135	Macedo (2008) Mills at 65 bar/480 C, CEST systems; process steam consumption ~340 kg steam/tonne cane
Longer-term	Bagasse + 50% trash for electricity	67-100	Smeets (2008), Combustion, condensing steam turbine, 80 bar, -480C
2020+	Bagasse + 50% trash for electricity	135-200	Smeets (2008), Gasification, steam-injected gas turbine

2.4.7.5.6.1 Average Brazilian Grid Electricity versus Marginal Grid Electricity

We have factored in credit in our analyses for the excess electricity generated from the burning of bagasse and potentially trash in the future. This, however, is dependent on the type of electricity displaced. Several comments on our rule indicate that the cogeneration in Brazil should displace the marginal power supplier (i.e., thermoelectric power plants running on natural gas or heavy fuel oil) instead of average grid electricity (i.e., hydroelectricity).[623] See **Table 2.4-65** for the Brazil average fuel mix in 2007.

Table 2.4-65.
Brazilian average fuel mix for electricity generation in 2007[624]

Fuel	%
Petroleum	2.83%
Natural Gas	3.63%
Coal	1.34%
Biomass	3.47%
Nuclear	2.54%
Hydro	77.28%
Others	8.94%
Total	100.0%

We believe the use of marginal grid electricity instead of average electricity is reasonable given that 1.) We are crediting on the basis of displacement 2.) Electricity produced at the sugarcane ethanol facility is always dispatched when a mill is operating and this allows for reduction of the use of other thermal power plants. **Table 2.4-66** shows the average fuel mix for Brazil's operating margin in 2008.

Table 2.4-66. Brazilian Grid Operating Margin average fuel mix for electricity generation in December 2008.[625]

Fuel	%
Petroleum	3.63%
Natural Gas	60.24%
Coal	14.37%
Biomass	0.00%
Nuclear	18.99%
Hydro	1.11%
Others	1.65%
Total	100.0%

As natural gas is the predominant fuel use, we have chosen to assume that marginal electricity in Brazil will displace electricity derived from natural gas.

2.4.8 Fuel Transport

The greenhouse gas impacts associated with the transportation and distribution of biofuels depend the average distance the fuel is transported from the plant to the retail location and the mode of transport (barge, rail, truck, etc.). This section summarizes the assumptions used in this analysis to represent the transport of biodiesel, and domestic and imported ethanol. A recent release of GREET[626] was utilized to estimate the GHG emissions based on these assumptions.

2.4.8.1 Biodiesel

For biodiesel transport, GREET default values were used to represent the average distances biodiesel is transported by barge, pipeline, rail, and truck from the plant to the terminal where it is blended with petroleum-based diesel fuel. The percentage of fuel transported by each mode was chosen to be consistent with the cost analysis described in Chapter 4. These inputs are summarized in **Table 2.4-67**.

GREET default values were used to represent the transport of biodiesel from the terminal to the retail location. These defaults assume 100% of biodiesel shipped by truck a distance of 30 miles.

Table 2.4-67. Biodiesel Assumptions for Transport from Plant to Terminal

Mode	%	Distance (miles)
Barge	5%	520
Pipeline	0%	400
Rail	45%	800
Truck	50%	50

2.4.8.2 Corn and Cellulosic Ethanol

Oak Ridge National Laboratory (ORNL)[627] recently conducted a study that models the transportation of ethanol from production or import facilities to petroleum blending terminals by domestic truck, marine, and rail distribution systems. We used ORNL's transportation projections for 2022 under the EISA policy scenario to estimate the percentage of corn and cellulosic ethanol transported by each mode and the averaged distance traveled. These assumptions are summarized in **Table 2.4-68**. More details on the ORNL study and the transportation projections can be found in Sections 1.6 and 3.3.

Since the study did not address the transport of ethanol from the terminal to refueling station, we used the GREET default assumptions of 100% shipped by truck a distance of 30 miles.

Table 2.4-68. Corn and Cellulosic Ethanol Assumptions for Transport from Plant to Terminal

Mode	%	Distance (miles)
Barge	12%	336
Rail	77%	629
Truck	17%	68
Local Truck[172]	83%	6.5

2.4.8.3 Sugarcane Ethanol

This analysis accounts for the transportation of sugarcane ethanol within Brazil, en route to U.S. import facilities, and within the United States. GREET default values are used to represent the transport of ethanol from a production facility in Brazil to a Brazilian port. Specifically, we assumed that 50% of the ethanol is transported via pipeline and the other 50% by rail an average distance of 500 miles (for each mode).

The ethanol is then loaded onto ocean tankers for transport to the United States. As described in Chapter 1, we projected that 46% of imported ethanol in 2022 would be shipped directly from Brazil, while 54% would first be shipped to a country in the Caribbean Basin Initiative (CBI) and then to the United States. For the latter case, we assumed 20% would be imported from Costa Rica, 20% from El Salvador, 30% from Jamaica, 15% from Trinidad and Tobago, and 15% from the Virgin Islands (see Table 1.8-11). Table **2.4-69** summarizes EPA estimates for the average distance ethanol is transported by ocean tanker for each of these paths. For these estimates, we used EIA data on fuel ethanol imports from 1993 to August 2009[628] to determine the fraction of ethanol shipped to different U.S. ports from Brazil and the CBI countries. We estimated the average distance imported ethanol travels by ocean tanker, accounting for all of these paths, to be 7,348 miles.

We received comment that assuming ocean tankers bringing ethanol from Brazil to the United States return to Brazil empty is incorrectly attributing emissions of an ocean tanker's round trip to sugarcane ethanol[629,630]. We, therefore, assume that emissions from back-haul are negligible for this analysis.

[172] The ORNL study includes a second transportation mode for trucks, called "Local Trucks", which transport ethanol from dedicated ethanol terminals to blending terminals. Ethanol that travels directly from a refinery to a petroleum blending terminal would not be transported by local truck.

Table 2.4-69. Average Ocean Tanker Distances for Sugarcane Ethanol Transport from Brazil and CBI Countries to the United States[173]

	Average distance to U.S. import facilities (miles)	Total distance, including distance from Brazil (miles)
Costa Rica	3375	10398
El Salvador	3691	11011
Jamaica	2466	7393
Trinidad & Tobago	2766	6590
Virgin Islands	1702	5919
Brazil (direct)	6141	6141

Within the United States, ORNL's transportation projections were used to estimate the average distance sugarcane ethanol is transported from an import facility to a petroleum blending terminal and the percentage that travels by each mode. **Table 2.4-70** summarizes transport assumptions for sugarcane ethanol from production facilities in Brazil to blending terminals in the United States. As with corn and cellulosic ethanol, we used the GREET default assumptions to represent the transport of sugarcane ethanol from the terminal to a refueling station. These assumptions were 100% shipped by truck a distance of 30 miles.

Table 2.4-70. Sugarcane Ethanol Assumptions for Transport from Plant to Terminal

Mode	%	Distance (miles)
Pipeline (in Brazil)	50%	500
Rail (in Brazil)	50%	500
Ocean Tanker	100%	7348
Barge (in U.S.)	12%	336
Rail (in U.S.)	77%	629
Truck (in U.S.)	17%	68
Local Truck (in U.S.)	83%	6.5

2.4.9 Biofuel Tailpipe Combustion

Combustion CO_2 emissions for ethanol and biomass-based diesel were based on the carbon content of the fuel. However, over the full lifecycle of the fuel, the CO_2 emitted from biomass-based fuels combustion does not increase atmospheric CO_2 concentrations, assuming the biogenic carbon emitted is offset by the uptake of CO_2 resulting from the growth of new biomass. As a result, CO_2 emissions from biomass-based fuels combustion are not included in their lifecycle emissions results. Net carbon fluxes from changes in biogenic carbon reservoirs

[173] Distances between ports were calculated using www.distances.com. For Brazil and CBI Countries, the following representative ports were used: Santos in Brazil, Puntarenas in Costa Rica, Acajutla in El Salvador, Kingston in Jamaica; Port of Spain in Trinidad and Tobago, and St. Croix in the Virgin Islands.

in wooded or crop lands are accounted for separately in the land use change analysis as outlined in the agricultural sector modeling above.

When calculating combustion GHG emissions, however, the CH_4 and N_2O emitted during biomass-based fuels combustion are included in the analysis. Unlike CO_2 emissions, the combustion of biomass-based fuels does result in net additions of CH_4 and N_2O to the atmosphere. Therefore, combustion CH_4 and N_2O emissions are included in the lifecycle GHG emissions results for biomass-based fuels.

Combustion related CH_4 and N_2O emissions for biomass-based fuels are based on EPA MOVES model results. The values used are shown in **Table 2.4-71**. CO_2 emissions from biofuels are shown for illustrative reasons, but as mentioned above are not included in the analysis because they are assumed to be offset by carbon uptake from plant growth.

Table 2.4-71.
Tailpipe Combustion Emissions for Bio-Based Fuels

	CO_2	CH_4	N_2O
Fuel Type	**(g/mmBTU)**	**(g/mmBTU)**	**(g/mmBTU)**
Ethanol	75,250	269	611
Biodiesel	81,044	11	689

2.4.10 Other Indirect Impacts

In the analysis of the proposed rulemaking the Agency conducted a study of the U.S. energy sector impacts of increased biofuel production. Using an EPA version of the Energy Information Administration's National Energy Modeling System (NEMS) we attempted to determine the effects of biofuel production energy use, for example increased natural gas use for corn ethanol production and the impact that has on natural gas and other fuel sources price and use. The EPA-NEMS is a modeling system that simulates the behavior of energy markets and their interactions with the U.S. economy by explicitly representing the economic decision-making involved in the production, conversion, and consumption of energy products.

There were several problems encountered with the modeling done for the proposal, mainly in trying to isolate the impacts of a specific fuel and of the specific impact of biofuel energy use so the results were not used in the analysis. However, we indicated that we would continue exploring this modeling for the final rule.

Therefore, for the final rule we created a scenario in EPA-NEMS to simulate the RFS2 volumes, reaching 31.8 billion gallons of biofuels production in 2022. This scenario was compared to AEO 09, which estimated 13.8 billion gallons of biofuel production. This allowed us to see the energy system impacts of an increase in renewable fuels of 18 billion gallons.

The increase in renewable fuels supply triggered a decrease in gasoline demand. This led to a 0.73 million barrel per day decrease in crude oil imports and a 0.18 million barrel per day decrease in refined product imports. As a result of declining demand, crude oil prices decreased from \$117.11/barrel to \$116.43/barrel and petroleum product prices also decreased slightly. In addition, prices for natural gas and electricity declined significantly. The only price increases were a \$0.10/mmbtu increase in the price of motor gasoline and a \$1.49/mmbtu increase in the price of E85.

The overall CO_2 impact was a 34,736 grams CO_2 decrease for each mmbtu increase in renewable fuels over the baseline, or -34,736 grams CO_2/mmbtu. Reduced consumption of gasoline, diesel, and still gas (for refining) resulted in an overall decrease in emissions of 86.6 mmt CO_2. This decrease in emissions was partially offset by natural gas consumption for production of renewable fuels and by increased coal consumption for power generation, yielding an overall decrease in the domestic energy sector of 61.5 mmt CO_2.

The EPA-NEMS results were used in part to estimate the crude oil import reductions from the increased renewable fuel volumes mandated by this rulemaking, as discussed in Chapter 5. However, we have not used this analysis at this point in calculations of renewable fuel threshold analysis or for the overall rule impacts because of double counting issues regarding GHG emissions sources.

The final rule EPA-NEMS analysis eliminated some of the problems with the proposal modeling by considering a larger increase in biofuels consumption and by not specifically trying to isolate the impacts of one type of fuel. However, there were still issues with how this analysis compares to the other lifecycle modeling work conducted for this rulemaking. The main issue is double counting between the EPA-NEMS analysis and our lifecycle work. Both account for renewable fuel production energy use, which is difficult to separate in the EPA-NEMS modeling (especially for purchased electricity). Both also account for gasoline and diesel fuel reduction, both end use and refining energy. This is also difficult to back out of the EPA-NEMS modeling. Therefore, it is difficulty to isolate only the secondary or energy sector impacts that are not already covered elsewhere. There is also the issue that the EPA-NEMS model is only domestic and does not capture any potential international energy sector impacts. We will continue to study this modeling as part of any ongoing work on biofuel analysis.

2.4.11 Other Modeling Approaches Considered

2.4.11.1 Analysis with the GTAP Model

The Global Trade Analysis Project (GTAP) model is an economy-wide multi-region general equilibrium (GE) model coordinated by the Center for Global Trade Analysis at Purdue University. GTAP is a publicly available global model that was originally developed for addressing international agricultural trade issues. An advantage of GE models such as GTAP is that they take into account how changes in U.S. biofuel policies affect world prices, output, and trading patterns for a wide variety of commodities that extend beyond the agricultural sector. The GTAP data base is peer reviewed and updated triannually. The GTAP databases and versions of the model are widely used internationally by a large modeling community.[631] Since its inception in 1993, GTAP has rapidly become a common "language" for many of those conducting global economic analysis. For example, the WTO and the World Bank co-sponsored two conferences on the so-called Millennium Round of Multilateral Trade talks in Geneva.

Here, virtually all of the quantitative, global economic analyses were based on the GTAP framework. The use of the GTAP data base and model has been increasing with the growing research interests in international trade policies, energy policies, and climate change policies. Because GTAP is publicly available, there are numerous versions of the GTAP-based model. However, the GTAP Center has a peer review process which includes replication of results by independent scientists. Those versions of GTAP which have been through this process, including the versions used in this analysis, qualify as peer-reviewed, published models.

The GTAP Version 6 data base divides the global economy into 57 sectors and 87 regions, some of which have been aggregated in the results presented below for simplification. Over the past few years, several improvements have been made to the model. For example, a version of the model was developed to explicitly account for substitution between energy commodities.[632] Another version of the model was developed to explicitly model global competition among different land types (e.g., forest, agricultural land, pasture) and different qualities of land based on the relative value of the alternative land-uses.[633] More recently the above two frameworks were combined and modified to include biofuel substitutes for gasoline and diesel.[634] The California Air Resources Board (CARB) has utilized the GTAP model to assess biofuel land use impacts in its recent rulemaking on a Low Carbon Fuel Standard. Current research is ongoing to add additional detail on the biofuels market, some of which is described below.

2.4.11.1.1 Partial Equilibrium versus General Equilibrium Modeling

Although we have used the partial equilibrium (PE) models FASOM and FAPRI-CARD as the primary tools for evaluating whether individual biofuels meet the GHG thresholds, as part of the peer review process, we explicitly requested input on whether GE models should be used. None of the commenters recommended using a GE model as the sole tool for estimating GHG emissions, although several reviewers discussed some of the advantages of GE models compared to PE models. For example, GTAP captures the interaction between different sectors of the economy. As discussed by the peer reviewers, the link between the agricultural and the energy markets has become increasingly important given the increased production of renewable fuels from agricultural products. Higher crude oil prices and policies to increase demand for renewable fuels have increased the linkages between these two markets, and increased renewable fuel production could have impacts on food security, international trade, and natural resources. These linkages can be captured in a sufficiently detailed GE model. The literature on economic modeling of biofuels suggest that for analyzing the long-term consequences on consumption, the GTAP model is a suitable economic tool to link energy and crop demand.[635]

One of the major benefits of using the GTAP model is that it explicitly models land-use conversion decisions. GTAP is designed with the framework of predicting the amount and types of land needed in a region to meet demands for both food and fuel production. The GTAP framework also allows predictions to be made about the types of land available in each region to meet the needed demands, since it explicitly represents different land types within the model.

In theory, a detailed GE model would be the ideal modeling framework. However, as described in other sections, there is currently no single model that captures all of the necessary aspects of lifecycle GHG emissions. In their current state of development, GE models alone, including GTAP, are not yet adequate for determining whether biofuels meet greenhouse gas emission thresholds for the following reasons.

First, most GE models do not contain the level of detail in the agriculture sector required to determine acreage and production changes by crop by region. Because GE models must account for all sectors of the global economy, simplifications have been made to capture many of the complex interactions. Therefore, some level of aggregation of regions, markets, and relationships is necessary. For example, GTAP contains only an aggregated "coarse grain" crop and does not provide information specific to corn acres and production. Similarly, GTAP contains only a generic oilseed crop and does not include information about soybean-specific production and usage data. As a result, palm oil and soybean oil are aggregated into a single sector, even though these two crops may have very different resource implications. Furthermore, the GTAP model does not yet contain cellulosic feedstocks such as switchgrass or corn stover.

Second, the version of GTAP used for biofuels is a static model that does not currently capture changes over time. (The dynamic GTAP model has yet to be modified for use in energy and land use issues.) The GTAP Version 6 data base, the version used for this analysis, is based on a 2001 world economy. The model has been validated against historical data from 2001 through 2006 and the resulting 2006 baseline is used for biofuels policy analyses. Due to its static nature, the GTAP biofuels model is not able to project the time path of the global economy through 2022, which is the timeframe of primary interest for this rulemaking. Since we expect trends such as increases in crop yields, oil prices, population growth, and GDP growth to continue in the future, it is essential that our modeling framework captures these dynamics.

Third, the GTAP model relies on differences in land rental rates to determine which lands will be converted to crop land as a result of increasing biofuel demand. Land rents are the indicators of productivity in each agro-ecological zone (AEZ). In the GTAP data base, Lee *et al.* (2009) determine land rents for cropland, pasture, and forest based on the yearly economic activity in a given AEZ.[636] By definition, land rents are largest in those AEZs where high value crops are grown. For determining land rents for the livestock sector, Lee *et al.* draw on the direct competition between these sectors with grazing land. For computing livestock sectors' land rent, Lee *et al.* use the average coarse grain yield in each AEZ (as there is no 'forage crop' sector in the GTAP data base) and multiply it by the pasture land cover hectares. Finally, Lee *et al.* compute the forest land rents by using information on timberland land rent and timberland area offered by Sohngen *et al.* (2009). One of the major limitations of this methodology is that unmanaged land, which represents approximately 34% of the land cover in the GTAP model, is not allowed to be brought into productive use (e.g., as pasture). The unmanaged land category in GTAP varies significantly across countries, but includes a substantial amount of shrubland, savanna, and grassland in many areas (e.g., 20% of the land area covered in Brazil and 40% of the land area covered in Argentina).

Fourth, although most of the behavioral parameters (e.g., international trade elasticities, agricultural factor supply) contained in GTAP are estimated econometrically, some of the key relationships are actually based on literature reviews, theory, and analyst judgment.[637] In theory, all the relationships in the model could be based on regionally-specific empirical data, however in practice this is often not the case. For example, the elasticity of transformation (i.e., the measure of how easily land can be converted between forest, pasture, and crop land) is an important parameter in the GTAP model. However, the global value used for this parameter relies on a single study that is based on U.S. data. Ideally, this value would be based on empirical data that is specific to each region in the model, since this response is likely to be different in different parts of the world.

Given the relative advantages of PE and GE models, we opted to use the GTAP model to provide another estimate of the quantity and type of land conversion resulting from an increase in corn ethanol and biodiesel given the competition for land and other inputs from other sectors of the economy. These results help to bracket the land use changes estimated by the FAPRI-CARD model.

2.4.11.1.2 Comparison of GTAP and FAPRI-CARD Model Results

One of the advantages of the GTAP model is that it is an open source framework in which many different groups can conduct research simultaneously. As a result, there are many different "variations" of the GTAP model in existence, each of which is in a different state of peer-review. As researchers publish papers using their updated variation of the model, the programming code is generally published so that others may benefit from these model enhancements. For our corn ethanol analysis, we used a slightly modified version of the GTAP model that was extensively reviewed as part of the California Air Resources Board (CARB) for their Low Carbon Fuel Standard rulemaking.[638] However, one of the criticisms of the CARB analysis was the treatment of biodiesel byproducts. New research by Taheripour et al[639] has been recently conducted to explicitly model the production and substitution of oilseed meal as a byproduct of biodiesel production, which provides a more accurate representation of the soybean biodiesel market interactions. We have therefore used this variation of the GTAP model to conduct the soybean biodiesel analysis.[174]

We made three revisions to the CARB modeling inputs to make our corn ethanol and soybean biodiesel analysis more consistent. First, we changed the elasticity of crop yields with respect to area expansion. This parameter is a measure of how much crop yields will decrease as agriculture expands onto new land. In theory, the most productive agricultural lands are already in use, therefore expanding production into more marginal lands will result in a decrease in average crop yields. CARB used a factor of 0.5 in its analysis, which implies that each new acre of land is only 50% as productive as an existing acre of land. However, more recent analysis suggests that a value of 0.66 may be more appropriate, indicating that for every two acres of additional cropland needed, three acres of forest or pasture lands must be converted to new cropland.[640] Therefore, we have used 0.66 as the elasticity for our analysis of corn ethanol and biodiesel. Second, we adjusted the 2006 baseline ethanol and biodiesel production levels. Our modified version of the CARB model used in this study has 4.25 BG of corn-ethanol and 0.14 BG of biodiesel in the 2006 baseline. Finally, since our baseline included a crude oil price shock

[174] This version of the model was in press at the time of this rulemaking. As a result, the code was not available to use this variation of the GTAP model for the corn ethanol analysis, hence our use of the CARB model for the corn ethanol analysis.

from \$25/barrel in 2001 to \$60/barrel in 2006, our biofuel scenarios started with a \$60 oil price laden economy versus \$25 in the CARB biofuel scenarios.

Because the GTAP model is static, it was not possible to analyze the exact same corn ethanol and soybean biodiesel scenarios in GTAP that we analyzed using the FAPRI-CARD model. Therefore, we analyzed a 2 billion gallon increase in corn ethanol over the 2006 updated baseline level of 4.25 BG. Similarly, our soybean biodiesel shock imposed a 1 BG increase in U.S. soybean biodiesel production over the 2006 updated baseline level of 0.14 BG. In order to compare the results of the GTAP model to the FAPRI-CARD model, we then "normalized" the land cover changes to obtain an acreage change per BTU of the biofuel shock. Other simplifications were also required. For example, GTAP aggregates regions differently than FAPRI-CARD, therefore we have summarized the results into larger regions for comparison purposes. Despite these shortcomings and compromises in trying to compare results from GTAP and FAPRI-CARD, the relative impacts on land use we believe are informative in that GTAP confirms that there are significant impacts on international land use due biofuel production from food and feed crops.

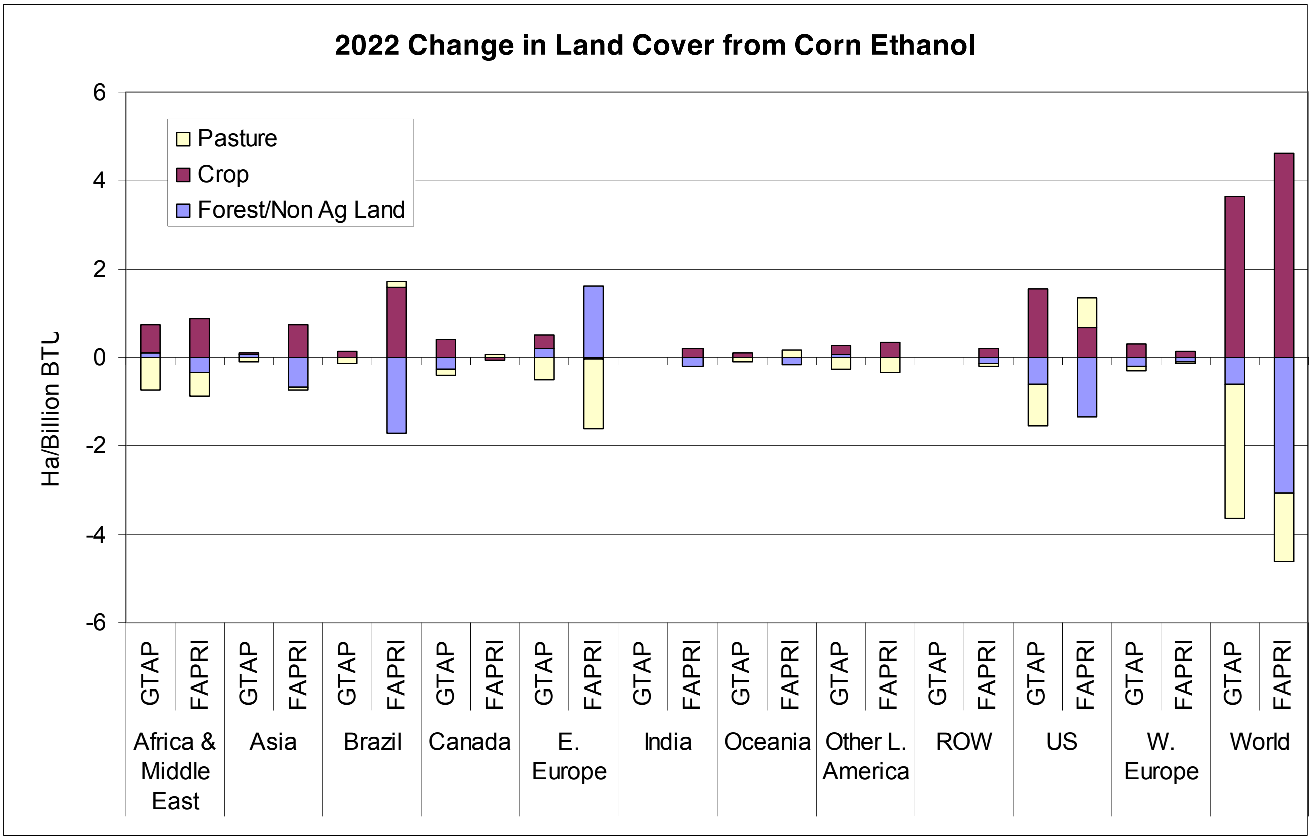
2.4.11.1.3 Comparison of GTAP and FAPRI-CARD Corn Ethanol Results

Despite differences in the way the corn ethanol scenarios were implemented, the quantity of total acres converted to crop land projected by GTAP were similar in scale to the changes projected by the FAPRI-CARD results when normalized on a per BTU basis. However, the mean estimates for land converted to crops projected by GTAP were smaller than the changes predicted by FAPRI-CARD, which is most likely due to several important differences in the modeling frameworks.

First, the GTAP model incorporates a more optimistic view of intensification options by which higher prices induced by renewable fuels results in higher yields, not just for corn, but also for other displaced crops. Second, the demands for other uses of land are explicitly captured in GTAP. Therefore, when land is withdrawn from these uses, the prices of these products rise and provide a certain amount of "push-back" on the conversion of land to crops from pasture or forest. Third, none of the peer-reviewed versions of GTAP currently contain unmanaged land, thereby omitting additional sources of land. In **Figure 2.4-46** and **Figure 2.4-47**, the GTAP results assume all land that is not crop or pasture is forest. However, the FAPRI-CARD results allow land that is not crop or pasture to come from a variety of other non agricultural land such as grassland, savanna, shrubland and wetlands. The disaggregation of FAPRI-CARD "non ag land" is described in more detail in Section 2.4.4.2.5.

Although the global aggregated results are similar, the regional distribution of land cover change varies between the FAPRI-CARD and GTAP models. Both models predict similar changes in India, Oceana, non-Brazilian Latin America, and Africa/Middle East. However, the FAPRI-CARD model predicts significant increases in crop acres in Brazil and Asia, whereas the GTAP model projects limited land use change in those regions. In contrast, the GTAP model projects more crop acre conversion in the U.S. for corn ethanol scenarios. These differences are due to the result of contrasting international trade structures in the models. FAPRI-CARD includes more flexible agricultural trade patterns, and projects agricultural expansion in lower cost of production regions that show the greatest capacity for expansion. In contrast, GTAP tends to maintain existing trade patterns, so it is more likely to project changes in countries that are already major trading partners of the U.S. A formal econometric analysis of these differences is offered in Villoria and Hertel (2009).[641]

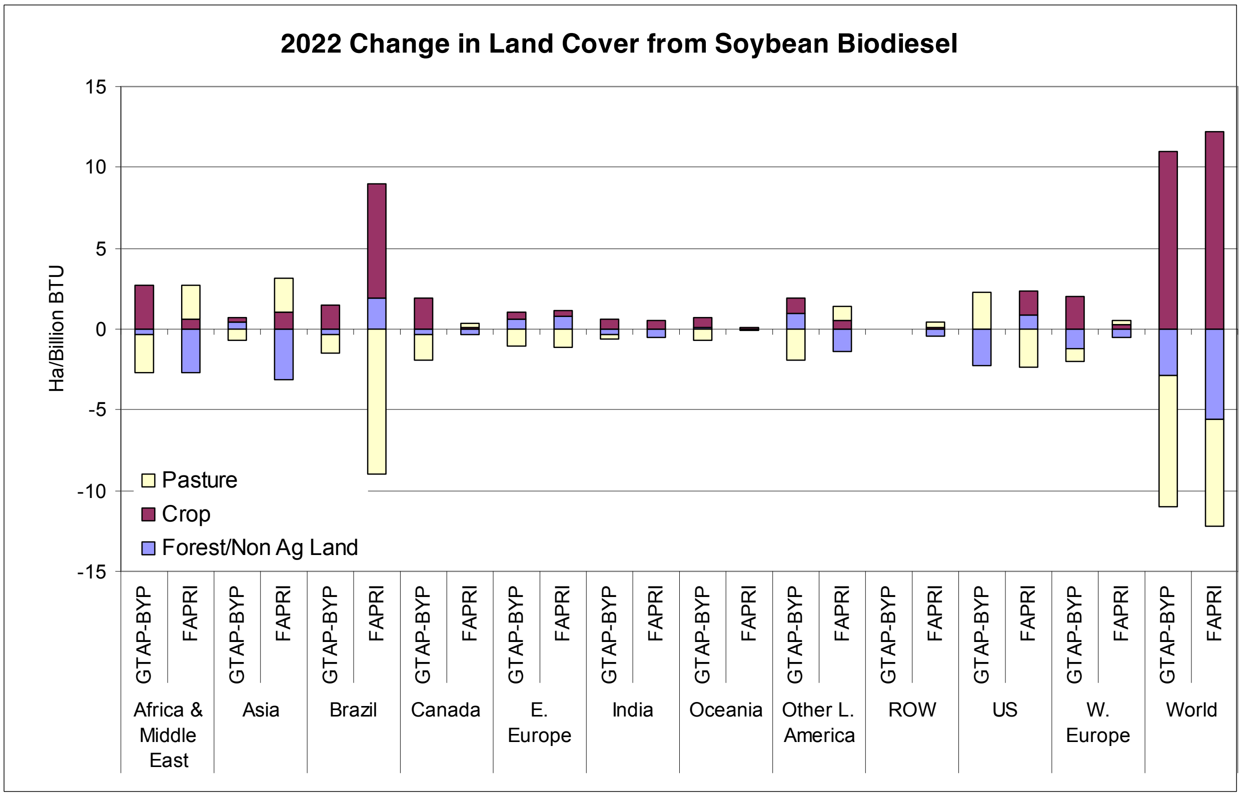
Figure 2.4-46. Changes in Land Cover from an increase in Corn Ethanol



2.4.11.1.4 Comparison of GTAP and FAPRI-CARD Soybean Biodiesel Results

In the soybean biodiesel analysis, the total increase in crop acres aggregated at the global level is similar in the FAPRI-CARD and GTAP results. As with the corn ethanol analysis, the regional distribution of these changes also varies. While both models predict similar impacts in Eastern Europe and India, once again the FAPRI-CARD model estimates much larger increases in crop acres in Brazil than the GTAP model. The GTAP model estimates a larger increase in crop acres in Africa and the Middle East and Canada compared to the FAPRI-CARD model. The changes in the U.S. are also different. Whereas the FAPRI-CARD model predicts some increase in crop and forest acres, the GTAP model predicts almost no change in crop acres. Instead, the GTAP model estimates that there will be an increase in pasture land as a result of increasing soybean biodiesel in the U.S. These differences appear to be based on the fact that the GTAP model assumes the price of soybean meal will decrease significantly as a result of the increase in soybean crushing required to produce oil for biodiesel. GTAP projects that the decrease in soybean meal prices will lead to increased beef production, which requires additional grazing land to complement the use of soybean meal for beef production. In contrast, the FAPRI-CARD model assumes that increased biodiesel production will lead to a decrease in U.S. beef production, since the relative price of non-grazing animals (e.g., poultry and pork) will decrease more than the price of beef as a result of lower soybean prices. As a result, U.S. beef production and pasture land decreases in FAPRI-CARD and we believe this is a more rational outcome.

Figure 2.4-47. Changes in Land Cover from an increase in Soybean Biodiesel



2.4.11.1.5 Systematic Sensitivity Analysis with the GTAP Model

As mentioned above, there are several parameters that have a significant impact on the amount and type of land conversions resulting from an increase in biofuel demand. Due to uncertainty in the past and future values of these parameters, it is possible to use the GTAP model to perform a systematic sensitivity analysis (SSA). Traditional uncertainty analysis relies on a Monte Carlo simulation which solves for equilibrium conditions using a large number of draws from the underlying distribution of potential parameter values. However, Monte Carlo analysis is not generally practical for a large CGE model. Instead, previous researchers have performed a SSA with Gaussian Quadrature numerical integration. This methodology uses a small number of draws from the distribution of random variables to provide a robust range of results that can be used to develop a confidence interval around the mean estimates.[642]

In our analysis, the parameters that appear to have the largest impact on the results include the elasticity of crop yields, the elasticity of harvested acreage response, and the elasticity of transformation across cropland, pasture, and forest land. The elasticity of crop yields, often referred to as "price induced yields" is the measure of how much a particular crop's yield will increase in response to an increase in the price of that crop. The larger the value of the elasticity, the more the increase in yields is expected to increase in response to higher prices. In our analysis, we used Keeney & Hertel's recommended mean value of 0.25, which indicates that a 1% increase in coarse grain prices leads to a 0.25% increase in coarse grain yields.[175] For the SSA, the range of values analyzed was from a low end of 0 (i.e., yields do not respond to price changes) to a high end of 0.5.[643] The elasticity of transformation of crop land is a measure of how easily crop acres can be converted between types of crops. For example, the larger the value, the more easily coarse grain acres can be converted to oilseed acres in response to a change in land rental rates. For our analysis, we used a mean value of -0.5 with a lower bound of -0.1 and an upper bound of -1.0.[644] The elasticity of transformation of land supply is a measure of how easily land can be converted between land cover types (e.g., from forest to crop or pasture). The larger the value of this elasticity, the more land will be converted to different types of land cover in response to changes in relative land rental rates. For our SSA, we used a mean value of -0.2, with a lower range of -0.04 and an upper range of -0.36.[645]

2.4.11.1.5.1 GTAP Systematic Sensitivity Analysis for Corn Ethanol

As shown in Table 2.4-48, there is a wide range of potential values for the amount of crop cover changes by region. However, it is important to note that for almost all regions, the range of potential values does not cross the X-axis. Thus, we interpret these results to imply that there is a statistically significant change in crop acres in most of the GTAP regions as a result of the increase in corn ethanol. Similarly, as shown in Figure 2.4-49, the range in potential values of pasture cover does not generally cross the X-axis for most of the regions. We therefore conclude that the decrease in pasture acres is statistically significant in most regions as a result of the increase in corn ethanol. Finally, Figure 2.4-50 shows that the mean estimate for some regions show an increase in forest acres, while other regions show a decrease in forest acres. Again, the confidence intervals around these estimates do not generally cross the X-axis, therefore we interpret these results to be statistically significant.

[175] As discussed in RIA Chapter 5, our FAPRI-CARD projections include disaggregated price-induced yield elasticities that vary by region, crop and time period.

Figure 2.4-48. Crop cover change due to U.S. corn-ethanol production (million acres)

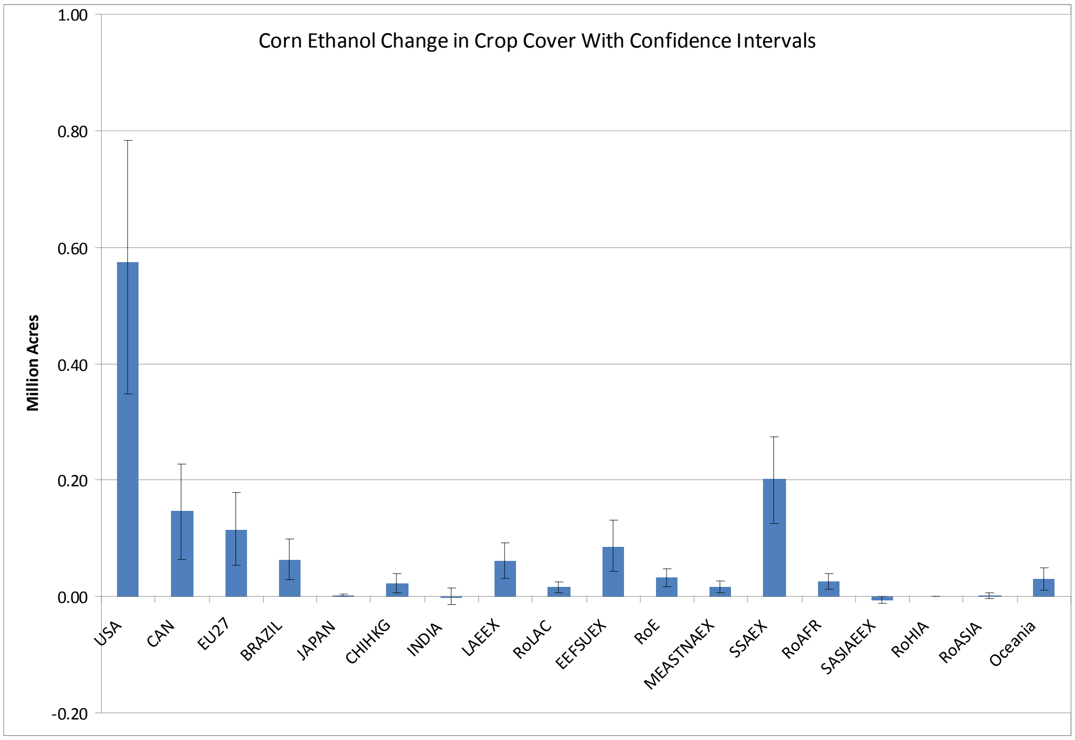


Figure 2.4-49. Pasture cover change due to U.S. corn-ethanol production (million acres)

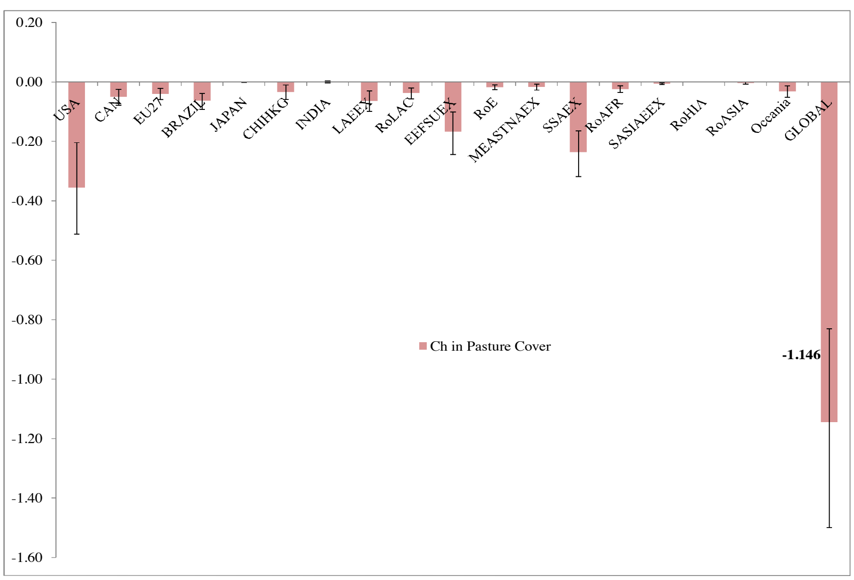
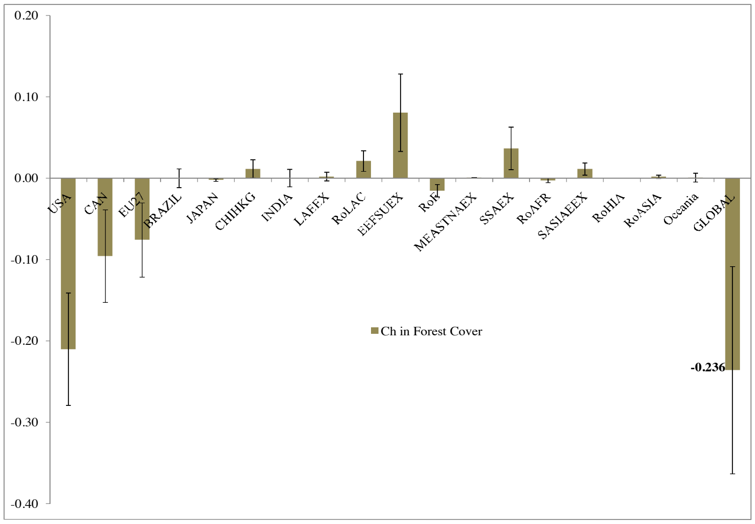


Figure 2.4-50. Forest cover change due to U.S. corn-ethanol production (million acres)



2.4.11.1.5.2 GTAP Systematic Sensitivity Analysis for Soybean Biodiesel

Similar to the corn ethanol results, the SSA for biodiesel generally shows that the land cover changes are statistically significant for the crop, pasture, and forest acre changes predicted by GTAP. As shown in the following figures, most of the confidence intervals do not cross the X-axis, therefore indicating that that the results are robust.

Figure 2.4-51. Crop cover change due to U.S. biodiesel production (million acres)

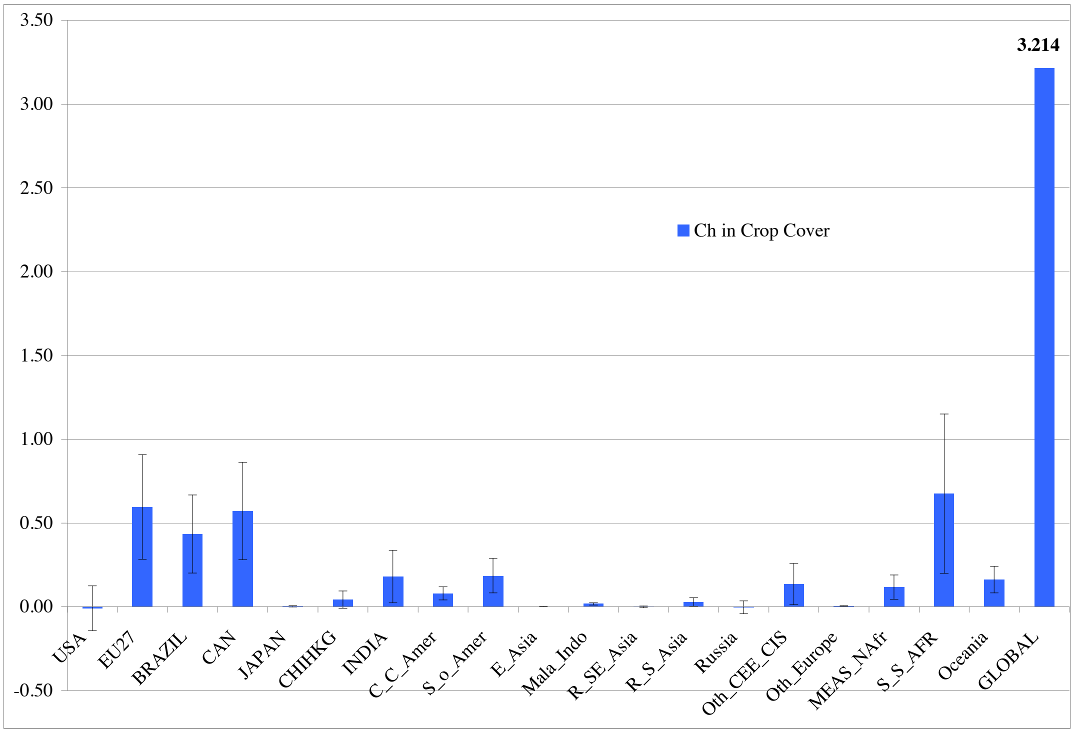


Figure 2.4-52. Pasture cover change due to U.S. biodiesel production (million acres)

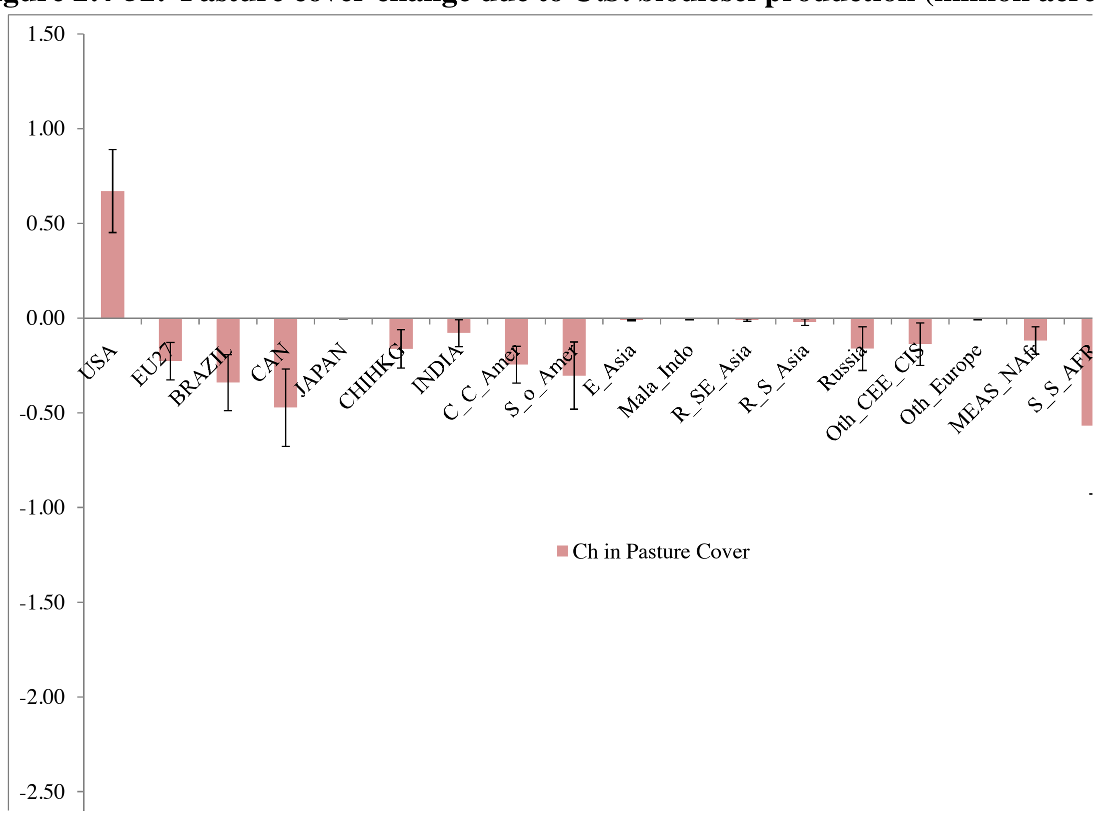
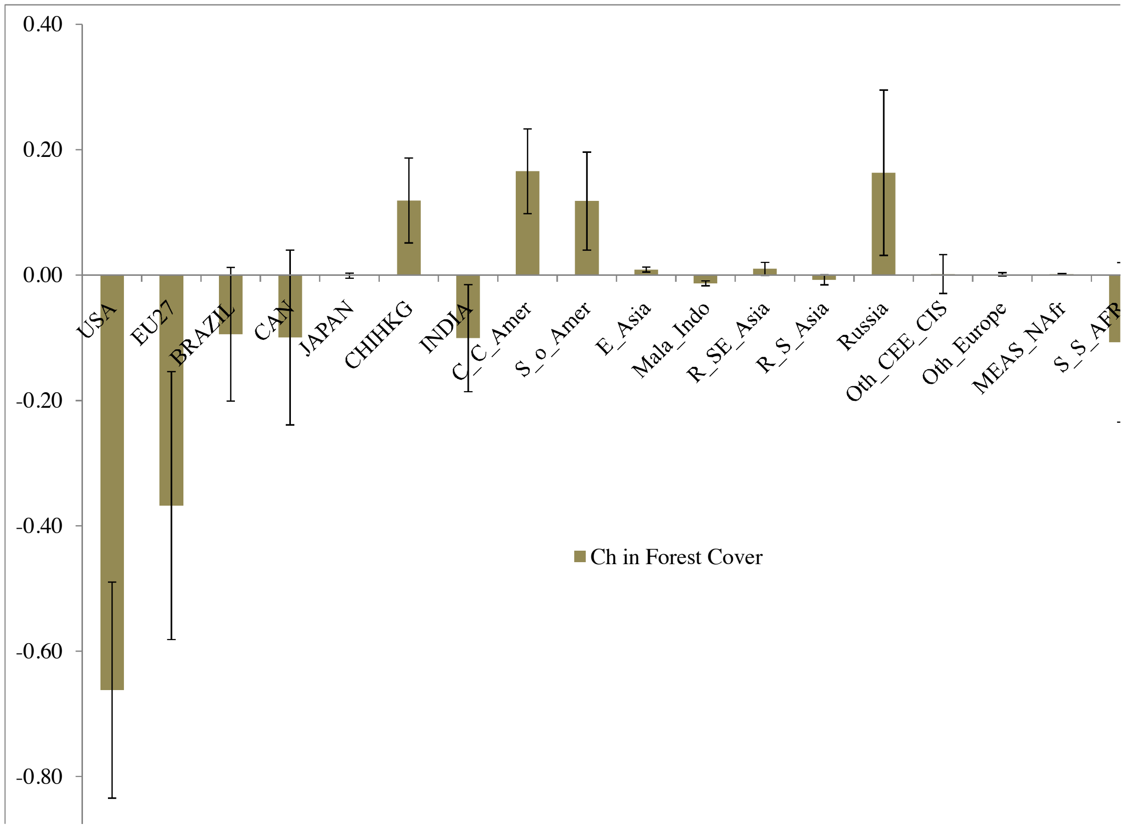


Figure 2.4-53. Forest cover change due to U.S. biodiesel production (million acres)



2.4.11.2 Evaluation of International Land Conversions with Higher Resolution Satellite Data

EPA worked with remote sensing experts from Integrity Applications Inc. (IAI) to analyze higher resolution satellite imagery in regions that factored prominently into our land use change analysis. The purpose of this analysis was to compare the Version 5 MODIS imagery with 500-m resolution to an imagery data set with much higher resolution. As discussed in preamble Section V and above, EPA only uses satellite imagery to evaluate recent land use change patterns, which are the results of many factors. Satellite imagery is not used to determine the amount of land conversion caused specifically by biofuel production. As discussed below, we found that the higher resolution LandSat data set with 30-m resolution provided similar results.

Based on resources and data availability, three regions were chosen for analysis: Brazil, India and the Indonesian island of Sumatra. Brazil was chosen because it was, and remains, the country with the largest agricultural land use response in our modeling of the indirect impacts of U.S. biofuel consumption. In the proposed rule analysis, India was the most important region in Asia. Based on modeling updates, the response in India was much smaller in our final rule analysis. However, it is still a good country to analyze with higher resolution data because it is a major agricultural producer with crops and land cover types distinct from what is found in Brazil.

Finally, Indonesia was chosen because it is a major producer of palm oil in a region with peat soils. We narrowed our focus to the island of Sumatra because satellite imagery for Indonesia suffered from significant cloud cover problems.

Our high resolution analysis relied on the Landsat Global Land Surveys for the years 2000 and 2005; these Global Land Surveys are mosaics (i.e., compilations) of multi-spectral digital images produced to represent the entire earth during the growing season of a specific year. For optimal comparison of land cover categories, the MODIS data set was used as training data to classify the raw Landsat imagery. **Table 2.4-72** summarizes the characteristics of the data used.

Table 2.4-72. Characteristics of Satellite Data for High Resolution Analysis

	Landsat	**MODIS**
Data use	IAI: land use classification and change detection	IAI: training data to classify raw Landsat data Winrock: land use classification and change detection
Data source	Landsat Global Land Survey	MODIS V5[646]
Years covered	Effectively 2000 and 2005	2001, 2005 and 2007
Temporal resolution	+/- 3 years; data acquired every 16 days	Every one to two days
Spatial resolution	30-m	500-m
Public Availability	US Geological Survey (USGS) Archive[647]	LP DAAC Data Pool[648]

By calibrating the land cover classification definitions to those used by MODIS, we converted the true color Landsat images into corresponding classification maps (see Figure 1). The color key for the classification map is provided below in Figure 2.4-54.

Figure 2.4-54. Example of a true color Landsat image (left) and the corresponding land cover classification map (right)

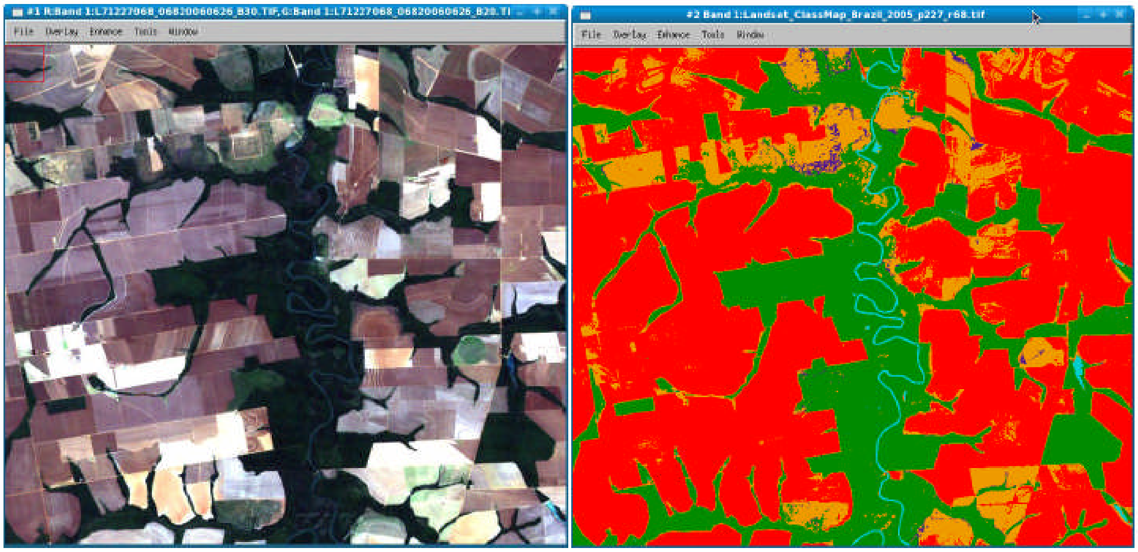


Figure 2.4-55. Land categories and corresponding colors

Land Use Category	Color in Class Map
Forest	Dark Green
Shrubland	Yellow
Savannah	Orange
Grassland	Light Green
Cropland	Red
Natural/Mixed Vegetation	Purple
Wetlands	Cyan
Barren	Pink
Water	Blue
Urban/built-up	White

Classification maps from 2000 and 2005 were compared to find areas where land changed from one category to another. For comparison with EPA's MODIS analysis, the resulting change matrices were aggregated by Administrative Unit and we analyzed the types of land converted to cropland. For most regions, the higher resolution data found deforestation rates somewhere in between the original and corrected MODIS data (see Section 2.4.4 for an explanation of the MODIS correction process). Validation data similar to the confusion matrix used to correct the MODIS data set was not available for the Landsat data, therefore it is difficult to directly compare these results. However, in general, the results do suggest that the resolution of the Version 5 MODIS data is adequate (i.e., provides similar results as higher resolution imagery), especially after it has been corrected with data validation procedures. Figure 2.4-54.

Figure 2.4-54 Figure 2.4-54 shows the share of deforestation from crop expansion in each region analyzed, and

Table 2.4-73 Table 2.4-73 includes all of the land types converted to cropland. The Indonesia results are omitted because of the cloud cover issues mentioned previously. More details about the Landsat data analysis are provided in a technical report by IAI available on the docket.[649]

Figure 2.4-56. Share of Deforestation from Crop Expansion Measured with MODIS and Landsat Satellite Imagery

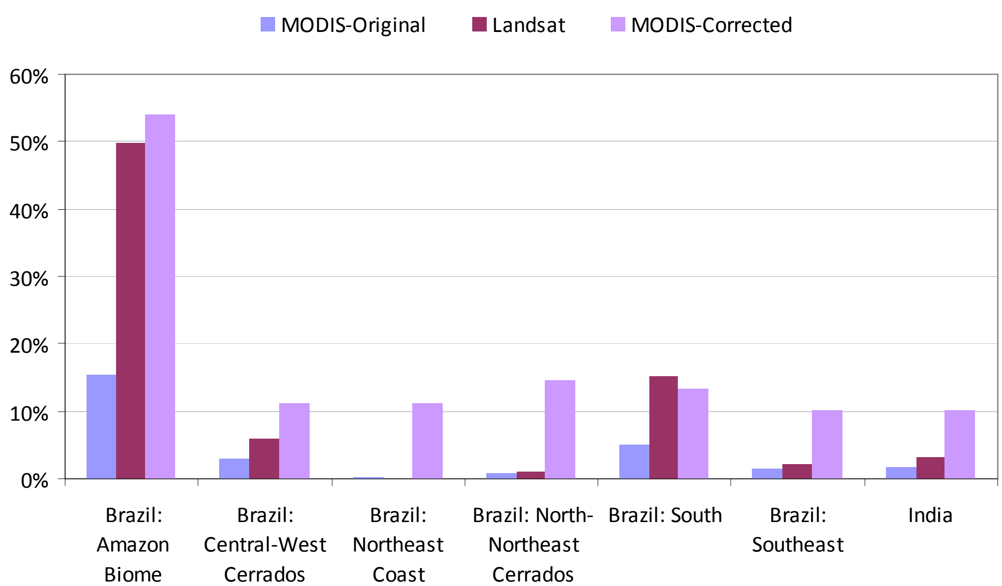


Table 2.4-73. Types of Land Converted to Cropland by Data Source and Region

		Region						
	Data Source	Brazil: Amazon Biome	Brazil: Central-West Cerrados	Brazil: Northeast Coast	Brazil: North-Northeast Cerrados	Brazil: South	Brazil: Southeast	India
Forest	Landsat	50%	6%	0%	1%	15%	2%	3%
	MODIS-Corrected	54%	11%	11%	15%	13%	10%	10%
Grassland	Landsat	8%	19%	8%	12%	14%	10%	5%
	MODIS-Corrected	8%	26%	19%	16%	23%	18%	21%
Mixed	Landsat	11%	20%	28%	14%	55%	53%	27%
	MODIS-Corrected	15%	20%	19%	10%	28%	30%	30%
Savanna	Landsat	26%	55%	54%	67%	14%	34%	49%
	MODIS-Corrected	20%	36%	41%	49%	29%	36%	19%
Shrubland	Landsat	2%	0%	9%	5%	1%	1%	14%
	MODIS-Corrected	2%	6%	8%	9%	6%	6%	17%
Wetlands	Landsat	2%	0%	0%	1%	1%	0%	0%
	MODIS-Corrected	1%	0%	0%	0%	0%	0%	1%
Barren	Landsat	0%	0%	1%	0%	0%	0%	2%
	MODIS-Corrected	0%	0%	1%	1%	0%	0%	2%

2.5 Baseline Gasoline and Diesel Fuel

2.5.1 Background

Section 201 of the Energy Independence and Security Act (EISA) mandated that a baseline for gasoline and diesel fuel be established against which renewable fuels were to be compared:

> *The term 'baseline lifecycle greenhouse gas emissions' means the average lifecycle greenhouse gas emissions, as determined by the Administrator, after notice and opportunity for comment, for gasoline or diesel (whichever is being replaced by the renewable fuel) sold or distributed as transportation fuel in 2005.*

For the proposed rule, the Agency used the GREET model (Version 1.8b) to calculate the baseline GHG impacts of gasoline and diesel fuel production. However, we received numerous comments stating that GREET was not the best tool to use to calculate the petroleum baseline. Hence, to estimate the lifecycle GHG emissions associated with baseline gasoline and diesel transportation fuel for the final rule, we utilized the 2009 analysis performed by the National Energy Technology Laboratory (NETL), "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels", which was specifically directed at establishing this 2005 baseline. NETL stated that the goal of their study was to "determine the life cycle greenhouse gas emissions for liquid fuels (conventional gasoline, conventional diesel, and kerosene-based jet fuel) production from petroleum as consumed in the U.S. in 2005 to allow comparisons with alternative transportation fuel options on the same basis (i.e., life cycle modeling assumptions, boundaries, and allocation procedures)." Furthermore, NETL stated that "[t]he study goals and scope were aligned to meet the definition of "baseline lifecycle greenhouse gas emissions" as defined in the Energy Independence and Security Act of 2007 (EISA 2007), Title II, Subtitle A, Sec. 201." Specific detail on NETL's analysis can be found in their report.[650]

2.5.2 Crude Oil Extraction

NETL determined the emissions associated with extraction and processing for crude oil and synthetic crude oil, natural gas liquids (NGLs), and unfinished oils as feedstocks to U.S. petroleum refineries and to foreign refineries producing gasoline and diesel imported by the U.S. in 2005.

2.5.2.1 U.S. Refineries

The input of crude oil, natural gas liquids, and unfinished oils to domestic refineries was determined from EIA data and is summarized in **Table 2.5-1** below.

Table 2.5-1. Feedstock inputs to U.S. refineries

	Feedstock Input (thousand bbl/day)
Crude Oil	15,220
Natural Gas Liquids	432
Unfinished Oils (net)	569

The crude oil mix to U.S. refineries was also determined from EIA data and is reflected in **Table 2.5-2**.

Table 2.5-2. Crude oil imports to U.S. refineries

	U.S. Crude Oil Sources Production/Import as % of Refinery Crude Input (Year 2005, EIA)
U.S. Crude Oil	33.8%
Canada Crude Oil	10.7%
Canada Oil Sands	
Mexico Crude Oil	10.2%
Saudi Arabia Crude Oil	9.4%
Venezuela Crude Oil	8.1%
Nigeria Crude Oil	7.1%
Iraq Crude Oil	3.4%
Angola Crude Oil	3.0%
Ecuador Crude Oil	1.8%
Algeria Crude Oil	1.5%
Kuwait Crude Oil	1.5%
Other	9.5%

Country-specific crude oil extraction profiles were obtained by NETL from PE International for all major oil exporters to the U.S. aside from Canada and are available in the docket, EPA-HQ-OAR-2005-0161. Canadian crude oil extraction emissions are more difficult to estimate, as the U.S. imports both conventional oil and oil sands from Canada. To estimate emissions from Canadian conventional crude extraction, the U.S. conventional crude extraction profile was utilized, while incorporating Canada-specific data on venting and flaring rates.[176] For Canadian oil sands, extraction emission rates were derived using emissions reported by two major oil sands producers. These estimated values for oil sands production were comparable to those found by Charpentier et al. (2009)[651]. 9.5% of oil imports were grouped into a category termed "other", which consisted of imports from 31 countries. Due to the complexity and uncertainty associated with developing estimates for each of these countries, extraction emissions for this group were assumed to be the average of the conventional crude extraction emissions from the other importers for which specific extraction estimates were developed.

[176] The U.S. extraction profile was used as a surrogate for extraction of Canadian conventional crude oil, as most data sources do not separate out emissions for Canadian conventional crude production from oil sands.

Extraction emissions for unfinished oils[177] were assumed to be the same as for crude oil extraction, with the addition of emissions for an atmospheric/vacuum distillation step after extraction. Unfinished oils were assumed to be of the same import mix as crude oil. Emissions associated with NGLs extraction were estimated using Canadian data for upstream oil and gas operations.

2.5.2.2 Foreign Refineries

Countries exporting gasoline and diesel to the U.S. were determined from EIA data. **Table 2.5-3** reflects the percentage that imports made up of total U.S. consumption of gasoline and diesel.

Table 2.5-3. Imports as a Percentage of 2005 U.S. Consumption

Product	Percentage of U.S. Consumption
Conventional Gasoline	12.7%
Conventional Diesel	5.2%

Canada and the Virgin Islands were the primary liquid fuel exporters to the U.S., so extraction emissions associated with fuels imported from those countries were estimated more rigorously. Canada consisted of 25% of the finished motor gasoline imported to the U.S. and 32% of the diesel imported, while the Virgin Islands accounted for 17% of the gasoline and 29% of the diesel. For both of these countries, the crude oil import mix was known, so crude oil extraction emissions were estimated using the PE International extraction profiles.

The estimation method for other liquid fuel exporters to the U.S. depended on the origin of the crude oil utilized. In some cases, crude oil was extracted in the same country in which it was refined, so extraction emissions could be estimated from PE International extraction profiles. In other cases, crude oil was imported from one country for refining in another, and the crude import mix was not entirely clear. For most of these countries, PE International's GaBi 4 Life Cycle Assessment Software[178] was utilized to provide estimates of extraction emissions.

This still left a handful of countries for which there was no method to estimate extraction emissions. For these cases, "surrogate" profiles were used. For instance, for European countries for which a country-specific profile was not available, the EU-15 or EU-25 extraction profile was utilized. For South Korea, it is known that the source of crude oil is primarily Saudi Arabia, so the Saudi profile was utilized to estimate extraction emissions. For the remainder of countries, the extraction emissions were estimated to be the foreign average of all crude profiles. In total, the foreign average profile was used for 9% of the gasoline crude oil mix and 12% of the diesel crude oil mix.

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[177] "All oils requiring further processing, except those requiring only mechanical blending. Unfinished oils are produced by partial refining of crude oil and include naphthas and lighter oils, kerosene and light gas oils, heavy gas oils, and residuum." Department of Energy: U.S. Energy Information Administration. "Glossary" http://www.eia.doe.gov/glossary/glossary_u.htm.

[178] "[PE International's] GaBi software allows all the GHG emissions of your product to be captured in a systematic and transparent way. Primary data specific to your product can then be incorporated into your analyses and combined with secondary data on GHG emissions available from the GaBi databases." PE International. Product Carbon Footprint. < http://www.pe-international.com/consulting/carbon-footprint/product-carbon-footprint>

2.5.3 Crude Oil Transport

For domestic refineries, the NETL report states that "[c]rude oil transport to U.S. refineries includes pipeline transport within the exporting country, ocean tanker transport to the U.S., and domestic crude oil transport to refineries via a combination of pipeline, water carrier, rail, and truck." All crude is assumed to be transported by pipeline 100 miles to the U.S. border or to a port for shipping to the U.S., with the energy intensity for pipeline transport assumed to be 260 Btu/ton-mile. Based on EIA data, the distance from the foreign port to the U.S receiving port was estimated for the top ten countries from which crude oil was imported. For all other countries, the one-way travel distance was assumed to be 10,000 nautical miles.

Table 2.5-4. Travel distance for crude oil based on country of origin

Crude Oil Sources	Import as % of Refinery Crude Input (Year 2005, EIA)	Country-Specific Average One-Way Travel Distance (nautical miles)
Canada Waterborne	3.0%	675
Canada Pipeline	7.7%	NA
Mexico Crude Oil	10.2%	1,061
Saudi Arabia Crude Oil	9.4%	12,018
Venezuela Crude Oil	8.1%	1,789
Nigeria Crude Oil	7.1%	5,672
Iraq Crude Oil	3.4%	12,370
Angola Crude Oil	3.0%	6,736
Ecuador Crude Oil	1.8%	5,653
Algeria Crude Oil	1.5%	4,452
Kuwait Crude Oil	1.5%	12,526
Other	9.5%	10,000

Emissions arising from domestic transport of crude were estimated using the breakout of crude oil transportation modes for 2004, as illustrated in **Table 2.5-5**.

Table 2.5-5. Domestic transportation breakout for crude oil

Pipelines	Water Carriers	Motor Carriers	Railroads
75.9%	23.7%	0.3%	0.1%

For foreign refineries where extraction and refining occurred in the same country, transport of 100 miles by pipeline from well to refinery was assumed. For countries which imported crude, refined it into liquid fuels, and exported the liquid fuels to the U.S., the GaBi 4 Life Cycle Assessment Software gave estimates of the emissions associated with crude oil transport. For Canada, the Virgin Islands, and South Korea, crude oil transport distances by tanker were estimated, with the only exception that crude exported from the U.S. to Canada traveled by pipeline. Transport of crude oil from the port of entry into the United States to the petroleum refinery is not included in the model, since an analysis of petroleum refinery locations indicated that most refineries are geographically located near the port of entry. The exclusion of this transport operation was determined to have a negligible effect on the final results.

Transport of unfinished oils was modeled in the same way as crude oil transport. Transport of NGLs was modeled in similar way to transport and distribution of petroleum products, which is described in Section 2.5.4, “Fuel Transport and Distribution”.

2.5.4 Refining

NETL’s refining emissions estimation accounts for the following:

- Acquisition of fuels
  - Indirect emissions associated with purchased power and steam
  - Emissions associated with the acquisition of coal and natural gas purchased and consumed at the refinery as fuels
  - Emissions associated with production of fuels at the refinery which are subsequently consumed as fuels (i.e. still gas, petroleum coke)
- Combustion of fuels at the refinery
- Hydrogen production (on-site and off-site)
  - Upstream emissions associated with natural gas feed
  - CO_2 process emissions from steam methane reforming (SMR)
  - Fuel combustion and upstream emissions associated with natural gas fuel and indirect (electricity) emissions for *off-site* hydrogen production
- Flaring
- Venting and fugitive emissions

The NETL report indicates that, “The emissions above will be organized into a refinery emissions pool and a hydrogen emissions pool and subsequently allocated between the various refinery products. There are no individual assignments of energy sources to unit operations or refinery products.”

To determine the GHG emissions from the refining of gasoline and diesel, NETL first determined the total refining emissions from fuels combustion, fuels acquisition, flaring, hydrogen production, and methane venting. For each of the refinery units, they then used the capacity/throughput, energy, hydrogen consumption, and contribution to the final product slate to allocate emissions to gasoline and diesel production.

A domestic refinery model was used as a surrogate for all foreign refinery operations. A review of foreign refinery models from PE Americas indicated that differences in boundary conditions and allocation procedures introduced greater uncertainty in the final results than using the domestic refinery model as a surrogate for foreign refinery operations. The use of the domestic refinery model for foreign refinery operations was noted by NETL as a data limitation to the study.

2.5.5 Fuel Transport and Distribution

"Product transport includes transport of imported liquid fuels from the exporting nations to the U.S. as well as domestic transport of both imported fuels and domestically produced liquid fuels." Foreign transport consists of tanker and/or pipeline transport of imported products to U.S. ports. The products are assumed to be shipped 10 miles by pipeline to a port or the U.S. border. Specific port-to-port travel distances were calculated for imports from Canada and the U.S. Virgin Islands. All other product imports were assumed to travel 5,000 nautical miles to the U.S. Emissions arising from domestic transport were estimated using the breakout of petroleum product transportation modes for 2004, as shown in Table 2.5-6.

Table 2.5-6. Domestic transportation breakout for petroleum products

Pipelines	Water Carriers	Motor Carriers	Railroads
59.8%	29.9%	6.3%	4.0%

2.5.6 Tailpipe Emissions

We updated the CO_2 emission factors for gasoline and diesel to reflect revisions in the factors made by EPA, which were used in the September 28, 2009 proposed rule to establish GHG standards for light-duty vehicles. We have also updated the CO_2 emissions factors for ethanol and biodiesel to be consistent with those used in the October 30, 2009 final rulemaking for the Mandatory GHG Reporting Rule. For the final rule, we have maintained the same CH_4 and N_2O emission factors used for the proposed rule, which were based on EPA MOVES model run results.

Table 2.5-7. Tailpipe emissions for relevant fuels (g/mmBTU)

Fuel Type	CO_2	CH_4	N_2O
Gasoline	77,278	3	5
Diesel	78,308	1	2
Ethanol	75,885	13	2
Biodiesel	79,837	1	2

2.5.7 Land Use Change GHG Emissions

For the final rule, we performed an estimate of land use change emissions associated with oil extraction and production to determine if the value was significant enough to be included in our petroleum baseline calculation. As oil sands production incurs a greater degree of land use change versus conventional crude oil production, we started with an estimate of emissions from the conversion of Alberta forest for oil sands production.

Jordaan et al. (2009) estimated the land use change intensity for oil sands surface mining and in-situ development, using data on project area and established reserves. They estimated an average of 0.42 m^2/m^3 synthetic crude oil (SCO) for surface mining and 0.11 m^2/m^3 SCO for in-situ. These intensity values were based on dividing the area of land disturbance by the total volume of SCO produced over the lifetime of the project. Jordaan also calculated values for land use change associated with upgrading of oil sands and for the extraction of natural gas utilized for oil sands production. However, we restricted our calculation to consider only the land-use change associated with oil sands production to be consistent with the life cycle analysis methodology that we established for renewable fuels.[179]

We then utilized the Winrock database values to determine GHG emissions from land use change of Alberta forest, the assumed area where oil sand extraction would occur. Per IPCC Guidelines, we assumed that 20% of the soil carbon was lost from conversion, which gave an overall value of 278.25 grams CO_2/hectare over a 30 year timeframe. We multiplied the land use change intensity and the GHG emissions from land-use change to yield a GHG intensity value. This calculation yielded values of 1,858 (1,460-2,787) grams CO_2/bbl for surface mining and 487 (310-708) grams/bbl for in-situ. These values were considerably lower (approximately 98%) than the oil sands extraction estimates determined by NETL and used in our petroleum baseline (81,000-122,000 g CO_2/bbl).

On a gasoline basis, the land-use change values were 380 (298-570) g CO_2/mmbtu for surface mining and 99 (63-145) g CO_2/mmbtu for in-situ. Since oil sands only comprised about 5% of the crude oil mix to domestic refineries in 2005, these estimates were adjusted to determine their impact on the aggregate well-to-tank petroleum baseline totals. For surface mining, the oil sands land use change value was on the order of 0.1% of total well-to-tank CO_2 emissions, and, for in-situ, it was 0.06%. Although these values likely represent the worst-case land use impact of petroleum extraction, they are still negligible in the total well-to-tank values and including them would not change the overall petroleum baseline values. We anticipate that future work will help to quantify these values, and we can evaluate the appropriateness of including a land use estimate in the future.

2.5.8 Petroleum Fuel 2005 Baseline Well-to-Tank GHG Emissions

The results for each of the lifecycle stages were combined to give a well-to-tank lifecycle GHG value for 2005 gasoline and diesel as shown in **Table 2.5-8**. Tailpipe combustion emissions for the two fuels are described in Section 2.5.6. When combined with the tailpipe emissions values, a well-to-wheels result for gasoline of 98,205 grams CO_2eq/mmBTU and 97,006 grams CO_2eq/mmBTU was obtained.

Table 2.5-8. Gasoline and diesel baseline well-to-tank GHG emissions (g/mmbtu of fuel)

	CO_2	CH_4	N_2O	CO_2eq.
Gasoline	16,816	2,282	103	19,200
Diesel	15,838	2,066	94	17,998

[179] In other words, when considering the GHG impacts of renewable fuels, we did not consider GHG emissions from land use change associated with infrastructure or natural gas extracted and used for renewable fuels production.

2.6 Fuel-Specific Lifecycle Greenhouse Gas Emissions Results

In this section we present detailed lifecycle GHG analysis results, including the results of sensitivity and scenario analyses on key assumptions. As discussed above, to implement the EISA the crucial result that determines which renewable fuel pathways qualify for RFS2 credits is the percent reduction in lifecycle GHG emissions compared to the average lifecycle greenhouse gas emissions for gasoline or diesel sold or distributed as transportation fuel in 2005. To compare lifecycle GHG emissions from renewable fuels and petroleum, we present the grams of CO_2-equivalent emissions per BTU of fuel produced (gCO_2eq/mmBTU). The previous sections in this chapter discussed our methodology for calculating lifecycle GHG emissions for each component of the renewable fuel lifecycle, and for the 2005 petroleum baseline. In this section we present and compare the GHG emissions results for each of these components in the fuel lifecycle. We also discuss how key assumptions can change the GHG emissions from each component of the fuel lifecycle, and how they influence the final GHG percent reduction estimates.

In addition to estimating GHG emissions at every stage of the fuel lifecycle, EPA's task in this rulemaking is to integrate the GHG emissions estimates from all stages of the lifecycle in order to estimate lifecycle GHG percent reductions for each renewable fuel pathway. We have considered a number of ways to meet this challenge, and have identified several key methodological issues that can influence whether a particular renewable fuel pathway meets the thresholds set forth in the EISA.

2.6.1 Renewable Fuel Lifecycle GHG Results

This section presents fuel specific lifecycle GHG results for the different renewable fuels compared to the petroleum baseline fuel replaced. Results are presented for the baseline set of assumptions including:

- Business as usual yields
- 30 year 0% discounted
- 2022 year for results

Sensitivity around these assumptions are presented in Section 2.6.2. This section presents the results as a range based on the uncertainty analysis conducted around the land use change emissions.

2.6.1.1 Corn Ethanol Results

EPA analyzed the lifecycle GHG performance of a variety of ethanol from corn starch pathways. The results presented here are for an average natural gas fired dry mill plant in 2022. We predict approximately 90% of all plants will be producing corn oil as a by-product either through a fractionation or extraction process; it is likely most if not all new plants will elect to include such technology. We also expect that, to lower their operating costs, most facilities will sell a portion of their co-product DGS prior to drying thus reducing energy consumption and improving the efficiency and lifecycle GHG performance of the plant. The current national average plant sells approximately 37% of the DGS co-product prior to drying.

Figure 2.6-1 shows the percent change in the lifecycle GHG emissions compared to the petroleum gasoline baseline in 2022 for a corn ethanol dry mill plant using natural gas for its process energy source, drying the national average of 63% of the DGS it produces and employing corn oil fractionation technology. Lifecycle GHG emissions equivalent to the gasoline baseline are represented on the graph by the zero on the X-axis. The 20% reduction threshold is represented by the dashed line at -20% on the graph. The results for this corn ethanol scenario are that the midpoint of the range of results is a 21% reduction in GHG emissions compared to the gasoline 2005 baseline. The 95% confidence interval around that midpoint ranges from a 7% reduction to a 32% reduction compared to the gasoline baseline based on the uncertainty in the land use change assumptions.

Figure 2.6-1. Distribution of Results for a New Natural Gas Fired Corn Ethanol Plant Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)

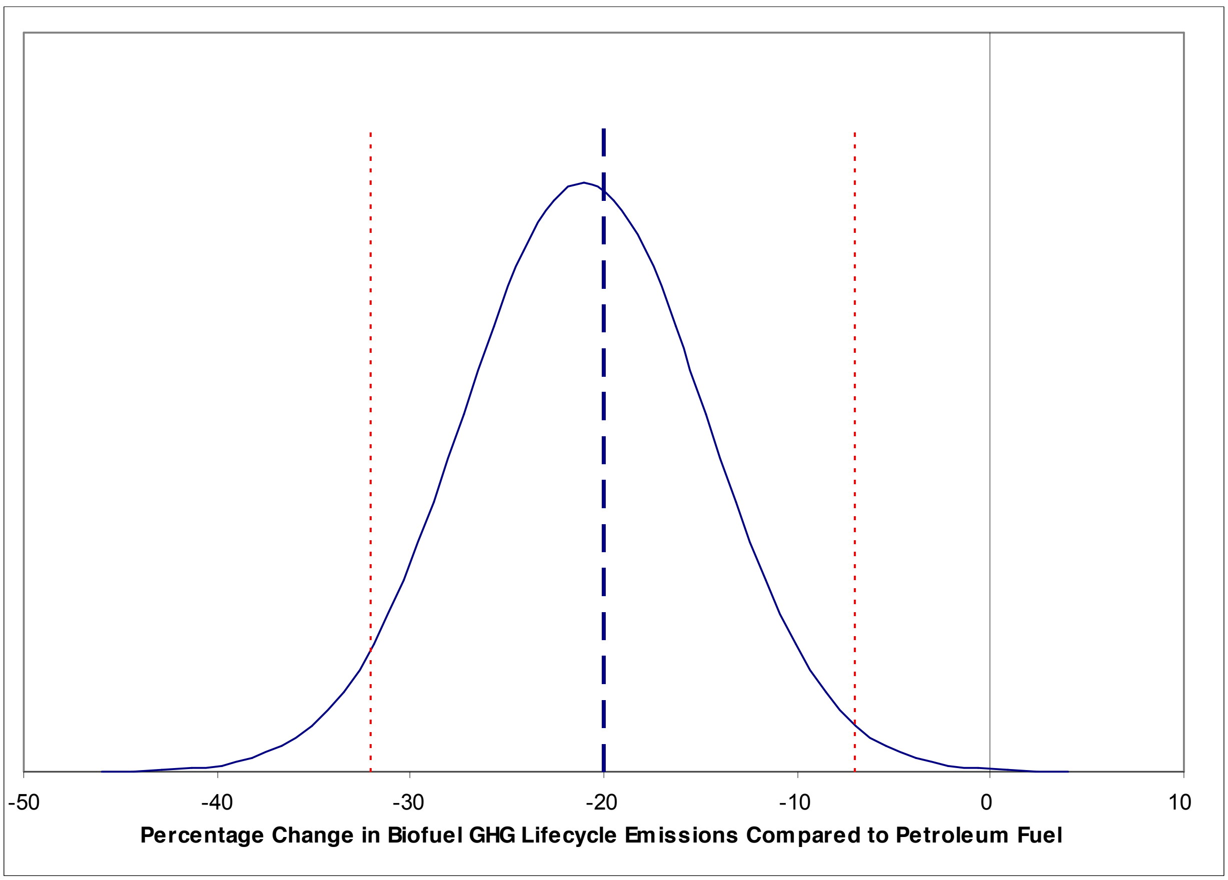
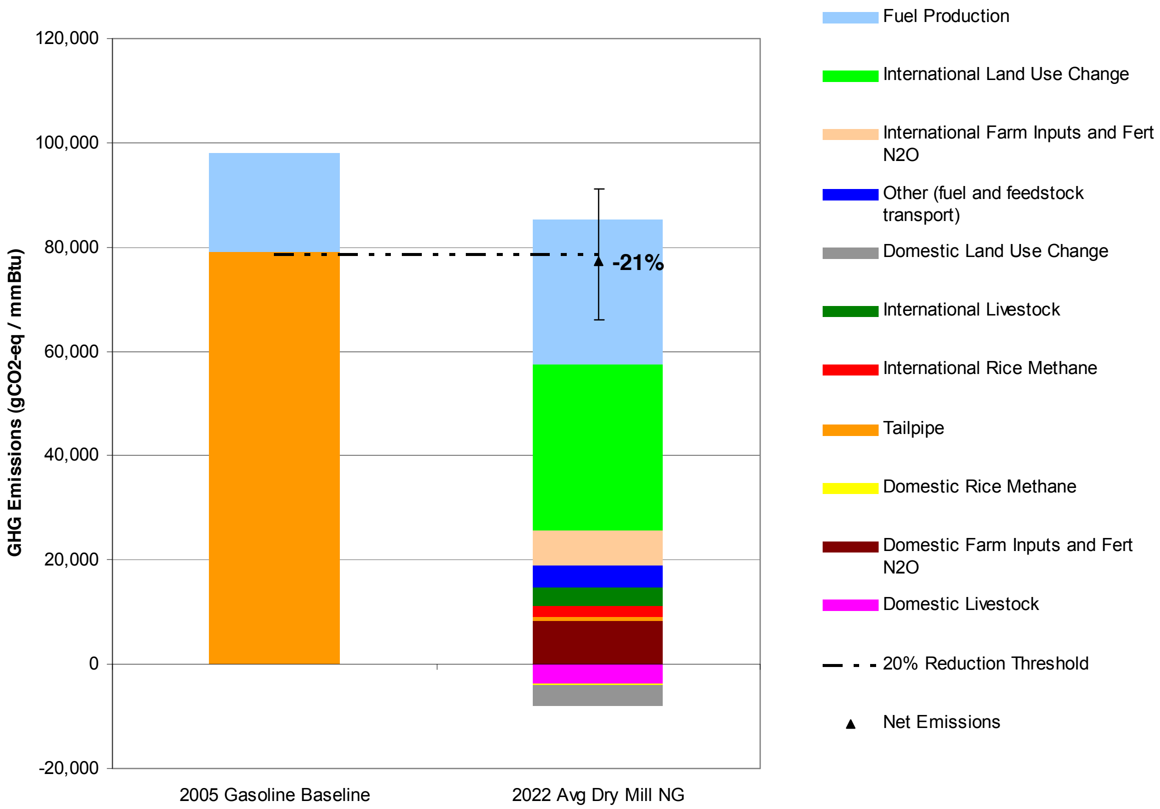


Figure 2.6-2 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the typical corn ethanol depicted in Figure 2.6-1 compared to the 2005 baseline average for gasoline. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU). Figure 2.6-2 includes our mean

estimate of international land use change emissions as well as the 95% confidence range from our uncertainty assessment, which accounts for uncertainty in the types of land use changes and the magnitude of resulting GHG emissions. For the petroleum baseline, the fuel production stage includes emissions from extraction, transport, refining and distribution of petroleum transportation fuel. Petroleum tailpipe emissions include CO_2 and non-CO_2 gases emitted from fuel combustion.

Figure 2.6-2. Results for a New Natural Gas Fired Corn Ethanol Plant by Lifecycle Stage Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)



We also looked at a number of different plat types, technologies and fuel types used. Figure 2.6-3 shows the results for an average 2022 corn ethanol dry mill plant (fractionation and 63% dry DGS) but with different fuel sources, natural gas coal and biomass.

Figure 2.6-3. Results for New Corn Ethanol Plants by Fuel Source and Lifecycle Stage Average 2022 plant: 63% dry, 37% wet DGS (w/ fractionation)

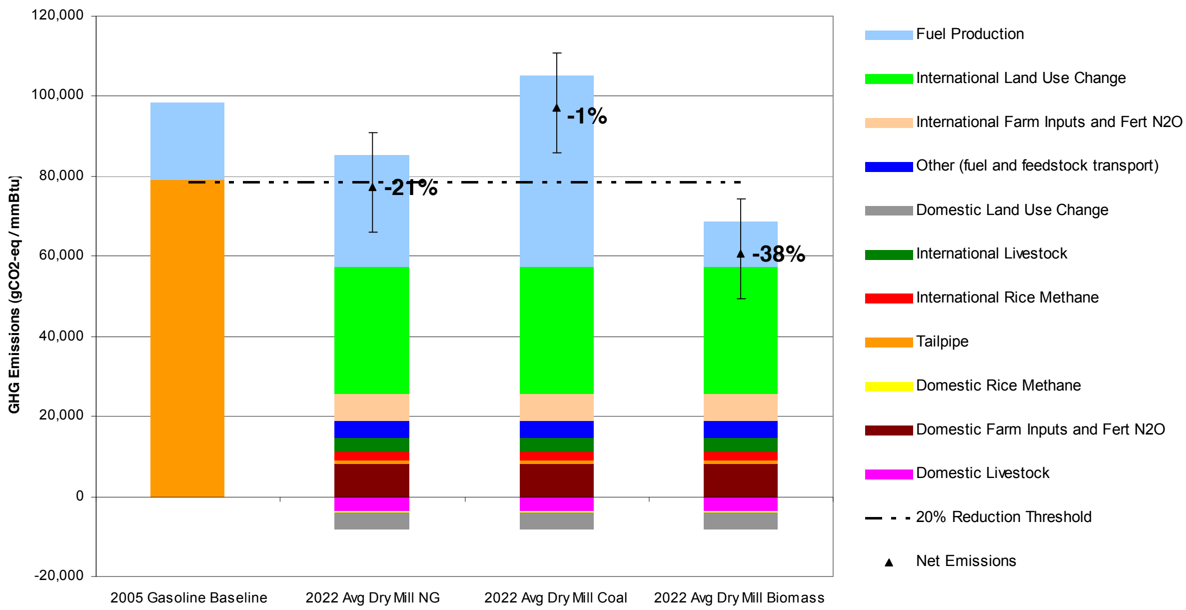


Table 2.6-1 shows the results for all of the different corn ethanol pathways considered.

Table 2.6-1. Results for New Corn Ethanol Plants by Type

Plant Type	Plant Technology	Percent Change in Lifecycle GHG Emissions		
	Time Horizon (years) Discount Rate Range	30 0% Low	30 0% Mean	30 0% High
Dry Mill NG	Base Plant (dry DGS)	-28%	-17%	-3%
Dry Mill NG	w/ CHP (dry DGS)	-31%	-20%	-6%
Dry Mill NG	w/ Fractionation (dry DGS)	-30%	-18%	-4%
Dry Mill NG	w/ CHP and Fractionation (dry DGS)	-33%	-22%	-7%
Dry Mill NG	w/ Fractionation and Membrane Separation (dry DGS)	-33%	-22%	-8%
Dry Mill NG	w/ CHP, Fractionation and Membrane Separation (dry DGS)	-37%	-25%	-11%
Dry Mill NG	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-38%	-26%	-12%
Dry Mill NG	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-41%	-30%	-15%
Dry Mill NG	Base Plant (wet DGS)	-39%	-27%	-13%
Dry Mill NG	w/ CHP (wet DGS)	-42%	-30%	-16%
Dry Mill NG	w/ Fractionation (wet DGS)	-38%	-26%	-12%
Dry Mill NG	w/ CHP and Fractionation (wet DGS)	-41%	-29%	-15%
Dry Mill NG	w/ Fractionation and Membrane Separation (wet DGS)	-41%	-30%	-16%
Dry Mill NG	w/ CHP, Fractionation and Membrane Separation (wet DGS)	-44%	-33%	-19%
Dry Mill NG	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-44%	-33%	-18%
Dry Mill NG	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-47%	-36%	-22%
Dry Mill Coal	Base Plant (dry DGS)	1%	12%	26%
Dry Mill Coal	w/ CHP (dry DGS)	-1%	10%	24%
Dry Mill Coal	w/ Fractionation (dry DGS)	-7%	5%	19%
Dry Mill Coal	w/ CHP and Fractionation (dry DGS)	-9%	3%	17%
Dry Mill Coal	w/ Fractionation and Membrane Separation (dry DGS)	-14%	-3%	11%

Plant Type	Plant Technology	Percent Change in Lifecycle GHG Emissions		
Dry Mill Coal	w/ CHP, Fractionation and Membrane Separation (dry DGS)	-16%	-5%	9%
Dry Mill Coal	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-23%	-12%	2%
Dry Mill Coal	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-25%	-14%	0%
Dry Mill Coal	Base Plant (wet DGS)	-21%	-10%	4%
Dry Mill Coal	w/ CHP (wet DGS)	-23%	-12%	2%
Dry Mill Coal	w/ Fractionation (wet DGS)	-23%	-11%	3%
Dry Mill Coal	w/ CHP and Fractionation (wet DGS)	-25%	-13%	1%
Dry Mill Coal	w/ Fractionation and Membrane Separation (wet DGS)	-30%	-19%	-5%
Dry Mill Coal	w/ CHP, Fractionation and Membrane Separation (wet DGS)	-32%	-21%	-7%
Dry Mill Coal	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-36%	-24%	-10%
Dry Mill Coal	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-38%	-26%	-12%
Dry Mill Biomass	Base Plant (dry DGS)	-51%	-40%	-26%
Dry Mill Biomass	w/ CHP (dry DGS)	-59%	-47%	-33%
Dry Mill Biomass	w/ Fractionation (dry DGS)	-49%	-38%	-24%
Dry Mill Biomass	w/ CHP and Fractionation (dry DGS)	-57%	-45%	-31%
Dry Mill Biomass	w/ Fractionation and Membrane Separation (dry DGS)	-49%	-38%	-24%
Dry Mill Biomass	w/ CHP, Fractionation and Membrane Separation (dry DGS)	-56%	-45%	-31%
Dry Mill Biomass	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-49%	-38%	-24%
Dry Mill Biomass	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (dry DGS)	-57%	-45%	-31%
Dry Mill Biomass	Base Plant (wet DGS)	-52%	-41%	-27%
Dry Mill Biomass	w/ CHP (wet DGS)	-59%	-48%	-34%
Dry Mill Biomass	w/ Fractionation (wet DGS)	-50%	-39%	-25%
Dry Mill Biomass	w/ CHP and Fractionation (wet DGS)	-57%	-46%	-32%
Dry Mill Biomass	w/ Fractionation and Membrane Separation (wet DGS)	-50%	-38%	-24%
Dry Mill Biomass	w/ CHP, Fractionation and Membrane Separation (wet DGS)	-57%	-45%	-31%
Dry Mill Biomass	w/ Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-50%	-38%	-24%
Dry Mill Biomass	w/ CHP, Fractionation, Membrane Separation, and Raw Starch Hydrolysis (wet DGS)	-57%	-46%	-32%
Wet Mill	with NG	-19%	-7%	7%
Wet Mill	with Coal	8%	19%	33%
Wet Mill	with Biomass	-59%	-48%	-33%

2.6.1.2 Corn Butanol Results

We analyzed corn butanol, similar to corn ethanol in terms of types of plants and technologies.

Figure 2.6-4 shows the percent change in the lifecycle GHG emissions compared to the petroleum gasoline baseline in 2022 for a corn butanol dry mill plant using natural gas for its process energy source, drying the national average of 63% of the DGS it produces and employing corn oil fractionation technology. Lifecycle GHG emissions equivalent to the gasoline baseline are represented on the graph by the zero on the X-axis. The 20% reduction threshold is represented by the dashed line at -20 on the graph. The results for this corn butanol scenario are that the midpoint of the range of results is a 31% reduction in GHG emissions compared to the gasoline 2005 baseline. The 95% confidence interval around that midpoint ranges from a 20% reduction to a 40% reduction compared to the gasoline baseline based on the uncertainty in the land use change assumptions.

The butanol results in slightly greater GHG reductions compared to corn ethanol because of the greater energy content of the fuel. There is actually slightly more energy used in processing but there is a greater energy production output. Therefore, on a per mmBTU basis there are less GHG emissions produced across all the lifecycle.

Figure 2.6-4. Distribution of Results for a New Natural Gas Fired Corn Butanol Plant Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)

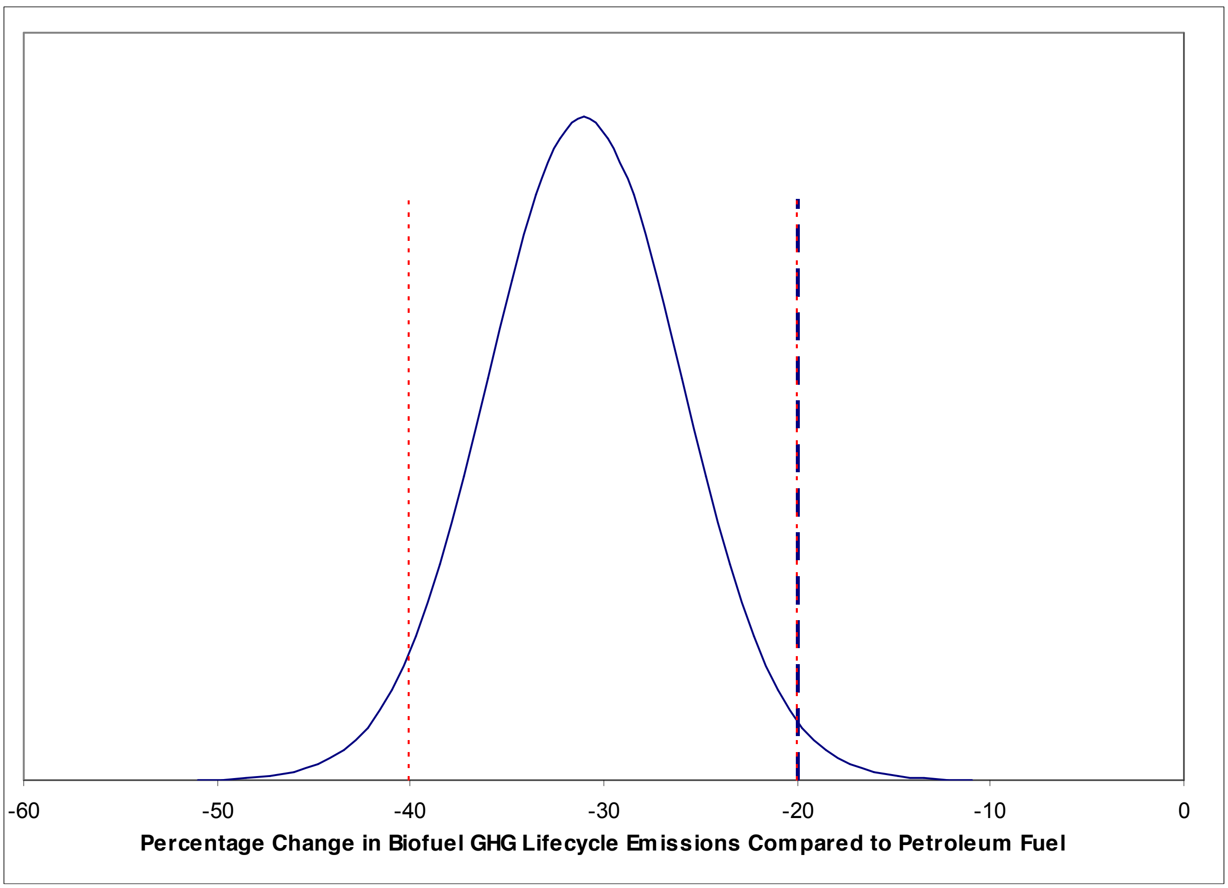
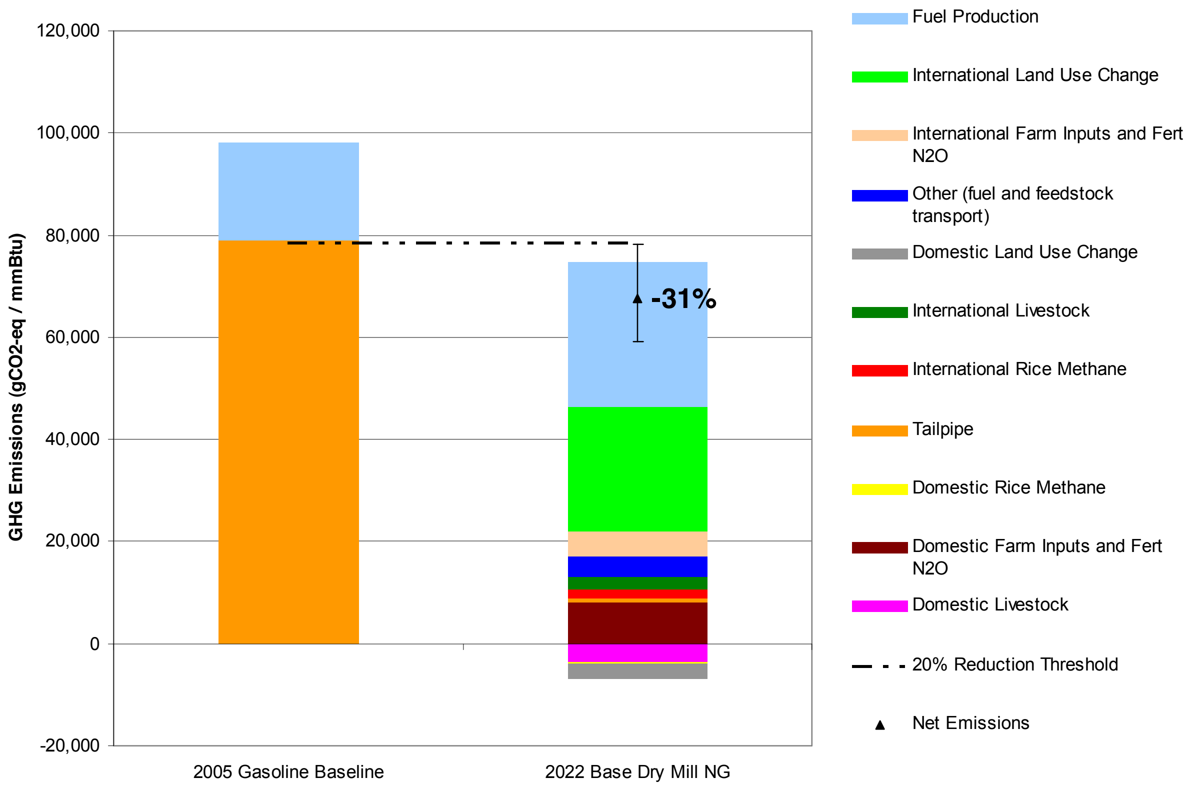


Figure 2.6-5 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the typical corn butanol plant depicted in Figure 2.6-5 compared to the 2005 baseline average for gasoline. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-5 includes our mean estimate of international land use change emissions as well as the 95% confidence range from our uncertainty assessment, which accounts for uncertainty in the types of land use changes and the magnitude of resulting GHG emissions.

Figure 2.6-5. Results for New Corn Butanol Plants by Lifecycle Stage
Average 2022 plant: 63% dry, 37% wet DGS (w/ fractionation)



2.6.1.3 Biodiesel Results

Figure 2.6-6 shows the percent change in the typical 2022 soybean biodiesel lifecycle GHG emissions compared to the petroleum diesel fuel 2005 baseline. Lifecycle GHG emissions equivalent to the diesel fuel baseline are represented on the graph by the zero on the X-axis. The 50% reduction threshold is represented by the dashed line at -50 on the graph. The results for soybean biodiesel are that the midpoint of the range of results is a 57% reduction in GHG emissions compared to the diesel fuel baseline. The 95% confidence interval around that midpoint results in range of a 22% reduction to an 85% reduction compared to the diesel fuel 2005 baseline.

Figure 2.6-6. Distribution of Results Soybean Biodiesel
Average 2022 plant; natural gas

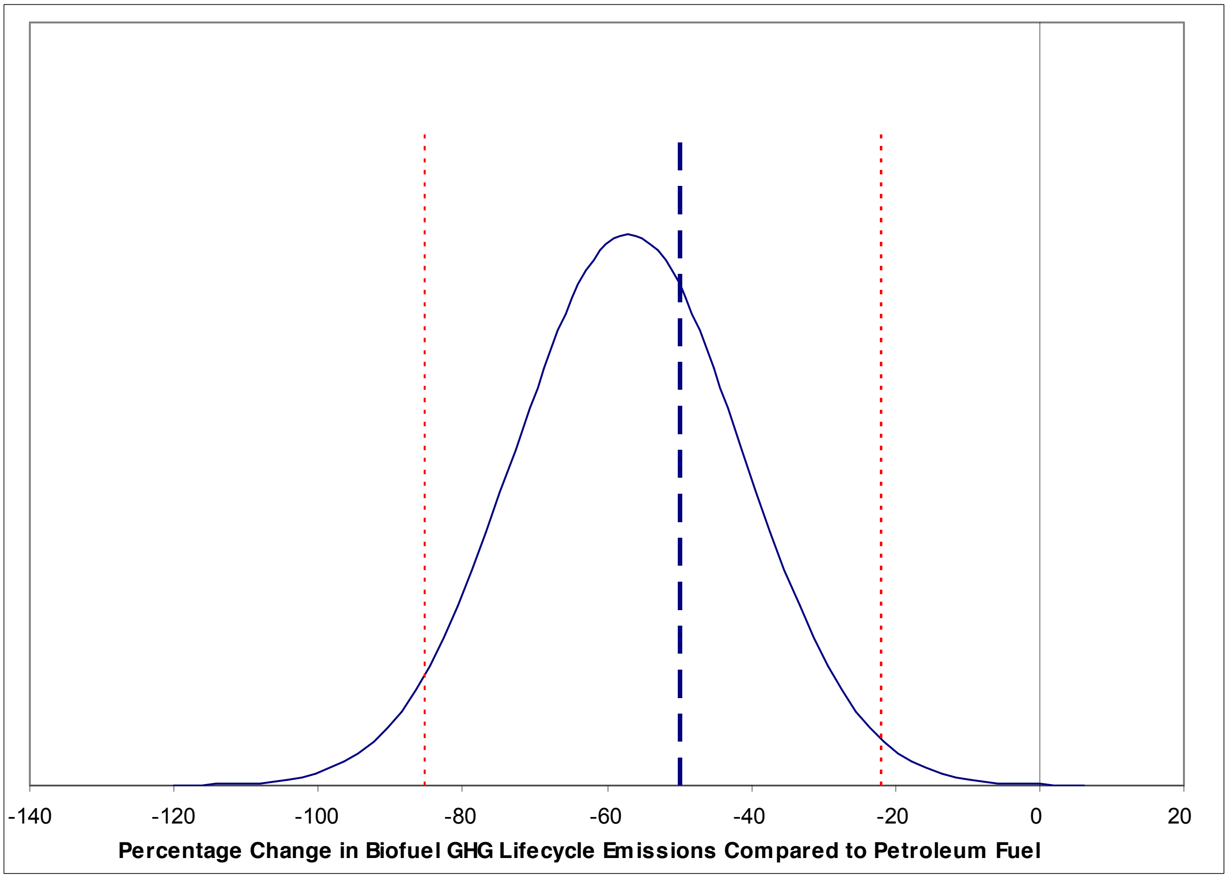


Figure 2.6-7 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the typical soybean biodiesel plant depicted in

Figure 2.6-6 Figure 2.6-6 compared to the 2005 baseline average for diesel fuel. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-7 Figure 2.6-7 includes the mean estimate of international land use change emissions as well as the 95% confidence range from our uncertainty assessment, which accounts for uncertainty in the types of land use changes and the magnitude of resulting GHG emissions.

Figure 2.6-7 Figure 2.6-7 also includes emissions from waste grease based biodiesel. The waste grease biodiesel does not have any agricultural or land use emissions and therefore only a point source estimate is shown for that pathway.

Figure 2.6-7. Results for Biodiesel by Lifecycle Stage
Soybean and Waste Grease Feedstock

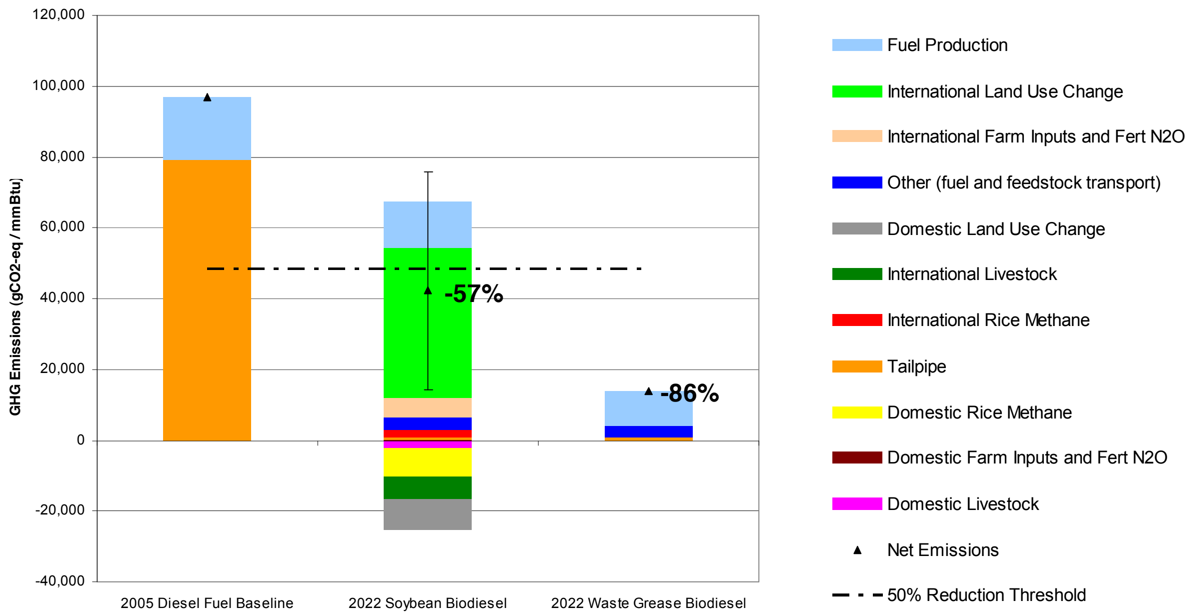
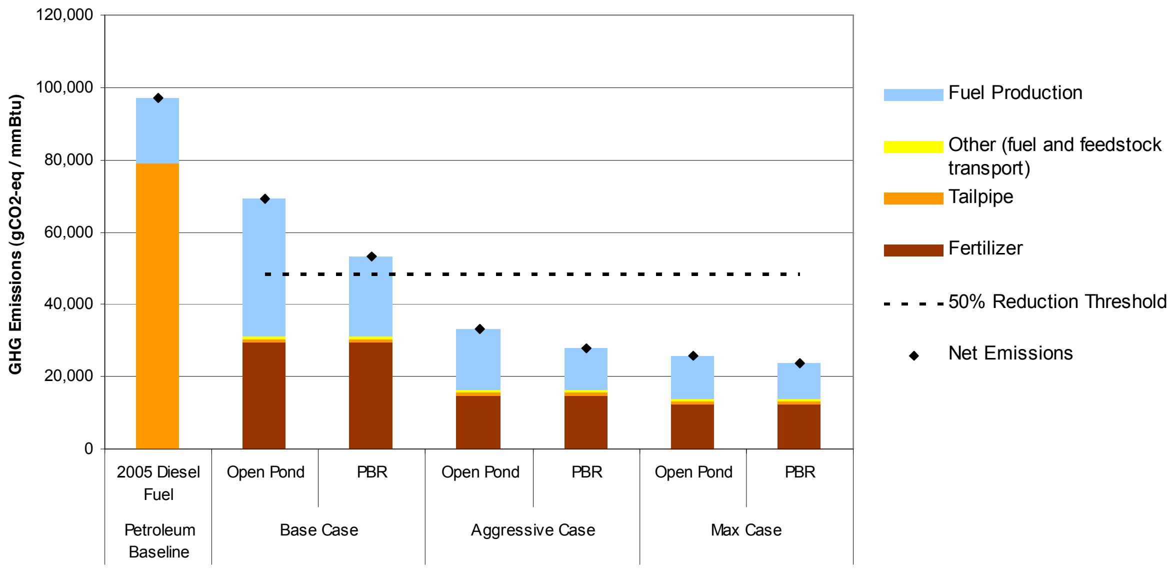


Figure 2.6-8 shows lifecycle GHG emissions broken down by several stages of the lifecycle impacts for algae oil to biodiesel compared to the 2005 baseline average for diesel fuel. Results are shown for the different cases of production described in Section 2.4.7.3.3. The algae oil biodiesel does not have any agricultural or land use emissions and therefore only a point source estimate is shown for each pathway.

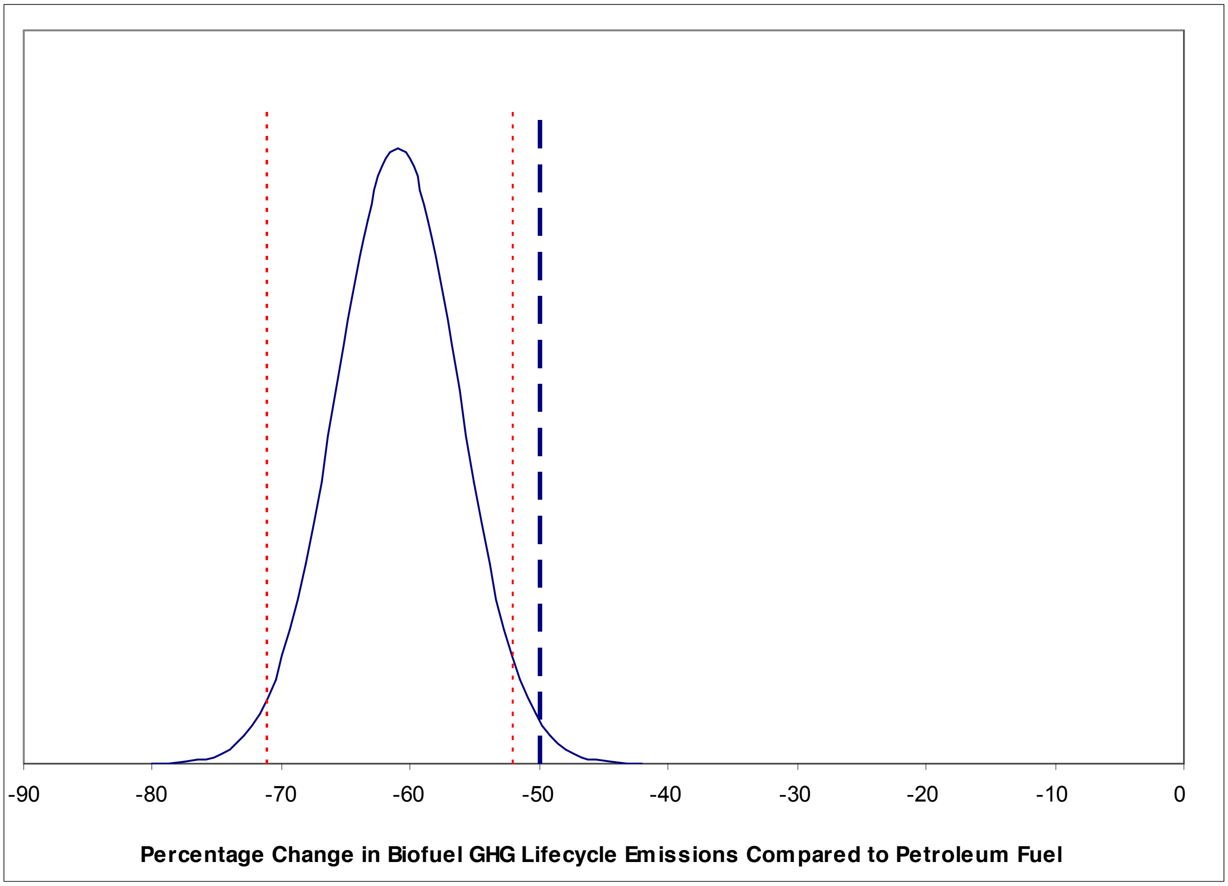
Figure 2.6-8. Results for Algae Biodiesel by Lifecycle Stage
Algae Oil Feedstock



2.6.1.4 Sugarcane Ethanol Results

Figure 2.6-9 shows the percent change in the average 2022 sugarcane ethanol lifecycle GHG emissions compared to the petroleum gasoline 2005 baseline. These results assume the ethanol is produced and dehydrated in Brazil prior to being imported into the U.S. and that the residue is not collected. Lifecycle GHG emissions equivalent to the gasoline baseline are represented on the graph by the zero on the X-axis. The 50% reduction threshold is represented by the dashed line at -50 on the graph. The results for this sugarcane ethanol scenario are that the midpoint of the range of results is a 61% reduction in GHG emissions compared to the gasoline baseline. The 95% confidence interval around that midpoint results in a range of a 52% reduction to a 71% reduction compared to the gasoline 2005 baseline.

Figure 2.6-9. Distribution of Results for Sugarcane Ethanol
Average 2022 plant: no residue collection

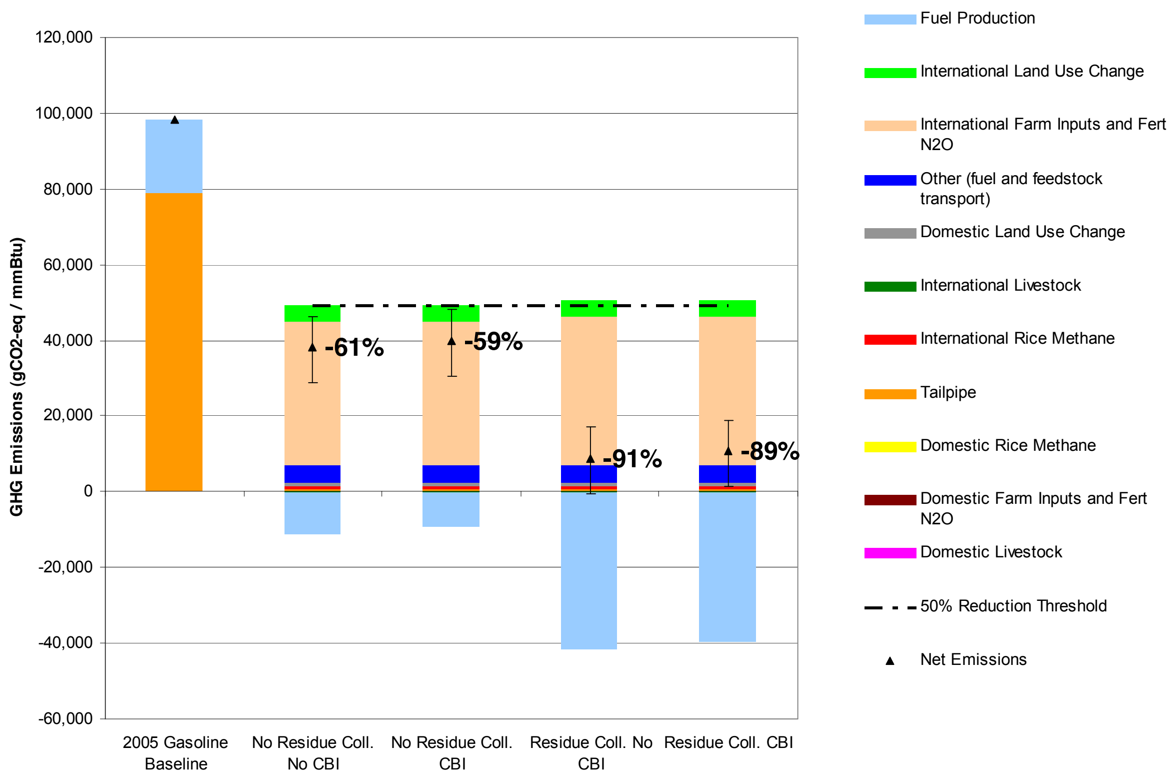


We also considered pathways assuming most crop residue of the leaves as well as stalks are collected (and therefore available for burning as process energy) or without the extra crop residue being neither collected nor burned as fuel. We also analyzed pathways assuming the ethanol is distilled in Brazil or alternatively being distilled in the Caribbean ("CBI").

Figure 2.6-10 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the difference sugarcane ethanol scenarios compared to the 2005 baseline average for gasoline. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-10 includes the mean estimate of international land use change emissions as well as the 95% confidence range from our uncertainty assessment, which accounts for uncertainty in the types of land use changes and the magnitude of resulting GHG emissions.

Figure 2.6-10. Results for Sugarcane Ethanol by Lifecycle Stage With and without residue collection and CBI



As

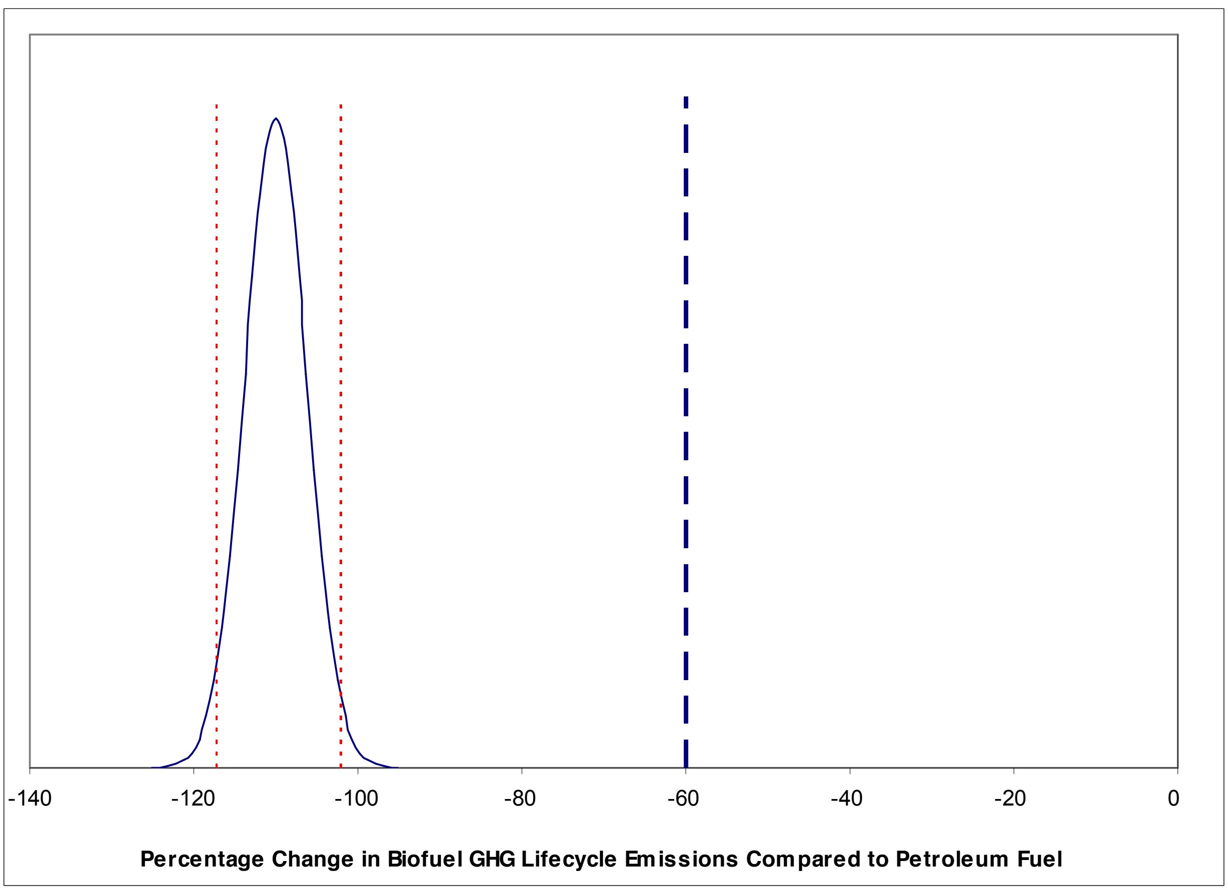
Figure 2.6-10 indicates, the sugarcane ethanol scenarios with residue collection have greater GHG reductions compared to the no collection cases. For residue collection there is slightly more energy and emissions needed for crop production due to collection and transport of the residue. However, there are significantly more GHG savings at the plant due to more excess electricity production from burning the collected residues.

The CBI cases in which the ethanol is distilled in the Caribbean add slightly more GHG emissions from burning fossil fuels for dehydration. This is slightly offset by the additional excess electricity from the sugarcane ethanol plant that does not need to dehydrate the ethanol. Energy used for dehydration at the ethanol plant could then be used to generate excess electricity that offsets grid electricity production, and results in GHG savings.

2.6.1.5 Cellulosic Biofuels Results

Figure 2.6-11 shows the percent change in the average lifecycle GHG emissions in 2022 for ethanol produced from switchgrass using the biochemical process compared to the petroleum gasoline 2005 baseline. Lifecycle GHG emissions equivalent to the gasoline baseline are represented on the graph by the zero on the X-axis. The 60% reduction threshold is represented by the dashed line at -60 on the graph. The results for this switchgrass ethanol scenario are that the midpoint of the range of results is a 110% reduction in GHG emissions compared to the gasoline baseline. The 95% confidence interval around that midpoint ranges from 102% reduction to a 117% reduction compared to the gasoline baseline.

Figure 2.6-11. Distribution of Results for Switchgrass Biochemical Ethanol
Average 2022 plant: biochemical process producing ethanol, excess electricity production



We have also analyzed additional cellulosic biofuel pathways (i.e., thermochemical cellulosic ethanol and a BTL diesel pathway) as well as considered crop residues as a cellulosic feedstock. Figure 2.6-12 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the different cellulosic feedstock to ethanol production scenarios compared to the 2005 baseline average for gasoline. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-12 includes the mean estimate of international land use change emissions as well as the 95% confidence range from our uncertainty assessment, which accounts for uncertainty in the types of land use changes and the magnitude of resulting GHG emissions. The residues to ethanol scenarios do not have any international land use emissions and therefore only a point source estimate is shown for those pathways.

Figure 2.6-12. Results for Cellulosic Ethanol by Lifecycle Stage Biochemical and Thermochemical for Switchgrass and Corn Stover

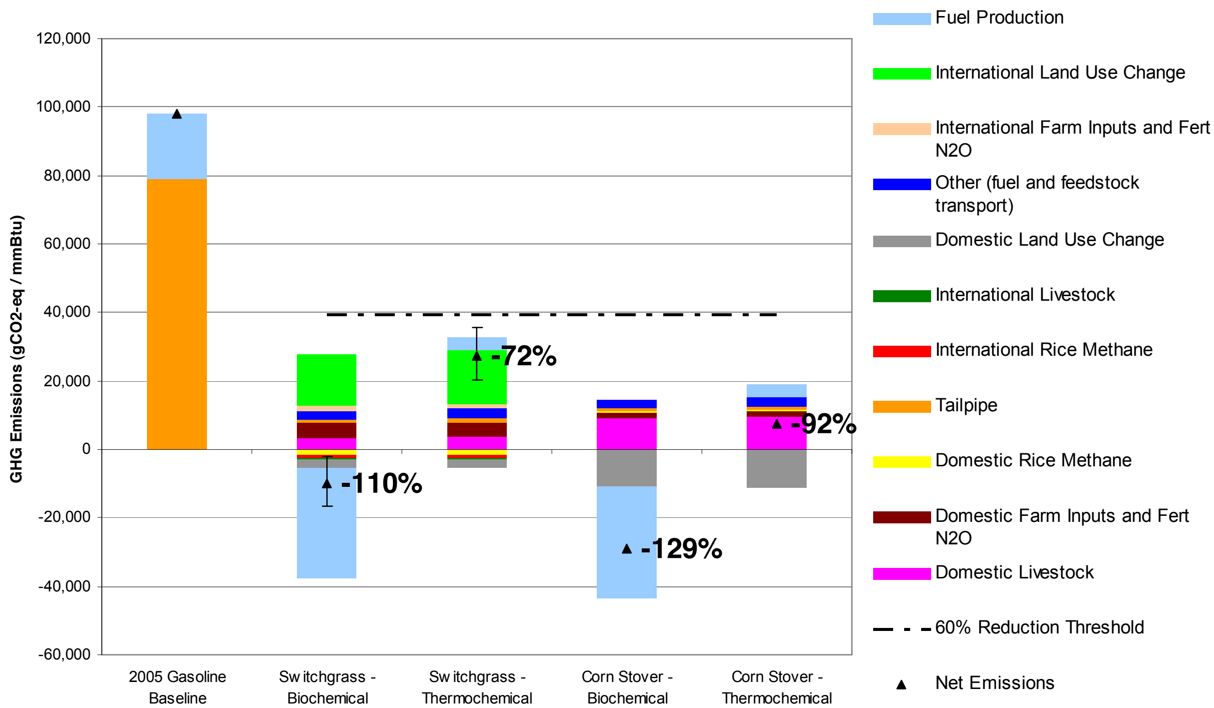
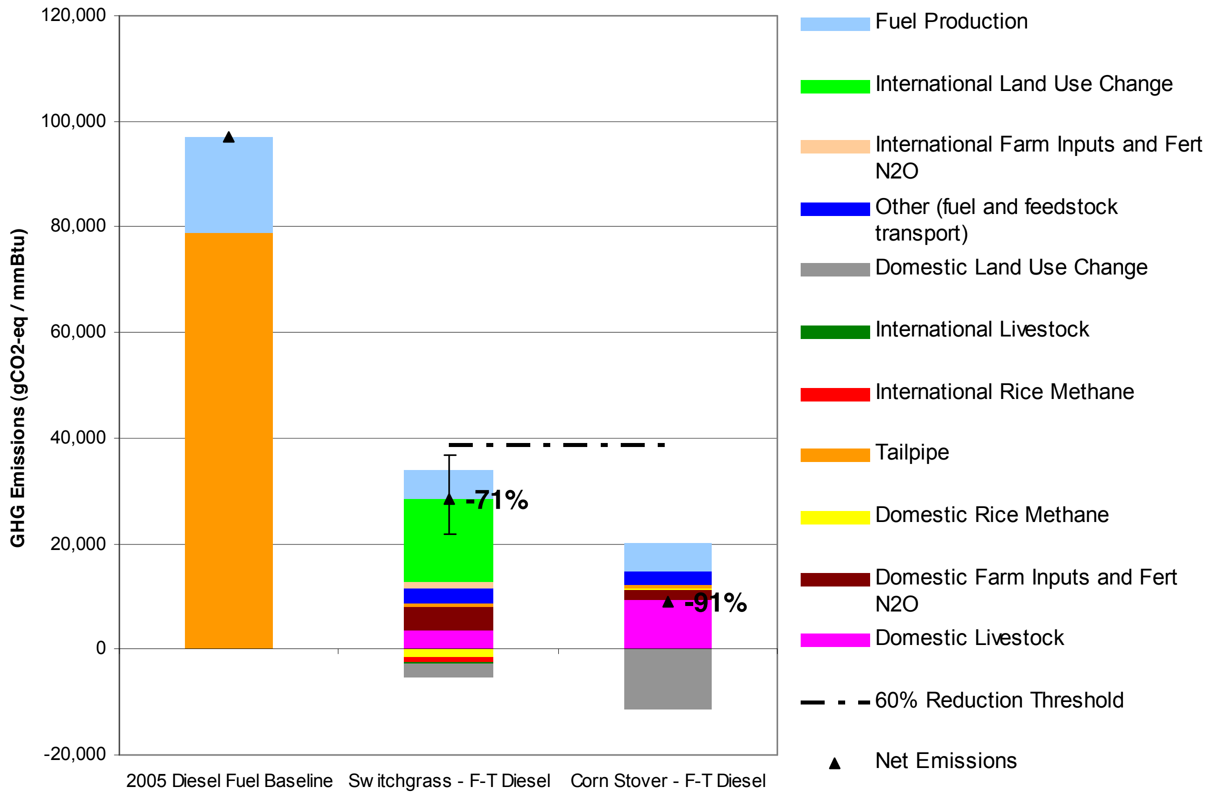


Figure 2.6-13 Figure 2.6-13 below includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the different cellulosic feedstock to F-T diesel fuel production scenarios compared to the 2005 baseline average for diesel fuel. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced ($gCO_2e/mmBTU$).

Figure 2.6-13. Results for Cellulosic Diesel Fuel by Lifecycle Stage
F-T Diesel Fuel for Switchgrass and Corn Stover



Biochemical ethanol production results in greater GHG savings compared to the thermochemical or F-T diesel fuel scenarios due to the excess electricity production from the lignin generated from the biochemical process. The corn stover scenarios have less overall agricultural sector GHG emissions compared to the switchgrass scenario and do not have international land use change emissions and therefore greater GHG savings.

2.6.2 Sensitivity Analysis

This section presents the results or several sensitivity analyses performed around the different main components of the lifecycle analysis. Some of the sensitivity analysis impact all fuels considered while some only impact specific fuels.

2.6.2.1 Timing and Discount Rate

In addition to estimating GHG emissions at every stage of the fuel lifecycle, EPA's task in this rulemaking is to integrate the GHG emissions estimates from all stages of the lifecycle in order to estimate lifecycle GHG percent reductions for each renewable fuel pathway. We have considered a number of ways to meet this challenge, and have identified several key methodological issues that can influence whether a particular renewable fuel pathway meets the thresholds set forth in the EISA. For example, one issue that deserves attention is the timing of lifecycle GHG emissions.

Section 2.4.5 explained that the lifecycle GHG emissions associated with biofuels can vary over time. Clearing forests, grasslands, and other types of land that sequester carbon, for crop production can results in GHG emissions for many years. As depicted in **Figure 2.6-14**, this type of land conversion produces large immediate GHG emissions, followed by a lesser stream of emissions that can last for many years. Biomass feedstocks grown annually on new cropland can be converted to biofuels that offer a GHG benefit relative to the petroleum product they replace, but these benefits may be small compared to the upfront GHG emissions associated with land clearing to expand crop production. Depending on the specific biofuel in question, it can take many years for the benefits of the biofuel to make up for the large initial releases of carbon that result from land conversion (e.g., the payback period).

The payback period calculation, presented graphically in **Figure 2.6-14**, represents the time it takes for the emissions savings from the production of biofuels to equal the potentially large initial emissions from land use changes. Although we do not believe it is appropriate to use the payback period for RFS2 compliance purposes, this calculation helps to illustrate the importance of the time dimension of renewable fuel lifecycle GHG emissions.

Figure 2.6-14. Corn Ethanol Payback Period

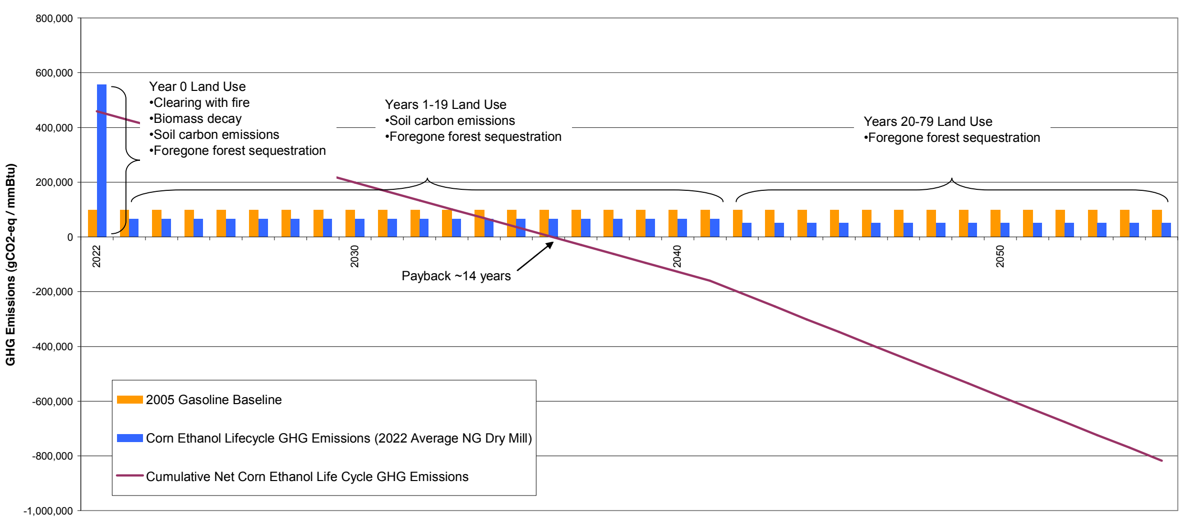


Figure 2.6-14 shows the baseline lifecycle GHG emissions from the 2022 average corn ethanol natural gas fired dry mill with fractionation and drying 63% of DGS, and from the 2005 gasoline baseline. In the first year, in this case 2022, corn ethanol lifecycle GHG emissions are more than five times greater than the gasoline it replaces. However, corn ethanol has ongoing GHG benefits in every subsequent year. It takes approximately 14 years for the annual GHG benefits of corn ethanol compared to gasoline to pay back the initial GHG releases from land clearing. This tells us that unless we analyze the lifecycle GHG emissions of corn ethanol over more than 14 years, corn ethanol from this pathway will not achieve a reduction compared to gasoline. As we extend our analysis beyond 14 years we will see increasing GHG reductions associated with the use of corn ethanol.

The same is true for other renewable fuels that result in land use change, soybean biodiesel, sugarcane ethanol, and switchgrass biofuels. Furthermore, the uncertainty in the land use change emissions results in a range of payback periods depending on the range of land use change emissions. **Table 2.6-2** shows the different payback periods for the different biofuels and for the high and low range of land use change emissions.

Table 2.6-2. Payback Periods for Different Fuels

	Payback Period (years)		
Type of Biofuel	Low	Midpoint	High
Corn Ethanol (2022 average plant)	7	14	24
Soybean biodiesel	5	9	21
Sugarcane ethanol (no residue collection, no CBI)	1	2	4
Switchgrass Ethanol (biochemical)	0	0	1
Switchgrass Ethanol (thermochemical)	1	1	2
Switchgrass Diesel (F-T diesel)	1	1	2

The payback periods shown in **Table 2.6-2** represent the time needed for the renewable fuels to break even in terms of GHG emissions compared to the petroleum fuel replaced. However, the threshold determinations needed for the rulemaking are based on the fuels reaching a percentage reduction compared to the petroleum fuels replaced. The threshold reduction time period is longer than just the breakeven point. **Table 2.6-3** shows the threshold requirements and time periods to reach those threshold reductions for each fuel.

Table 2.6-3. Threshold Periods for Different Fuels

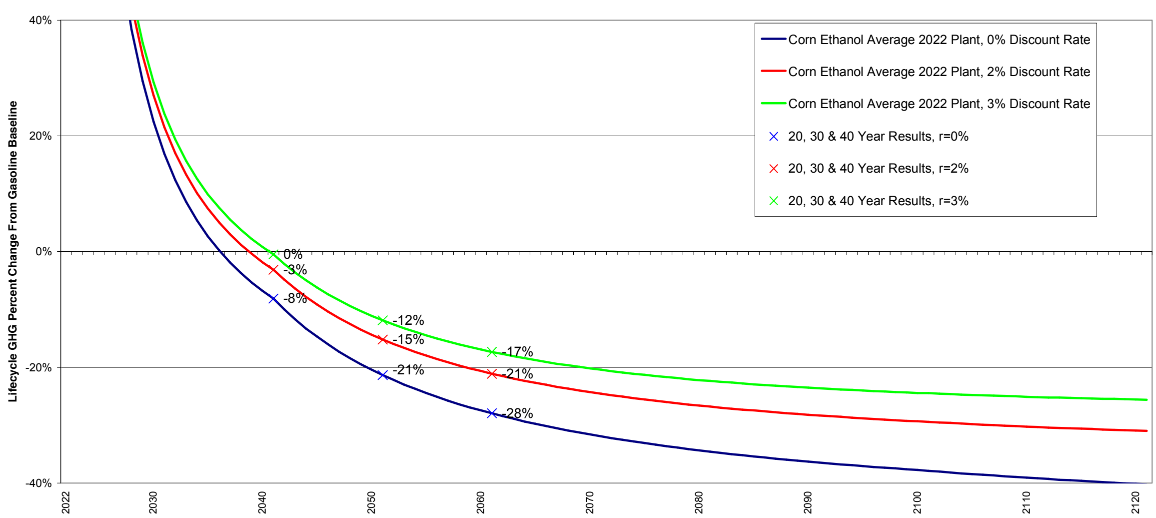
	Threshold Reduction	Threshold Period (years)		
Type of Biofuel	%	Low	Midpoint	High
Corn Ethanol (2022 average plant)	20	15	28	43
Soybean biodiesel	50	10	24	50
Sugarcane ethanol (no residue collection, no CBI)	50	6	12	24
Switchgrass Ethanol (biochemical)	60	2	3	5
Switchgrass Ethanol (thermochemical)	60	7	12	24
Switchgrass Diesel (F-T diesel)	60	7	14	26

The payback period concept helps to demonstrate the importance of the choice of a discount rate and time horizon for this analysis. These factors are so important because of the variation in GHG emissions from renewable fuels over time, and the contrasting steady annual emissions from the petroleum baseline. For the final rule threshold determinations we rely on a

30 year time horizon and a 0% discount rate. A longer time horizon would result in greater benefits for biofuels, and a higher discount rate would result in lower GHG reductions.

Figure 2.6-15 includes lifecycle GHG results for the 2022 average corn ethanol produced in a natural gas-fired dry mill over a continuum of time horizons. The horizontal axis is the choice of time horizon. As discussed above, our results indicate that the payback period for an average 2022 corn ethanol pathway is approximately 14 years. With a zero percent discount (the blue line in **Figure 2.6-15**) corn ethanol reduces GHG emissions by 21 percent over 30 years, and reduces emissions by 8 percent and 28 percent over 20 and 40 years respectively. With higher discount rates, it takes longer for the future benefits of corn ethanol production to payback earlier land clearing emissions. When we use a discount rate greater than zero, future benefits are discounted, causing the curves in **Figure 2.6-15** to flatten out over time. Results for the midpoint of land use change uncertainty are shown in **Figure 2.6-15**, the high and low land use change uncertainty results would shift the results. Low land use change results would shift the curves down, high land use change results would shift the curves up.

Figure 2.6-15. Lifecycle GHG Results for 2022 Average Corn Ethanol (Percent Change from Gasoline with Different Discount Rates and Time Horizons)



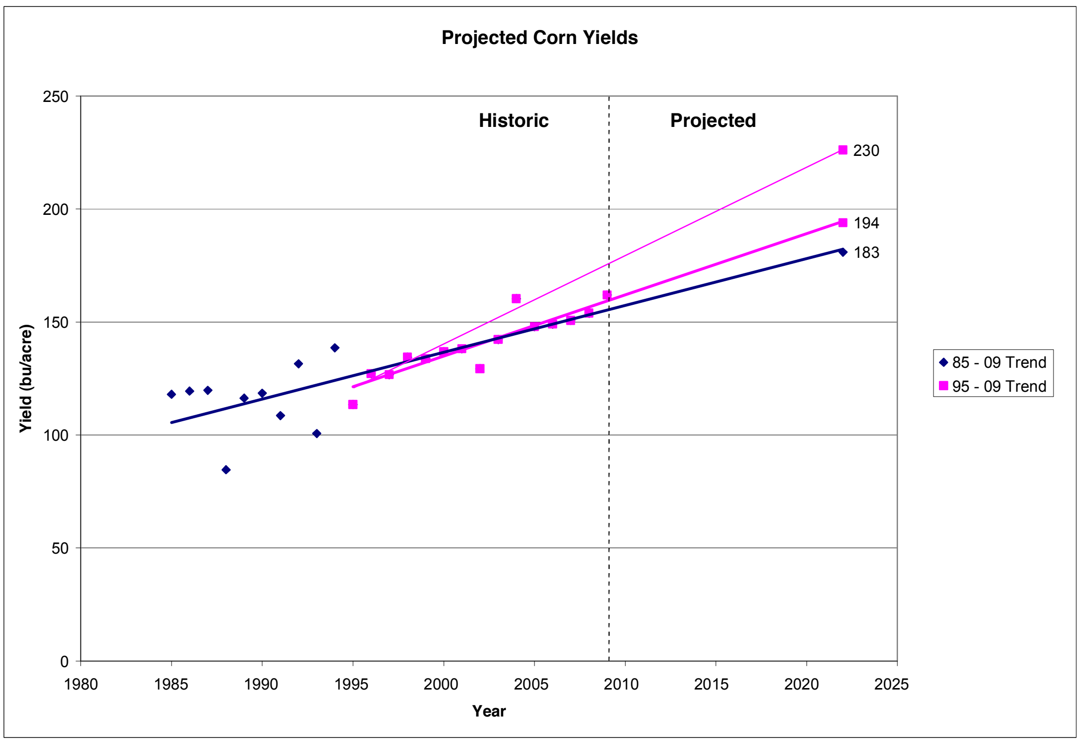
2.6.2.2 High Yield Scenario Results

There are many factors that go into the economic modeling but the yield assumptions for different crops has one of the biggest impacts on land use and land use change. Therefore, for this analysis we ran a base yield case and a high yield sensitivity case.

EPA's base yield projections are derived from extrapolating through 2022 long-term historical U.S. corn yields from 1985 to 2009. This estimate, 183 bushels/acre for corn and 48 bushels/acre for soybeans, is consistent with USDA's method of projecting future crop yields. During the public comment process we learned that numerous technical advancements--including better farm practices, seed hybridization and genetic modification--have led to more rapid gains in yields since 1995. In addition, commenters, including many leading seed companies, provided data supporting more rapid improvements in future yields. For example, commenters pointed to recent advancements in seed development (including genetic modification) and the general accumulation of knowledge of how to develop and bring to market seed varieties—factors that would allow for a greater rate of development of seed varieties requiring fewer inputs such as fertilizer and pest management applications.

Therefore, in coordination with USDA experts, EPA has developed for this final rule a high yield case scenario of 230 bushels/acre for corn and 60 bushels/acre for soybeans. These figures represent the 99% upper bound confidence limit of variability in historical U.S. yields. This high yield case represents a feasible high yield scenario for the purpose of a sensitivity test of the impact on the results of higher yields. **Figure 2.6-16** shows the historic data and trends for U.S. corn yields.

Figure 2.6-16. U.S. Historic and Projected Corn Yields



Feedback we received indicated that corn and soybean yields respond in tandem and that a high yield corn case would also imply a higher yield for soybeans as well. The high yield case is therefore based on higher yield corn and soybeans in the U.S. as well as in the major corn and soybean producing countries around the world. For international yields, it is reasonable to assume the same percent increases from the baseline yield assumptions could occur as we are estimating for the U.S. Thus in the case of corn, 230 bushels per acre is approximately 25% higher than the U.S. baseline yield of 183 bushels per acre in 2022. This same 25% increase in yield can be expected for the top corn producers in the rest of the world by 2022, as justified improvements in seed varieties and, perhaps even more so than in the case of the U.S., improvements in farming practices which can take more full advantage of the seed varieties' potential. For example, seeds can be more readily developed to perform well in the particular regions of these countries and can be coupled with much improved farming practices as farmers move away from historical practices such as saving seeds from their crop for use the next year and better understand the economic advantages of modern farming practices. So the high yield scenarios would not have the same absolute yield values in other countries as the U.S. but would have the same percent increase.

Figure 2.6-17 shows the results for the 2022 average corn ethanol plant with the base and high yield scenarios. The high yield scenario has a modest change in the overall GHG reductions of corn ethanol. With the high yield estimates the 2022 average corn ethanol plant reduces GHG emissions compared to the gasoline baseline by 23%, compared to reductions of 21% for the base case scenario.

Figure 2.6-17.
Distribution of High and Base Yield Results for a
New Natural Gas Fired Corn Ethanol Plant
Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)

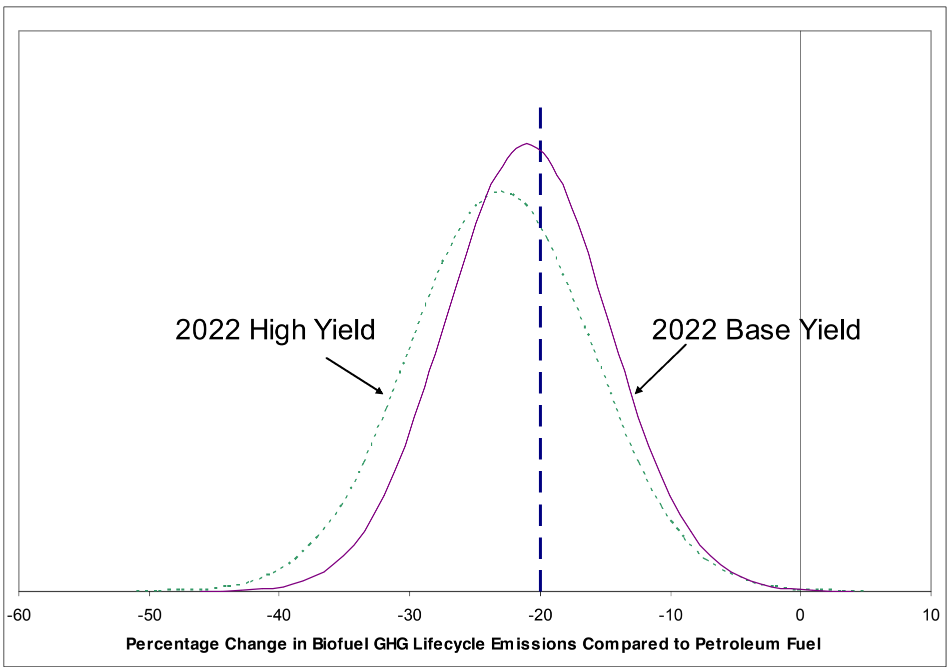
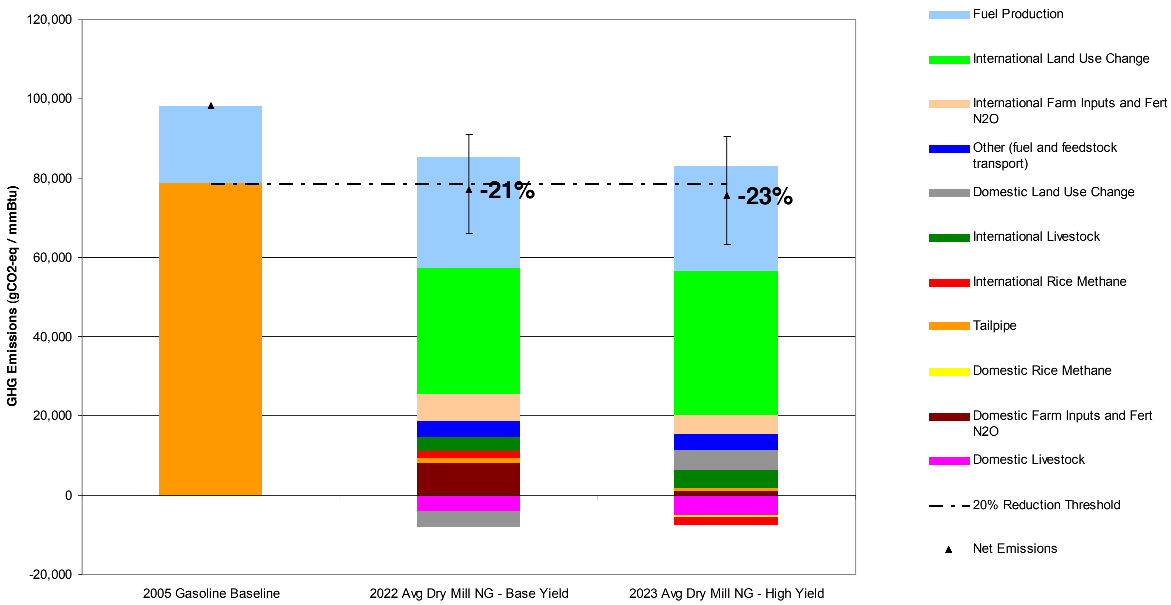


Figure 2.6-18 Figure 2.6-18 includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for the 2022 average corn ethanol plant for the base and high yield scenario compared to the 2005 baseline average for gasoline. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-18. High and Base Yield Results for a New Natural Gas Fired Corn Ethanol Plant by Lifecycle Stage
Average 2022 plant: natural gas, 63% dry, 37% wet DGS (w/ fractionation)



The main difference with the high yield scenario is that as ethanol production expands there is less overall land use and crop shifting needed domestically, reflected by lower domestic Farm input impacts. However, there is actually a greater impact on livestock compared to the base case. There is a greater shifting to grazing livestock internationally which results in more pasture land needed and slightly higher international land use change emissions.

Figure 2.6-19 Figure 2.6-19 shows the results for soybean biodiesel with the base and high yield scenarios. The high yield scenario has a fairly significant change in the overall GHG reductions of soybean biodiesel. With the high yield estimates soybean biodiesel reduces GHG emissions compared to the diesel fuel baseline by 70%, compared to reductions of 57% for the base case yield scenario.

Figure 2.6-19. Distribution of High and Base Yield Results for Soybean Biodiesel

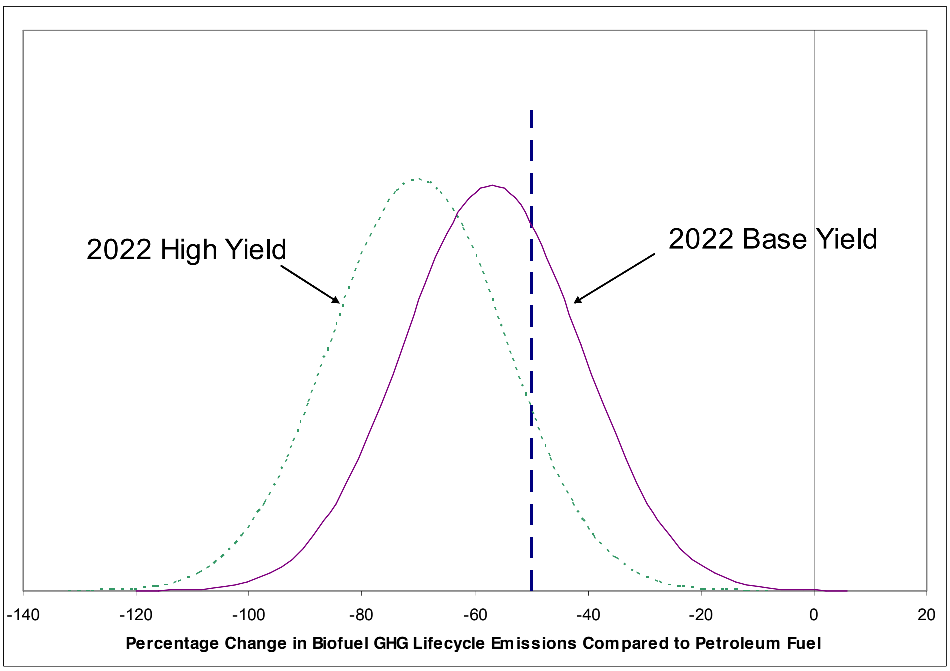
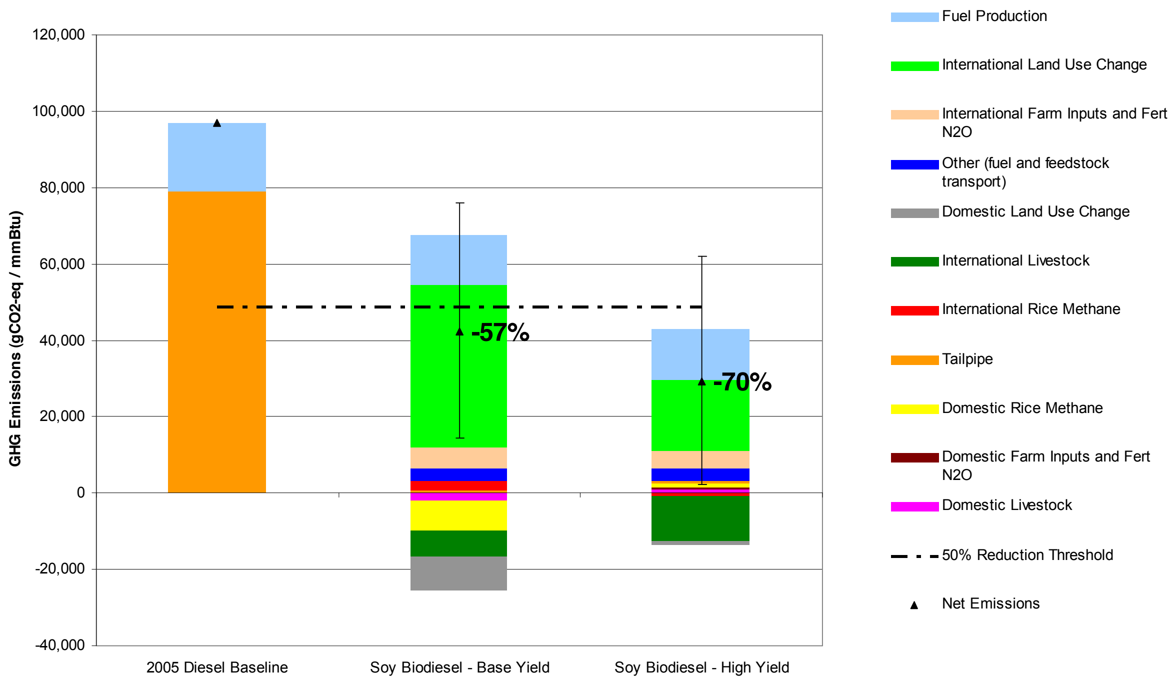


Figure 2.6-20 Figure 2.6-20 includes lifecycle GHG emissions broken down by several stages of the lifecycle impacts for soybean biodiesel for the base and high yield scenario compared to the 2005 baseline average for diesel fuel. Lifecycle emissions are normalized per energy unit of fuel produced and presented in grams of carbon-dioxide equivalent GHG emissions per million British Thermal Units of fuel produced (gCO_2e/mmBTU).

Figure 2.6-20. High and Base Yield Results for Soybean Biodiesel



Similar to the corn ethanol high yield scenario for the soybean high yield case the biggest impact is on livestock changes compared to the base case. There is a greater shifting in the high yield case away from grazing livestock internationally which results in less pasture land needed and lower international land use change emissions.

2.7 Overall Lifecycle Greenhouse Gas Emissions Results of Rulemaking Volumes Compared to AEO Projected Volumes

Our analysis of the overall GHG emission impacts of this proposed rulemaking was performed in parallel with the lifecycle analysis performed to develop the individual fuel thresholds described in previous sections. The same system boundaries apply such that this analysis includes the effects of three main areas: a) emissions related to the production of biofuels, including the growing of feedstock (corn, soybeans, etc.) with associated domestic and international land use change impacts, transport of feedstock to fuel production plants, fuel production, and distribution of finished fuel; b) emissions related to the extraction, production and distribution of petroleum gasoline and diesel fuel that is replaced by use of biofuels; and c) difference in tailpipe combustion of the renewable and petroleum based fuels.

Consistent with the fuel volume feasibility analysis and criteria pollutant emissions evaluation, our analysis of the GHG impacts of this proposed rulemaking was conducted by comparing the difference between a 2022 reference case and a 2022 control case with volumes of renewable fuels meeting the RFS2 mandate. Similar to what was done to calculate lifecycle thresholds for individual fuels we considered the change in 2022 of these two volume scenarios of renewable fuels to determine overall GHG impacts of the rule. The reference case for the

GHG emission comparisons was taken from the AEO 2007 projected renewable fuel production levels for 2022 prior to enactment of EISA. This scenario provided a point of comparison for assessing the impacts of the RFS2 standard volumes on GHG emissions. We ran these multi fuel scenarios through our FASOM and FAPRI-CARD models and applied the satellite data land use change assumptions to determine to overall GHG impacts of producing this increase in renewable fuels.

The main differences between this overall impacts analysis and the analysis conducted to develop the threshold values for the individual fuels were that we analyzed the total change in renewable fuels in one scenario as opposed to looking at individual fuel impacts. When analyzing the impact of the 2022 EISA mandate, we also took into account the agricultural sector interactions necessary to produce the full complement of feedstock.

We also considered a mix of plant types and configurations for the 2022 renewable fuel production representing the mix of plants and feedstock we project to be in use in 2022. **Table 2.7-1** shows the types of plants considered and the volumes produced by each in the analysis for the references and control cases.

Table 2.7-1. Types of Plants and Volumes Considered in 2022

	Plant Configuration and Energy Used (Btu/gal)							Volume (Bgal)		
		NG Use	Coal Use	Biomass Use	Diesel Fuel Use	Purchased Elec	Sold Elec	Reference Case	Policy Case	Difference
Corn Ethanol – Dry Mill NG	- Base Plant (dry DDGS)	25,672				2,165		4.2	5.2	1.0
	- Base Plant (wet DGS)	16,320				2,165		2.5	3.1	0.6
	- Integrated Biogas System (dry DGS)	11,459				231		0.9	1.2	0.2
	- Integrated Biogas System (wet DGS)	7,285				231		0.6	0.7	0.1
Corn Ethanol – Dry Mill Coal	- Base Plant (dry DDGS)		34,773			231		0.3	0.3	0.1
	- Base Plant (wet DGS)		22,106			231		0.2	0.2	0.0
Corn Ethanol – Dry Mill Biomass	- Base Plant (dry DDGS)			33,147		1,679		1.5	1.8	0.4
	- Base Plant (wet DGS)			21,072		1,679		0.9	1.1	0.2
Corn Ethanol – Wet Mill	- Plant with NG	45,950						0.0	0.02	0.02
	- Plant with coal		45,950					1.4	1.4	0.0
Cellulosic Ethanol – Enzymatic	- Switchgrass feedstock & lignin used as fuel			72,144			-12,249	0.0	1.5	1.5
	- Corn stover feedstock & lignin used as fuel			68,431			-12,249	0.2	1.0	0.7
Cellulosic Ethanol – Thermochemical	- Switchgrass feedstock			100,543	177			0.0	1.5	1.5
	- Corn stover feedstock			95,369	177			0.0	1.0	1.0
Biodiesel	- Soybean oil feedstock	18,913				3,205		0.4	1.4	1.1
	- Yellow grease / tallow feedstock	21,051				494		0.0	0.2	0.2
Renewable Diesel	- Yellow grease / tallow feedstock					838		0.0	0.2	0.2
Cellulosic Diesel – F-T	- Farmed trees feedstock			198,429	327	13		0.0	6.5	6.5
Sugarcane Ethanol - CBI	- Marginal Elec	2,592		84,241	2,606		-7,287	0.6	2.2	1.6

The upstream feedstock production and processing impacts for each of the different fuel technologies were modeled based on the same assumptions used in determining the per fuel lifecycle GHG results described in previous sections.

For this overall impacts analysis we also used a different petroleum baseline fuel that is offset from renewable fuel use. The lifecycle threshold values are required by EISA to be based on a 2005 petroleum fuel baseline. For this analysis of the overall impacts of the rule we considered the crude oil and finished product that would be replaced in 2022.

For this analysis we consider that 25% of displaced gasoline will be imported gasoline and 0% of displaced diesel fuel will be imported diesel fuel. For the types of gasoline displaced we assume 65% of the displaced gasoline will be conventional gasoline and 35% will be RFG blendstock gasoline. We assume 100% of the displaced diesel fuel will be low sulfur diesel fuel.

In order to come up with GHG emissions for average crude oil used in producing gasoline and diesel fuel in 2022 we assumed 7.6% would be from tar sands and 3.8% would be from Venezuelan heavy crude. The basis for this was EIA projections for 2022[652]. EIA projects that roughly 64% of total Canadian crude oil production will be oil sand production in 2022, and that roughly 40% of total Venezuelan crude oil production will be heavy crude production in 2022. EIA also has assumptions on how much crude oil will be imported into the U.S. from Canada and Venezuela in 2022. We assumed the percentage of this imported Canadian and Venezuelan crude oil that would be oil sands and heavy oil was the same percentage of total production that is unconventional crude in those countries (~64% for Canada and ~41% for Venezuela). Based on the percent of Canadian and Venezuelan imports to total crude oil projected in 2022, oil sands represented 7.6% and heavy oil represented 3.8% of total crude oil use.

For this analysis we did not assume any efficiency improvements at the petroleum refining portion of the gasoline and diesel fuel lifecycle. Therefore the same refining energy use and emissions was assumed that was used to represent the 2005 petroleum fuel baseline. One the one hand this may be overestimating energy use and emission from petroleum refining, however, this also does not factor in recent regulations that might increase energy use and emissions, such as increased desulfurization of both gasoline and diesel fuel.

Furthermore, the tailpipe emissions changes were determined based on the specific volumes and blends of fuel considered as opposed to looking at only the difference between the renewable fuel and petroleum fuel replaced. For highway vehicles, the impact of this rule on Methane (CH_4) and Nitrous Oxide (N_2O) emissions is primarily due to vehicles switching from gasoline to E85 fuel. Based on available data, we projected no change in N_2O or CH_4 emissions from highway vehicles that switched from conventional gasoline to E10. For diesel highway vehicles, emissions of N_2O and CH_4 are almost one hundred times less than emissions from gasoline vehicles,[653] thus diesels were omitted from this analysis.

To estimate the inventory-wide impact, we used MOVES to model CH_4 and N_2O for highway gasoline vehicles using reference case fuels. Because MOVES does not vary CH_4 and N_2O emissions by temperature or by gasoline fuel properties, the model was run at the annual, national level. FFV use was assumed to be limited to light duty cars and light duty trucks. We multiplied the appropriate E85 factor by the emissions for that model year and then computed a weighted average of E85 and E10 emissions for both CH_4 and N_2O. In order to compare the results in a meaningful way, we also computed the CO_2 equivalent by multiplying the tons for each pollutant by the Global Warming Potential (310 for N_2O, 21 for CH_4[654]) and summing the products. The results are summarized in **Table 2.7-2** below.

Table 2.7-2. Tailpipe Nitrous Oxide and Methane Emissions in 2022

	Pollutant	Reference Case Tons	Control Case Tons	Percent Change
LDGV & LDGT	N_2O	31,447	29,191	-7%
	CH_4	50,683	61,853	22%
	CO_2 equiv.	10,812,803	10,348,003	-4%
All Gasoline Highway Vehicles	N_2O	33,997	31,741	-7%
	CH_4	55,277	66,447	20%
	CO_2 equiv.	11,699,809	11,235,009	-4%

Given these many differences, it is clearly not possible to simply add up the individual lifecycle results described in Section 2.6 multiplied by their respective volumes to assess the overall rule impacts. The two analyses are separate in that the overall rule impacts capture interactions between the different fuels but can not be broken out into per fuels impacts, while the threshold values represent impacts of specific fuels but do not account for all the interactions.

For example, when we consider the combined impact of the different fuel volumes the overall land use change is less than when considering each fuel independently, as shown in Table 2.7-3.

Table 2.7-3. Comparison of International Land Use Change ('000 Hectares)

	Considering Only Change in Soybean Based Biodiesel Fuel Volumes	Considering Only Change in Corn Ethanol Fuel Volumes	Considering Only Change in Brazilian Sugarcane Ethanol Fuel Volumes	Considering Change of all Fuel Volumes Combined
Land Use Change	678.4	789.3	395.4	794.4

Overall rule impacts were determined for the different components of the lifecycle analysis as described in previous sections. The domestic agricultural sector impacts include changes in energy use GHG emissions and fertilizer / soil N_2O emissions as well as changes in livestock and rice production GHG emissions.

Our analysis indicates that overall domestic agriculture emissions would increase. There is a relatively small increase in total domestic crop acres however, there are additional inputs required to grow the biofuel feedstock crops. These additional inputs result in GHG emissions from production and from N_2O releases from application. This effect is somewhat offset by reductions due to lower livestock production and reductions in rice methane.

As with domestic agriculture impacts, the international agricultural sector impacts include changes in energy use GHG emissions and fertilizer / soil N_2O emissions as well as changes in livestock and rice production GHG emissions. Increased crop production internationally resulted in increased fertilizer and fuel use emissions.

We estimate the largest overall agricultural sector impact is an increase in land use change impacts, reflecting the shift of crop production both domestically and internationally to meet the biofuel demand in the U.S., and land use change emissions associated with converting land into crop production.

Other portions of the biofuel lifecycle include fuel production and feedstock and fuel transport. We project reductions in GHG emissions from the renewable fuel production portion of the lifecycle due to the generation of electricity along with the increased production of cellulosic ethanol and diesel fuel.

CO_2 produced in the combustion of biofuels is offset by the uptake of CO_2 in the biomass crop used to produce the fuel, resulting in a significant net reduction of CO_2 compared to fossil fuel tailpipe combustion. Net carbon fluxes from changes in biogenic carbon reservoirs in wooded or crop lands associated with land use change are accounted for in the domestic and international agriculture impacts shown in upstream impacts. In addition we assume biofuel use is offsetting petroleum fuel production which also results in GHG emissions reductions from reduced upstream emissions of petroleum fuel production (crude oil extraction and transport, refining, transport).

The results of the individual lifecycle stage results can be summed to determine the overall GHG impact of the proposed rulemaking. As discussed in previous sections on lifecycle GHG thresholds there is an initial one time release from land conversion and smaller ongoing releases but there are also ongoing benefits of using renewable fuels over time replacing petroleum fuel use. **Figure 2.7-1** shows the GHG emissions impact of the change in fuel volumes considered over time.

Figure 2.7-1. GHG Impacts over time

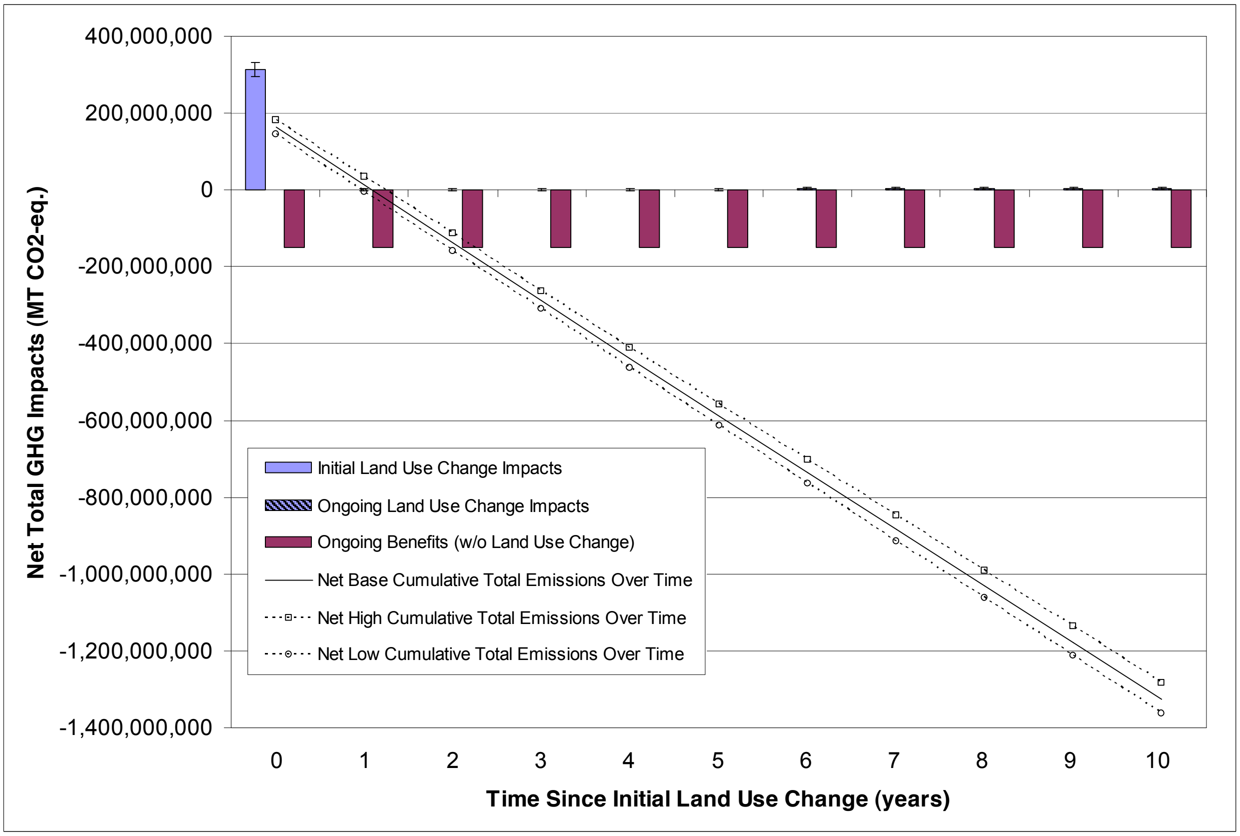


Figure 2.7-1 shows the baseline estimates for land use change as well as the range of results based on the uncertainty in the international land use change modeling. The net GHG emissions over time are also shown as a range of results based on the uncertainty in the land use change emissions.

Based on the volume scenario considered, the one time land use change impact results in a baseline estimate of 312.8 million metric tons of CO_2-eq. emissions with a range of 296.9 to 331.9 million metric tons CO_2-eq. There are however, based on the biofuel use replacing petroleum fuels, annual reduction benefits of 150 million metric tons of CO_2-eq. emissions. This results in a less than two year payback period before the ongoing benefits of the biofuels use offsets the initial land use impacts.

The timing of the impact of land use change and ongoing renewable fuels benefits were discussed in the previous lifecycle results section. The issue is slightly different for this analysis since we are considering absolute tons of emissions and not determining a threshold comparison to petroleum fuels. However the results can be presented in a similar manner to our individual fuels analysis in that we can determine net benefits over a 30 year time period with no discounting. Assuming a 0% discount rate over 30 years would result in an estimate of 4.15 billion tons of discounted GHG emission reductions.

Furthermore, for the calculations of the monetized GHG benefits we calculate an annualized NPV GHG reduction. This annualized value is based on converting a lump sum present value into its annualized equivalent. For this analysis we convert the NPV results into an annualized stream such that the NPV of the annualized emissions will equal the NPV of the emission stream over 30 years with a 0% discount rate. This results in an annualized emission reduction of 138.4 million metric tons of CO_2-eq. emissions (ranging from 136.1 to 140.3 based on uncertainty in the land use change results).

However, there may be additional indirect impacts associated with the production and use of petroleum-based fuels in the real world that are not completely captured by this analysis. For example, it is possible that renewable fuels may actually displace fuels at the margin which have higher GHG lifecycle emissions than the average (e.g., tar sands instead of conventional crude).

To examine the question of what type of marginal crude would be displaced by biofuels use, we performed an analysis using the Department of Energy's Energy Technology Perspectives (ETP) model, which is a partial equilibrium model used to analyze the international energy system. For our analysis, we created a scenario that increased domestic gasoline demand, as we wanted to isolate the impacts of petroleum use. The scenario roughly represented the additional amount of gasoline that would be required if the RFS2 renewable fuel mandates were not in effect. Our results showed that the increased gasoline demand was primarily met through production of conventional crude oil, along with a small amount of oil sands/bitumen production. The primary exporters of conventional crude oil to meet the additional demand were Middle Eastern countries. Using well-to-tank GHG values for crude extracted from various countries[655], we were able to determine an approximate "marginal petroleum baseline" by applying the factors to the countries where crude production increased. We found that the marginal baseline was, for an average gallon of gasoline, not statistically different than the average baseline value used in this final rulemaking. More details on this analysis can be found in the memo, "Petroleum Indirect Impacts Analysis" at EPA-HQ-OAR-2005-0161.

There may be other indirect impacts as well. For instance, we considered whether the displacement of petroleum fuels could also displace petroleum co-products, thus increasing the GHG reductions associated with biofuels use. When crude oil is refined to produce gasoline and diesel, petroleum co-products are also produced. Petroleum co-products include residual fuel oil and petroleum coke, which are utilized as fuels in the energy system. An increase in the demand for renewable fuels could also impact the energy system's utilization of petroleum co-products due to the ripple effects of price impacts.

While it is difficult to predict how the energy system would be affected in such an event, we expect that an increase in domestic renewable fuels demand will lead to a decrease in domestic crude oil consumption due to lower demand for gasoline and diesel. However, a decrease in demand for gasoline and diesel is unlikely to significantly impact demand for petroleum co-products unless the price for these co-products is significantly affected. Refiners respond to demand for fuels, and they may choose to produce a larger percentage of petroleum co-products per barrel of crude then they had in the past in response to lower gasoline or diesel demand. This increased supply and possible lower refinery costs could translate into a slight decrease in co-product cost and therefore marginally impact demand. We have not modeled this demand increase or what its impact might be on total GHG emissions, but we expect that it would have a negligible GHG effect for the rule overall. Thus, we are assuming no change in petroleum co-products supply and no shift in the energy system as a result.

Increased renewable fuel use domestically is expected to also have the effect of lowering the world crude oil price and therefore increase international demand for petroleum-based fuels and increase GHG emissions. As stated above, we expect that an increase in domestic renewable fuels demand will lead to a decrease in domestic crude oil demand. This decrease in U.S. oil demand could cause a decline in the world oil price, which would spur increased oil consumption abroad. This increase in demand outside of the U.S. due to price changes would partially negate the decrease in GHG emissions domestically from reduced petroleum fuel demand due to biofuels. This impact of biofuels use on crude oil imports and world crude oil price is included in our Energy Security Analysis discussed in Chapter 5.

2.8 Effects of GHG Emission Reductions and Changes in Global Temperature and Sea Level

The reductions in CO_2 and other GHGs associated with this final rule will affect climate change projections. GHGs mix well in the atmosphere and have long atmospheric lifetimes, so changes in GHG emissions will affect future climate for decades to centuries. Two common indicators of climate change are global mean surface temperature and global mean sea level rise. This section estimates the response in global mean surface temperature and global mean sea level rise projections to the estimated net global GHG emissions reductions associated with this final rule (see Section 2.7 for the estimated net reductions in global emissions over time by GHG).

EPA estimated changes in projected global mean surface temperatures to 2050 using the MiniCAM (Mini Climate Assessment Model) integrated assessment model[180] coupled with the MAGICC (Model for the Assessment of Greenhouse-Gas Induced Climate Change) simple climate model.[181] MiniCAM was used to create the globally and temporally consistent set of

[180]MiniCAM is a long-term, global integrated assessment model of energy, economy, agriculture and land use, that considers the sources of emissions of a suite of greenhouse gases (GHGs), emitted in 14 globally disaggregated global regions (i.e., U.S., Western Europe, China), the fate of emissions to the atmosphere, and the consequences of changing concentrations of greenhouse related gases for climate change. MiniCAM begins with a representation of demographic and economic developments in each region and combines these with assumptions about technology development to describe an internally consistent representation of energy, agriculture, land-use, and economic developments that in turn shape global emissions. Brenkert A, S. Smith, S. Kim, and H. Pitcher, 2003: Model Documentation for the MiniCAM. PNNL-14337, Pacific Northwest National Laboratory, Richland, Washington. For a recent report and detailed description and discussion of MiniCAM, see Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA, 154 pp.

[181] MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single framework. The framework allows the user to determine changes in GHG concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), reactive gases (e.g., CO, NO_x, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO2). MAGICC emulates the global-mean temperature responses of more sophisticated

climate relevant variables required for running MAGICC. MAGICC was then used to estimate the change in the global mean surface temperature over time. Given the magnitude of the estimated emissions reductions associated with the proposed rule, a simple climate model such as MAGICC is reasonable for estimating the climate response.

EPA applied the estimated annual GHG emissions changes for the final rule to a MiniCAM baseline emissions scenario.[182] Specifically, the CO_2, N_2O, and CH_4 annual emission changes from 2022-2052 from Section 2.7 were applied as net reductions to this baseline scenario for each GHG.

The tables below provide our estimated reductions in projected global mean surface temperatures and mean sea level rise associated with the increase in renewable fuels in 2022 required by this final rule. We modeled three scenarios using different values for the estimated net global GHG reduction associated with this rule; we utilized the average, low, and high values for GHG emissions reduced, as presented in Section 2.7. To capture some of the uncertainty in the climate system, we estimated the changes in projected temperatures and sea level across the most current Intergovernmental Panel on Climate Change (IPCC) range of climate sensitivities, 1.5°C to 6.0°C.[183]

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coupled Atmosphere/Ocean General Circulation Models (AOGCMs) with high accuracy. Wigley, T.M.L. and Raper, S.C.B. 1992. Implications for Climate and Sea-Level of Revised IPCC Emissions Scenarios Nature 357, 293-300. Raper, S.C.B., Wigley T.M.L. and Warrick R.A. 1996. in Sea-Level Rise and Coastal Subsidence: Causes, Consequences and Strategies J.D. Milliman, B.U. Haq, Eds., Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 11-45. Wigley, T.M.L. and Raper, S.C.B. 2002. Reasons for larger warming projections in the IPCC Third Assessment Report J. Climate 15, 2945-2952.

[182] The reference scenario is the MiniCAM reference (no climate policy) scenario used as the basis for the Representative Concentration Pathway RCP4.5 using historical emissions until 2005. This scenario is used because it contains a comprehensive suite of greenhouse and pollutant gas emissions including carbonaceous aerosols. The four RCP scenarios will be used as common inputs into a variety of Earth System Models for inter-model comparisons leading to the IPCC AR5 (Moss et al. 2008). The MiniCAM RCP4.5 is based on the scenarios presented in Clarke et al. (2007) with non-CO_2 and pollutant gas emissions implemented as described in Smith and Wigley (2006). Base-year information has been updated to the latest available data for the RCP process.

[183] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The IPCC states that climate sensitivity is "likely" to be in the range of 2°C to 4.5°C and described 3°C as a "best estimate." The IPCC goes on to note that climate sensitivity is "very unlikely" to be less than 1.5°C and "values substantially higher than 4.5°C cannot be excluded." IPCC WGI, 2007, *Climate Change 2007 - The Physical Science Basis,* Contribution of Working Group I to the Fourth Assessment Report of the IPCC, http://www.ipcc.ch/.

Table 2.8-1. Estimated Reductions in Projected Global Mean Surface Temperature and Global Mean Sea Level Rise from Baseline for the Average Case for the Final Rule in 2020-2050

Climate Sensitivity						
	1.5	2	2.5	3	4.5	6
Year	**Change in global mean surface temperatures (degrees Celsius)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	0.000	0.000	0.000	0.000	0.000	0.000
2035	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2040	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2045	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002
2050	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Year	**Change in global mean sea level rise (centimeters)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2035	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003
2040	-0.003	-0.004	-0.004	-0.005	-0.005	-0.006
2045	-0.005	-0.006	-0.006	-0.007	-0.008	-0.009
2050	-0.006	-0.008	-0.009	-0.009	-0.011	-0.012

Table 2.8-2. Estimated Reductions in Projected Global Mean Surface Temperature and Global Mean Sea Level Rise from Baseline for the Low Case for the Final Rule in 2020-2050

Climate Sensitivity						
	1.5	2	2.5	3	4.5	6
Year	**Change in global mean surface temperatures (degrees Celsius)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	0.000	0.000	0.000	0.000	0.000	0.000
2035	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2040	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2045	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002
2050	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Year	**Change in global mean sea level rise (centimeters)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2035	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003
2040	-0.003	-0.004	-0.004	-0.005	-0.005	-0.006
2045	-0.005	-0.006	-0.006	-0.007	-0.008	-0.009
2050	-0.006	-0.008	-0.009	-0.009	-0.011	-0.012

Table 2.8-3. Estimated Reductions in Projected Global Mean Surface Temperature and Global Mean Sea Level Rise from Baseline for the High Case for the Final Rule in 2020-2050

Climate Sensitivity						
	1.5	2	2.5	3	4.5	6
Year	**Change in global mean surface temperatures (degrees Celsius)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	0.000	0.000	0.000	0.000	0.000	0.000
2035	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2040	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2045	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002
2050	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Year	**Change in global mean sea level rise (centimeters)**					
2020	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000
2030	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
2035	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003
2040	-0.003	-0.004	-0.004	-0.004	-0.005	-0.006
2045	-0.005	-0.006	-0.006	-0.007	-0.008	-0.008
2050	-0.006	-0.007	-0.008	-0.009	-0.011	-0.012

The results in table above show small reductions in the global mean surface temperature and sea level rise projections across all climate sensitivities. Overall, the reductions are small relative to the IPCC's "best estimate" temperature increases by 2100 of 1.8ºC to 4.0ºC.[656] Although IPCC does not issue "best estimate" sea level rise projections, the model-based range across SRES scenarios is 18 to 59 cm by 2099.[184] While the distribution of potential temperatures in any particular year is shifting down, the shift is not uniform. The magnitude of the decrease is larger for higher climate sensitivities. The same pattern appears in the reductions in the sea level rise projections. For instance, in 2050, the reduction in projected temperature (for all cases) for climate sensitivities of 3 and 6 is approximately 50% and 99% greater than the reduction for a climate sensitivity of 1.5. The same pattern appears in the reductions for the sea level rise projections.[185]

Thus, we can conclude that the impact of this final rule is to lower the risk of climate change, as the probabilities of temperature increase and sea level rise are reduced.

[184] "Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise." IPCC Synthesis Report, p. 45
[185] In 2050, the reduction in projected sea level rise (for all cases) for climate sensitivities of 3 and 6 is approximately 45% and 86% greater than the reduction for a climate sensitivity of 1.5.

Chapter 3: Impacts of the Program on Non-GHG Pollutants

In addition to the GHG impacts laid out in Chapter 2, we project that the increased use of renewable fuels required by RFS2 will affect emissions of "criteria" pollutants (those pollutants for which a National Ambient Air Quality Standard has been established), criteria pollutant precursors, and air toxics. Changes in these emissions would derive from the direct effect of renewable fuels on the tailpipe and evaporative emissions of vehicles and off-road equipment; and increased renewable fuel production and distribution including the effect of decreases in the production and distribution of gasoline and diesel displaced by renewable fuel. For this analysis we have focused on estimating the change in mass emissions for these pollutants across the entire U.S. in 2022, when the program is fully implemented, and we have also conducted a full-scale air quality modeling and health impact assessment that accounts for geographic differences in impacts at the county level. This chapter presents national emission impacts for nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), particulate matter 10 microns in diameter and less (PM10), particulate matter 2.5 microns in diameter and less (PM2.5), sulfur dioxide (SO2), ammonia (NH3), benzene, 1,3-butadiene, acrolein, formaldehyde, acetaldehyde, naphthalene, and ethanol, including the methodology for developing these estimates. Section 3.3 discusses the differences between the final rule emission inventories presented in Sections 3.1 and 3.2 compared to the inventories that were used for air quality modeling. Section 3.4 of this chapter presents the methodology and results of air quality modeling, and Sections 3.5 and 3.6 address health and environmental impacts of today's rule.

3.1 Methodology for Calculating Non-GHG Emission Impacts

Our analysis focused on the projected impact of the renewable fuel volumes required in 2022, the first year the RFS2 program is fully implemented. The emission impacts of the 2022 RFS2 volumes are quantified in Section 3.2 for a range of renewable fuel scenarios relative to two reference cases discussed in detail above in Section 1.2.1. In order to allow assessment of total emission impacts of mandated renewable fuel volumes, the main reference case presented in this analysis was the RFS1 mandate volume of 7.5 billion gallons of renewable fuel (6.7 billion gallons ethanol). We are also presenting impacts relative to the 13.6 billion gallons of renewable fuels projected by the Department of Energy (DOE) Annual Energy Outlook (AEO) 2007 to show the impact of the RFS2 renewable fuel volumes incremental to the projected renewable market pre-EISA.

Our analysis of non-GHG emissions impacts was comprised of a) an analysis of direct impacts on motor vehicles, off-road equipment and other sources from burning (or evaporating) renewable fuels in place of petroleum-based fuels; and b) the emissions impacts from the production and distribution of renewable fuels. These analyses are discussed separately in Sections 3.1.1 and 3.1.2.

3.1.1 Impact on Non-GHG Emissions from Motor Vehicles and Equipment

The volumes of renewable fuel called for in today's rule will directly affect emissions from most mobile source categories, and for this analysis we have quantified the effects on exhaust and evaporative emissions of gasoline-fueled vehicles and equipment including passenger cars, light trucks, heavy trucks, motorcycles and off-road sources such as lawn mowers, recreational boats and all-terrain vehicles. We have also estimated the impact of ethanol on emissions from portable fuel containers, and increased refueling emissions due to higher volatility of ethanol-blended fuel and increased refueling events due to lower energy content of biofuels. The emissions impacts of biodiesel were also estimated on heavy-duty diesel vehicles, assuming additional biodiesel would be burned by on-road sources only.

A considerable source of uncertainty in estimating the emission impacts of renewable fuels is the effect ethanol blends will have on emissions of cars and light trucks. Under today's action every gasoline vehicle and piece of equipment would be fueled on at least E10. For the proposal, the uncertainty in the emission impacts of E10 was reflected by showing emission impacts under two cases representing different levels of sensitivity in the emissions of cars and light trucks to ethanol. In the final rule, we are reflecting preliminary results from work sponsored by EPA and DOE which suggests that emissions from Tier 2 vehicles show little sensitivity to E10.[657] In addition to E10, many flexible-fueled passenger vehicles may need to be operated on E85 to consume the increased volumes of renewable fuels. The amount of E85 needed will depend on the volume of ethanol as opposed to other renewable fuels utilized in the future. Data on E85 continues to be limited, and emission results have shown large variability of emission effects in some pollutants. As a result, for the final rule we have decided to assign no emission effect to the use of E85, except for the emissions of acetaldehyde and ethanol.

For the analysis of all gasoline-fueled highway vehicles except motorcycles, a preliminary version of MOVES2010 was used to generate national inventories for the control and reference cases modeled for the RFS2 final rule. This version reflected updates to fuel effects made to the model since the analysis for the proposal and air quality modeling versions, based on data made available since these analyses were performed; these fuel effect updates were eventually finalized in the recently released version of MOVES2010.[658],[659] We decided to use a draft version of MOVES for this analysis to begin to reflect significant updates in emissions, and in particular fuel effects, from MOBILE6. As the other mobile source categories in MOVES were still under development at the time of this analysis, all onroad diesel, motorcycle and off-road equipment emissions were calculated with the National Mobile Inventory Model (NMIM), a platform which generates emission inventories based on EPA's MOBILE6 and NONROAD models.

The development of vehicle and equipment emission impact estimates for today's rule required: a) developing fuel supply inputs at the county level for the 2005 base year and 2022 reference and control cases which accounted for the projected change in fuel properties due to today's action; b) developing individual vehicle fuel effects; and c) running MOVES and NMIM to produce raw inventory estimates and post-processing these results as needed to account for different baselines, to apply "off model" corrections, or to estimate impacts not accounted for in the models. Each of these steps are detailed in the following sections

3.1.1.1 Fuel Inputs

As inputs to our emissions modeling, we developed a detailed profile of fuels for each modeling case. We prepared county-level databases of fuel properties and fuel market shares for the 2005 base case, the RFS1 reference case, the 2022 AEO reference case, and the 2022 control case. These county-level databases were applied in both NMIM and MOVES for consistency in fuel inputs across the different mobile source categories.

The 2005 base case fuel properties were derived from 2005 historical data. These data included national summer and winter fuels surveys, studies that tracked the total amount of ethanol produced for use in gasoline each year, and Reformulated Gasoline (RFG) surveys. Additional data were available on the fuel properties of all gasoline produced and imported annually by refiners, and on the distribution of gasoline to and from Petroleum Administration for Defense Districts (PADDs). Where survey data was available, it was used to determine a county's fuel properties for summer and winter. Where survey data was not available, fuel properties were set to equal the average fuel properties in that PADD. Special adjustments were made to some counties to account for local gasoline volatility control programs and winter oxygenated gasoline programs.

For the 2022 reference and control cases, the 2005 base case fuel properties were adjusted to account for implementation of other fuel regulations and to account for increased ethanol use. There is a greater percentage of ethanol in both the 2022 RFS1 and AEO 2007 reference cases than in the 2005 base case because methyl tert-butyl ether (MTBE) has been replaced with ethanol and because of increased ethanol usage mandated by RFS1 (the RFS1 reference case), and AEO-projected growth in ethanol production for 2022 (the AEO 2007 reference case). For this analysis, ethanol was allocated to the state and county level based on the economics of distribution and blending, as well as other factors (refer to Section 1.7.1 of this document for details). The 2022 control cases model three different approaches to meeting the renewable fuel volume requirements of EISA. Even in the low ethanol control case (17.5 billion gallons of ethanol), there would be enough ethanol in the fuel supply to require use of at least 10 percent ethanol (E10) in every county, while the choice of counties modeled with E85 was based on the economics and other factors.

Future fuel properties in both the reference and control cases were adjusted to account for widespread increases in ethanol. This was done using two assumptions: 1) ethanol has historically been splash blended in conventional gasoline (CG), and 2) it will be match-blended by 2022 (i.e., the changes associated with ethanol addition will be accounted for by refiners when producing the base gasoline). We believe this is reasonable given that there will be a large (and thus more geographically predictable) volume of ethanol used in gasoline, and that certain property changes that take place when ethanol is blended (such as octane increase) could be economically beneficial to refiners if they can be assumed when producing the base gasoline. Thus, we adjusted aromatics, olefins, T50, and T90 fuel parameters by first backing out the effects of any existing oxygenate (by reverse dilution), and then re-adjusting the properties for ethanol blends based on refinery modeling done for the RFS1 rulemaking that projected how gasoline properties were likely to change given widespread use of ethanol. Table 3.1-1 shows the adjustment factors used per volume percent ethanol blended. Reid Vapor Pressure (RVP) was increased 1.0 psi wherever ethanol was present in conventional gasoline unless there was a local volatility control.

Table 3.1-1. 2022 Adjustments for Ethanol Added to Conventional Gasoline

Additive change per vol% ethanol added	Aromatics (vol%)	Olefins (vol%)	E200 (vol%)	E300 (vol%)
Summer	-0.69	0.00	1.10	7.52
Winter	-0.68	0.00	0.78	7.21

For example, the adjusted summer aromatics value would be calculated as follows:

Current aromatics value – dilution effect of current ethanol level due to splash blending + (new volume percent ethanol x -0.69 for match blend effect)

For Reformulated Gasoline (RFG) areas, refiners already account for the blending of ethanol when producing the base gasoline, and therefore the properties are not predicted to change in the same ways as for conventional gasoline (CG). We used refinery modeling results for each PADD (produced using the same cases and renewable fuel volumes as described above for CG) to project the properties of fuel in RFG areas. RFG properties used in the reference and control cases in 2022 are shown here in Table 3.1-2. The 2022 reference and control cases also incorporate reductions in gasoline sulfur resulting from Tier 2 regulations. Fuel benzene levels presented in this table have been updated from what was used in the NPRM to reflect the 2007 mobile source air toxics (MSAT) rule, which mandates a 0.62% fuel benzene standard.[660]

Table 3.1-2. 2022 Reformulated Gasoline Properties by PADD

PADD [a]	RVP (psi)	Aromatics (vol%)	Benzene (vol%)	Olefins (vol%)	E200	E300
Summer						
1	7.0	19.9	0.54	8.1	52	95
2	7.0	18.8	0.60	6.8	52	95
3	7.0	18.4	0.55	5.6	51	95
5	6.8	21.5	0.62	5.7	54	86
Winter						
1	13.2	19.9	0.54	14.1	58	95
2	13.1	20.0	0.60	11.9	62	95
3	11.8	19.8	0.55	13.0	55	95
5	11.4	21.9	0.62	5.7	60	86

[a] There are no RFG areas in PADD 4.

Unlike the proposal, for the final rule we did not model the effects of flexible-fueled vehicles running on E85 for any pollutants except acetaldehyde and ethanol.

For each of the modeled scenarios, fuel information was input into an NMIM database and used for NMIM runs. For MOVES runs, the NMIM databases were converted into MOVES databases using a conversion program. To reduce time needed for MOVES runs, we reduced the size of the MOVES fuel database by processing the database with a "binner" program that grouped fuels with similar properties and assigned each group to a single fuel formulation identification number and a single set of fuel properties. A significant update to MOVES between the proposal and final rulemaking was the inclusion of direct calculation of fuel adjustments that allowed less aggregation in this binning approach, thus improving the resolution of fuel-based emission impacts.

3.1.1.2 Effect of Fuels on Non-GHG Emissions from Vehicles & Equipment

The average effect of renewable fuels on an individual vehicle/equipment basis, based on available research, is the foundation of the emission impact assessment. This section contains discussion of the effects used in the emission impact assessment for E10 on gasoline vehicles and equipment, for E85 on gasoline vehicles, and for biodiesel.

3.1.1.2.1 On-road Gasoline Vehicle E10 Effects

3.1.1.2.1.1 Exhaust Emissions

Ethanol blends can affect exhaust emissions from vehicles and off-road equipment. A comprehensive analysis of E10 impacts on exhaust emissions was undertaken for the RFS1 rule, as documented in Chapter 3 of the RFS1 Regulatory Impact Analysis.[661] This analysis considered previous EPA work in coming up with a so-called "Predictive Model" to assess California's request for an oxygenate waiver in 2000, as well as test data from several test programs conducted by the auto trade associations (AAM/AIAM), ExxonMobil, Toyota, and the Mexican Petroleum Institute. This assessment concluded that for Tier 1 and later vehicles (nominally model year 1996 and later, comprising the majority of the fleet in 2022) there was not enough consistency across these studies to confidently predict the impact of oxygenated fuel on exhaust HC and NOx emissions. As a result the RFS1 analysis carried forward two sets of fuel effects: a "primary" analysis assuming no effect of oxygen on non-methane hydrocarbon (NMHC) and NOx emissions from Tier 1 and later vehicles, and a "sensitivity" analysis which applied EPA's Predictive Model effects to Tier 1 and later vehicles. For the RFS2 proposal we characterized ethanol effect scenarios: "less sensitive" based on the "primary" case used in RFS1, and "more sensitive" based on the RFS1 "sensitivity" case.

We are now nearing completion of a large scale testing effort aimed at quantifying the effects on exhaust and evaporative emissions from Tier 2 vehicles of ethanol and several other fuel properties impacted by the blending of ethanol into gasoline.[662] Based on analysis of preliminary data from this test program, we are carrying forward effects that more closely reflect the "less sensitive" case, which does not apply any E10 effects to NOx or HC emissions for later model year vehicles, or E85 effects for most pollutants. While the effects of E10 on individual vehicles will vary depending on properties of the fuel (e.g., RVP, distillation, and aromatic content), Table 3.1-3 demonstrates the effects used for conventional and reformulated gasoline based on the fuel properties derived from Tables 3.1-1 and 3.1-2. For the "less sensitive" case for the proposal, the effects shown for NOx, HC and toxics were applied to only Tier 0 vehicles (mid 1990's and older); in our analysis for this final rule, we extended these effects to Tier 1 and NLEV cars and light trucks (through the 2003 model year) based on a recently published study from CRC.[663] However, our preliminary analysis of the EPA/DOE test program did not justify attributing these effects to Tier 2 vehicles.

Table 3.1-3. Exhaust Effect of E10 Relative to E0 for Pre-Tier 2 Vehicles [a]

Pollutant	Source	CG	RFG
Exhaust HC (VOC)	EPA Predictive Models	-7.4%	-9.7%
NOx		7.7%	7.3%
CO[b]	MOBILE6.2	-11% / -19%	-36%
Exhaust Benzene	EPA Predictive and Complex Models	-24.9%	-38.9%
Formaldehyde		6.7%	2.3%
Acetaldehyde		156.8%	173.7%
1,3-Butadiene		-13.2%	6.1%

[a]Assumes summer (July) conditions

[b]The first figure shown applies to normal emitters; the second applies to high emitters.

3.1.1.2.1.2 Evaporative Emissions

While E10 affects evaporative emissions from gasoline vehicles due to the increased volatility of E10 blends, the increased permeation of fuel vapors through tanks and hoses, and the increased vapor emissions due to the lower molecular weight of E10, for cars and light trucks by far the largest of these effects is permeation. For the final rule, we estimated only the impact of permeation using updated estimates in the draft MOVES model, which separates permeation emissions from vapor venting emissions to allow better accounting for this effect.

For the proposal, permeation effects were developed from Coordinating Research Council's (CRC) E-65 program[664], which measured evaporative emissions from ten fuel systems that were removed from the vehicles on E0 and E5.7 fuels; fuel systems were removed to ensure that all evaporative emissions measured were from permeation of the fuel through the different components of the fuel system. For that analysis, we estimated the effect by calculating the percent increase in average emissions from all vehicles between E0 and E5.7 fuels over the 65 to 105 degree Fahrenheit diurnal test. That value was 46 percent. In order to estimate the effect at E10 we simply multiplied this result by 1.75 (10/5.7), resulting in a 79 percent increase applied to cars and light trucks from all model years. That approach heavily weighted the emission contribution of older vehicles in the test program, and, in conjunction with lower emission rates for vehicles certified to Enhanced Evaporative and later standards in MOVES, served to underestimate the impact of E10 on permeation from newer vehicles.

The version of MOVES used for the FRM analysis significantly updates the permeation estimate used in the NPRM, particularly for newer technology vehicles, based on data collected by CRC in the followup E-65 program (E-65.3) and as part of their more recent E-77 series of evaporative emissions programs This new data allowed us to make a distinction between the relative impact of E10 on vehicles certified to the enhanced evaporative and later standards, vs. older technology vehicles. The data showed a significant change in the relative impact of E10, from a 65 percent increase for pre-enhanced vehicles, to a 213 percent increase for newer technology vehicles.[665] This analysis also confirmed the E-65.3 finding that there is no significant difference between emission effects on E5.7 and E10.

3.1.1.2.2 On-road Gasoline vehicle E85 effects

In the proposal, the "more sensitive" case included impacts of E85 on several pollutants, based on analysis of limited data from EPA and Environment Canada. For the final rule we have decided not to apply these effects to the potential increase in E85 use, with the exception of acetaldehyde and ethanol. The rationale for this is the large range of uncertainty imposed by the limited nature of the dataset. EPA expects more data to become available to help assess this issue for future analyses, as CRC, EPA and DOE are all engaged in programs that will expand this dataset. We are including the discussion of E85 data considered in this RIA to provide documentation of available data; no new information is presented here relative to the proposal, as no new data has been generated in the interim. The only difference between proposal and final is that, of the effects determine in this analysis, only acetaldehyde and ethanol were included in the final rule inventories.

For this analysis we identified three recent data sources that investigate the effects of E85 on current technology (i.e. Tier 2 and similar) vehicles[186].[666, 667, 668] Two of these sources are test programs conducted by Southwest Research Institute and Environment Canada, and the third is EPA certification data. This section briefly describes each data source and highlights the key findings, and explains how these data were used to generate E85 effects.

In 2006, Southwest Research Institute (SwRI) conducted a study for EPA on three model year 2005 Tier 2 FFVs (bins 5 and 8) operating on several gasoline and ethanol blends. This study was primarily focused on the impacts of fuel ethanol content and reduced ambient test temperature (tests were conducted at 75ºF and 20ºF) on VOC and PM emissions. Multiple fuel blends were evaluated in this program, although for this analysis we will focus only on E0 and E85 emissions at 75º F. At this test temperature, Tier 2 certification fuel was used as the non-oxygenated test fuel (E0) as well as the base gasoline for the splash-blended E10 and E85 fuels. Additionally, EPA certification "cold CO" wintertime gasoline was used for reduced ambient temperature (20 ºF) testing – used alone (E0) and as the base fuel for wintertime E10 and E70 blends. This base gasoline has a higher RVP than its summertime equivalent, which is necessary to ensure proper fuel vaporization at lower ambient temperatures. Repeat tests were conducted for the 20ºF tests on the winter fuel blends, but no repeats were run for 75ºF testing. In addition to the regulated pollutants, SwRI measured CO2, CH4, benzene, 1,3-butadiene, naphthalene, acetaldehyde, acrolein, and ethanol. This study saw reductions in PM 2.5, benzene, and 1,3-butadiene of 55% - 70% with E85 relative to E0. HC emissions increased while NOx and CO decreased. Emissions of methane, formaldehyde, and acetaldehyde were found to increase significantly with E85 use. Table 3.1-6 summarizes the average percent change in emissions with E85 vs. E0. This table also compares the findings of this dataset with the other two programs described below.

Environment Canada released a report in 2005 in which an NLEV and an interim non-Tier 2 vehicle were tested on Tier 2 certification fuel and a commercially available E85 blend. Repeat tests were conducted in this study so that each vehicle was tested three times on each

[186] EPA is aware of several test programs, either planned or underway, by CRC and others that may provide additional test data for future fuel effects modeling and rulemaking support.

fuel. The pollutants measured include NMOG, NMHC, CO, NOx, CO2, CH4, N20, benzene, 1,3-butadiene, acetaldehyde, formaldehyde, acrolein, and ethanol, among others. The results, summarized in Table 3.1-6 showed statistically significant reductions in CO and NOx (-48% and -40%, respectively) when switching from E0 to E85. E85 caused non-methane organic gases (NMOG) emissions to increase in one vehicle and decrease in the other. Toxics reductions were of a similar order of magnitude as the vehicles tested in the SwRI study discussed above

EPA's Certification and Fuel Economy Information System (CFEIS) database was accessed to identify data from five model year 2006 Tier 2 vehicles (bins 5, 8, and 9) tested on both E85 and Tier 2 certification gasoline. The E85 blend tested here was 85% denatured ethanol splash blended with 15% Tier 2 certification gasoline. Each vehicle was only tested once on each fuel. Weighted FTP results were reported for the regulated pollutants (except PM) as well as CO2, acetaldehyde, and ethanol (formaldehyde, acetaldehyde, and ethanol were only measured for tests where E85 was used; therefore these are expressed as fractions of NMOG here). This data indicates that E85 causes a slight increase in NMOG emissions, a slight decrease in NOx and CO2, and significant reductions in CO. The average percent change in each pollutant for these vehicles when operated on E85 is shown in Table 3.1-5, below.

Table 3.1-5.
Effect of E85 on LEV and Later Per-mile Exhaust Emissions Relative to Conventional Gasoline: Percent change separated by data source

	EPA – CFEIS	EPA - SwRI	Env. Canada
NMOG	10%	87%	5%
CO	-34%	-15%	-48%
NOx	-3%	-42%	-40%
Benzene	NA	-61%	-65%
1,3 Butadiene	NA	-66%	-74%
Acetaldehyde	12% of NMOG	5600%	3121%
Formaldehyde	2% of NMOG	116%	98%
Acrolein (E85 mg/mile emissions)	NA	0.023	0.010
Unburned Ethanol (E85 mg/mile emissions)	28.3 (55% of NMOG)	25.4 (33% of NMOG)	34.6 (48% of NMOG)
PM 2.5	NA	-68%	NA

Viewed independently, each study provides only limited insight on the effects of E85 on emissions relative to E0. Table 3.1-5 shows that while changes in some pollutants compare reasonably well between studies, others can vary widely. This makes it difficult to determine quantitative trends in emissions, since calculating an average percent change in emissions across all three studies does nothing to address the variability of the test data. Without this assessment of variability there is no way to estimate the statistical significance of the reported values. Only the Environment Canada conducted the repeat tests necessary to assess the test-to-test variability of a given vehicle, and none of the studies tested enough vehicles to confidently state that their findings can be applied to the Tier 2 FFV fleet as a whole. This clearly illustrates the need for additional testing in this area.

The fact that Environment Canada tested non-Tier 2 vehicles is noteworthy. The 2004 Chrysler Sebring was an interim non-Tier 2 bin 8 vehicle. Despite its name, however, the standard is equivalent to the final Tier 2 bin 8 FTP standards in all areas but the full useful life (120K miles vs. 100K miles). In fact this vehicle was cleaner than required by the standard, with observed emissions on E0 at the level of a Tier 2 bin 7 vehicle. The second vehicle tested by Environment Canada was a 2002 Dodge Caravan certified to the NLEV LEV LDT level. The standards at this certification level are considerably more relaxed than Tier 2 levels for some pollutants but not others. While these vehicles share the same NMOG certification standard (0.100 g/mi), the CO standard is roughly 30% higher and the NOx standard nearly 4 times higher than the Tier 2 bin 8 level. As a result of this difference in standards, the Caravan emitted about 20% more CO and 2.5 times more NOx than the Sebring. NMOG emissions were nearly the same for both vehicles with non-oxygenated gasoline. On a relative scale, both vehicles experienced similar percent changes in emissions between E0 and E85. The Sebring emitted more ethanol with E85 than did the Caravan, resulting in a higher E85 NMOG emissions factor for that vehicle.

The variability in the magnitude of these changes, however, is what weakens the analysis. Had additional observations been made, these results may have become more significant for more pollutants. For this final rule analysis we are only modeling emission effects with use of E85 in flex-fueled vehicles relative to E0 for two of the pollutants: ethanol and acetaldehyde, for which data suggests the effects are more certain. For the “more sensitive case” presented in the NPRM, and used in the air quality modeling, we had estimated changes to additional pollutants (including significant PM reductions) based on the limited data from the studies discussed above. However, until such time as additional data is collected to enhance this analysis we believe it is premature to use such assumptions.

The “more sensitive” case in the NPRM also included a 50 percent reduction in evaporative emissions with use of E85 based on results from just one vehicle from CRC’s E-65 evaporative permeation program. Given the variability in not only vehicles, but also E85 volatility in-use, we do not believe it appropriate to rely on just one data point, and as a result this reduction was also not applied in the final rule.

Data from the analyses discussed above, and an additional dataset from a 1995 test program conducted by EPA’s Office of Research and Development, were used to develop inputs for MOVES, in order to model E85 impacts on air toxics inventories. Since MOBILE6 does not model air toxics for E85, ratios were developed to apply to E85 hydrocarbon or PM mass (Table 3.1-6). The exhaust ratios for all pollutants except naphthalene were obtained from data on seven vehicles from the 1995 test program in EPA’s Office of Research and Development, along with the previously discussed 2007 test program at Southwest Research Institute,[669] and the 2005 test program at Environment Canada.[670, 671] The data from the ORD test program is unpublished, but is available in the docket for this rule. Naphthalene inputs for E85 were derived from estimates from E10 values based on dilution of fuel with ethanol. The only data available on evaporative emissions were results of hot soak tests from the Auto/Oil Air Quality Improvement Research Program.[672]

Table 3.1-6. Toxic to THC/PM Ratios used for E85 Fuel in MOVES

Pollutant	Exhaust/Ratio Type	Evaporative/Ratio Type
Benzene	0.0036/THC	0.0054/THC
1,3-Butadiene	0.0005/THC	N.A.
Acetaldehyde	0.0673/THC	N.A.
Formaldehyde	0.0093/THC	N.A.
Acrolein	0.0002/THC	N.A.
Ethanol	0.3316/THC	0.6123/THC
Naphthalene	0.0126/PM	0.00006/THC

3.1.1.2.3 Spark-Ignited Off-Road Engines

Effects of E10 relative to E0 on exhaust as well as fuel tank and hose permeation emissions from gasoline-fueled off-road engines are contained in EPA's NONROAD model, based on limited data. The effects on exhaust HC, NOx, and CO are shown in Table 3.1-7. Effects on tank and hose permeation emissions vary by equipment type and were recently updated to reflect new information on uncontrolled emissions and their control due to recently finalized new standards.[673] For most small spark-ignition engines and recreational marine engines in 2022 E10 is estimated to double the tank and hose permeation emissions. There can also be increases in diurnal and refueling emissions with E10 if the fuel volatility of the blend is allowed to be greater than E0. These volatility effects are accounted for in the NMIM model that has the county-specific fuel properties that were used to generate the emission inventory impacts for this rule presented below in Section 3.2.

Table 3.1-7.
Exhaust Effect of Ethanol (E10) on Spark-Ignited Gasoline Emissions

	4 stroke	2 stroke
HC exhaust	-15.75%	-2.1%
NOx	+40.25%	+65.1%
CO	-21.7%	-22.75%

EPA and the California Air Resources Board (ARB) are in the midst of additional testing of off-road engines with gasoline and ethanol blends.[674, 675] and DOE completed a report in early 2009 which included small SI emission evaluation on a variety of ethanol blend fuels.[676] Although preliminary results support the type of effects listed here, there are also upcoming allowances for manufacturers to start certifying small spark ignition engines on E10 fuel rather than the current E0 gasoline sometime in the 2011-2012 timeframe.[677] If those plans proceed as expected, by 2022 most or all of the in-use small SI engines will have been certified on E10; thus we would expect none of the exhaust effects that we currently assume. Much of the in-use fleet of equipment will have turned over to new equipment certified on E10, and those that were originally certified on E0 are likely to be recalibrated. As a result, emissions are expected to result in roughly the same emissions on E10 as they currently achieve on E0. The NOx inventory increase and HC and CO decreases associated with increasing E10 market share estimated for the final rule will likely go away by 2022, since many of the E0 certified engines will have been replaced by E10 certified engines by then. However, there will still likely be effects on the mix of hydrocarbons emitted, including increased proportions of ethanol and aldehydes in the exhaust HC.

3.1.1.2.4 Biodiesel Effects on Diesel Emissions

As discussed in Appendix A to this RIA, for the proposal we investigated the emission impacts on NOx, PM, HC, and CO of 20 volume percent biodiesel fuels on emissions from heavy-duty diesel vehicles.[678] Average NOx emissions were found to increase 2.2 percent, while PM, HC, and CO were found to decrease 15.6 percent, 13.8 percent, and 14.1 percent, respectively, for all test cycles run on 20 volume percent soybean-based biodiesel fuel (Table 3.1-8). These results are generally consistent with the exhaust emission impacts for heavy-duty, in-use diesel engines found in our previous work on this subject.,[679] and we have retained these effects for the final rule. The effects in Table 3.1-8 are for B20, while we assume biodiesel is mostly used in concentrations of 5% or less. In applying the emission impacts to the emission inventory we assumed that the effects were proportional to biodiesel concentration based on a resent investigation into the issue, so the inventory impacts are proportional to the overall biodiesel volume used. (Cite to Chien Sze et.al. SAE Paper). For our estimate of biodiesel impacts on toxics we applied the HC emission change from Table 3.1-8 to toxic emissions.

Table 3.1-8. B20 Emission Impacts

	Percent change in emissions
NOx	+2.2%
PM	-15.6%
HC	-13.8%
CO	-14.1%

3.1.1.3 Non-GHG Emission Impact Scenarios Analyzed

For today's rule we are estimating emission impacts of three different renewable fuel volume scenarios, as presented in Chapter 1.2, which are meant to bracket the range of likely combinations of renewable fuel volumes, and these are each analyzed relative to two different reference case ethanol volumes. To assess the impact of today's rule relative to the current mandated volumes, we analyzed impacts relative to the RFS1 mandate of 7.5 billion gallons of renewable fuel use by 2012, which was estimated to include 6.7 billion gallons of ethanol. In order to assess the impact of the increased use of renewable fuels needed to meet the RFS2 standards relative to a level of ethanol projected to already be in place by 2022, the AEO2007 projection of 13.2 billion gallons of ethanol (13.6 billion gallons of total renewable fuel) in 2022 was analyzed.

3.1.1.4 Non-GHG Emission Impact Calculation Methodology

3.1.1.4.1 On-Road Gasoline

Emissions from gasoline highway vehicles were generated with a preliminary version of EPA's final MOVES2010 model, which reflects significant updates in gasoline vehicle emissions from MOBILE6. Exhaust emission rates for HC, CO and NOx were developed based on an analysis of state inspection/maintenance and roadside remote sensing data from millions of vehicles.[680] Emissions of particulate matter are based on EPA's recent Kansas City gasoline PM study.[681,682] Evaporative emission rates have been updated based on extensive evaporative testing conducted by EPA and the Coordinating Research Council (CRC) since the release of MOBILE6, including investigations quantifying the effects of ethanol on permeation emissions.[683] For this assessment of toxics, MOVES applies toxic ratios from the MOBILE6.2 model to updated MOVES HC estimates within the model.[684]

As detailed in a memo to the docket, for the final rule, separate MOVES runs were configured for 2022 for two reference cases (RFS1 mandate and AEO) and for a control case that reflected 100 percent E10 (since we did not estimate E85 impacts for most pollutants, there was no difference between 100 percent E10 and the three volume cases - low, mid, and high ethanol - analyzed for the rule). Each of these runs required a unique "run specification" file and bundle of input databases to allow modeling of differences in analysis year and fuel supplies. Reference and control case runs in 2022 were run with estimates of fuel formulations and market shares by county as we project in 2022.

MOVES allows different levels of pre-aggregation depending on the level of resolution needed. For regional inventory applications, the finest level of aggregation the model can run is by county for each hour of the day, which maximizes the influence of inputs such as county-level fuel effects, hourly temperatures and activity patterns; however, since running the model at this level for the entire nation over multiple years and scenarios would be time prohibitive, the model was run at a higher level of aggregation to reduce run time. For the final rule inventories, new exhaust and evaporative permeation emissions were run at the national aggregation for all cases, meaning that county-level inputs were aggregated to a national average before being processed into MOVES, and hourly inputs were aggregated into an average monthly value for January and July – these monthly values were then weighted together to estimate annual emissionsWhile aggregation does lose some resolution in the overall emission results, test runs indicated that emissions differences are within a few percent of fully disaggregated runs and acceptable for estimating the emission impacts of the control programs. One key aspect of this approach is that even for higher levels of aggregation, fuel supply inputs are retained at the county level in order to maintain the resolution of fuel effects.

Because at the time of this final rule analysis the MOVES module for automating the calculation of E85 emissions from flexible fueled vehicles (FFVs) was not complete, we used estimates done for the NPRM for the E85 impact on acetaldehyde and ethanol, which were calculated by running a pre-draft version of MOVES2009 for all E85 and for all E10 and then weighting the emissions in a post-processing step. To run MOVES for "all E85" we created a special set of MOVES input files that essentially set all gasoline vehicles to run on E85. We created MOVES fuel supply and fuel adjustment tables that applied multiplicative E85 fuel adjustments from Table 3.1-6 to all gasoline vehicle emissions.[187] Because sulfate and vapor venting emissions are calculated using fuel properties (sulfur level and RVP) rather than fuel adjustments, we also created a specific MOVES table of E85 fuel properties as described in Section 3.1.1.1 In a post-processing step, we calculated a weighted average of the "all E85" results and the 2022 control case, sensitivity analysis results (called "all E10" results here). We chose to use the "sensitivity" results for consistency with its premise that modern vehicles are responsive to changes in fuel characteristics. The all E85 and all E10 results were weighted together by state, model year, and vehicle type using a weighting factor that was the product of the FFV fraction and the E85 market share, where FFV fraction is the fraction of that vehicle type and model year that are projected to be E85 flexible-fueled vehicles, and the E85 marketshare is the state fraction of FFV energy use that we project will be provided by E85. These fractions were generated using the assumptions described in the sections in Chapter 1, Section 1.7.1 pertaining to Primary FFV Growth Assumptions and Projected Growth in E85 Access. We performed this calculation for passenger cars and trucks and light commercial trucks only since the number of heavy-duty vehicles using E85 is expected to be small.

Toxic emissions were still in development for MOVES at the time of this analysis; for this analysis some post-processing was required to generate complete inventory estimates. Specific toxic:hydrocarbon ratios by fuel formulation, vehicle class and model year were developed from a series of MOBILE6 runs and fed into MOVES, which applied these ratios to HC emissions to produce emissions of benzene, acetaldehyde, 1-3 butadiene, formaldehyde and acrolein for all of these cases analyzed. Naphthalene from heavy-duty vehicles was ratioed to PM 10 in MOVES. For light-duty vehicles, naphthalene emissions were calculated as the sum of PM 2.5 elemental carbon and PM 2.5 organic carbon emissions times a ratio of 0.088. Aggregate ratios from the running emissions were also applied to start emissions to develop overall toxic emission inventories. E85 emissions were calculated in MOVES using the factors in Table 3-1.6.

3.1.1.4.2 Off-Road Gasoline

Emissions from nonroad gasoline equipment were developed by running the National Mobile Inventory Model (NMIM), a consolidated emissions modeling system for EPA's MOBILE6 and NONROAD models.[685] The key feature of NMIM is a national county database (NCD), which includes county-level information on temperatures, fuel properties, equipment populations, etc. NMIM runs MOBILE6 and NONROAD based on information in the NCD. The NCD used to produce these inventories was updated as part of the 2005 National Emission Inventory (NEI) process.[686] The NCD also included the 2005 and 2022 fuels described in Section 3.1.1.2. The version of the NONROAD Model used included the effects of the 2008 Final Rule: Control of Emissions of Air Pollution from New Nonroad Spark-Ignition Engines,

[187] The MOVES fuel adjustment table developed for this analysis contained all E85 fuel effects from Table 3.1-9, including the not statistically significant NOx and NMHC results; however, only results pollutants identified as statistically significant in Table 3.1-9 are reported in the sensitivity case inventory results

Equipment, and Vessels.[687] It is also capable of modeling the effects of gasoline blends containing 10 percent or less of ethanol.

Emissions from onroad and nonroad diesel equipment were also developed by running NMIM (see above), using the same NCD and version of the NONROAD Model described above. The version of MOBILE was MOBILE6.2. Diesel fuels are less fully characterized than gasoline, since the only property used by MOBILE and NONROAD is fuel sulfur.

Most toxic emissions for off-road equipment were taken directly from NMIM. The one exception was ethanol, which is not estimated by NMIM, so ethanol emissions were based on VOC speciation from light-duty gasoline vehicles. Ethanol inventories for the control case were developed by applying ratios of the aggregate MOVES ethanol exhaust, evaporative and refueling emissions for on-road gasoline for control versus reference cases, to the reference case ethanol emissions for off-road equipment.

3.1.1.4.3 On-Road Diesel

As it is likely that biodiesel will be consumed in a variety of blend levels (e.g. 20 percent, 5 percent, 2 percent) by light-duty diesel vehicles and off-road diesel equipment as well as heavy-duty diesel vehicles, we assumed for this analysis that the effects of biodiesel on emissions are linear with biodiesel concentration as demonstrated by Sze, et al,[688] and that impacts can be analyzed assuming all biodiesel is blended as B20. We applied the B20 effects discussed in Section 3.1.1.2.4 to baseline heavy-duty emissions generated by NMIM, as MOVES heavy-duty diesel estimates were not available in time for this analysis. Biodiesel impacts were using the following formula:

Biodiesel Impact $_{P}$ *= Base HD Emissions* $_{P}$ ** Effect* $_{P}$ ** (Increase in B20 Volume / Total Diesel Volume)*

Where:

P = pollutant
Effect = Percent change with B20 blend from Section 3.1.1.3.3
*Increase in B20 Volume= Change in B20 volume from 2022 reference case to control case in billion gallons of B20 blend (ie, change in gallons of biodiesel * 5)*
Total Volume = Total Highway Diesel Volume in 2022 in billion gallons

Toxic effects were calculated using the HC effects from Table 3.1-8.

It should be noted that the emission inventory impacts estimated for biodiesel used baseline diesel emissions from NMIM (using MOBILE6), which are significantly lower than the updated estimates in MOVES2010. Using MOVES, the increase in NOx and decrease in PM from the projected biodiesel volumes may be twice the magnitude of those reported in this rule.

3.1.1.4.4 Portable Fuel Containers

There are several sources of emissions associated with portable fuel containers (PFC) used for gasoline. These sources include vapor displacement and spillage while refueling the gas can at the pump, spillage during transport, permeation and evaporation from the gas can during transport and storage, and vapor displacement and spillage while refueling equipment. As the calculation of emissions for refueling non-road equipment includes spillage and some vapor displacement, these impacts are not included here. For the final rule we did not update these estimates from the proposal.

As part of the 2007 regulation controlling emissions of hazardous pollutants from mobile sources (MSAT2 rule), EPA promulgated requirements to control VOC emissions from gas cans. The methodology used to develop emission inventories for gas cans is described in the regulatory impact analysis for the rule and in an accompanying technical support document.[689, 690]

Based on the MSAT work, we generated two sets of hypothetical nationwide annual estimates of PFC VOC emissions, for calendar years 2017 and 2030, based on all E0 and all E10. Interpolation can be used to estimate PFC VOC emissions for the reference cases. Proportions of national E0 and E10 fuel use were calculated for the 2022 reference and control cases. The reference case featured a mix of 89.1% E10 and 10.9% E0, while the policy case featured 100% E10. While E85 is used in flexible fueled highway vehicles, it is unlikely to be used in the near future in non-road equipment, and is therefore unlikely to be stored or dispensed from PFCs.

MSATs found in liquid gasoline will be present as a component of VOC emissions. These MSATs include benzene and naphthalene. Ethanol is present as well in VOC emissions from ethanol blends. Inventories for these pollutants were estimated by the application of toxic to VOC ratios.

For benzene emissions from all sources except permeation, the following formula was used to calculate toxic to VOC ratios:

$$PFC\ Benzene\ Emissions =$$
$$PFC\ VOC\ Emissions \times \left(\frac{\mathrm{Re}\,fueling\ Benzene_{LDGV}}{\mathrm{Re}\,fueling\ VOC_{LDGV}} \right) \times 0.36$$

where the ratio of refueling benzene to VOC was estimated using average nationwide fuel properties for zero and 10 percent ethanol gasoline from refinery modeling, done for RFS rule, and applied to EPA's Complex Model for reformulated gasoline.[691, 692] The 0.36 multiplier corrects for the difference in the percentage of gasoline in refueling emissions at 90° F, the temperature assumed for the algorithm in the Complex Model, versus a more typical lower fuel temperature of 60 ° F for gas cans. The basis of this adjustment is discussed in more detail in the regulatory impact analysis for the Mobile Source Air Toxics Rule. An additional adjustment factor is applied to the ratio for permeation emissions, based on a recent study[693] that suggests that the ratio of benzene from permeation to total VOC from permeation is about 1.77 times higher than the ratio associated with evaporation, according to the following formula:

$$PFC\ Benzene\ Emissions =$$
$$PFC\ VOC\ Emissions \times \left(\frac{\mathrm{Re}\,fueling\ Benzene_{LDGV}}{\mathrm{Re}\,fueling\ VOC_{LDGV}} \right) \times 0.36\ x\ 1.77$$

The resulting ratios for 0% and 10% ethanol did not differ at the fifth decimal place, and were 0.0135 for all sources except for permeation, and 0.00239 for permeation. Thus, impacts of this rule on benzene emissions are due to the overall impact of RVP changes on total VOC emissions.

A naphthalene to VOC ratio was estimated using the following formula:

$$PFC\ Naphthalene\ Emissions =$$
$$PFC\ VOC\ Emissions \times \left(\frac{Evaporative\ Naphthalene_{LDGV}}{Evaporative\ VOC_{LDGV}} \right) \times 0.0054$$

An evaporative naphthalene to VOC ratio for light-duty gasoline vehicles of 0.0004 was obtained from analyses done for the Mobile Source Air Toxics Rule, and did not vary by fuel type. The 0.0054 adjustment was based on a recent analysis of average nationwide percentage of naphthalene in gasoline vapor from gasoline distribution with an RVP of 10 psi at 60 degrees Fahrenheit.[694, 695] The resulting ratio applied to PFC emissions was 0.0000022.

For E10 fuel, we assumed 16.74 percent of the evaporative emissions were ethanol (SPECIATE profile 1301)[696] and 33.34 percent of permeation emissions were ethanol.[697]

3.1.1.4.5 Refueling Emissions

Refueling emissions were calculated by NMIM, based on MOBILE6 refueling module. Emissions are impacted by the increase in RVP due to ethanol, and also because the reduced energy density of ethanol would require more fillups. NMIM directly provides the emission increase due to increased RVP for the areas allowing the 1.0 psi waiver, so no additional processing was required to estimate RVP effects on refueling. For the final rule we did not update these estimates from the proposal, except to account for the different control cases.

In order to estimate the emission impact of the increase in refueling events, we developed ton per gallon refueling emission factors based on NMIM by dividing total refueling emissions from NMIM for each case by the number of gallons consumed in the AEO case. The ton per gallon emission factors were then applied to the total volume in gallons in each case. Fuel volumes for the RFS 1 mandate and AE0 reference cases compared to the NPRM and final rule control cases are listed in Table 3.1-9. Our estimates of total gallons were calculated from energy balance, reflecting the various numbers of gallons needed to consume the same energy. We assume the number of trips to the pump will increase in proportion to the increased gallons estimated for the rule.

Table 3.1-9. Gasoline Volumes (Billion Gallons)

	RFS 1 Mandate	AEO 2007	NPRM Control Case	RFS1 Mandate 2022	AEO 2008 rev 2022	FRM RFS2 Control Low EtOH	FRM RFS2 Control Primary	FRM RFS2 Control High EtOH
E0	107.51	16.03	0	65.72	6.46	0.00	0.00	0.00
E10	36.40	131.00	124.6	70.46	131.82	134.25	128.79	115.82
E85	0.00	0.11	29.3	0.00	0.00	5.49	12.54	29.26
Total Gallons	**143.91**	**147.14**	**153.9**	**136.18**	**138.28**	**139.74**	**141.32**	**145.08**

3.1.2 Impact on Non- GHG Emissions from Fuel Production and Distribution

In addition to the effects of increased renewable fuel use on emissions from the vehicles and equipment that use the fuels, as discussed above, there are shifts in the fuel production and transport/distribution methods that can have substantial impacts on emissions. These "upstream" emissions are associated with all stages of biofuel production and distribution, including biomass production (agriculture, forestry), fertilizer and pesticide production and transport, biomass transport, biomass refining (corn or cellulosic ethanol production facilities), biofuel transport to blending/distribution terminals, and distribution of finished fuels to retail outlets. Additionally, changes in agricultural economics associated with increased biomass production can result in shifts in related agricultural production, such as livestock.

This section describes the changes in upstream emission sources and related emission rates connected with the renewable fuel use. The emission inventory impacts resulting from these changes are described in Section 3.2. This section is divided into two major sub-sections, the first covering emissions of criteria pollutants, their precursors, and ammonia, and the second covering non-criteria air toxic emissions and ethanol. The specific air toxics covered are: benzene, acetaldehyde, formaldehyde, 1,3-butadiene, acrolein, and naphthalene.

3.1.2.1 Upstream Criteria Pollutants

3.1.2.1.1 Agricultural Sector

Introduction

In prior EPA estimates, such as the RFS1 rule, changes in agricultural emissions were based solely on the increases in bushels of corn (and soybeans for biodiesel), and the necessary acreage to produce those additional bushels. Given the greater pressure on farmland use likely in the 2022 timeframe for today's rule (15 billion gallons of corn ethanol plus up to 16 billion gallons of cellulosic ethanol) compared to the 2012 assessment for RFS1 (6.7 or 9.6 billion gallons of ethanol depending on scenario), additional factors have been added to the agricultural analysis, such as likely shifts of acreage to corn from certain other crops as corn prices increase.

The number of acres of cropland for corn, soy, and all other principle crops were estimated using the FASOM agriculture and forestry model, as described in Section 5.1 of this document. We are using the change in total acres of planted cropland to estimate changes in certain agricultural emissions, such as tillage dust, that are not directly calculated by FASOM. Another substantial source of agricultural emissions (especially ammonia and methane) is livestock. Changes in livestock-related emissions are estimated based on the change in head counts of cattle, swine, and poultry predicted by FASOM.

The impacts relative to the RFS1 mandate reference case (6.7 billion gallons of ethanol) rely only on applying ethanol volume proportions to the modeling results of the AEO reference case (13.2 billion gallons). Due to the complex interactions involved in projections in the agricultural modeling, we did not attempt to adjust the agricultural inputs of the AEO reference case for the RFS1 reference case. So the fertilizer and pesticide quantities, livestock counts, and total agricultural acres were the same for both reference cases. The agricultural modeling that had been done for the RFS1 rule itself was much simpler and inconsistent with the new modeling, so it would be inappropriate to use those estimates. We had planned to conduct additional agricultural modeling specifically for the RFS1 mandate case prior to finalizing this rule, but there was not sufficient time and resources to accomplish that after all the other updates and sensitivities analyzed for the AEO case alone for the final rule.

3.1.2.1.1.1 VOC/NOx/CO/SOx/PM2.5

Criteria pollutants related to agricultural operations come from five major sources: farm equipment (mainly diesel engine emissions), fertilizer production and application, pesticide production and application, burning of crop residue, and fugitive dust from field tilling and related activities.

Agricultural Equipment Emissions

Changes in farm equipment emissions were estimated by multiplying an average fuel-based emission factor for diesel or gasoline farm equipment by the change in farm fuel consumption predicted by FASOM. The emission factors for each pollutant in units of grams emitted per million BTU of fuel burned were calculated from EPA NONROAD2005 nationwide modeling outputs for 2022 (pollutant tons emitted, gallons of fuel consumed) for each year of interest. The diesel emissions include all agricultural diesel equipment, which are dominated by agricultural tractors, while the gasoline emissions include only the limited number of larger agricultural gasoline-fueled equipment, such as tractors, combines, balers, swathers, and irrigation sets. The fuel energy contents (lower heating value) used for the unit conversions were 115,000 BTU/gallon for gasoline and 130,000 BTU/gallon for diesel. For comparison, the corresponding 2020 emission factors from GREET are shown, where available. Most of the differences between NONROAD and GREET are small and are likely attributable to the difference between 2020 and 2022 values. And although the gasoline equipment emission factors for VOC and CO from NONROAD are much greater than those used in GREET, this does not have much impact on emission inventories due to the small number of gasoline-fueled equipment used in agriculture relative to diesel equipment.

Table 3.1-10.
Agricultural Equipment Emission Factors
(grams per mmBTU of fuel burned)

Pollutant	**Diesel**		**Gasoline**	
	NONROAD	GREET	NONROAD	GREET
NOx	306	298	204	208
VOC	30.55	34.87	355.53	52.30
PM10	21.12	22.67	7.49	9.07
PM2.5	20.49	20.41	6.89	8.34
CO	130	136	10,067	204
Benzene	0.62	--	11.90	--
Ethanol	0.00	--	0.00	--
1,3-Butadiene	0.057	--	1.90	--
Acetaldehyde	1.62	--	1.63	--
Formaldehyde	3.61	--	3.17	--
Naphthalene	0.027	--	0.66	--
Acrolein	0.09	--	0.14	--
SO2	0.44	--	15.88	--
NH3	0.68	--	1.01	--

Fertilizer and Pesticide Production

The manufacturing processes for agricultural fertilizer and pesticides generate a variety of air pollutants. The agricultural inputs from GREET provide emission factors in grams of pollutant per ton of nutrient for various types of fertilizers, herbicides, and insecticide, as shown in Table 3.1-12. These air emission factors were multiplied by the changes in fertilizer and pesticide use predicted by FASOM, as shown in Table 3.1-11, to give projected changes in nationwide agricultural fertilizer and pesticide production emissions.

Table 3.1-11.
Changes in Agricultural Chemical Use for 2022 RFS2 Control Case Relative to AEO2007 Reference Case

	Nitrogen (average)	**Phosphate** (P2O5)	**Potash** (K2O)	**Limestone** (CaCO3)	**Herbicides**	**Pesticides**
Annual Short Tons	750,629	357,069	662,157	260,304	-750	-381
Percentage	5.73%	12.72%	20.16%	2.55%	-0.38%	-0.86%

Table 3.1-12.
Agricultural Chemical Production & Transport Air Emission Factors
(grams per ton of nutrient)

Pollutant	**Nitrogen** (average)	**Phosphate** (P2O5)	**Potash** (K2O)	**Limestone** (CaCO3)	**Herbicides**	**Pesticides**
NOX	1,605	4,484	734	573	19,371	21,628
VOC	2,761	240	40.7	56.8	1,575	2,040
PM10	454	1,551	148	506	10,840	11,746
PM2.5	262	1,018	74.5	167	4,869	5,479
CO	2,595	790	129	186	5,417	6,872
Benzene	0.00	0.00	0.00	0.00	3.21	4.16
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00
1,3-Butadiene	0.000	0.000	0.000	0.000	0.576	0.745
Acetaldehyde	0.018	0.001	0.000	0.000	0.082	0.106
Formaldehyde	20.75	1.55	0.19	0.41	18.11	23.44
Naphthalene	0.033	0.117	0.010	0.039	114.4	124.0
Acrolein	0.009	0.001	0.000	0.000	0.024	0.031
SO2	703	53,299	321	701	11,300	12,895
NH3	0.00	0.00	0.00	0.00	0.00	0.00

Until the 1990s it was reasonable to assume that all fertilizers and pesticides used on domestic agriculture were produced within the U.S. This has been less true in recent years as more agricultural chemicals, especially fertilizers, are being imported from countries with a greater availability of natural gas at lower costs. For greenhouse gases the location of these emissions is of less importance, but for criteria pollutants and toxics it is important to reduce the estimated impacts by the percentage of production and transportation occurring outside of the U.S. Using data from USDA[698,699] the percentages applied from domestic sources are shown in Table 3.1-13. After applying these percentages to the production and initial transportation portions of the GREET emission factors, the unadjusted final (domestic) transportation portion of the GREET emission factors was added back in. Since the relative emissions from production versus transportation vary by pollutant, the net adjustments to the GREET emission factors also vary by pollutant, as shown in the second Section of Table 3.1-13. To calculate an overall factor for nitrogen fertilizers, the proportions from GREET were used: 70.7% ammonia, 21.1% urea, and 8.2% ammonium nitrate. The pesticide adjustment does not vary by pollutant because virtually all of the pesticide emissions come from actual production rather than transportation/distribution.

Table 3.1-13.
Domestic Fractions of Fertilizer and Pesticide Production Applied to Crops

	Nitrogen Fertilizers	Potash	Phosphate	Pesticides
Domestic Fraction of Production	50%	20%	94%	76%
Net Adjustment to Production, Transportation & Distribution Emission Factor from GREET				
VOC	50.63%	94.85%	53.62%	76%
CO	52.47%	94.92%	54.37%	76%
NOx	73.34%	94.92%	65.55%	76%
PM10	52.64%	94.12%	24.06%	76%
PM2.5	53.67%	94.14%	28.31%	76%
SOx	60.48%	94.02%	33.66%	76%

Fertilizer and Pesticide Application

In addition to the agricultural equipment emissions mentioned above, the application of fertilizer and pesticides (herbicides, insecticides, fungicides, etc.) to agricultural fields causes the release of certain types of pollutants into the air. For nitrogen fertilizers the only pollutant considered to be significant is ammonia (NH_3), the estimation of which is covered in Section 3.1.3.1.1.2. Pesticide application emissions are mainly VOC and various individual organic compounds, most notably benzene and acrolein. A discussion of the toxic pollutant emissions as a fraction of VOC is presented in Section 3.1.3.2.2, but the resulting emission factors and inventory impacts are shown here in Table 3.1-14. There are also potential toxicity concerns with volatilization of the pesticide active ingredients, and this is discussed in Section 3.4 of this document.

The basis of the pesticide application emissions for this analysis was the 2002 NEI area-source inventory. The ton per year emissions data from the NEI was used with USDA pesticide application data for 2002 (or the nearest year for which data were collected) to generate an overall average estimate of the pesticide application emissions per ton of pesticide applied. This ratio of pollutant tons (for VOC, benzene, and acrolein) per ton of pesticide applied was then multiplied by the change in total pesticide tons used (including herbicides) as projected by FASOM and shown in Table 3.1-11 to give the projected change in nationwide agricultural pesticide application emissions in Table 3.1-14.

Table 3.1-14.
Herbicide and Pesticide Application Air Emission Factors and Impacts for 2022 RFS2 Control Case Relative to AEO2007 Reference Case

Pollutant	Emission Factor	Air Emission Impact
	(tons per ton applied)	(annual short tons)
VOC	0.543	-614
Benzene	0.142	-161
Acrolein	0.0036	-4.06

Agricultural Residue Burning Emissions

One source of air pollution related to crop farming is the burning of crop residues. This practice is one of the methods that is used to clear fields between crop cycles so that the old crop residue does not build up and clog or otherwise hinder the tilling of the fields in preparation for new crop planting. This practice is mainly used for grassy crops like wheat, rye, and barley, but in some areas it is also used for corn and other crops.

Crop residue burning produces substantial emissions of CO2, VOC, CO, NOx, as well as ammonia and toxic pollutants such as benzene, formaldehyde, 1,3-butadiene, and acrolein.

The use of crop residue burning is quite variable from area to area and among individual farmers, since there are alternative methods to deal with crop residue, including use of conservation tillage methods and equipment that allows planting through the residue. In some locations and time periods crop residue burning has been prohibited by law, due to the possible health effects in nearby residential areas. Another aspect of uncertainty in estimating crop burning emissions is that the NEI does not currently cover all states where crop residue burning occurs. Despite these data limitations, the NPRM used the available data to generate a rough overall estimate of the average crop burning emissions per acre of planted crops, and then multiplied that emission rate to the change in total crop acres predicted by FASOM to generate an estimated emission inventory impact.

For this final rule analysis we have reconsidered the inclusion of any crop residue burning impact and decided not to include it. This reconsideration was driven by the facts that (a) the crops most likely to be impacted by this rule do not tend to be ones for which residue burning is used, and (b) even for those crops affected by this rule that might otherwise have their residue burned, for this analysis they would much more likely have that residue harvested and used as cellulosic feedstock in a biofuel plant. Given the uncertainty in projecting these emission impacts, we did not want any rough assumptions made to unduly influence the emission impact assessment.

Agricultural Dust Emissions

Soil and related dust particles (e.g., fertilizer, pesticide, manure) become airborne as a result of field tillage and animal grazing/foraging, especially in drier areas of the country. Some of this dust is in a size range that is a concern for human health and welfare. The NEI includes estimates of these particulate emissions by county.

The agricultural dust data from the 2002 NEI was used to generate an estimate of the average fugitive dust emissions per acre of planted crops for the crop related dust, and per head of cattle for the dust related to cattle. This was done using 2002 nationwide crop acreage and livestock inventory data from USDA/NASS. The calculated pollutant mass (tons of PM) per total acre farmed was then multiplied by the change in total planted acres projected by FASOM to give a projected change in nationwide crop related dust emissions. And the calculated PM tons per head of cattle was multiplied by the change in cattle inventory projected by FASOM to give a projected change in nationwide livestock related dust emissions.

The emission factors and inventory impacts of fugitive dust from crop related activities and livestock are shown in Table 3.1-15 and 3.1-16. The ton per year impacts for the crop-related emissions are based on a modeled increase of 8.1 million farmed acres (2.65 percent) in 2022 relative to the AEO2007 reference case. The changes in fugitive dust from livestock operations are based on the head count changes shown in Table 3.1-18.

Table 3.1-15.
2022 Crop-related Dust Emission Impacts for the 2022 RFS2 Control Case Relative to AEO2007 Reference Case

Pollutant	**Emission Factors**	**Inventory Impacts**
	(Tons per thousand acres farmed)	(annual short tons)
PM10	6.807	55,182
PM2.5	1.021	8,277

Table 3.1-16.
2022 Livestock-related Dust Emission Impacts for the 2022 RFS2 Control Case Relative to the AEO2007 Reference Case

Pollutant	**Beef Cattle Dust Emissions**		**Dairy Cattle Dust Emissions**	
	(kg/head/year)	(annual short tons)	(kg/head/year)	(annual short tons)
PM10	0.888	-139.68	0.172	-8.34
PM2.5	0.089	-14.00	0.017	-0.82

3.1.2.1.1.2 Ammonia (NH3)

The two primary sources of ammonia emissions into the air on farms are fertilizer application and livestock waste. Fertilizer application emissions were estimated using an average emission factor of 57,428.71 grams per ton of fertilizer nitrogen applied for all forms of nitrogen, which is a weighted average of the standard EPA emission factors that are used to generate the NEI. The weightings for each type of fertilizer come from USDA Economic Research Service data for 2006. The individual emission factors, weightings, and resulting average emission factor are shown in Table 3.1-17. This average emission factor was multiplied by the nitrogen application quantities generated by the FASOM model for each scenario.

Table 3.1-17. Fertilizer Ammonia Emission Factors

Fertilizer Type	SCC	Emission Factor (lbs NH3/Ton Nitrogen)	USDA 2006 all crops Weighting
Anhydrous Ammonia	2801700001	24	15.46%
Aqua Ammonia	2801700002	24	1.61%
Nitrogen Solutions	2801700003	61	40.88%
Urea	2801700004	364	21.73%
Ammonium Nitrate	2801700005	49	3.9%
Ammonium Sulfate	2801700006	194	4.93%
Ammonium Thiosulfate	2801700007	64	
Other Straight Nitrogen	2801700008	61	11.49%
Ammonium Phosphates	2801700009	97	
N-P-K	2801700010	97	
avg lbs/ton			**126.61**
avg grams/ton			**57428.71**

Changes in ammonia emissions from livestock waste were estimated using emission factors (kg/head/year) multiplied by the change in animal head counts predicted by FASOM. The ammonia emission factors and livestock head changes used in this analysis, along with resulting ammonia inventory impacts are shown in Table 3.1-18. This analysis was limited to these four types of livestock because they are the ones specifically modeled by FASOM.

Table 3.1-18. Livestock Ammonia Emission Impacts for 2022 RFS2 Control Case Relative to the AEO2007 Reference Case

Livestock Type	kg NH3 per head per year[a]	Head count change (million head)	Percent change	Change in NH3 emissions (annual short tons)
Beef Cattle	9	-0.143	-0.23%	-1,416
Dairy Cattle	25	-0.044	-0.65%	-1,212
Swine	5	3.95	3.24%	21,711
Poultry	0.22	-73.5	-0.98%	-17,798

[a] Source: EPA/600/R-02-017, "Review of Emission Factors and Methodologies to Estimate Ammonia Emissions From Animal Waste Handling," April 2002.

Although it is a minor source of ammonia compared to fertilizer and livestock emissions described above, changes in farm equipment ammonia emissions were estimated by multiplying an average fuel-based emission factor for diesel or gasoline farm equipment by the change in farm fuel consumption predicted by FASOM. The ammonia emission factors in units of grams emitted per million BTU of fuel burned were calculated from the default ammonia emission factors used in the EPA NMIM model: 116 mg per gallon of gasoline burned; and 88.3 mg per gallon of diesel fuel burned.

3.1.2.1.2 Biofuel Production

Emissions from the production of biofuels include the emissions from the production facility itself as well as the emissions from production and transport of the biomass and any other fuels used by the biofuel plant, such as natural gas, coal, and electricity. The biomass feedstock production emissions are discussed above in the section on agricultural emissions. The calculation of emissions from corn ethanol, cellulosic ethanol, and biodiesel plants, including feedstock transport, was done using the basic methodology of the GREET model. But some updates and enhancements were made to GREET, including updated feedstock energy requirements and estimates of excess electricity available for sale from new cellulosic ethanol plants, based on modeling by the National Renewable Energy Laboratory (NREL). Since certain biofuel production processes generate co-products that could also be used in the gasoline market, we have accounted for those by decreasing the refined gasoline volume on an equal fuel energy basis to the co-products. This was done in two cases -- co-product naphtha from the Fischer-Tropsch process and C3+ alcohols from the thermochemical ethanol from mixed alcohols process.

The facility emission factors used are shown in Table 3.1-19. These have been updated for this final rule based on new analyses of projected plant efficiency improvements, rather than using older analyses, such as dry mill corn plant emission data from plants existing in 2005 as was used for the NPRM and air quality modeling inventories. These new analyses, discussed in Section 1.5.1.3 for corn ethanol, Section 1.5.3 for cellulosic ethanol and diesel, and Section 1.5.4 for biodiesel, provide projections of energy and feedstock requirements for biofuel production. These energy requirements are then multiplied by emission factors (grams per mmBTU of feedstock consumed) from the GREET model to yield the gram per gallon emission factors presented here.

Table 3.1-19.
Biofuel Production Plant Emission Factors in 2022
(grams per gallon produced)

Biofuel Plant Type	VOC	CO	NOx	PM10	PM2.5	SOx	NH3
Corn Ethanol, Dry Mill NG	2.29	0.58	0.94	0.94	0.23	0.01	0.00
Corn Ethanol, Dry Mill NG (wet DGS)	2.27	0.37	0.60	0.91	0.20	0.00	0.00
Corn Ethanol, Dry Mill Biogas	2.29	0.62	1.00	0.94	0.23	0.01	0.00
Corn Ethanol, Dry Mill Biogas (wet DGS)	2.27	0.39	0.63	0.91	0.20	0.00	0.00
Corn Ethanol, Dry Mill Coal	2.31	2.65	3.68	3.64	1.54	3.48	0.00
Corn Ethanol, Dry Mill Coal (wet DGS)	2.28	1.68	2.34	2.62	1.03	2.21	0.00
Corn Ethanol, Dry Mill Biomass	2.42	2.55	3.65	1.28	0.36	0.14	0.00
Corn Ethanol, Dry Mill Biomass (wet DGS)	2.35	1.62	2.32	1.12	0.28	0.09	0.00
Corn Ethanol, Wet Mill NG	2.33	1.04	1.68	1.00	0.29	0.01	0.00
Corn Ethanol, Wet Mill Coal	2.33	3.50	4.86	4.53	1.98	4.60	0.00
Cellulosic Ethanol (Enzymatic, switchgrass or corn stover)	1.45	4.68	6.71	1.63	0.53	0.25	0.00
Cellulosic Ethanol (Enzymatic, forest waste)	1.46	4.93	7.06	1.67	0.55	0.26	0.00
Cellulosic Ethanol (Thermochemical, switchgrass or corn stover)	0.49	6.99	10.03	1.16	0.58	0.37	0.00
Cellulosic Ethanol (Thermochemical, forest waste)	0.49	6.99	10.03	1.16	0.58	0.37	0.00
Biodiesel, Soybean oil	0.04	0.43	0.69	0.06	0.06	0.01	0.00
Biodiesel, Yellow grease/tallow	0.04	0.50	0.80	0.07	0.07	0.01	0.00
Biodiesel, Fuel grade corn oil	0.04	0.50	0.80	0.07	0.07	0.01	0.00
Biodiesel, Algae	0.01	0.10	0.16	0.01	0.01	0.00	0.00
Renewable Diesel*, Yellow grease	0.00042	0.00475	0.00767	0.00065	0.00065	0.00006	0.00
Cellulosic Diesel (Thermochemical, Fischer-Tropsch forest waste)	0.91	13.39	20.22	2.39	1.20	1.80	0.00

* The renewable diesel emission factors are based only on the energy needed for hydrotreating at an existing refinery, which is different from stand-alone facilities we project in Section 1 will be making renewable diesel (RD). An RD plant would have more feedstock handling, pumping, etc., as well as general plant energy overhead than for a marginal unit in a refinery.

3.1.2.1.3 Crude Oil Production/Transport/Refining

The estimate of emissions associated with production of gasoline and diesel fuel from crude oil is based on emission factors in the GREET model. The actual calculation of the emission inventory impacts of the decreased gasoline and diesel production is done in EPA's spreadsheet model for upstream emission impacts.[700] This model uses the decreased volumes of the crude based fuels and the various crude production and transport emission factors from GREET to estimate the net emissions impact, which is shown below in Section 3.2 (see the displaced gasoline row of Table 3.2-5).

3.1.2.1.4 Finished Fuel Transport and Distribution

Transfer and Storage Evaporative Emissions from Gasoline, Gasoline/Ethanol Blends, and Ethanol -- VOC emissions are produced by transfer and storage activities associated with distribution of gasoline, gasoline/ethanol blends, and ethanol. These are referred to as Stage I emissions.[701] Stage I distribution begins at the point the fuel leaves the production facility and ends when it is loaded into the storage tanks at dispensing facilities.

There are five types of facilities that make up this distribution chain for gasoline. Bulk gasoline terminals are large storage facilities that receive gasoline directly from the refineries via pipelines, barges, or tankers (or are collocated at refineries). Gasoline from the bulk terminal storage tanks is loaded into cargo tanks (tank trucks or railcars) for distribution to smaller intermediate storage facilities (bulk plants), or directly to gasoline dispensing facilities (retail public service stations and private service stations). When ethanol is blended into gasoline it usually occurs in the pipes which supply the tank trucks.

There are two types of pipeline facilities found at various intervals along gasoline distribution pipelines: pipeline breakout stations and pipeline pumping stations. Pipeline breakout stations receive gasoline via pipelines, store it in storage tanks, and re-inject it into pipelines as needed to meet the demand from downstream facilities. Pipeline pumping stations are located along the entire length of a pipeline at about 40 mile intervals. Their purpose is to provide the extra ''push'' needed to move the product through the pipeline. They do not normally have gasoline storage capability.

Bulk plants are intermediate storage and distribution facilities that normally receive gasoline or gasoline/ethanol blends from bulk terminals via tank trucks or railcars. Gasoline and gasoline/ethanol blends from bulk plants are subsequently loaded into tank trucks for transport to local dispensing facilities.

Gasoline and gasoline/ethanol blend dispensing facilities include both retail public outlets and private dispensing operations such as rental car agencies, fleet vehicle refueling centers, and various government motor pool facilities. Dispensing facilities receive gasoline and gasoline/ethanol blends via tank trucks from bulk terminals or bulk plants. Inventory estimates for this source category only include the delivery of gasoline at dispensing facilities and does not include the vehicle or equipment refueling activities.

Emission factors (EFs) for gasoline were based on inventory estimates from the 2002 NEI.[702] We used these data to develop E0 gasoline emission factors even though the 2002 emissions included the E10 that was in the fuel pool at that time. In 2002 this was still a relatively small proportion of gasoline consumption, so it should not substantially affect the national E0 estimates. Since ethanol is blended with gasoline at bulk terminals to produce E10 and E85 at the point fuel is loaded into tank trucks, we assumed bulk terminal emissions were associated with unblended gasoline. We then divided emissions into a refinery to bulk terminal component and a bulk terminal to dispensing facility component. Total nationwide emissions for these two components were divided by the energy content of the total volume of gasoline distributed in 1999, to obtain the emission factor in g/mmBTU. Total volume of gasoline was based on gasoline sales as reported by the Energy Information Administration.[703] These emission factors are provided in Table 3.1-20.

We also developed emission factors for Stage 1 emissions of E10 and E85 subsequent to blending at bulk terminals. These emission factors were calculated by applying adjustment factors to the gasoline EF. The adjustment factors for E10 and E85 were based on an algorithm from the 1994 On-Board Refueling Vapor Recovery Rule[704]:

$$EF\ (g/gal) = \exp[-1.2798 - 0.0049(\Delta T) + 0.0203(Td) + 0.1315(RVP)] \qquad (1)$$

where delta T is the difference in temperature between the fuel in the tank and the fuel being dispensed, and Td is the temperature of the gasoline being dispensed. We assumed delta T is zero, temperature of the fuel being dispensed averages 60 degrees over the year, and that the RVP of conventional gasoline is 8.7 psi, 10% ethanol is 9.7, and 85% ethanol is 6.2. Using these assumptions, the adjustment factor is +14% for E10 and -30% for E85. Emission factors in grams per million BTU of fuel transferred are given in Table 3.1-20.

In addition to these Stage I emissions for gasoline and gasoline/ethanol blends, transport of ethanol to bulk terminals also results in evaporative emissions of ethanol, a VOC. For the NPRM analysis these emissions were estimated using a very simplified approach based on an adjustment to the gasoline transport VOC emissions to account for the much lower vapor pressure and molecular weight of ethanol versus gasoline. Using that method the NPRM assumed an emission factor of 3.56 g/mmBTU ethanol, which greatly underestimated the ethanol vapor and VOC losses, since it did not attempt to account for differences between ethanol and gasoline transport modes, distances, or transfer methods in movement of the fuel from production facility to the bulk distribution terminal.

For the air quality analysis and final rule analysis this method was replaced using data from an Oak Ridge National Laboratory (ORNL) analysis of projected ethanol transport modes, distances, and volumes transferred under various ethanol volume scenarios.[728] The final results of that study yielded greatly increased EFs of 26.9 - 31.7 g/mmBTU (2.04 - 2.41 g/gal) depending on the scenario, due to the added fuel transfer losses compared to pipeline-based transport of gasoline. The EF shown in Table 3.1-20 (28.78 g/mmBTU) corresponds to the High Ethanol minus RFS1 reference case, and was used for calculation of VOC and ethanol vapor for all cases in this FRM analysis. The air quality analysis used preliminary results of the ORNL analysis, which yielded somewhat greater ethanol and VOC emission rates than used for this FRM analysis. Further discussion of these calculations can be found in Section 3.3 of this RIA chapter.

Significant evaporative emissions are not expected from storage and transport of biodiesel fuel due to its low volatility.

Table 3.1-20.
VOC Emission Factors for Gasoline and Gasoline/Ethanol Blend Storage and Transfer Emissions (Stage 1)

Process	Blend	EF(g/mmBTU)
Refinery to Bulk Terminal	E0	14.94
Refinery to Bulk Terminal	E100	28.78[a]
Bulk Terminal to Pump	E0	27.79
Bulk Terminal to Pump	E10	32.74
Bulk Terminal to Pump	E85	25.93

[a] E100 ethanol vapor EF ranges from 26.9 - 31.7 depending on scenario. EF shown corresponds to the High Ethanol minus RFS1 reference case, and was used for calculation of all cases in this FRM analysis.

Combustion Emissions from Transport and Distribution of Fuels and Feedstocks -- Emissions are produced by the vehicles and engines used to transport feedstocks such as crude oil, corn, and cellulosic biomass to fuel production facilities, as well as transport/distribution of the finished fuels from the production plants to distribution terminals and retail outlets. For example, corn would be transported from farms and grain facilities to ethanol plants by truck and possibly rail. The finished ethanol would be transported from there to bulk distribution terminals by truck, rail, or barge, and distribution from terminal to retail outlet is by truck. The emission factors for the year 2022 in Table 3.1-21 are taken from the most recent rulemaking analyses, accounting for the mix of newer better controlled engines (including trucks meeting the standards for 2008 and later engines[705] and engines meeting the 2008 locomotive/marine diesel engine rule[706]), as well as any remaining older engines subject to less stringent standards. The truck EFs are given in terms of grams per vehicle mile traveled, while the other EFs are in grams per million BTU of fuel burned by the engine. The ocean tanker emission factors are from the base case analysis of the Category 3 ocean-going vessel proposed rule.[734]

To estimate the net emission rates for the assumed mix of transport modes for each fuel type, these emission factors were incorporated into a modified version of GREET[707], [708], since GREET 1.7 and 1.8 retained emission factors based only on earlier regulations. Thus, the miles traveled and quantities of fuel burned are those used by GREET for each transport mode and fuel being transported. For the final rule air quality analysis we will have a more detailed analysis of miles and fuel volumes transported by mode within each county.

Table 3.1-21. 2022 Criteria Emissions from Fuel and Feedstock Transport/Distribution

Transport Mode	Year	VOC	CO	NOx	PM10	PM2.5
Class 2B HD Diesel Trucks (g/mile)	2005	0.282	1.303	3.594	0.163	0.139
	2022 (2020)	0.137	0.205	0.483	0.033	0.019
Medium HD DIesel Trucks (g/mile)	2005	0.653	2.482	8.297	0.309	0.271
	2022 (2020)	0.289	0.417	1.243	0.053	0.035
Locomotive (g/mmBTU of fuel burned)	2005	84.733	212.861	1620.376	51.575	50.028
	2022 (2020)	34.070	203.984	815.271	19.015	18.445
Barge (avg of C1 & C2 vessels)[709]	2005	26.761	237.513	1276.901	47.923	46.485
(g/mmBTU of fuel burned)	2022 (2020)	15.527	188.994	676.097	22.017	21.356
Ocean Tanker (C3 vessels)	2005	79.298	180.314	2176.240	179.982	165.408
(g/mmBTU of fuel burned)	2022 (2020)	79.160	179.525	2038.314	179.645	165.273

3.1.2.2 Upstream Air Toxics

3.1.2.2.1 Upstream Air Toxics Reference Case

Air toxic emissions are associated with a variety of upstream processes. These processes include production of agricultural pesticides and fertilizers, as well as their application, operation of petroleum refineries, operation of ethanol and biodiesel production facilities, operation of electrical production facilities which supply power to these facilities, and distribution of agricultural pesticides and fertilizers, feedstocks, gasoline, gasoline/ethanol and biodiesel blends.

Although a large number of compounds which are considered air toxics could be impacted by this rule, we focused on those which were identified as national and regional-scale cancer and noncancer risk drivers in the 2002 NATA[710] and were also likely to be significantly impacted by this rule. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Naphthalene impacts were included for petroleum refineries, since it is a significant emission product for those facilities. Ethanol impacts were also included in our analyses because of health concerns (Section 3.4.5) and its role as an acetaldehyde precursor.

2002 air toxic emissions for stationary sources, other than for fires, were obtained from the 2002 National Emissions Inventory (NEI), version 3. Future year emissions of benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein were estimated for sectors only, rather than individual sources. These sectors included non-EGU (electric generating unit) point sources, EGU point sources, the nonpoint storage and transfer subsector, and other nonpoint sources. Emissions were estimated by applying the 2002 air toxics to VOC ratio to the future year VOC emission estimates. Air toxics from fires were estimated by applying toxics-to-VOC ratios to the VOC emissions from a fire inventory developed for air quality modeling. 2002 and future year ethanol emissions were estimated by speciating the VOC estimates. This was done using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system, version 2.3. More details on the methods and data used to develop these inventories are found in a memo included in the docket for this rule.[711]

Air toxic emission estimates for agricultural equipment (mainly diesel agricultural tractors) were obtained from the EPA NMIM model, as described for criteria pollutants in Section 3.1.2.1.1.1.

3.1.2.2.2 Upstream Air Toxics Control Cases

As described below, we developed emission factors for several air toxics using the most recent available data. These emission factors were used with estimates of changes in fuel volumes and associated energy outputs to estimate inventory changes associated with the RFS2 volumes. In general, emission factors are expressed as grams per million BTU (g/mmBTU) of energy produced or distributed as part of the process. Underlying data are available in the docket for the rule.

Agricultural Pesticides and Fertilizers – The estimation of air toxic emissions from production and application of pesticides and fertilizers was done using toxic fractions of the corresponding VOC emissions described in Section 3.1.3.1.1.1. Table 3.1-22 shows the toxic fractions, which were calculated from the 2002 NEI inventories for VOC and each of the listed toxic pollutants. All the pollutants except acrolein from pesticide application are based on nationwide inventories. California was the only state that reported acrolein emissions associated with pesticide application, so the 0.66% value shown in the table represents the sum of acrolein emissions divided by the sum of VOC emissions from pesticide application for all counties in California in 2002. The fertilizer and pesticide application data come from queries of the NEI area source inventories for SCCs like "28017*" (for fertilizer application) and SCCs like "246180*" or like "246185*" (for pesticide application).

The production and blending data for fertilizer and pesticides come from queries of the NEI point source data that were submitted by 40 states and Puerto Rico for the following MACT codes:

0911 - Pesticide Active Ingredient Production
0960 - Agricultural Chemicals and Pesticides Manufacturing
1410 - Phosphate Fertilizers Production

The data for these codes was compiled for the following four categories: Fertilizer production (F), Fertilizer mixing blending (FMB), Pesticide production (P), and Pesticide mixing blending (PMB).

Table 3.1-22. Air Toxic Fractions of VOC for Fertilizers and Pesticides

	Fertilizer Production & Blending	Pesticide Production & Blending	Fertilizer Application	Pesticide Application
1,3-Butadiene	--	0.0003653	--	--
Acetaldehyde	6.530 E-06	5.198 E-05	--	--
Acrolein	3.320 E-06	1.513 E-05	--	0.0066
Benzene	--	0.002038	--	0.2615
Ethanol	--	--	--	--
Formaldehyde	0.007517	0.011494	--	--

Petroleum Refineries – Total nationwide emissions of air toxics for 153 U. S. petroleum refineries in 2002 were obtained from data collected as part of a risk and technology review (RTR) for EPA's proposed rule, "National Emission Standards for Hazardous Air Pollutants From Petroleum Refineries."[712] These emissions were divided by BTUs of energy produced by those refineries in 2002 to obtain emission factors in g/mmBTU. Thus the resultant emission factors represent 2002 technology and emission standards. Energy output estimates included all refinery products, such as conventional and reformulated gasoline, aviation gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, petrochemical feedstocks, naphthas, lubricants, and other miscellaneous products. Energy output was estimated by multiplying volume of each product supplied[713] by its heating value in BTUs per gallon.

Resultant emission factors are provided below in Table 3.1-24, along with those for ethanol and electricity production.

Ethanol Production Facilities – There are a number of processes at ethanol production facilities that result in emissions of air toxics. These processes include fermentation, distillation of the resultant mash, and drying of spent wet grain to produce animal feed. Emissions of air toxics vary tremendously from facility to facility due to a variety of factors, and it is difficult to determine how differences in the production processes individually impact emissions. Numerous production facilities have commenced operation in the last few years. To develop emission factors we used the most recent available inventory for benzene, formaldehyde, acetaldehyde, and acrolein, from calendar year 2005. These data were obtained from two sources:

1) 2005 NEI State submittals for SCCs associated with ethanol production facilities
2) the 2005 Toxics Release Inventory (TRI)

2005 NEI data submittals were obtained from EPA's Office of Air Quality Planning and Standards. These data are included in the docket for the rule. Additional data for facilities not included in these submittals were obtained from the 2005 TRI (http://www.epa.gov/triexplorer/list-chemical-hap.htm). Where emissions data were not available for a facility, the facility was excluded from subsequent calculations. It should be noted that not all States submitted data for ethanol production facilities, which could potentially introduce some bias into estimated emission rates.

Only a few facilities reported very low emissions of 1,3-butadiene, and the rest reported no emissions, so emissions of this pollutant from ethanol production facilities were assumed to be insignificant. Almost all of the data were from dry mill plants running on natural gas, so it was not possible to develop separate emission factors for wet and dry mill plants, or those running on coal or natural gas.

Energy output for each facility was estimated by multiplying production capacity by the heating value for ethanol. Since data on actual production by facility were not available, all plants were assumed to operate at capacity. Estimates of production capacity were obtained from data collected by the Renewable Fuels Association (http://www.ethanolrfa.org/industry/locations/). For some major ethanol producers production capacity was not available for specific facilities.

Data for facilities where both emissions and production capacity were available were used to estimate nationwide emission rates in g/mmBTU. Table 3.1-23 lists the number of ethanol production facilities with emissions data for various air toxics, as well as production capacity estimates.

Table 3.1-23.
Number of Facilities with Emission Inventory Data by Pollutant and Production Capacity Estimates

Pollutant	No. of Facilities with Emissions Data and Production Capacity Estimates.
Benzene	30
Formaldehyde	35
Acetaldehyde	50
Acrolein	22

An emission factor for ethanol was estimated using data collected in Minnesota from 16 facilities, all of which were dry mill plants.[714] Since most ethanol emissions occur during fermentation, and new production of ethanol is likely to occur at dry mill facilities, these data are likely to provide representative estimates of future year increases in ethanol emissions under the control scenarios modeled. The resultant emission factors for ethanol production facilities are provided in Table 3.1-24.

Distillers' grains with solubles (DGS) is a co-product of dry mill corn ethanol production that can be used as animal feed. Corn oil remaining in the DGS can be extracted and sold for commercial uses, such as biodiesel production, at a relatively high value compared to the DGS itself. The oil can be extracted by gravimetric methods or by extraction with n-hexane, which is a potentially important toxic emission associated with increased ethanol production. Capital costs for solvent extraction are higher, but so are yields.

Corn oil for food grade use is produced by a process wherein corn is separated into component parts, prior to fermentation, with the starch heavy dehulled-degermed corn portion fed to the ethanol plant and the corn germ fed to a hexane-based corn oil extraction facility. This process is capital intensive and must be designed into the plant. We expect the food grade extraction process to be less widespread than commercial grade processes for these reasons.

VeraSun recently submitted an application to the Iowa Department of Natural Resources (IDNR) to add a facility for solvent extraction of corn oil to an ethanol plant in Fort Dodge Iowa.[715] In this application, Verasun proposed to control particulate matter emissions from the process using a baghouse, and to minimize VOC emissions through good design and operating processes. Verasun estimated that this plant, with an annual DDGS capacity of 455,000 tons of DDGS per year, would produce 305 tons of VOCs per year, with n-hexane emissions of 295 tons per year. PM_{10} emissions would be about 13 tons.

EPA used the Verasun application data to develop an estimate of potential nationwide n-hexane emissions from ethanol plants nationwide. EPA estimates that about 40% of ethanol production will have corn oil extraction by 2022; thus, we assumed that about half of this would be from solvent extraction and 20% of dry mill plants would employ this process. It is likely a number of plants will use gravimetric recovery, since it can be easily retrofitted to any size plant at modest capital cost. First, we developed emission rates per ton of DDGS production. Then we developed an estimate of DDGS produced nationwide, using industry characterization estimates of 13.67 billion gallons of dry mill ethanol production in 2022, and 0.00334 tons DDGS per gallon of ethanol produced by dry mills.[716] Multiplying the emission rate from the Verasun application by total production of DDGS, EPA estimates these facilities could emit about 9,000 tons of n-hexane nationwide. However, given the very limited data on emissions from such facilities and the nascent nature of this process at ethanol production facilities, such estimates should be regarded as highly uncertain.

Biodiesel Production Facilities -- To estimate emission factors for biodiesel production facilities, we identified air toxic emission data for individual facilities developed for the 2005 NEI. Unfortunately, only toxics data for two existing biodiesel facilities could be found. These data were used to develop toxic to VOC ratios, then applied to VOC emission factors for biodiesel plants obtained from GREET, with modifications to add energy used in crushing soybeans. VOC emission rates vary by feedstock. Toxic to VOC ratios, VOC emission rates, and resultant toxic emission rates in grams per gallon are given in Table 3.1-25.

Transportation and Distribution of Gasoline, Ethanol, Gasoline/Ethanol Blends and Biodiesel -- Air toxic emissions associated with distributing fuel and fuel blends come from two sources. The first source is evaporative, spillage and permeation emissions from storage and transfer activities, and the second source is emissions from vehicles and pipeline pumps used to transport the fuels. Since a pipeline system does not exist for ethanol, increased ethanol use is likely to increase toxic emissions from vehicles used to transport it, while a corresponding decrease in gasoline distribution would decrease any emissions related to pipeline pumping.

Storage and transfer activities result in evaporative emissions of benzene and ethanol from gasoline, ethanol, and gasoline/ethanol blends. Evaporative emissions from biodiesel fuel are not expected to be significant. Emissions of ethanol occur both during transport of ethanol from production facilities to bulk terminals, and after blending, at bulk terminals. In addition, emission factors for benzene must be estimated separately for fuel before and after blending. As previously discussed, we assumed bulk terminal emissions were associated with unblended gasoline. We then divided emissions into a refinery to bulk terminal component and a bulk terminal to dispensing facility component. Benzene emission factors for gasoline transport from refinery to bulk terminals were weighted by the fraction of 2002 VOC emissions for this part of the process, whereas emission factors for E0 gasoline, E10 gasoline, and E85 were weighted by the fraction of 2002 VOC from the bulk terminal to the pump. Benzene emission rates from these activities also vary with the year being modeled, since phase-in of the recently finalized Mobile Source Air Toxics Rule will substantially reduce the amount of benzene in gasoline beginning in 2011.[717] Thus, one set of emission factors were developed for 2002, and a separate set of emission factors for the reference case in that year. The reference case also includes impacts of the 2007 renewable fuels standard.[718] Thus, the reference case already reflects ethanol volumes mandated by RFS1.

The emission factors used for 2002 were derived from the estimated gasoline distribution inventory for benzene in 1999, estimated for the Mobile Source Air Toxics Rule.[719] Total nationwide emissions were divided by the energy content of the total volume of gasoline distributed in 1999, to obtain the emission factor in g/mmBTU. Total volume of gasoline was based on gasoline sales as reported by the Energy Information Administration.[720] To estimate the energy content, sales of fuel types (conventional, Federal reformulated, California reformulated) were multiplied by their respective heating values.

The emission factors used for the reference case in 2022 were derived from an estimated gasoline distribution inventory for that year. This inventory estimate was calculated by linear interpolation of 2020 and 2030 inventories from the Mobile Source Air Toxics Rule. Total nationwide emissions were divided by the energy content of the total volume of gasoline projected for 2022 by the Energy Information Administration.[721] To estimate the energy content, the projected gasoline volume was multiplied by the heating value for low-sulfur gasoline (115,000 BTU/gallon).

We assumed that in order to attain the fuel benzene standard for gasoline promulgated in the Mobile Source Air Toxics Rule, E10 would have the same fuel benzene content per gallon as E0 . However, for E10 the E0 emission factor was adjusted to account for the lower energy content of E10 relative to E0. For E85, the E0 emission factor was adjusted to account for 66% lower benzene emissions per gallon, as well as the lower energy content of E85.

The emission factors for benzene are provided in Table 3.1-26.

To estimate ethanol emissions associated with the distribution of E10 and E85, ethanol to benzene emission ratios were applied to benzene estimates. The ratios were 14.8 for E10 and 112.8 for E85. The ratio for E10 was obtained from the profile for composite evaporative emissions from U. S. EPA's SPECIATE database, profile 1301.[722] The ratio for E85 was obtained from analyses of evaporative emissions from three vehicles tested as part of the Auto/Oil program in the early 1990's.[723] These emission factors are reported in Table 3.1-26.

Table 3.1-24. Air Toxic Emission Factors for Petroleum Refineries, Ethanol Refineries, and Electricity Production (g/mmBTU of fuel or electricity produced)

Pollutant	Petroleum Refinery	Ethanol refinery	Electricity Production
1,3-butadiene	0.0014	N. A.	0.0001
Acetaldehyde	0.0002	3.0585	0.0297
Acrolein	0.0001	0.1323	0.0115
Benzene	0.0264	0.0998	0.0443
Ethanol	0.0000	21.6858	
Formaldehyde	0.0042	0.5263	0.0629
Naphthalene	0.0029		

Table 3.1-25. Air Toxic Emission Factors for Biodiesel Production Facilities (g/gallon produced)

Pollutant	Toxic/VOC Ratio	Biodiesel Soybean Oil EF (g/gal)	Biodiesel Yellow Grease/tallow (g/gal)	Renewable Biodiesel Soybean Oil (g/gal)
VOC		0.040	0.042	0.029
Benzene	7.4×10^{-7}	3.0×10^{-8}	3.1×10^{-8}	2.1×10^{-8}
1,3-Butadiene	0	0	0	0
Formaldehyde	3.5×10^{-5}	1.4×10^{-6}	1.5×10^{-6}	1.0×10^{-6}
Acetaldehyde	5.6×10^{-6}	2.3×10^{-7}	2.4×10^{-7}	1.6×10^{-7}
Acrolein	4.8×10^{-6}	1.9×10^{-7}	2.0×10^{-7}	1.4×10^{-7}
Ethanol	0	0	0	0
Naphthalene	6.3×10^{-7}	2.5×10^{-8}	2.6×10^{-8}	1.8×10^{-8}

Table 3.1-26. Air Toxic Evaporative Emission Factors for Gasoline, Ethanol, and Blend Transport and Distribution (g/mmBTU of fuel transported)

Pollutant	Process	Year	Fuel	EF (g/mmBTU)
Benzene	Refinery to Bulk Terminal	2002	E0	0.0488
	Refinery to Bulk Terminal	2022	E0	0.0270
	Bulk Terminal to Pump	2002	E0	0.0908
	Bulk Terminal to Pump	2022	E0	0.0502
	Bulk Terminal to Pump	2022	E10	0.0519
	Bulk Terminal to Pump	2022	E85	0.0228
Ethanol	Bulk Terminal to Pump	2022	E10	1.8591
	Bulk Terminal to Pump	2022	E85	7.1432

As mentioned previously, ethanol vapor emissions during transport from the ethanol plant to the bulk terminal are based on an adjustment to the gasoline transport VOC emissions to account for the much lower vapor pressure and molecular weight.

There are also toxic emissions associated with combustion of fuels used in transport and distribution of feedstocks and fuels. The emission factors for these are shown in Table 3.1-27 as fractions of exhaust VOC, or PM10 for exhaust naphthalene. The VOC and PM10 emission factors that these fractions are applied to are presented above in Table 3.1-21. The locomotive, marine distillate, and residual boiler estimates come from a 2005 EPA report.[724] The heavy-duty diesel truck emission fractions come from a 2002 report documenting the toxics module of EPA's MOBILE6.2 model,[725] and the pipeline values come from the EPA AP-42 document.[726]

Table 3.1-27.
Toxic Fractions of Exhaust VOC (or fraction of PM10 for exhaust naphthalene)
(grams toxics per gram of VOC or PM10)

Mode	Source	1,3-Butadiene	Acetaldehyde	Acrolein	Benzene	Formaldehyde	Naphthalene
Rail	Diesel Locomotive	0.003246519	0.018786	0.0031238	0.002587511	0.04328653	0.0018716
Barge	Marine Diesel – Distillate	0.00061	0.074298	0.0035	0.020344	0.1496	0.0018716
Ocean Tanker	Residual Boiler	0	0.003858	0	0.000165354	0.02645669	0.0025885
Truck	HD Diesel Trucks	0.00061	0.0288	0.0035	0.0105	0.0782	0.00128892
Pipeline	Natural Gas Turbines	0	0.019048	0.0030476	0.005714286	0.33809524	
Gasoline Farm Equip	HD Gasoline Trucks						0.088005387

3.2 Non-GHG Emission Impact Results

3.2.1 U.S. Total Reference Case Inventories for All Sectors (AEO 2007 only)

The reference case emission inventories used for this final rule analysis are based on different sources depending on sector, and for most sectors they match what was used for the proposed rule and air quality analysis.

For stationary/area sources and aircraft we used the 2002 National Emissions Inventory (NEI), Version 3, including the NEI projections for 2020. The development of these inventories is documented in the November 27, 2007, memo titled, "Approach for Developing 2002 and Future Year National Emission Summaries," from Madeleine Strum to Docket EPA-HQ-OAR-2007-0491. That memo summarizes the methodologies and additional reference documents for criteria air pollutants (CAP) and mobile source air toxics (MSATs).

For onroad mobile sources we used a special version of the MOVES model that estimates emissions from light-duty and heavy-duty gasoline vehicles, except for motorcycles. For other onroad vehicles including diesel vehicles and motorcycles, we relied on the MOBILE6.2 model as run using the NMIM platform with county specific fuel properties and temperatures. Most nonroad equipment was modeled with NONROAD2005d using NMIM, which is a version of the NONROAD that includes the benefits of the two nonroad regulations published in 2008 (the locomotive and marine diesel rule and the small spark-ignition and recreational marine engine rule).

Inventories for locomotives and commercial marine vessels are not covered by the NONROAD model, and they have been updated since the 2002 NEI was published. Thus we used the more recent inventories published in the regulatory impact analyses of their respective recent rulemakings. Locomotives and C1/C2 commercial marine vessel inventories come from the spring 2008 final rule, and the C3 commercial marine emission inventory is from the Notice of Proposed Rulemaking (NPRM) published in August 2009.[734]

Table 3.2-1 shows the total 2022 mobile and non-mobile source inventory projections that were used as the basis for the impact percentages shown above in Table 3.2-1 through 3.2-4. The mobile source values in this table use the inventory values of the AEO 2007 reference case.

Table 3.2-1. 2022 AEO 2007 Reference Case Emissions by Sector

	VOC	CO	NOx	PM10	PM2.5	SO2	NH3
Onroad Gasoline	981,432	26,547,169	2,001,543	46,284	42,619	34,031	390,486
Onroad Diesel	140,854	243,820	1,307,150	62,253	37,357	4,352	11,426
Nonroad Gasoline	1,440,414	14,924,581	269,443	56,660	52,305	1,836	1,112
Other Nonroad[a]	270,707	1,402,948	3,353,753	230,305	209,516	1,026,510	3,034
Stationary/Area	8,740,057	11,049,239	5,773,927	3,194,610	3,047,714	7,864,681	3,839,925
Total	11,573,464	54,167,758	12,705,817	3,590,112	3,389,512	8,931,411	4,245,983

Table 3.2-1 continued	Benzene	Ethanol	1,3-Butadiene	Acetal-dehyde	Formal-dehyde	Naphthalene	Acrolein
Onroad Gasoline	33,607	15,985	4,487	6,455	10,681	3,787	513
Onroad Diesel	1,749	0	958	3,857	10,589	20	513
Nonroad Gasoline	26,193	66,150	4,935	4,033	7,245	713	436
Other Nonroad[a]	3,815	5,294	939	9,550	22,355	24	1,021
Stationary/Area	111,337	462,566	1,847	13,118	23,846	9,404	3,412
Total	176,701	549,995	13,166	37,013	74,716	13,949	5,895

[a] Nonroad diesel, LPG, CNG engines and all locomotive, aircraft, and commercial marine

3.2.2 2022 RFS2 Total Non-GHG Emission Inventory Impacts

Our projected overall emission impacts for each of the analyzed RFS2 renewable fuel scenarios are shown in Table 3.2-2 and Table 3.2-3 for 2022, showing the expected emission changes for the U.S. relative to each of the reference cases. The percent contribution of these impacts relative to the total U.S. inventory across all sectors is also shown, using the AEO 2007 reference case totals from Table 3.2-1. .

Table 3.2-2.
RFS2 Emission Impacts in 2022 Relative to the AEO2007 Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	208,316	1.64%	184,820	1.45%	131,124	1.03%
HC	20,123	0.17%	24,523	0.21%	35,342	0.31%
PM10	71,779	2.00%	63,323	1.76%	44,099	1.23%
PM2.5	17,355	0.51%	14,393	0.42%	7,678	0.23%
CO	-364,400	-0.67%	-376,419	-0.69%	-404,199	-0.75%
Benzene	-979	-0.55%	-1,004	-0.57%	-1,056	-0.60%
Ethanol	33,749	6.14%	54,137	9.84%	102,359	18.61%
1,3-Butadiene	59	0.45%	59	0.45%	59	0.45%
Acetaldehyde	1,978	5.34%	3,108	8.40%	5,757	15.56%
Formaldehyde	113	0.15%	130	0.17%	170	0.23%
Naphthalene	-4	-0.03%	-4	-0.03%	-4	-0.03%
Acrolein	16	0.28%	21	0.35%	31	0.53%
SO2	20,456	0.23%	5,065	0.06%	-30,058	-0.34%
NH3	48,711	1.15%	48,711	1.15%	48,709	1.15%

Table 3.2-3.
RFS2 Emission Impacts in 2022 Relative to the RFS1 Mandate Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	271,100	2.13%	247,604	1.95%	193,907	1.53%
HC	96,362	0.83%	100,762	0.87%	111,581	0.96%
PM10	77,469	2.16%	69,013	1.92%	49,791	1.39%
PM2.5	18,511	0.55%	15,549	0.46%	8,834	0.26%
CO	-2,857,823	-5.28%	-2,869,842	-5.30%	-2,897,622	-5.35%
Benzene	-4,240	-2.40%	-4,264	-2.41%	-4,316	-2.44%
Ethanol	79,736	14.50%	100,123	18.20%	148,345	26.97%
1,3-Butadiene	224	1.70%	224	1.70%	224	1.70%
Acetaldehyde	4,718	12.75%	5,848	15.80%	8,497	22.96%
Formaldehyde	338	0.45%	355	0.48%	395	0.53%
Naphthalene	-1	0.00%	-1	-0.01%	-1	0.00%
Acrolein	18	0.31%	22	0.38%	33	0.56%
SO2	18,678	0.21%	3,286	0.04%	-31,836	-0.36%
NH3	48,711	1.15%	48,711	1.15%	48,709	1.15%

Fuel production and distribution emission impacts of the RFS2 program were estimated in conjunction with the development of life cycle GHG emission impacts, and the GHG emission inventories discussed in Chapter 2. These emissions are calculated according to the breakdowns of agriculture, feedstock transport, fuel production, and fuel distribution; the basic calculation is a function of fuel volumes in the analysis year and the emission factors associated with each process or subprocess. Additionally, the emission impact of displaced petroleum is estimated, using the same domestic/import shares discussed in chapter 2.

In general the basis for this life cycle evaluation was the analysis conducted as part of the Renewable Fuel Standard (RFS1) rulemaking, but enhanced significantly. While our approach for the RFS1 was to rely heavily on the "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) model, developed by the Department of Energy's Argonne National Laboratory (ANL), we are now able to take advantage of additional information and models to significantly strengthen and expand our analysis for this rule. In particular, the modeling of the agriculture sector was greatly expanded beyond the RFS1 rule analysis, employing economic and agriculture models to consider factors such as land-use impact, agricultural burning, fertilizer, pesticide use, livestock, crop allocation, and crop exports.

Other updates and enhancements to the GREET model assumptions include updated emission factors for NOx, CO, and SO2 from new cellulosic ethanol plant modeling by the National Renewable Energy Laboratory (NREL), and updated fuel and feedstock transport emission factors that account for recent EPA emission standards and modeling, such as the Tier 4 diesel truck standards published in 2004 and the locomotive and commercial marine standards finalized in 2008. Emission factors for new corn ethanol plants continue to use the values developed for the RFS1 rule, which were based on data submitted by states for dry mill plants. There are no new standards planned at this time that would offer any additional control of emissions from corn or cellulosic ethanol plants. In addition, GREET does not include air toxics or ethanol. Thus emission factors for ethanol and the following air toxics were added: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein and naphthalene.

Results of these calculations relative to each of the reference cases for 2022 are shown in Table 3.2-4 and Table 3.2-5 for the criteria pollutants, ammonia, ethanol and individual air toxic pollutants. It should be noted that the impacts relative to the RFS1 reference case use the same agricultural impacts as for the AEO 2007 reference case, since there was no agricultural modeling done for the RFS1 case. Due to the complex interactions involved in projections in agricultural modeling, it was not considered reasonable to attempt any sort of proportional adjustments to the AEO 2007 agricultural projections to approximate the RFS1 case.

The fuel production and distribution impacts of today's rule on VOC are mainly due to increases in emissions connected with biofuel production, countered by decreases in emissions associated with gasoline production and distribution as ethanol displaces some of the gasoline. Increases in PM2.5, SOx and especially NOx are driven by stationary combustion emissions from the substantial increase in corn and cellulosic ethanol production. Biofuel plants (corn and cellulosic) tend to have greater combustion emissions relative to petroleum refineries on a per-BTU of fuel produced basis. Increases in SOx emissions are also due to increases in agricultural chemical production and transport, while substantial PM increases are also associated with fugitive dust from agricultural operations. Ammonia emissions are expected to increase substantially due to increased ammonia from fertilizer use.

Ethanol vapor and most air toxic emissions associated with fuel production and distribution are projected to increase. Relative to the US total reference case emissions with RFS1 mandate ethanol volumes, the primary RFS2 control case is estimated to yield increases of 4-13 percent for acetaldehyde and ethanol vapor, driven directly by the increased ethanol production and distribution. Formaldehyde and acrolein increases are smaller, on the order of 0.4-1 percent. There are also very small decreases in benzene, 1,3-butadiene and naphthalene relative to the US total emissions.

Table 3.2-4. Fuel Production and Distribution Impacts for 2022 RFS2 Control Cases Relative to the AEO 2007 Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	187,666	1.48%	164,170	1.29%	110,473	0.87%
HC	16,604	0.14%	19,737	0.17%	27,547	0.24%
PM10	72,348	2.02%	63,892	1.78%	44,669	1.24%
PM2.5	17,670	0.52%	14,707	0.43%	7,993	0.24%
CO	142,191	0.26%	130,172	0.24%	102,392	0.19%
Benzene	-208	-0.12%	-236	-0.13%	-298	-0.17%
Ethanol	20,291	3.69%	35,865	6.52%	72,815	13.24%
1,3-Butadiene	0	0.00%	0	0.00%	0	0.00%
Acetaldehyde	823	2.22%	933	2.52%	1,193	3.22%
Formaldehyde	170	0.23%	187	0.25%	227	0.30%
Naphthalene	-5	-0.04%	-6	-0.04%	-7	-0.05%
Acrolein	33	0.56%	37	0.63%	48	0.81%
SO2	20,435	0.23%	5,044	0.06%	-30,078	-0.34%
NH3	48,711	1.15%	48,711	1.15%	48,709	1.15%

Table 3.2-5. Fuel Production and Distribution Impacts for 2022 RFS2 Control Cases Relative to the RFS1 Mandate Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	193,161	1.52%	169,665	1.34%	115,969	0.91%
HC	73,881	0.64%	77,014	0.67%	84,825	0.73%
PM10	78,039	2.17%	69,583	1.94%	50,360	1.40%
PM2.5	18,826	0.56%	15,864	0.47%	9,149	0.27%
CO	147,677	0.27%	135,658	0.25%	107,878	0.20%
Benzene	-203	-0.12%	-231	-0.13%	-294	-0.17%
Ethanol	53,871	9.79%	69,445	12.63%	106,395	19.34%
1,3-Butadiene	-1	-0.01%	-1	-0.01%	-1	-0.01%
Acetaldehyde	1,507	4.07%	1,617	4.37%	1,877	5.07%
Formaldehyde	276	0.37%	293	0.39%	333	0.45%
Naphthalene	-7	-0.05%	-8	-0.06%	-9	-0.06%
Acrolein	62	1.06%	67	1.13%	77	1.31%
SO2	18,657	0.21%	3,266	0.04%	-31,857	-0.36%
NH3	48,711	1.15%	48,711	1.15%	48,709	1.15%

A breakout of these upstream emissions by where they occur in the production/distribution chain is shown in Table 3.2-6. The displaced gasoline line of this table refers to the impacts of decreasing the petroleum based gasoline and diesel fuel production as some of the needed energy is replaced with ethanol and biodiesel fuels.

Table 3.2-6. Emission Inventory Impacts by Fuel Production/Distribution Segment for the Primary RFS2 Control Case Relative to the AEO 2007 Reference Case (annual short tons)

	VOC	CO	NOx	PM10	PM2.5	SO2	NH3
Agriculture	2,398	11,831	6,597	56,512	9,169	22,157	48,709
Biofuel Feedstock Transport	355	508	1,440	239	106	584	0
Biofuel Production	18,867	129,586	193,040	22,621	11,241	8,932	2
Biofuel Transport & Distribution	18,041	3,316	7,599	323	219	962	0
Displaced gasoline	-19,925	-15,069	-44,506	-15,803	-6,028	-27,591	0
Total Upstream	19,737	130,172	164,170	63,892	14,707	5,044	48,711

Table 3.2-6 continued	**Benzene**	**Ethanol**	**1,3-Butadiene**	**Acetal-dehyde**	**Formal-dehyde**	**Naphthalene[b]**	**Acrolein**
Agriculture	-145.8	0	1.99	13.51	47.89	0.73	-3.24
Biofuel Feedstock Transport	3.73	0	0.22	10.24	27.80	0.31	1.24
Biofuel Production	28.86	6,435	0.01	906.9	154.9	0.02	39.01
Biofuel Transport & Distribution	-30.84	29,430	1.18	11.01	25.67	0.57	1.46
Displaced gasoline	-91.80	0	-3.84	-8.72	-69.50	-7.55	-1.27
Total Upstream	-235.8	35,865	-0.44	933.0	186.8	-5.92	37.21

Tables 3.2-7 and 3.2-8 summarize the vehicle and equipment emission impacts in 2022, including the biodiesel impacts. Table 3.2-9 shows that the biodiesel contribution to these impacts is quite small; as noted earlier, using MOVES2010 as baseline emissions for diesels would likely double the NOx and PM impacts relative to the NMIM-based impacts shown While the three fuel effect scenarios were only modeled for passenger cars and trucks, these totals reflect the net emissions from all mobile sources, including passenger cars and trucks, heavy duty trucks, off-road sources and portable fuel containers, using the same emissions in all three cases for the non-passenger car/truck categories. A full description of the basis of these vehicle and equipment emission impacts is given in Section 3.1.1 of this document.

Carbon monoxide, benzene, and acrolein are projected to decrease in 2022 under today's rule, while NOx, HC and the other air toxics, especially ethanol and acetaldehyde, are projected to increase due to the impacts of E10.

Table 3.2-7.
2022 Vehicle and Equipment Emission Impacts for the RFS2 Control Cases Relative to the AEO 2007 Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	20,650	0.16%	20,650	0.16%	20,650	0.16%
HC	3,519	0.03%	4,786	0.04%	7,795	0.07%
PM10	-569	-0.02%	-569	-0.02%	-569	-0.02%
PM2.5	-315	-0.01%	-315	-0.01%	-315	-0.01%
CO	-506,591	-0.94%	-506,591	-0.94%	-506,591	-0.94%
Benzene	-771	-0.44%	-768	-0.43%	-758	-0.43%
Ethanol	13,459	2.45%	18,272	3.32%	29,544	5.37%
1,3-Butadiene	59	0.45%	59	0.45%	59	0.45%
Acetaldehyde	1,155	3.12%	2,175	5.88%	4,564	12.33%
Formaldehyde	-57	-0.08%	-57	-0.08%	-57	-0.08%
Naphthalene	2	0.01%	2	0.01%	3	0.02%
Acrolein	-16	-0.28%	-16	-0.28%	-16	-0.28%
SO2	21	0.00%	21	0.00%	21	0.00%
NH3	0	0.00%	0	0.00%	0	0.00%

Table 3.2-8.
2022 Vehicle and Equipment Emission Impacts for the RFS2 Control Cases Relative to RFS1 Mandate Reference Case

Pollutant	Low Ethanol Scenario		Mid (Primary) Ethanol Scenario		High Ethanol Scenario	
	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory	Annual Short Tons	% of Total US Inventory
NOx	77,939	0.61%	77,939	0.61%	77,939	0.61%
HC	22,480	0.19%	23,748	0.21%	26,756	0.23%
PM10	-569	-0.02%	-569	-0.02%	-569	-0.02%
PM2.5	-315	-0.01%	-315	-0.01%	-315	-0.01%
CO	-3,005,500	-5.55%	-3,005,500	-5.55%	-3,005,500	-5.55%
Benzene	-4,036	-2.28%	-4,033	-2.28%	-4,022	-2.28%
Ethanol	25,864	4.70%	30,678	5.58%	41,950	7.63%
1,3-Butadiene	225	1.71%	225	1.71%	225	1.71%
Acetaldehyde	3,210	8.67%	4,231	11.43%	6,620	17.89%
Formaldehyde	62	0.08%	62	0.08%	62	0.08%
Naphthalene	7	0.05%	7	0.05%	8	0.06%
Acrolein	-44	-0.75%	-44	-0.75%	-44	-0.75%
SO2	21	0.00%	21	0.00%	21	0.00%
NH3	0	0.00%	0	0.00%	0	0.00%

Table 3.2-9.
2022 Biodiesel Emission Impacts for All RFS2 Control Cases
Relative to Reference Cases
(these impacts are included in Tables 3.2-7 and 3.2-8)

Pollutant	**Biodiesel Impacts**
	Annual Short Tons
NOx	1,346
HC	-2,422
PM10	-569
PM2.5	-315
CO	-4,104
Benzene	-30.08
Ethanol	0.00
1,3-Butadiene	-16.48
Acetaldehyde	-66.34
Formaldehyde	-182.09
Naphthalene	-0.38
Acrolein	-8.82
SO2	0
NH3	0

Table 3.2-10 shows a breakout of the relative impacts of the RFS2 volumes on the various types of vehicle and equipment emissions for the primary (mid-ethanol) case relative to the AEO 2007 reference case. The gasoline vehicle exhaust emission values were generated by MOVES, while the NMIM model was used to generate the other vehicle and equipment emission impacts. The impacts on portable fuel container emissions were estimated using an analysis of available data, adjusted for the ethanol and gasoline fuel volumes in this rule. The methods used are described above in Section 3.1.1. The substantial CO reductions and NOx and ethanol increases from light-duty vehicles and nonroad gasoline equipment are due to the effects of increased E10 marketshare with no E0 remaining in the market. Evaporative and refueling vapor emissions only include VOC, ethanol, benzene, and naphthalene.

Table 3.2-10. Vehicle and Equipment Emission Inventory Impacts by Source Type for the Primary RFS2 Control (mid-ethanol) Case Relative to the AEO 2007 Reference Case (annual short tons)

	VOC[a]	CO	NOx	PM10	PM2.5	SO2	NH3
Light-duty gasoline vehicle exhaust	-1,437	-72,872	10,034	0.0	0.0	0.0	0.0
Light-duty gasoline vehicle evap	3,447	n/a [b]	n/a	n/a	n/a	n/a	n/a
Light-duty gasoline vehicle refueling	2,015	n/a	n/a	n/a	n/a	n/a	n/a
Heavy-duty gasoline vehicle exhaust	2,168	-21,163	58	0.0	0.0	0.0	0.0
Heavy-duty gasoline vehicle evap	-750	n/a	n/a	n/a	n/a	n/a	n/a
Heavy-duty gasoline vehicle refueling	440	n/a	n/a	n/a	n/a	n/a	n/a
Nonroad gasoline equipment exhaust	-6,413	-408,453	9,212	0.0	0.0	20.7	0.0
Nonroad gasoline equipment evap	6,702	n/a	n/a	n/a	n/a	n/a	n/a
Nonroad gasoline equipment refueling	563	n/a	n/a	n/a	n/a	n/a	n/a
Portable fuel containers	1,037	n/a	n/a	n/a	n/a	n/a	n/a
Onroad diesel vehicles	-2,422	-4,104	1,346	-569	-315	0.0	0.0

Table 3.2-10 continued	Benzene	Ethanol	1,3-Butadiene	Acetal-dehyde	Formal-dehyde	Naph-thalene	Acrolein
Light-duty gasoline vehicle exhaust	-287	8,773	21.5	2,034	73	0.00	0.65
Light-duty gasoline vehicle evap	6.65	500	n/a	n/a	n/a	1.28	n/a
Light-duty gasoline vehicle refueling	6.63	770	n/a	n/a	n/a	0.82	n/a
Heavy-duty gasoline vehicle exhaust	-47	57	0.00	19	-2.11	0.00	0.00
Heavy-duty gasoline vehicle evap	-1.31	315	n/a	n/a	n/a	0.09	n/a
Heavy-duty gasoline vehicle refueling	1.25	157	n/a	n/a	n/a	0.05	n/a
Nonroad gasoline equipment exhaust	-737	2,497	57.4	189	54	0.00	-7.95
Nonroad gasoline equipment evap	106	4,556	n/a	n/a	n/a	0.00	n/a
Nonroad gasoline equipment refueling	106	972	n/a	n/a	n/a	0.00	n/a
Portable fuel containers	-0.30	646	n/a	n/a	n/a	0.13	n/a
Onroad diesel vehicles	-30.08	0.00	-16.48	-66.34	-182.09	-0.38	-8.82

[a] "VOC" values shown are actually THC for onroad gasoline exhaust and evaporative emissions.
[b] n/a = Not applicable

Table 3.2-11 shows the relative impacts of various types of renewable fuels on the basis of tons per million BTUs of renewable fuel consumed. These values include all vehicle/equipment as well as upstream fuel production/distribution impacts.

Table 3.2-11. Emission Inventory Impacts by Type of Renewable Fuel for the Primary RFS2 Control Case Relative to the AEO 2007 Reference Case (tons per mmBTU)

	VOC	CO	NOx	PM10	PM2.5	SO2	NH3
Ethanol from domestic corn (except coal)	10,301	4,013	3,128	12,175	1,991	3,403	8,420
Ethanol from domestic corn (coal)	439	317	320	1,330	351	427	349
Ethanol from domestic cellulosic	10,121	29,888	32,440	13,168	2,350	-8,377	15,107
Ethanol from imported sugarcane	1,717	-830	-2,621	-1,116	-418	-1,916	44
Biodiesel	-1,049	913	-290	4,268	632	1,580	4,171
Renewable Diesel	-1,602	23	-26.3	-102	-27	-169	0.0
Cellulosic Diesel	-190	95,847	131,218	34,169	9,831	10,096	21,085
Table 3.2-11 continued	**Benzene**	**Ethanol**	**1,3-Butadiene**	**Acetal-dehyde**	**Formal-dehyde**	**Naph-thalene**	**Acrolein**
Ethanol from domestic corn (except coal)	30.1	10,870	0.097	335	67.6	-0.617	141
Ethanol from domestic corn (coal)	1.2	451	0.004	13.8	2.8	-0.026	5.8
Ethanol from domestic cellulosic	39.3	17,024	0.078	245	47.1	-1.223	237
Ethanol from imported sugarcane	26.4	5,220	-0.185	0.25	-3.0	-0.500	77.5
Biodiesel	10.4	0	-0.188	1.64	0.77	-0.658	62.6
Renewable Diesel	65.6	0	0.009	0.45	0.51	-0.061	0.06
Cellulosic Diesel	-0.9	2,299	-0.26	337	71.0	-2.84	331

3.3 Emission Inventories Used in the Air Quality Modeling

3.3.1 Overview of Inventory Differences

Section 3.2 above describes our latest emission inventory impacts projected to result from the increased use of renewable fuels as required by the RFS2 standards. However, the air quality modeling had to be started long before these latest emission inventory impacts could be determined. The air quality modeling presented in Section 3.4 utilized inventory impact estimates based in large part on the analysis conducted for the NPRM, but with a few enhancements. Below is an overview of the differences between these inventory impact estimates. Details of the differences between these inventories are presented in Section 3.3.2 of this RIA.

To put the differences in context, Table 3.3-1 shows the different renewable fuel volumes considered for the three analyses. This shows that the volumes used for the NPRM analysis were also the basis of the inventories used for the air quality modeling. The RFS1 reference case listed here is the RFS1 mandate case. The primary (mid-ethanol) case considered for this final rule includes much less cellulosic ethanol than in the prior analyses, but makes up for that with diesel fuel produced from cellulosic feedstocks. The final rule case that is most comparable to the RFS2 control case considered in the NPRM and air quality analyses is the high ethanol case shown in the last row of the table.

Table 3.3-1.
Renewable Fuel Volumes Used in Each Analysis
(Bgal/year in 2022)

Analysis	Scenario	Ethanol				Biodiesel	Renewable Diesel	Cellulosic Diesel
		Corn	Cellulosic	Imported	Total			
NPRM & AQ	RFS1 Ref	5.81	0.25	0.64	6.70	0.38	0.0	0.0
	AEO Ref	12.29	0.25	0.64	13.18	0.38	0.0	0.0
	RFS2	15.0	16.0	3.14	34.14	0.81	0.38	0.0
FRM	RFS1 Ref	7.046	0.0	0.0	7.046	0.303	0.0	0.0
	AEO Ref	12.29	0.25	0.64	13.18	0.38	0.0	0.0
	Low Ethanol	15.0	0.25	2.24	17.49	1.67	0.15	9.26
	Mid-Ethanol (Primary)	**15.0**	**4.92**	**2.24**	**22.16**	**1.67**	**0.15**	**6.52**
	High Ethanol	15.0	16.0	2.24	33.24	1.67	0.15	0.0

Tables 3.3-2 and 3.3-3 summarize the differences between the US total sum of the county-level impacts used for the air quality modeling and the final rule nationwide impacts relative to the RFS1 mandate and AEO 2007 reference cases.

Table 3.3-2.
Comparison of Air Quality Inventory Impacts to FRM Impacts in 2022 Relative to the RFS1 Reference Case

Pollutant	Air Quality Inventory Impacts	FRM Mid (Primary) Ethanol Impacts		FRM High Ethanol Impacts	
	Annual Short Tons	Annual Short Tons	% Change vs AQ	Annual Short Tons	% Change vs AQ
NOx	365,968	247,604	-32%	193,907	-47%
HC	119,873	100,762	-16%	111,581	-7%
PM10	68,646	69,013	1%	49,791	-27%
PM2.5	18,199	15,549	-15%	8,834	-51%
CO	-4,619,904	-2,869,842	38%	-2,897,622	37%
Benzene	-9,662	-4,264	56%	-4,316	55%
Ethanol	N/A[b]	100,123	--	148,345	--
1,3-Butadiene	-194	224	216%	224	216%
Acetaldehyde	7,317	5,848	-20%	8,497	16%
Formaldehyde	173	355	105%	395	128%
Acrolein	79	22	-71%	33	-58%
SO2	57,380	3,286	-94%	-31,836	-155%
NH3	141	48,711	34352%	48,709	34351%

[a] Ethanol emissions for air quality modeling were generated by application of VOC speciation profiles in SMOKE, the emissions pre-processor for air quality modeling, so they were not one of the air quality inventory inputs..

Table 3.3-3.
Comparison of Air Quality Inventory Impacts vs FRM Impacts in 2022 Relative to the AEO 2007 Reference Case

Pollutant	Air Quality Inventory Impacts	FRM Mid (Primary) Ethanol Impacts		FRM High Ethanol Impacts	
	Annual Short Tons	Annual Short Tons	% Change vs AQ	Annual Short Tons	% Change vs AQ
NOx	258,357	184,820	-28%	131,124	-49%
HC	38,186	24,523	-36%	35,342	-7%
PM10	55,877	63,323	13%	44,099	-21%
PM2.5	17,277	14,393	-17%	7,678	-56%
CO	-1,743,352	-376,419	78%	-404,199	77%
Benzene	-4,094	-1,004	75%	-1,056	74%
Ethanol	N/A[b]	54,137	--	102,359	--
1,3-Butadiene	-291	59	120%	59	120%
Acetaldehyde	4,727	3,108	-34%	5,757	22%
Formaldehyde	-127	130	202%	170	234%
Acrolein	47	21	-55%	31	-33%
SO2	15,311	5,065	-67%	-30,058	-296%
NH3	210	48,711	23065%	48,709	23064%

[a] Ethanol emissions for air quality modeling were generated by application of VOC speciation profiles in SMOKE, the emissions pre-processor for air quality modeling, so they were not one of the air quality inventory inputs..

Table 3.3-4 shows the US total emission inventories used for each of the air quality modeling cases along with the percent change from each reference case to the control case.

Table 3.3-4.
Air Quality Modeling Inventories and Percent Impacts in 2022

Pollutant	US Total RFS1	US Total AEO	US Total RFS2	RFS2 vs RFS1	RFS2 vs AEO
	Annual Short Tons	Annual Short Tons	Annual Short Tons	Percent Change	Percent Change
NOx	11,415,147	11,522,759	11,781,115	3.21%	2.24%
HC	10,292,785	10,374,472	10,412,658	1.16%	0.37%
PM10	11,999,983	12,012,752	12,068,629	0.57%	0.47%
PM2.5	3,371,024	3,371,946	3,389,223	0.54%	0.51%
CO	51,631,075	48,754,523	47,011,171	-8.95%	-3.58%
Benzene	226,683	221,115	217,021	-4.26%	-1.85%
Ethanol[a]	--	--	--	--	--
1,3-Butadiene	14,458	14,554	14,264	-1.34%	-2.00%
Acetaldehyde	58,405	60,995	65,722	12.53%	7.75%
Formaldehyde	140,156	140,456	140,330	0.12%	-0.09%
Acrolein	6,399	6,431	6,477	1.23%	0.73%
SO2	8,878,706	8,920,775	8,936,086	0.65%	0.17%
NH3	4,213,048	4,212,979	4,213,189	0.00%	0.00%

[a] Ethanol emissions were generated by application of VOC speciation profiles in SMOKE, the emissions pre-processor for air quality modeling, so they were not one of the air quality inventory inputs..

3.3.1.1 Major Differences Between Air Quality Modeling Inventory and Nationwide NPRM and FRM Inventories

In attempting to compare the inventory used for air quality modeling with the nationwide inventories presented in either the draft RIA of the proposed rule or this final RIA it is important to keep in mind that (a) the air quality inventories are actual estimates of total ton per year emissions for all sectors, whereas the emission inventory impacts presented in the RIA are only ton per year changes (increases or decreases) for the sectors that we consider to be affected by the rule, and (b) as described in Section 3.3.2, very different methods are used calculate the incremental upstream changes at a national level for the RIA versus the adjusted total county-level upstream inventories used for air quality modeling.

Differences Between NPRM and Air Quality Modeling Inventories

- The renewable fuel volumes that were considered for the NPRM and air quality modeling were the same, as shown in Table 3.3-1, but there were substantial changes in some portions of the emission inventories.

- The air quality modeling inventory used a greatly increased estimate of ethanol transport VOC and ethanol vapor losses, based on preliminary results of the ORNL analysis of ethanol transport modes and distances.[728] This is discussed in section 3.3.2.1.1 of this RIA.

- The method used to calculate the upstream portion of the air quality modeling inventory differs from the method used to calculate the estimated nationwide impacts of the rule. The main difference was for certain non-mobile source sectors where adjustment factors were applied to existing air quality modeling inventories, rather than attempting to add/subtract the absolute tons of impact within each county for each source (SCC). This difference applies mainly to agriculture, crude oil production and transport, and gasoline refining and distribution. A more detailed description of these methodological differences is provided in section 3.3.2 of this RIA.

- The downstream portion of the air quality modeling inventory was produced by running an updated version of the MOVES model at the state-month level and the NMIM model at the county-month level to generate the downstream impacts (vehicle and equipment emissions). More details are presented in Section 3.3.2.2 below.

Differences Between Air Quality Modeling and FRM Inventories

- The FRM inventory uses the final results of the ORNL analysis of ethanol transport modes and distances rather than the preliminary results used for the air quality modeling inventory analysis. Relative to the version used for the air quality modeling this included slightly increased truck and water transport, slightly less rail transport, and 16 percent less ethanol volume loaded into transport or storage tanks in the RFS2 control case (34 bgal ethanol), due to use of fewer total mode transfers.

- The FRM inventory also includes a substantial reduction of cellulosic biofuel plant energy requirements to account for the portion of the biomass feedstock that is not combusted for process heat.

- The FRM downstream inventory incorporates a revision of E85 effects to remove all but ethanol and acetaldehyde emission effects, due to lack of sufficient data to justify any effects on other pollutants.

- The FRM downstream inventory uses a hybrid approach, applying "more sensitive" impacts for E10 on pre-Tier 2 light duty vehicles, and applying the "less sensitive" E10 effects for Tier 2 light duty cars and trucks (meaning no impact for NOx or exhaust NMHC due to E10 for the majority of the fleet on the road in 2022).

- The FRM downstream inventory uses updated estimates of evaporative permeation impacts of E10 based on recent studies.

3.3.2 Detailed Explanation of Inventory Differences

This section describes how the county-level emission inventories were prepared for use in air quality modeling, and how they differ from the NPRM nationwide inventories and the final rule nationwide inventories. Air quality modeling requires much more detail and in some cases a very different method than estimation of nationwide totals. The information provided here only addresses the first step of inventory preparation for air quality modeling. The final steps involve processes like hourly allocation and certain types of temperature adjustments. Those steps, as well as application of adjustments related to the affected stationary (point and non-point) source categories, are explained in greater detail in a separate technical support document.[727]

3.3.2.1 Differences in Upstream Impacts between Inventories

3.3.2.1.1 Calculation of Vapor Losses During Ethanol Transport

For "upstream" emissions associated with fuel production and distribution, the largest change from the NPRM to the air quality modeling analysis was the improved estimate of VOC and ethanol vapor emissions during ethanol transport, made possible by a detailed analysis of costs and transport modes conducted by Oak Ridge National Laboratory (ORNL).[728] This change substantially increased the ethanol and VOC emissions associated with this rule.

For the NPRM analysis these emissions were estimated using a very simplified approach based on an adjustment to the gasoline transport VOC emissions to account for the much lower vapor pressure (approximately 3 psi at 100F for denatured ethanol versus 9 psi for gasoline) and molecular weight (48.7 for denatured ethanol versus approximately 72 for gasoline vapor). The net factor is 0.23 x gasoline evap VOC. Using the gasoline VOC EF of 14.94 g/mmBTU from Table 3.1-21 yields an EF of 5.20 g/mmBTU as shown in the following calculation. However, an oversight in the NPRM upstream impacts spreadsheet model resulted in use of an earlier estimate of the gasoline VOC EF of 10.2137 g/mmBTU for this ethanol calculation, which meant that the reported ethanol EF used in the NPRM was actually 3.56 g/mmBTU.

5.20 g/mmBTU of ethanol
= 0.23 x gasoline VOC per-gallon EF / ethanol energy content
= 0.23 x (14.94 g/mmBTU x 115000 BTU/gal) / 76000 BTU/gal

As mentioned in the NPRM, the main shortcoming of this methodology was that it did not account for differences between ethanol and gasoline transport modes, distances, or transfer methods in movement of the fuel from production facility to the bulk distribution terminal. For the air quality modeling analysis and final rule analysis this method was replaced using data from the ORNL analysis of projected ethanol transport modes, distances, and volumes transferred under various ethanol volume scenarios. That newer method yielded greatly increased ethanol vapor and VOC emissions. The air quality modeling analysis used preliminary results of the ORNL study, which yielded average ethanol EFs of 34.09, 36.06, and 37.94 g/mmBTU for the RFS1 reference, AEO reference, and RFS2 control cases, respectively, when averaged across all the types of tank loading.[729] For air quality modeling the detailed emission factors for each type of tank loading, shown in Table 3.3-7, were multiplied by the preliminary ORNL ktons loaded by type of tank for each county.[730,731,732]

For the FRM analysis the use of the final ORNL results yielded EFs of 26.9 - 31.7 g/mmBTU of ethanol (2.04 - 2.41 g/gal) depending on scenario, due to the added fuel transfer losses compared to pipeline-based transport of gasoline. The EF shown earlier in Table 3.1-21 (28.78 g/mmBTU) corresponds to the High Ethanol minus RFS1 reference case, and was used for calculation of VOC and ethanol vapor for all cases in this FRM analysis.

Table 3.3-5 summarizes the ethanol transport mode and volume analysis conducted by ORNL. It shows the ethanol quantities loaded into the tanks of each transport mode, which is used to calculate ethanol vapor losses during tank filling. The first three rows show the preliminary set of model results that was used to generate emission impacts for the air quality analysis. The next three rows show corrected results from the final ORNL report, which was too late to be included in the air quality modeling. These corrected results were then used as the basis for the ethanol transport emission estimates in this final rule, shown in the final three rows. Because the final rule ethanol volumes differ from the proposed rule and air quality analysis volumes, especially for the primary (mid) and low ethanol cases, we have estimated transport volumes and distances for the final rule by interpolation from the final corrected ORNL values.

Table 3.3-5. Ethanol Transport Tank Loading Volumes in 2022

Source	Case	Bgal Ethanol	Kilotons Ethanol Loaded or Transferred into Each Mode[a]			
			Truck	Rail	Water	Local Truck
AQ modeled values	RFS1	6.69	3,434	18,565	2,679	20,952
AQ modeled values	AEO	13.18	6,005	35,555	3,860	42,915
AQ modeled values	RFS2	34.14	17,012	76,053	11,959	133,907
Corrected FRM Basis	RFS1	6.69	3,131	18,565	2,816	18,431
Corrected FRM Basis	AEO	13.18	5,597	35,553	4,178	36,736
Corrected FRM Basis	RFS2	34.14	17,151	76,023	11,619	82,460
FRM Control	Low	17.49	7,973	43,875	5,708	46,138
FRM Control	Mid	22.16	10,547	52,892	7,366	56,326
FRM Control	High	33.24	16,654	74,285	11,299	80,496

[a] Includes original loading at ethanol production or import facility plus loading during transfer from another mode.

The VOC EFs shown in Table 3.3-7 are from AP-42[733] 10 psi gasoline emission rates adjusted for ethanol vapor pressure and molecular weight (net factor = 0.20 = 3 psi / 10 psi x 48.7 MW / 72 MW). In calculating the vapor losses associated with the local truck ethanol volumes, a factor of two was applied to account for the losses during both loading of the truck and loading of the retail underground storage tank from the truck.

Table 3.3-6. SCC Assignments Used for Ethanol Tank Loading

SCC	SCC Description	Segments of ORNL Analysis Applied to SCC
30205031	Denatured Ethanol Storage Working Loss	All other tank loading
30205052	Ethanol Loadout to Truck	All truck loading
30205053	Ethanol Loadout to Railcar	All railcar loading

Table 3.3-7 Ethanol Tank Loading Vapor Emission Factors

ORNL Ethanol Transport Category	Description	Applied to SCC	EF (tons ethanol vapor per thousand tons ethanol)
H_Ld_Kt	Initial transport truck loading	30205052	0.243
R-H_Trf	Transfer from rail to truck	30205052	0.243
W-H_Trf	Transfer from barge to truck	30205052	0.243
LocTrkKt	Local distribution truck loading	30205052	0.243
R_Ld_Kt	Initial Railcar Loading	30205053	0.243
H-R_Trf	Transfer from truck to rail	30205053	0.243
W-R_Trf	Transfer from barge to rail	30205053	0.243
W_Ld_Kt	Initial barge loading	30205031	0.103
R-W_Trf	Transfer from railcar to barge	30205031	0.103
H_ULd_Kt	Unloading from transport truck to terminal tank	30205031	0.222
R_ULd_Kt	Unloading from rail to terminal tank	30205031	0.222
W_ULd_Kt	Unloading from barge to terminal tank	30205031	0.222
LocTrkKt	Unloading from local truck to retail tank	30205031	0.222[a]

[a] This local truck loading EF was also applied to loading the retail underground tank from the truck, using the same ethanol volume.

3.3.2.1.2 Calculation of Combustion Emissions From Ethanol Transport

Table 3.3-8 summarizes the kiloton-miles transported by mode from the ORNL analysis, which is used for combustion (vehicle exhaust) emission impacts for tanker trucks, locomotives, and water (barge) transport.

Table 3.3-8. Ethanol Transport by Mode in 2022

Source	Case	Bgal Ethanol	Kiloton-miles Ethanol Transport by Mode			
			Truck	Rail	Water	Local Truck
AQ modeled values	RFS1	6.69	228,831	18,436,891	1,565,254	138,811
AQ modeled values	AEO	13.18	436,498	30,543,455	2,415,480	268,368
AQ modeled values	RFS2	34.14	1,053,071	49,422,639	3,628,079	695,386
Corrected FRM Basis	RFS1	6.69	290,156	18,630,606	1,498,611	131,712
Corrected FRM Basis	AEO	13.18	491,458	30,650,028	2,538,867	253,239
Corrected FRM Basis	RFS2	34.14	1,164,335	47,822,752	3,905,640	534,322
FRM Control	Low	17.49	629,822	34,181,251	2,819,916	311,038
FRM Control	Mid	22.16	779,742	38,007,426	3,124,441	373,665
FRM Control	High	33.24	1,135,442	47,085,374	3,846,952	522,253

3.3.2.1.2.1 Combustion Emissions from Rail Transport of Ethanol

The emission impacts of projected increases in rail transport of ethanol resulting from this rule were calculated by multiplying locomotive emission factors by the added ton-miles of ethanol transport. For the air quality modeling analysis and this FRM analysis we were able to make use of the ORNL projected ton-miles of rail transport of ethanol by county for each of the three cases of the air quality analysis, as summarized in Table 3.3-8. These ton-miles by county were then multiplied by the g/mmBTU EFs shown in Tables 3.1-22 and 3.1-28 along with a fuel consumption of 2.38 gallons per thousand ton-miles[188] and 130,000 BTU/gallon, to determine the additional emissions by county.

For the air quality modeling these were then added to the base case (NEI 2020 projection) emissions of Class I locomotive emissions (SCC 2285002006) to obtain the county-specific emissions for the RFS1 mandate reference case, AEO reference case, and RFS2 control cases. The 2020 NEI projection values were used as the base case because they were the closest year with data readily available, and the difference between 2020 and 2022 was not considered to be important for this analysis. As described elsewhere, it was later discovered that an error had been introduced during the data handling

For the FRM analysis we used the final set of projections from ORNL, which included a 3.2 percent lesser estimate of rail transport of ethanol for the RFS2 control case compared to the values used for the air quality modeling. When put into terms of average one-way miles per trip for the nationwide upstream impacts spreadsheet, the final ORNL values yield a rail transport distance of 629 miles, compared to the 800 miles from GREET that was used for the NPRM

[188] Per 2006 American Association of Railroads, "Railroad Facts" 2007 edition, in 2006 4,214,459 gallons of diesel fuel were consumed transporting 4,214,459 million ton-miles of goods, which equates to 2.38 gallons per thousand ton-miles.

analysis. This value was calculated by dividing the 47,822,752 kton-miles by 76,023 kilotons loaded into rail tank cars in the RFS2 control (EISA) case.

3.3.2.1.2.2 Combustion Emissions from Water Transport of Ethanol

Air quality modeling inventories for marine vessels using Category 3 (C3) propulsion engines (i.e., ocean-going vessels such as container ships), for calendar year 2022 were generated for a reference case and the RFS2 control case. Since ethanol imports were assumed to be zero under both RFS1 and AEO reference cases, the 2022 base case gridded inventory was used for both reference cases. The 2022 base case inventory accounts for growth and the current Tier 1 NOX controls for C3 engines and was developed using the methodology outlined in the C3 NPRM.[734]

For the RFS2 control case, the port portion of the 2022 base case inventory was adjusted to account for projected imported ethanol volumes. Gram per freight ton emission factors (EFs) by port were developed by dividing the emissions for each port by the corresponding commodity tonnage.[735] The projected imported ethanol volumes by port were then converted to tons and multiplied by the gram per freight ton EFs to determine the additional emissions by port due to imported ethanol.[736] These were then added to the 2022 base case port emissions to obtain the port-specific 2022 emissions for the RFS2 control case. The 2022 gridded inventory for the RFS2 control case air quality model run was then developed by incorporating the adjusted port inventories.

For vessels using Category 1 (C1) and Category 2 (C2) propulsion engines (i.e., harbor craft), calendar year 2022 emissions by county were calculated for the two reference cases and the RFS2 control case. The starting point was calendar year 2020 C1/C2 base case emissions by county. Given the low growth estimated for this source category and the absence of a county-level 2022 inventory, the 2020 inventory was used for this analysis. A ton per ton-mile EF for each pollutant was then developed. For the numerator, the national level tons values for 2020 were taken from the 2008 locomotive/marine FRM.[706] For the denominator, projected ton-miles for U.S. domestic shipping for 2020 was used.[737] ORNL supplied EPA with ton-miles of barge traffic by county for each of the three cases, as summarized in Table 3.3-8. For the air quality modeling the ton-miles by county were then multiplied by the tons per ton-mile EFs to determine the additional emissions by county for each case. These were then added to the base case emissions to obtain the county-specific emissions for the two reference cases and the RFS2 control case.

For the FRM analysis we used the final set of projections from ORNL, which included a 7.6 percent greater estimate of water transport of ethanol for the RFS2 control case compared to the values used for the air quality modeling. When put into terms of average one-way miles per trip for the nationwide upstream impacts spreadsheet, the final ORNL values yield a barge transport distance of 336 miles, compared to the 520 miles from GREET that was used for the NPRM analysis. This value was calculated by dividing the 3,905,640 kton-miles by 11,619 kilotons loaded into barges in the RFS2 control case.

3.3.2.1.2.3 Combustion Emissions from Truck Transport of Ethanol

For the NPRM analysis we relied on the nationwide average truck transport distances assumed in GREET for transport to distribution/blending terminals (80 miles) and for local trucks distributing ethanol-gasoline blends from the terminal to the retail station (30 miles). For the air quality modeling and FRM analyses we were able to use the ORNL study described above, which supplied kton-miles of tank truck ethanol transport by county. VMT was calculated based on an average tank truck load of 52,720 lbs of ethanol. We doubled the VMT to account for return trips. Non-GHG emissions from heavy-duty diesel trucks were adjusted in the affected counties in proportion to their VMT increase. Excel versions of the ORNL data files plus calculations are available in the docket.[738]

3.3.2.1.3 Calculation of Biofuel Plant Emissions

For the county-level air quality modeling emission inventories we treated the corn ethanol plants as point sources wherever possible, since most of them are either existing plants or under construction or planned with a specific location. The choice of corn/starch ethanol plant locations and capacities for the 2005 baseline air quality modeling run and each of the three 2022 cases is described in Section 1.8.1.1 of this RIA. The emissions attributed to each plant were calculated using the emission rates presented in the NPRM DRIA Table 3.1-20 multiplied by the reported or planned capacities of each plant for each of the ethanol volume scenarios.[739,740,741,742]

For the county-level air quality modeling emission inventories we treated the cellulosic biofuel plants as area sources spread across the entire area of whatever county they were considered to be located in. The choice of plant locations and capacities is described in Section 1.8.1.3 of this RIA. They were not treated as point sources because of the substantial uncertainty about where they might actually be built, and if their emissions were treated as a point source their human exposures and health impacts would have been highly dependent on proximity to urban areas. Cellulosic plant emissions were only included in the RFS2 control (EISA) case, since the production capacities of existing and planned corn ethanol plants was sufficient to meet the RFS1 reference case and AEO reference case ethanol volumes. The emission rates used for the cellulosic plants in the air quality modeling were presented in the NPRM DRIA Table 3.1-20. Those emission rates were multiplied by the assumed cellulosic ethanol plant capacities ranging from 14 - 300 million gallons per year (MGY) from forest waste, 63 - 129 MGY from corn stover, and 91 - 149 MGY from switchgrass.[743]

Biodiesel plant emissions were also treated as area sources in the air quality modeling. All three modeled cases used the same set of 35 biodiesel plants, but used different plant "capacities" (actually just different plant operation factors applied to the same total capacity). The choice of plant locations and capacities is described in Section 1.8.1.4 of this RIA. The assumed capacities for the RFS1 reference case ranged from 50,000 to 34 million gallons per year with a combined capacity of 303 MGY. The AEO reference case capacities ranged from 63,000 to 42 million gallons per year with a total capacity of 380 MGY, and the RFS2 control (EISA) case capacities ranged from 135,000 to 90 million gallons per year with a total capacity of 810 MGY. Projected emissions for each plant were calculated using the emission factors for soybean oil based biodiesel plants given in DRIA Table 3.1-20.[744,745,746]

Significant updates have been made to emissions from cellulosic plants, in part to reflect the assumed shift in volumes from cellulosic ethanol to diesel between the proposed and final rules. In addition, after the air quality modeling was done, we discovered that for cellulosic ethanol plants the calculation of emissions had been overestimated by a factor of about two due to failing to account for the portion of biomass that is not used for process energy. This change decreases the estimated NOx and CO impacts on the order of 50 percent, and shifts the PM impact from an increase to a small decrease. However, these changes are counterbalanced to varying degrees by shifting some of the cellulosic volume from ethanol to diesel, which requires nearly twice the biomass to produce one gallon of fuel. While the net effect of the changes in cellulosic plant emissions is a significant decrease in NOx and CO emissions, the shift to cellulosic diesel under the primary scenario results in a larger increase in "upstream" PM emissions than reported in the NPRM or used in the air quality modeling analysis.

3.3.2.1.4 Calculation of Agricultural Emissions

The county-level agriculture-related emission inventories for air quality modeling were based on the 2002 NEI, since the NEI does not include any changes in its projections to 2022. That inventory was used for both the RFS1 and AEO reference cases. For the RFS2 control (EISA) case that inventory was modified to account for the changes in domestic agricultural activity predicted by the FASOM model, as described in Section 5.1 of the DRIA. Later modifications to the FASOM modeling that were done for the final rule analysis were not available in time for the air quality modeling. Since FASOM was only run for the AEO reference case and the RFS2 control (EISA) case, the air quality modeling did not attempt to account for any differences between the RFS1 and AEO reference cases.

The RFS2 control case agricultural emissions were estimated by applying adjustment factors shown in Table 3.3-9 to the NEI inventories for the affected source categories. The pollutants affected by these adjustments depend on the source; for example, NEI includes livestock dust for beef and dairy cattle, but not for swine or poultry. These adjustments were applied equally to all counties having any of the affected sources. This is one area of uncertainty in the inventories, since there would likely be variation from one county to another depending on how much of the predicted agricultural changes occurred in which counties. By using percent change adjustments rather than attempting to calculate absolute ton changes in each county we have attempted to minimize the inventory distortions that could occur if the calculated change for a given county was out of proportion to the reference case emissions for that county. For instance, a different approach could estimate reductions that were larger than the reference case NEI emissions, since there was no linkage between the NEI inventories and the FASOM modeling. The specific sources (SCCs) and affected pollutants that these adjustments were applied to are listed in a docket reference.[747]

Table 3.3-9. Adjustments to Agricultural Emissions for RFS2 control Case

Source Description	FASOM Parameters Used (change from AEO to RFS2)	Adjustment of Air Quality inputs	Corresponding Changes in Final Ag Modeling
Nitrogen Fertilizer Application	Nitrogen fertilizer use	+2.42%	+5.73%
Pesticide Application	Pesticide + herbicide use	-4.56%	-0.46%
Pesticide Production & Transport	Pesticide + herbicide use	-4.56%	-0.46%
Livestock Waste	Beef+dairy cattle, swine, poultry head counts	-0.99%	-0.90%
Livestock Dust	Beef+dairy cattle head counts	-1.32%	-0.27%
Tilling/Harvesting Dust	Total acres in crop production	+0.79%	+2.65%
Crop Residue Burning	Total acres in crop production	+0.79%	--[a]

[a] Crop residue burning emissions are not included as impacts in the final rule analysis.

Updates to agricultural modeling assumptions that have been made since the proposal and air quality modeling have had a significant impact on ammonia (NH3) emissions. Final modeling reflects an increase in fertilizer use with the primary control case, which results in an increase in NH3 emissions, a change from the modest decrease projected for the proposal and air quality analyses.

3.3.2.1.5 Calculation of Petroleum Production Emissions

Petroleum production includes crude oil extraction and transport to refineries. For the RFS2 air quality modeling these impacts were not considered large enough relative to the other upstream impacts to attempt to model them. In our nationwide emissions analysis we assumed that (a) 75% of the change in gasoline supply was projected to come from domestic refineries, and (b) 33.1% of the change in crude being used by domestic refineries would be domestic crude. Thus, using our assumption that 1.0 gallon less of gasoline equates to approximately 1.0 gallon less crude throughput, the reduction in crude extraction and transport would equal about 25% of the change in gasoline volume. Table 3.3-10 shows what the domestic crude adjustments would have been in the air quality modeling if they had been accounted for.

Table 3.3-10.
Domestic Crude Oil Volume Reductions Associated with RFS2 in 2022

Scenario		Gasoline Volume Reduction (Bgal)	Domestic Crude Reduction (Bgal)
AQ Modeling	RFS2 vs RFS1	18.5	4.6
	RFS2 vs AEO	14.2	3.5
Final Rule: High Ethanol Case	RFS2 vs RFS1	17.3	4.3
	RFS2 vs AEO	13.3	3.3
Final Rule: Mid Ethanol Case	RFS2 vs RFS1	10.0	2.5
	RFS2 vs AEO	5.9	1.5
Final Rule: Low Ethanol Case	RFS2 vs RFS1	6.9	1.7
	RFS2 vs AEO	2.8	0.7

3.3.2.1.6 Calculation of Refinery Emissions (combustion and vapor)

For the air quality modeling of refinery emissions, adjustment factors were applied to existing NEI inventory projections for all SCCs related to refineries. These adjustments were based on ratios of crude throughput estimates from refinery modeling for each case, which varied by PADD. Different adjustment factors were applied for the AEO reference case and for the RFS2 control (EISA) case.[748] The RFS1 reference case was assumed to be the existing NEI projected inventory with no adjustments applied. Table 3.3-11 summarizes the adjustments that were used.

Table 3.3-11.
Refinery Emission Adjustments for RFS2 Air Quality Modeling

Scenario	PADD 1	PADD 2	PADD 3	PADD 4 & 5	PADD 5 (CA)	US Total
AEO Reference	0.0%	-2.5%	-1.8%	-0.4%	-0.7%	-1.5%
RFS2 (EISA)	0.0%	-9.2%	-6.7%	-1.6%	-2.5%	-5.7%

Note that this method used for estimation of county level refinery emissions is not directly comparable with the method used for nationwide impacts in the NPRM and FRM analyses, for which we used the GREET-based upstream impacts spreadsheet model to calculate the absolute change in tons for each stage of the upstream inventory.

3.3.2.1.7 Calculation of Gasoline Transport, Storage and Distribution emissions: (vapor)

With the displacement of some of the gasoline pool to E10 and E85 as predicted in this analysis there would be changes in the quantity of vapor losses during the transport and distribution of gasoline and gasoline-ethanol blends. The analysis of these impacts was separated into two segments: refinery to bulk terminal (RBT) and bulk terminal to pump (BTP). The reference cases analyzed would include some amount of E0 in the BTP segment, but the ethanol volumes considered as policy options in this rule are all beyond the volume that would require E10 blends for all gasoline-fueled engines (onroad and nonroad). Thus the transport of

E0 gasoline would only occur between refineries and blending terminals in the policy cases, i.e., the RBT segment. The BTP segment would include both E10 and E85.

E0 – Refinery to Bulk Terminal (RBT)
E0 – Bulk Terminal to Pump (BTP, used for reference cases only)
E10 – Bulk Terminal to Pump (BTP)
E85 – Bulk Terminal to Pump (BTP)

For each of the above fuel type and transport stage combinations, nationwide VOC impacts (ton deltas) (and benzene and ethanol vapor) were calculated using EPA's upstream impacts spreadsheet model for each control scenario (RFS2 control vs RFS1 mandate and RFS2 control vs AEO). For air quality modeling the three BTP values were combined into a total BTP impact for each scenario. These impact values were renormalized to be ton deltas relative to the RFS1 mandate reference case, which was treated as corresponding to the NEI. Then all the SCCs in the NEI related to gasoline transport, storage, and distribution (TS&D) were categorized as either RBT or BTP, and the NEI VOC emissions were summed for each category. The nationwide VOC percent change for the AEO case relative to the RFS1 mandate reference case for RBT was calculated as the AEO case RBT delta tons (versus RFS1) divided by the NEI RBT tons. Similarly, the nationwide VOC percent change for the AEO case for BTP was calculated as the AEO case BTP delta tons (versus RFS1) divided by the NEI BTP tons. The same calculations were done for the RFS2 control case to get RBT and BTP percent changes in VOC from the RFS1 mandate case.[749]

The county level air quality inventories for the AEO and RFS2 control cases were then calculated by applying these percent changes in VOC to the corresponding sets of SCCs (point and non-point sources) for every county. The same adjustment factors were applied to benzene, which is reasonable for the VOC decrease in the refinery to bulk terminal segment. But in the terminal to pump segment benzene would be expected to decrease while VOC increases, since the VOC increaase is due to addition of ethanol to the fuel, rather than any increase in gasoline itself.

3.3.2.2 Differences in Downstream Impacts between Inventories

3.3.2.2.1 On-Road Gasoline

In the proposal we provided two different analyses based on two different assumptions regarding the effects of E10 and E85 versus E0 on exhaust emissions from cars and trucks. Those were referred to as "less sensitive" and "more sensitive" cases. Based on analysis of recent emissions test data conducted since publication of the NPRM, we are modeling a single case. As detailed above in Section 3.2, the case modeled for the final rule is a hybrid approach, applying "more sensitive" impacts for E10 and pre-Tier 2 light duty vehicles, and applying the "less sensitive" E10 effects for Tier 2 light duty cars and trucks (meaning no impact for NOx or exhaust NMHC on the majority of light duty vehicles on the road in 2022). We have also updated our estimates of evaporative permeation impacts of E10 based on recent studies. Finally, for the final rule inventories we are only claiming emission effects with use of E85 in flex-fueled vehicles relative to E0 for two pollutants: ethanol and acetaldehyde, for which data suggests the effects are more certain. For the "more sensitive case" presented in the NPRM, and used in the air quality modeling, we had estimated changes to additional pollutants (including significant PM reductions) based on some very limited data. Until such time as additional data is collected to enhance this analysis it is premature to use such assumptions.

For the air quality inventory, EPA executed a preliminary version of MOVES dated 9/9/2008 using default database MOVESDB20080828 plus several modifications to the code and to the database. The MOVES runs produced emission factors at the state-month level for all onroad gasoline vehicles except motorcycles. Onroad gasoline inventories were generated by multiplying MOVES emission factors by VMT developed for the Office of Air Quality Planning and Standards's 2002 Version 3 Modeling Platform[750] and used in the recently published Locomotive-Marine Rule.[751] The MOBILE6 Model was M6203ChcOxFixNMIM, a special version that includes cold-start VOC and the cold-start controls of the Mobile Source Air Toxics Rule that go into effect in 2011. The NONROAD Model version was NR05d-Bond-Final, which is the same as the publically released version NONROAD2008. Both MOBILE6 and NONROAD were run using NMIM (version NMIM20071009) with NMIM County Database NCD20080724. NMIM supplied emissions from the NONROAD Model and from onroad sources not produced from MOVES. Onroad emissions generated at the state-month level from MOVES were distributed to the county-month level using the results from MOBILE6 as run by NMIM. For both NMIM and MOVES, temperatures and humidity were those of the air quality modeling base year 2005, and fuels for each case were those developed for this rule. Details of how MOVES and NMIM were configured and run are documented in a memo contained in the docket.[752]

Final rule inventories were updated using the 9/28/09 version of MOVES and database, which reflects fuel effects that are consistent with the final MOVES2010 version (baseline emission rates were still under development at this stage, so while the 9/28/09 version is updated from previous versions, results are not the same as final MOVES). Differences between the air quality modeling inventories and the NPRM and FRM inventories are due to differences in MOVES code and database versions, run granularity (national-annual vs. state-2-month vs. state-12-month), and running of the "more sensitive" case for the air quality modeling. One specific change from the NPRM version to the air quality and FRM versions was an update of reformulated gasoline properties to reflect the lower benzene levels called for by the MSAT rule, as described above in Section 3.1.1.1.

3.3.2.2.2 Off-Road Gasoline

For the NPRM, emissions from nonroad gasoline equipment were developed by running the National Mobile Inventory Model (NMIM) for January and July. We limited the runs to these months to speed the analysis while also capturing the temperature extremes that can affect emissions. The NMIM County Database (NCD) used by NMIM to produce those inventories was updated as part of the 2005 National Emission Inventory (NEI) process. The NCD also included the 2005 and 2022 fuels described in Section 3.1.1.2 of the DRIA. The version of the NONROAD Model used included the effects of the 2008 Final Rule: Control of Emissions of Air Pollution from New Nonroad Spark-Ignition Engines, Equipment, and Vessels.[753] It is also capable of modeling the effects of gasoline blends containing 10 percent or less of ethanol. That version of NONROAD was later released as NONROAD2008.

For air quality modeling and the final rule analysis, NMIM was also used, but all twelve months were run.

For the NPRM, emissions from onroad and nonroad diesel equipment were also developed by running NMIM, using the same NCD and version of the NONROAD Model described above. The version of MOBILE was MOBILE6.2. Diesel fuels are less fully characterized than gasoline, since the only property used by MOBILE and NONROAD is fuel sulfur.

For the NPRM, toxic emissions for off-road reference cases were taken directly from NMIM. Inventories for the control case were developed by applying ratios of the aggregate MOVES toxic exhaust, evaporative and refueling emissions for on-road gasoline for control versus reference case, to reference case toxic emissions for off-road from NMIM.

For the air quality modeling and FRM analysis of nonroad gasoline engine emissions we used the same version of NMIM. Most toxic emissions for off-road equipment were taken directly from NMIM. The one exception was ethanol, which is not estimated by NMIM, so ethanol emissions were based on VOC speciation from light-duty gasoline vehicles. Ethanol inventories for the control case were developed by applying ratios of the aggregate MOVES ethanol exhaust, evaporative and refueling emissions for on-road gasoline for control versus reference cases, to the reference case ethanol emissions for off-road equipment.

3.3.2.2.3 On-Road Diesel

For the NPRM the proposed increase in biodiesel to 0.81 billion gallons by 2022 was modeled assuming that the emission effects of biodiesel are linear with biodiesel concentration as demonstrated by Sze, et al,[754] and that impacts can be analyzed assuming all biodiesel is blended as B20. We applied the B20 effects discussed in Section 3.1.1.2.4 to baseline heavy-duty emissions generated by NMIM, as MOVES heavy-duty diesel estimates were not available in time for the NPRM analysis.

For the air quality and FRM analysis diesel emission inventories were generated using the same method as the NPRM.

3.3.2.2.4 Portable Fuel Containers

The NPRM and air quality analysis used the same projected inventories for VOC, benzene, and ethanol vapor as the FRM analysis described above in Section 3.1.1.4.4.

3.4 Air Quality Impacts

This section presents the methodology and results of our air quality modeling to determine the projected impact of the renewable fuel volumes required by this rule on ambient concentrations of criteria and air toxic pollutants. The air quality modeling results presented here reflect the impact of increased renewable fuels use required by RFS2 compared with two different reference cases that include the use of renewable fuels: a 2022 baseline projection based on the RFS1-mandated volume of 7.1 billion gallons of renewable fuels, and a 2022 baseline projection based on the AEO 2007 volume of 13.6 billion gallons of renewable fuels. Thus, the results represent the impact of an incremental increase in ethanol and other renewable fuels. We note that the air quality modeling results presented in this final rule do not constitute the "anti-backsliding" analysis required by Clean Air Act section 211(v). EPA will be analyzing air quality impacts of increased renewable fuel use through that study and will promulgate appropriate mitigation measures under section 211(v), separate from this final action. Following the discussion of modeling results in Section 3.4, Sections 3.5 and 3.6 describe the health and environmental effects associated with the criteria and air toxic pollutants that are impacted by the required renewable fuel volumes. In addition, Section 5.4 describes the methodology for calculating monetized benefits due to reductions in adverse health effects associated with $PM_{2.5}$ and ozone.

3.4.1 Air Quality Modeling Methodology

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis by assessing the effectiveness of control strategies. These models are applied at multiple spatial scales - local, regional, national, and global. This section provides detailed information on the photochemical model used for our air quality analysis (the Community Multi-scale Air Quality (CMAQ) model), atmospheric reactions and the role of chemical mechanisms in modeling, and model uncertainties and limitations. Further discussion of the modeling methodology is included in the Air Quality Modeling Technical Support Document (AQM TSD) found in the docket for this rule. Results of the air quality modeling are presented in Section 3.4.2.

3.4.1.1 Modeling Methodology

A national-scale air quality modeling analysis was performed to estimate future year annual $PM_{2.5}$ concentrations, 24-hour $PM_{2.5}$ concentrations, 8-hour ozone concentrations, air toxics concentrations, and nitrogen and sulfur deposition levels for future years. The 2005-based CMAQ modeling platform was used as the basis for the air quality modeling of the two future reference cases and the RFS2 future control scenario for this final rule. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The base year of data used to construct this platform includes emissions and meteorology for 2005. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

The CMAQ modeling system is a non-proprietary, publicly available, peer-reviewed, state-of-the-science, three-dimensional, grid-based Eulerian air quality grid model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given input sets of meteorological conditions and emissions.[755,756,757] The CMAQ model version 4.7 was most recently peer-reviewed in February of 2009 for the U.S. EPA.[189] The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[758,759,760] This 2005 multi-pollutant modeling platform used the latest publicly-released CMAQ version 4.7[190] with a minor internal change made by the U.S. EPA CMAQ model developers intended to speed model runtimes when only a small subset of toxics species are of interest.

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. We used the most recent CMAQ version (v4.7) which was officially released by EPA's Office of Research and Development (ORD) in December 2008, and reflects updates to earlier versions in a number of areas to improve the underlying science. These include (1) enhanced secondary organic aerosol (SOA) mechanism to include chemistry of isoprene, sesquiterpene, and aged in-cloud biogenic SOA in addition to terpene; (2) improved vertical convective mixing; (3) improved heterogeneous reaction involving nitrate formation; and (4) an updated gas-phase chemistry mechanism, Carbon Bond 05 (CB05), with extensions to model explicit concentrations of air toxic species as well as chlorine and mercury. This mechanism, CB05-toxics, also computes concentrations of species that are involved in aqueous chemistry and that are precursors to aerosols. Section 3.4.1.2.2 of this RIA discusses the chemical mechanism, SOA formation and details about the improvements made to the SOA mechanism within this recent release of CMAQ.

3.4.1.1.1 Model Domain and Configuration

The CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico. The modeling domain is made up of a large continental U.S. 36 kilometer (km) grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 3.4-1. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

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[189] Report on the peer-review is still being finalized. Draft available upon request from Director S.T.Rao, Atmospheric Modeling and Analysis Division; rao.st@epa.gov; 919-541-4541. Allen, D., Burns, D., Chock, D., Kumar, N., Lamb, B., Moran, M. (February 2009 Draft Version). Report on the Peer Review of the Atmospheric Modeling and Analysis Division, NERL/ORD/EPA. U.S. EPA, Research Triangle Park, NC.

[190] CMAQ version 4.7 was released on December, 2008. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org.

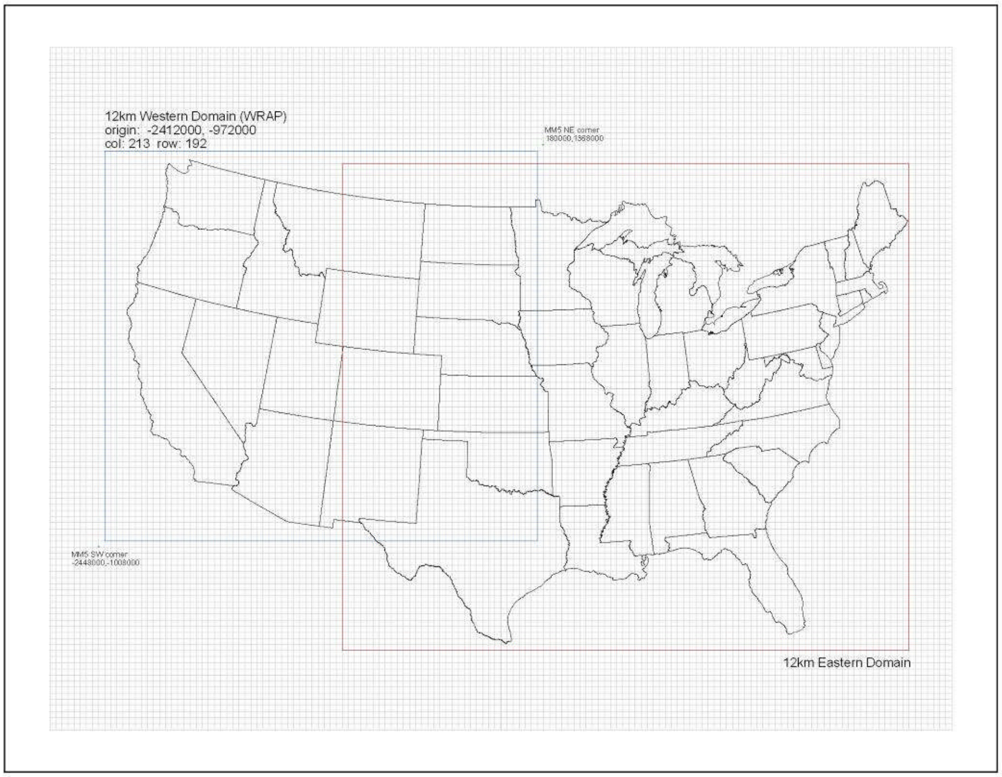

Figure 3.4-1. Map of the CMAQ Modeling Domain

3.4.1.1.2 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from simulations of the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model[761] for the entire year of 2005 over model domains that are slightly larger than those shown in Figure 3.4-1. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions.[762] The meteorology for the national 36 km grid and the two 12 km grids were developed by EPA and are described in more detail within the AQM TSD. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.4, for example: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[763]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[764] The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2005 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 30 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36 km CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

The emissions inputs used for the 2005 base year and each of the future year base cases and control scenarios analyzed for this rule are summarized in Section 3.3 of this RIA.

3.4.1.1.3 CMAQ Evaluation

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.), nitrate and sulfate deposition, and specific air toxics (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted using 2005 state/local monitoring data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. Model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[191] The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies.[192] Overall, the performance for the 2005 modeling platform is within the range or close to that of these other applications. The performance of the CMAQ modeling was evaluated over a 2005 base case. The model was able to reproduce historical concentrations of ozone and $PM_{2.5}$ over the land with low amounts of bias and error. Model predictions of annual formaldehyde, acetaldehyde and benzene showed relatively small bias and error percentages when compared to observations. The model yielded larger bias and error results for 1,3-butadiene and acrolein based on limited monitoring sites. A more detailed summary of the 2005 CMAQ model performance evaluation is available within the AQM TSD found in the docket of this rule.

3.4.1.1.4 Model Simulation Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, annual and seasonal air toxics concentrations, and nitrogen and sulfur deposition total levels for each of the following emissions scenarios:

- 2005 base year

- 2022 reference case projection (RFS1 Mandate; 6.7 Bgal of ethanol, 0.38 Bgal of biodiesel. See also Table 3.3.1)

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[191] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANE-VU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and Western Regional Air Partnership (WRAP).

[192] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

- 2022 reference case projection (AEO 2007; 13.18 Bgal of ethanol, 0.38 Bgal of biodiesel. See also Table 3.3.1)

- 2022 control case projection (RFS2 control,; 34.14 Bgal of ethanol, 0.81 Bgal of biodiesel, 0.38 Bgal of renewable diesel. See also Table 3.3.1)

It should be noted that the emission inventories used in the air quality and benefits modeling were somewhat enhanced compared to what was described in the proposal, but due to the timing of the analysis did not include some of the later enhancements and corrections of the final emission inventories presented in this FRM. The emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161), contains a detailed discussion of the emissions inputs used in our air quality modeling. Section 3.3 of this RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final regulatory scenario. These refinements, along with other inventory issues, have implications for modeling results. These implications are discussed in Sections 3.4.1.3 and 3.4.2.

We use the predictions from the model in a relative sense by combining the 2005 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate daily and annual $PM_{2.5}$ concentrations, and 8-hour ozone concentrations for each of the 2022 scenarios. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2003-2007).

The projected daily and annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the U.S. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[765] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Small SI Engine Rule modeling AQM TSD.[766] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[767]

Additionally, we conducted an analysis to compare the annual and seasonal, absolute and percent differences between the 2022 control case and the two 2022 reference cases for nitrate and sulfate deposition, ethanol, and five air toxics of interest (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein). These data were not compared in a relative sense due to the limited observational data available.

3.4.1.2 Chemical Mechanisms in Modeling

The RFS2 rule presents inventories for NO_X, VOC, CO, $PM_{2.5}$, SO_2, NH_3, ethanol and five air toxics: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Ethanol and the five air toxics are explicit model species in the CMAQv4.7 model with carbon bond 5 (CB05) mechanisms.[768] Emissions of all the pollutants included in the rule inventories, except ethanol, were generated using the Motor Vehicle Emissions Simulator (MOVES) hydrocarbon (HC) emissions and toxic-to-HC ratios calculated using MOBILE 6 (see Section 3.1.1.4.1 of the draft RIA).[769] Ethanol emissions for air quality modeling were based on speciation of VOC using different ethanol profiles (E0, E10, and E85). In addition to direct emissions, photochemical processes mechanisms are responsible for formation of some of these compounds in the atmosphere from precursor emissions. For formaldehyde and acetaldehyde, many photochemical processes are involved. CMAQ therefore also requires inventories for a large number of other air toxics and precursor pollutants. Inventories for toxic pollutants not estimated using MOVES and MOBILE6 ratios were developed by running the National Mobile Inventory Model (NMIM). Emissions of other precursor pollutants were estimated by application of speciation profiles to VOC.

In the CB05 mechanism, the chemistry of thousands of different VOCs in the atmosphere are represented by a much smaller number of model species which characterize the general behavior of a subset of chemical bond types; this condensation is necessary to allow the use of complex photochemistry in a fully 3-D air quality model.[770]

Complete combustion of ethanol in fuel produces carbon dioxide (CO_2) and water (H_2O). Incomplete combustion results in the production of other air pollutants, such as acetaldehyde and other aldehydes, and the release of unburned ethanol. Ethanol is also present in evaporative emissions. In the atmosphere, ethanol from unburned fuel and evaporative emissions can undergo photodegradation to form aldehydes (acetaldehyde and formaldehyde) and peroxyacetyl nitrate (PAN), and also plays a role in ground-level ozone formation. Mechanisms for these reactions are included in CMAQ. Additionally, other aromatic hydrocarbons (AHC) and hydrocarbons are considered because any increase in acetyl peroxy radicals due to ethanol increases might be counterbalanced by a decrease in radicals resulting from decreases in AHC and other hydrocarbons.

CMAQ includes 63 inorganic reactions to account for the cycling of all relevant oxidized nitrogen species and cycling of radicals, including the termination of NO_2 and formation of nitric acid (HNO_3) without PAN formation.[193]

$NO_2 + \cdot OH + M \rightarrow HNO_3 + M$ $\quad k = 1.19 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$ [771]

[193] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

The CB05 mechanism also includes more than 90 organic reactions that include alternate pathways for the formation of acetyl peroxy radical, such as by reaction of methylglyoxal, which is also formed from reactions of AHC. Alternate reactions of acetyl peroxy radical, such as oxidation of NO to form NO_2, which again leads to ozone formation, are also included. Atmospheric reactions and chemical mechanisms involving several key formation pathways are discussed in more detail in the following sections.

3.4.1.2.1 Acetaldehyde

Acetaldehyde is the main photodegradation product of ethanol, as well as other precursor hydrocarbons. Acetaldehyde is also a product of fuel combustion. In the atmosphere, acetaldehyde can react with the OH radical and O_2 to form the acetyl peroxy radical [$CH_3C(O)OO\cdot$].[194] This radical species can then further react with nitric oxide (NO), to produce formaldehyde (HCHO), or with nitrogen dioxide (NO_2), to produce PAN [$CH_3C(O)OONO_2$]. An overview of these reactions and the corresponding reaction rates are provided below.[195]

$\mathbf{CH_3CHO} + \cdot OH \rightarrow CH_3C\cdot O + H_2O$ $\quad$ $k = 1.5 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$ [772]

$CH_3C\cdot O + O_2 + M \rightarrow \mathbf{CH_3C(O)OO\cdot} + M$

$\mathbf{CH_3C(O)OO\cdot} + \boldsymbol{NO} \rightarrow CH_3C(O)O\cdot + \boldsymbol{NO_2}$ $\quad$ $k = 2.0 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$ [773]

$CH_3C(O)O\cdot \rightarrow \cdot CH_3 + CO_2$

$\cdot CH_3 + O_2 + M \rightarrow CH_3OO\cdot + M$

$CH_3OO\cdot + NO \rightarrow CH_3O\cdot + NO_2$

$CH_3O\cdot + O_2 \rightarrow \mathbf{HCHO} + HO_2$

$\mathbf{CH_3C(O)OO\cdot} + NO_2 + M \rightarrow \mathbf{CH_3C(O)OONO_2} + M$ $\quad$ $k = 1.0 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$ [774]

Acetaldehyde can also photolyze ($h\nu$), which predominantly produces $\cdot CH_3$ and HCO:

$\mathbf{CH_3CHO} + h\nu \rightarrow \cdot CH_3 + HCO$ $\quad$ $\lambda = 240\text{-}380\ nm$ [775]

As mentioned above, $\cdot CH_3$ is oxidized in the atmosphere to produce formaldehyde (HCHO). Formaldehyde is also a product of hydrocarbon combustion. In the atmosphere, formaldehyde undergoes photolysis and reaction with the OH radical, NO_3 radical, and ozone,

[194] Acetaldehyde is not the only source of acetyl peroxy radicals in the atmosphere. For example, dicarbonyl compounds (methylglyoxal, biacetyl, and others) also form acetyl radicals, which can further react to form peroxyacetyl nitrate (PAN).
[195] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

and the resulting lifetimes are ~4 hours, 1.2 days, 83 days, and >4.5 years, respectively.[196] Formaldehyde is removed mainly by photolysis whereas the higher aldehydes, those with two or more carbons such as acetaldehyde, react predominantly with OH radicals. The photolysis of formaldehyde is a source of additional radicals, and as shown above, these radicals can react with NO_2 to form PAN in the atmosphere.

HCHO + hν → H + HCO $\lambda = 240\text{-}360$ nm [776]

CB05 mechanisms for acetaldehyde formation warrant a detailed discussion given the increase in vehicle and engine exhaust emissions for this pollutant and ethanol, which can form acetaldehyde in the air. Acetaldehyde is represented explicitly in the CB05 chemical mechanism[777,778] by the ALD2 model species, which can be both formed from other VOCs and can decay via reactions with oxidants and radicals. The reaction rates for acetaldehyde, as well as for the inorganic reactions that produce and cycle radicals, and the representative reactions of other VOCs have all been updated to be consistent with recommendations in the literature.[779] The decay reactions of acetaldehyde are fewer in number and can be characterized well because they are explicit representations. Acetaldehyde can photolyze in the presence of sunlight or react with molecular oxygen ($O^3(P)$), hydroxyl radical (OH), or nitrate radicals. Of these reactions, both photolysis and reaction with OH are the most important reactions determining loss of acetaldehyde. The reaction rates are based on expert recommendations,[780] and the photolysis rate is from IUPAC recommendations.

In CMAQ v4.7, the acetaldehyde that is formed from photochemical reactions is tracked separately from that which is due to direct emission and transport of direct emissions. In CB05, there are 25 different reactions that form acetaldehyde in molar yields ranging from 0.02 (ozone reacting with lumped products from isoprene oxidation) to 2.0 (cross reaction of acylperoxy radicals, CXO3). The specific parent VOCs that contribute the most to acetaldehyde concentrations vary spatially and temporally depending on characteristics of the ambient air, but alkenes in particular are found to play a large role. The IOLE model species, which represents internal carbon-carbon double bonds, has high emissions and relatively high yields of acetaldehyde. The OLE model species, representing terminal carbon double bonds, also plays a role because it has high emissions although lower acetaldehyde yields. Production from peroxyproprional nitrate and other peroxyacylnitrates (PANX) and aldehydes with 3 or more carbon atoms also play an important role. Thus, the amount of acetaldehyde (and formaldehyde as well) formed in the ambient air as well as emitted in the exhaust (the latter being accounted for in emission inventories) is affected by changes in these precursor compounds due to the addition of ethanol to fuels (e.g., decreases in alkenes would cause some decrease of acetaldehyde, and to a larger extent, formaldehyde).

The reaction of ethanol (CH_3CH_2OH) with OH is slower than some other important reactions but can be an important source of acetaldehyde if the emissions are large. Based on kinetic data for molecular reactions, the only important chemical loss process for ethanol (and other alcohols) is reaction with the hydroxyl radical (·OH).[781] This reaction produces

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[196] Lifetime calculated using the following: for photolysis, with overhead sun (at noontime during the summer); for OH radical reactions, a 12-hour daytime average of 2.0×10^6 molecule cm^{-3}; for NO_3 radical reactions, a 12-hour nighttime average of 5×10^8 molecule cm^{-3}; and for ozone, a 24-hour average of 7×10^{11} molecule cm^{-3}.

acetaldehyde (CH_3CHO) with a 90% yield.[782] The lifetime of ethanol in the atmosphere can be calculated from the rate coefficient, k, and due to reaction with the OH radical, occurs on the order of a day in polluted urban areas or several days in unpolluted areas.[197]

$\mathbf{CH_3CH_2OH} + \cdot OH \rightarrow CH_3C\cdot HOH + H_2O$ $\qquad k = 3.2 \times 10^{-12}\ cm^3 molecule^{-1} s^{-1}$ [783]

$CH_3C\cdot HOH + O_2 \rightarrow \mathbf{CH_3CHO} + HO_2$

In CB05, reaction of one molecule of ethanol yields 0.90 molecules of acetaldehyde. It assumes the majority of the reaction occurs through H-atom abstraction of the more weakly-bonded methylene group, which reacts with oxygen to form acetaldehyde and hydroperoxy radical (HO2), and the remainder of the reaction occurs at the –CH3 and -OH groups, creating formaldehyde (HCHO), oxidizing NO to NO2 (represented by model species XO2) and creating glycoaldehyde, which is represented as ALDX:

CH3CHOH + OH → HO2 + 0.90 CH3CHO + 0.05 ALDX + 0.10 HCHO + 0.10 XO2

3.4.1.2.2 Secondary Organic Aerosols (SOA)

Secondary organic aerosol (SOA) chemistry research described below has led to implementation of new pathways for secondary organic aerosol (SOA) in CMAQ 4.7, based on recommendations of Edney et al. and the recent work of Carlton et al.[784, 785] In previous versions of the CMAQ model, all SOA was treated as semi-volatile, whereas in CMAQ v4.7, non-volatile SOA are simulated as well, including SOA originating from aromatic oxidation under low-NO_x conditions.

3.4.1.2.2.1 SOA Research

SOA results when products of atmospheric transformation or photooxidation of a volatile organic compound (VOC) form or partition to the particle phase. Current research suggests SOA contributes significantly to ambient organic aerosol (OA) concentrations, and in Southeast and Midwest States may make up more than 50% (although the contribution varies from area to area) of the organic fraction of $PM_{2.5}$ during the summer (but less in the winter).[786,787] A wide range of laboratory studies conducted over the past twenty years show that anthropogenic aromatic hydrocarbons and long-chained alkanes, along with biogenic isoprene, monoterpenes, and sesquiterpenes, contribute to SOA formation.[788,789,790,791,792] Anthropogenic SOA is a small portion of all SOA; most is biogenic and varies with season. Based on these laboratory results, SOA chemical mechanisms have been developed and integrated into air quality models such as the CMAQ model and have been used to predict OA concentrations.[793]

Over the past 10 years, ambient OA concentrations have been routinely measured in the U.S. and some of these data have been used to determine, by employing source/receptor methods, the contributions of the major OA sources, including biomass burning and vehicular gasoline and diesel exhaust. Since mobile sources are a significant source of VOC emissions, currently accounting for approximately 50% of anthropogenic VOC,[794] mobile sources are also

[197] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

an important source of SOA.

Toluene is an important contributor to anthropogenic SOA. Other aromatic compounds contribute as well, but the extent of their contribution has not yet been quantified. Mobile sources are the most significant contributor to ambient toluene concentrations as shown by analyses done for the 2002 National Air Toxics Assessment (NATA)[795] and the Mobile Source Air Toxics (MSAT) Rule.[796] 2002 NATA indicates that onroad and nonroad mobile sources accounted for 70% (2.24 $\mu g/m^3$) of the total average nationwide ambient concentration of toluene (3.24 $\mu g/m^3$), when the contribution of the estimated "background" is apportioned among source sectors.

The amount of toluene in gasoline influences the amount of toluene emitted in vehicle exhaust and evaporative emissions, although, like benzene, some toluene is formed in the combustion process. In turn, levels of toluene and other aromatics in gasoline are potentially influenced by the amount of ethanol blended into the fuel. Due to the high octane quality of ethanol, it greatly reduces the need for and levels of other high-octane components such as aromatics including toluene (which is the major aromatic compound in gasoline). Since toluene contributes to SOA and the toluene level of gasoline is decreasing, it is important to assess the effect of these reductions on ambient PM.

It is unlikely that ethanol would directly form SOA or affect SOA formation indirectly through changes in the radical populations from increasing ethanol exhausts. Nevertheless, scientists at the U.S. EPA's Office of Research and Development's National Exposure Research Laboratory recently directed experiments to investigate ethanol's SOA forming potential.[797] The experiments were conducted under conditions where peroxy radical reactions would predominate (irradiations performed in the absence of NOx and OH produced from the photolysis of hydrogen peroxide). This was the most likely scenario under which SOA formation could occur, since a highly oxygenated C4 organic would be potentially made. As expected, no SOA was produced. From these experiments, the upper limit for the aerosol yield would have been less than 0.01% based on scanning mobility particle sizer (SMPS) data. Given the expected negative result based on these initial smog chamber experiments, these data were not published.

In general, a review of the literature shows limited data on SOA concentrations, largely due to the lack of analytical methods for identifying and determining the concentrations of the highly polar organic compounds that make up SOA. The most widely applied method of estimating total ambient SOA concentrations is the EC tracer method using ambient data which estimates of the OC/EC ratio in primary source emissions.[798,799] SOA concentrations have also been estimated using OM (organic mass) to OC (organic carbon) ratios, which can indicate that SOA formation has occurred, or by subtracting the source/receptor-based total primary organic aerosol (POA) from the measured OC concentration.[800] Such methods, however, may not be quantitatively accurate and provide no information on the contribution of individual biogenic and anthropogenic SOA sources, which is critical information needed to assess the impact of specific sources and the associated health risk. These methods assume that OM containing additional mass from oxidation of OC comes about largely (or solely) from SOA formation. In particular, the contributions of anthropogenic SOA sources, including those of aromatic precursors, are required to determine exposures and risks associated with replacing fossil fuels with biofuels.

Upon release into the atmosphere, numerous VOC compounds can react with free radicals in the atmosphere to form SOA. While this has been investigated in the laboratory, there is relatively little information available on the specific chemical composition of SOA compounds themselves from specific VOC precursors. This absence of compositional data from the precursors has largely prevented the identification of aromatically-derived SOA in ambient samples which, in turn, has prevented observation-based measurements of the aromatic and other SOA contributions to ambient PM levels.

As a first step in determining the ambient SOA concentrations, EPA has developed a tracer-based method to estimate such concentrations.[801,802] The method is based on using mass fractions of SOA tracer compounds, measured in smog chamber-generated SOA samples, to convert ambient concentrations of SOA tracer compounds to ambient SOA concentrations. This method consists of irradiating the SOA precursor of interest in a smog chamber in the presence of NO_x, collecting the SOA produced on filters, and then analyzing the samples for highly polar compounds using advanced analytical chemistry methods. Employing this method, candidate tracers have been identified for several VOC compounds which are emitted in significant quantities and known to produce SOA in the atmosphere. Some of these SOA-forming compounds include toluene, a variety of monoterpenes, isoprene, and β-caryophyllene, the latter three of which are emitted by vegetation and are more significant sources of SOA than toluene. Smog chamber work can also be used to investigate SOA chemical formation mechanisms.[803,804,805,806]

Although these concentrations are only estimates, due to the assumption that the mass fractions of the smog chamber SOA samples using these tracers are equal to those in the ambient atmosphere, there are presently no other means available for estimating the SOA concentrations originating from individual SOA precursors. Among the tracer compounds observed in ambient $PM_{2.5}$ samples are two tracer compounds that have been identified in smog chamber aromatic SOA samples.[807] To date, these aromatic tracer compounds have been identified, in the laboratory, for toluene and *m*-xylene SOA. Additional work is underway by the EPA to determine whether these tracers are also formed by benzene and other alkylbenzenes (including *o*-xylene, *p*-xylene, 1,2,4-trimethylbenzene, and ethylbenzene).

One caveat regarding this work is that a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in this way. It is possible that these unstudied compounds produce SOA species which are being used as tracers for other VOCs. This means that the present work could overestimate the amount of SOA formed in the atmosphere by the VOCs studied to date. This approach may also estimate entire hydrocarbon classes (e.g., all methylsubstituted-monoaromatics or all monoterpenes) and not individual precursor hydrocarbons. Thus the tracers could be broadly representative and not indicative of individual precursors. This is still unknown. Also, anthropogenic precursors play a role in formation of atmospheric radicals and aerosol acidity, and these factors influence SOA formation from biogenic hydrocarbons. This anthropogenic and biogenic interaction, important to EPA and others, needs further study. The issue of SOA formation from aromatic precursors is an important one to which EPA and others are paying significant attention. For benzene, smog chamber studies show that benzene forms SOA possibly through reactions with NO_x. Early smog chamber work suggests benzene might be relatively inert in forming SOA, although this study may not be conclusive.[808] However, more recent work shows that benzene does form SOA in smog chambers.[809,810] This new smog chamber work shows that benzene can be oxidized in the presence of NO_x to form SOA with maximum mass of SOA being 8-25% of the mass of benzene. As mentioned above, work is needed to determine if a tracer compound can be found for benzene SOA which might indicate how much of ambient SOA comes from benzene.

The aromatic tracer compounds and their mass fractions have also been used to estimate monthly ambient aromatic SOA concentrations from March 2004 to February 2005 in five U.S. Midwestern cities.[811] The annual tracer-based SOA concentration estimates were 0.15, 0.18, 0.13, 0.15, and 0.19 μg carbon/m^3 for Bondville, IL, East St. Louis, IL, Northbrook, IL, Cincinnati, OH and Detroit, MI, respectively, with the highest concentrations occurring in the summer. On average, the aromatic SOA concentrations made up 17 % of the total SOA concentration. Thus, this work suggests that we are finding ambient PM levels on an annual basis of about 0.15 μg/m^3 associated with present toluene levels in the ambient air in these Midwest cities. Based on preliminary analysis of recent laboratory experiments, it appears the toluene tracer could also be formed during photooxidation of some of the xylenes.[812]

Over the past decade a variety of modeling studies have been conducted to predict ambient SOA levels, with most studies focusing on the contributions of biogenic monoterpenes and anthropogenic aromatic hydrocarbons. More recently, modelers have begun to include the contribution of the isoprene SOA to ambient OC concentrations.[813] In general, the studies have been limited to comparing the sum of the POA and SOA concentrations with ambient OC concentrations. The general consensus in the atmospheric chemistry community appears to be that monoterpene contributions, which are clearly significant, and the somewhat smaller aromatic contributions, are insufficient to account for observed ambient SOA levels.[814] Part of this gap has been filled recently by SOA predictions for isoprene. Furthermore, the identification in ambient SOA of a tracer compound for the sesquiterpene β-caryophyllene,[815] coupled with the high sesquiterpene SOA yields measured in the laboratory,[816] suggests this class of hydrocarbons should be included in SOA chemical mechanisms. In addition, recent data on SOA formation from aromatic hydrocarbons suggest their contributions, while much smaller than biogenic hydrocarbons, could be larger than previously thought.[817,818]

3.4.1.2.3 Ozone

As mentioned above, the addition of ethanol to fuels has been shown to contribute to PAN formation and this is one way for it to contribute therefore to ground-level ozone formation. PAN is a reservoir and carrier of NO_x and is the product of acetyl radicals reacting with NO_2 in the atmosphere. One source of PAN is the photooxidation of acetaldehyde (Section 3.4.1.2.1), but any hydrocarbon having a methyl group has the potential for forming acetyl radicals and therefore PAN.[198] PAN can undergo thermal decomposition with a lifetime of approximately 1 hour at 298K or 148 days at 250K.[199]

$\mathbf{CH_3C(O)OONO_2} + M \rightarrow CH_3C(O)OO\cdot + \mathbf{NO_2} + M$ $\qquad k = 3.3 \times 10^{-4}\ s^{-1}$ [819]

The reaction above shows how NO_2 is released in the thermal decomposition of PAN. NO_2 can also be formed in photodegradation reactions where NO is converted to NO_2 (see OH radical reaction of acetaldehyde in Section 3.4.1.2.1). In both cases, NO_2 further photolyzes to produce ozone (O_3).

$\mathbf{NO_2} + h\nu \rightarrow NO + O(^3P)$ $\qquad \lambda = 300\text{-}800$ nm [820]

$O(^3P) + O_2 + M \rightarrow \mathbf{O_3} + M$

The temperature sensitivity of PAN allows it to be stable enough at low temperatures to be transported long distances before decomposing to release NO_2. NO_2 can then participate in ozone formation in regions remote from the original NO_x source.[821] A discussion of CB05 mechanisms for ozone formation can be found in Yarwood et al. (2005).[822]

3.4.1.3 Modeling Uncertainties and Limitations

All the results presented below must be interpreted with the understanding that there are considerable uncertainties in inventories, atmospheric processes in CMAQ, and other aspects of the modeling process. While it is beyond the scope of this Regulatory Impact Analysis to include a comprehensive discussion of all limitations and uncertainties associated with air quality modeling, the key ones which could significantly impact analyses for this rule are addressed.

3.4.1.3.1 Emission Inventory Limitations

A key limitation of the analysis is that it employed interim emission inventories, which were enhanced compared to what was described in the proposal, but did not include some of the later enhancements and corrections of the final emission inventories presented in this FRM (Section 3.3). Most significantly, our modeling of the air quality impacts of the renewable fuel volumes required by RFS2 relied upon interim inventories that assumed that ethanol will make up 34 of the 36 billion gallon renewable fuel mandate, that approximately 20 billion gallons of this ethanol will be in the form of E85, and that the use of E85 results in fewer emissions of direct $PM_{2.5}$ from vehicles. The emission impacts and air quality results would be different if, instead of E85, more non-ethanol biofuels are used or mid-level ethanol blends are approved.

In fact, as explained in Chapter 1 of the RIA, our more recent analyses indicate that ethanol and E85 volumes are likely to be significantly lower than what we assumed in the

[198] Many aromatic hydrocarbons, particularly those present in high percentages in gasoline (toluene, m-, o-, p-xylene, and 1,3,5-, 1,2,4-trimethylbenzene), form methylglyoxal and biacetyl, which are also strong generators of acetyl radicals (Smith, D.F., T.E. Kleindienst, C.D. McIver (1999) Primary product distribution from the reaction of OH with m-, p-xylene and 1,2,4- and 1,3,5-Trimethylbenzene. J. Atmos. Chem., 34: 339- 364.).

[199] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

interim inventories. Furthermore, the final emission inventories do not include vehicle-related PM reductions associated with E85 use, as discussed in Section 3.1 and 3.3 above. There are additional, important limitations and uncertainties associated with the interim inventories that must be kept in mind when considering the results:

- Error in $PM_{2.5}$ emissions from locomotive engines

  After the air quality modeling was completed, we discovered an error in the way that $PM_{2.5}$ emissions from locomotive engines were allocated to counties in the inventory. Locomotive emissions between the two reference cases and the control case vary due to differences in activity for this sector due to transported volumes of ethanol. To account for these differences, adjustments were to be applied to a common base inventory developed for a 2022 projection of the 2005 air quality modeling platform (http://www.epa.gov/ttn/chief/emch/index.html). The result should have been inventories which reflected county emissions given the RFS1, AEO 2007 and RFS2 fuel volumes. However, in processing the data, errors were introduced which led to inconsistencies in the common base inventory used to develop the PM inventories for the three modeling cases. These errors were random, resulting in PM emission changes that were too high in some counties and too low in other counties. This error had very little impact on national-level $PM_{2.5}$ emissions. The error in locomotive $PM_{2.5}$ inventory impacts for the RFS2 control case versus the RFS1 mandate reference case was 111 tons, out of a total $PM_{2.5}$ inventory impact of about 18,000 tons. The error in the impact of the RFS2 control case versus the AEO 2007 reference case was 1377 tons, out of a total $PM_{2.5}$ inventory impact of about 16,000 tons. It is important to note that the total nationwide $PM_{2.5}$ inventory is projected to be over 3.3 million tons in 2022. However, an analysis of the error indicated local impacts in both cases were quite large, and in a number of locations, dominated $PM_{2.5}$ impacts. These impacts are summarized in a memorandum to the docket.[200] As a result of the error, we do not present the modeling results for specific localized $PM_{2.5}$ impacts. However, we have concluded that $PM_{2.5}$ modeling results are still informative for national-level benefits assessment, as described in Section 5.4 of the RIA.

- Sensitivity of light-duty vehicle exhaust emissions to ethanol blends

  As discussed above in Sections 3.1 and 3.3, the interim emission inventories used for the air quality modeling analysis are the "more sensitive" case described in the proposal. As a result, the interim inventories used for air quality modeling assume that vehicles operating on E10 have higher NOx emissions and lower VOC, CO and PM exhaust emissions compared to the FRM inventories.

- Cellulosic plant emissions

[200] Memorandum from Rich Cook to Docket ID No. EPA-HQ-OAR-2005-0161, "Impact of an Error in the Locomotive Particulate Matter (PM2.5) Inventory on RFS2 Modeling Results."

The interim emission inventories used in air quality modeling generally assumed higher emissions from cellulosic plants than the FRM inventories, which used revised estimates based on updates to the fraction of biomass burned at these plants. However, as noted in Section 3.1 and 3.3, the shift of some cellulosic volume from ethanol to diesel results in higher PM emissions from cellulosic plants in the final rule inventories than used in the air quality modeling inventories.

- Ethanol volume

  As mentioned above, the interim emission inventories used in our air quality modeling reflect the use of ethanol in about 34 of the mandated 36 billion gallons and do not include any cellulosic diesel. As shown in Table VI.A-1 of the preamble, the FRM inventories assume 22 billion gallons of ethanol in the primary case and 6.5 billion gallons of cellulosic diesel. The inventories used for air quality modeling assume ethanol volumes are more consistent with the FRM's high-ethanol case inventory, which reflects the use of 33 billion gallons of ethanol and no cellulosic diesel.

- Renewable fuel transport emissions

  As discussed in Section 3.3, the estimates of renewable fuel transport volumes and distances differ between the air quality modeling and final rule inventories.

There are also some important uncertainties associated with the emissions inventories, apart from the differences between the interim inventories and the FRM inventories. For example, E85 exhaust and evaporative emissions data are limited, as are data on E10 exhaust and evaporative emissions for nonroad spark ignition engines. There is also considerable uncertainty in how increased use of ethanol will impact other fuel properties which can affect emission inventories and air quality. There are also limited data on activity and emission rates for key upstream sources (especially future technology corn ethanol plants and cellulosic ethanol and diesel plants). There are uncertainties in the surrogates used to allocate emissions spatially and temporally; this is particularly significant in projecting the location of new ethanol plants, especially future cellulosic biofuel plants and the location of these emissions. These plants can have large impacts on local emissions. While most increased production of corn ethanol can reasonably be assumed to occur at existing or planned facilities, there is no way to know with certainty where cellulosic biofuel production will occur. Future cellulosic biofuel plant siting was based on the types of feedstocks that would be most economical, and we assumed refineries would be located in close proximity to feedstocks, as discussed in Section 1.8 of the RIA. While corn ethanol plants were treated as point sources, cellulosic biofuel plants were modeled as county-wide area sources, as described in Section 1.8. Finally, there are numerous assumptions about land use changes that impact inventories for upstream sources and consequently can impact air quality modeling results.

3.4.1.3.2 Uncertainties in Hydrocarbon Speciation Profiles

Another source of uncertainty involves the hydrocarbon speciation profiles, which are used in the air quality modeling emission pre-processor, SMOKE, to break total hydrocarbons down into individual constituent compounds. Given the complexity of the atmospheric chemistry, the hydrocarbon speciation has an important influence on the air quality modeling results. For example, we found that adjusting the speciation profile for gasoline headspace emissions changed the ambient concentration of acetaldehyde. SMOKE uses gasoline headspace profiles for E0 and E10 from EPA's SPECIATE database to speciate emissions from gasoline storage, gasoline distribution, and gas cans. These are key sources of upstream emissions affected by increased use of E10. The EPA profiles initially used in the reference case scenarios for gasoline headspace emissions (i.e., emissions from gas cans and tanker truck distribution – profiles 8736 and 8737 for E10 and E0) in EPA's SPECIATE4.2 database show much greater differences in alkene (olefin) compounds than one would expect between E0 and E10. Alkenes react in the atmosphere to form secondary acetaldehyde, and can also form ozone. E0 has 13% of the VOC (volatile organic compounds) as alkenes while the E10 profile has only 4% alkenes. By contrast, the profiles for exhaust from Tier 2 vehicles (8756 and 8757 for E0 and E10 respectively) show similar levels of alkenes for E0 and E10 (about 20%).[823] The evaporative emissions profiles (profiles 8753 and 8754 in EPA's SPECIATE4.2 database[824]) show lower olefin contents of 3% and 6% respectively.

One expects the headspace from E10 blends to have similar olefin content to that from E0 blends. Available data indicate that ethanol forms an azeotrope with various hydrocarbon compounds such as olefins.[825,826] That azeotrope for olefins would result in the partial vapor pressure of the olefins in the E10 blends being about the same or somewhat higher than in an E0 blends. The difference between the E0 and E10 profile is likely because the limited fuel samples taken for headspace analysis were taken in different locations and time periods.
Recent measurements of speciated gasoline headspace vapors were collected by EPA's Office of Research and Development (ORD) to compare differences between an E0 fuel and a splash-blended E10.[827] The addition of 10% ethanol to the base E0 fuel only slightly decreased the olefin content from 7.6% to 6.3% of total VOC observed in the headspace vapors. While there is some uncertainty in representativeness of the splash-blended fuel, a follow-up analysis of speciated headspace vapors from in-use E10 gasolines showed significant variation in olefin composition from one fuel to another, illustrating the need for speciation profiles collected under controlled conditions.[828]

Because the E0 and E10 headspace profiles initially used in the reference case scenarios have an uncharacteristic difference in relative alkene levels, EPA reran the control case using an adjusted E0 gasoline headspace profile.[201] However, due to time constraints, EPA did not rerun the two reference cases with the adjusted E0 profile, resulting in an inconsistency between the control case and the reference cases. Implications of this inconsistency are discussed in Section 3.4.2. EPA believes that it is important to correct the gasoline headspace profile, although we recognize that using an adjusted profile introduces inconsistencies between the reference and control cases. It should be noted that this is but one example of potential weaknesses in the emission speciation data. Profiles for a number of key sources are based on data with significant limitations.

[201] Use of the adjusted profile in the control case rerun is discussed in the emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161).

3.4.1.3.3 Uncertainties Associated with Chemical Mechanisms

Another key source of uncertainty is the photochemical mechanisms in CMAQ 4.7. Pollutants such as ozone, PM, acetaldehyde, formaldehyde, acrolein, and 1,3-butadiene can be formed secondarily through atmospheric chemical processes. Since secondarily formed pollutants can result from many different reaction pathways, there are uncertainties associated with each pathway. Simplifications of chemistry must be made in order to handle reactions of thousands of chemicals in the atmosphere. Mechanisms for formation of ozone, PM, acetaldehyde and peroxyacetyl nitrate (PAN) are particularly relevant for this rule, and are discussed in Section 3.4.1.2.

For PM, there are a number of uncertainties associated with SOA formation that should be addressed explicitly. As mentioned in Section 3.4.1.2.2, a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in detail. In addition, the amount of ambient SOA that comes from benzene is uncertain. Simplifications to the SOA treatment in CMAQ have also been made in order to preserve computational efficiency. These simplifications are described in release notes for CMAQ 4.7 on the Community Modeling and Analysis System (CMAS) website.[829]

3.4.2 Air Quality Modeling Results

As described above, we performed a series of air quality modeling simulations for the continental U.S in order to assess the impacts of the renewable fuel volumes required by RFS2. The results presented here are based on inventory projections for RFS2 compared against the AEO 2007 and RFS1 mandate reference cases, both of which include some usage of ethanol fuels. These results are important for understanding the potential differences between RFS2 volumes of ethanol and AEO 2007 or RFS1 mandate reference cases; however, these results do not constitute the "anti-backsliding" analysis required by Clean Air Act section 211(v). EPA will be analyzing air quality impacts of increased renewable fuel use through that study and will promulgate appropriate mitigation measures under section 211(v), separate from this final action. Notably, the anti-backsliding exercise will be able to include inventory improvements based on additional results from the EPAct test program which we could not include in this analysis due to time restraints.[830] The following results are based on the interim inventories detailed in Section 3.3 and subject to the uncertainties and limitation detailed in Section 3.4.1.3.

3.4.2.1 Current and Projected Ambient Levels of Pollutants

Although the purpose of this final rule is to implement the renewable fuel requirements established by the Energy Independence and Security Act (EISA) of 2007, the renewable fuel volumes required by this rule would also impact emissions of criteria and air toxic pollutants and their resultant ambient concentrations. The fuels changes detailed in Section 3.1 of the RIA will influence emissions of VOCs, PM, NO_X, SO_X, CO and air toxics. Air quality modeling performed for this final rule illustrates the changes in ambient concentrations of $PM_{2.5}$ and ozone as well as changes in ambient concentrations of ethanol and the following air toxics: acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. These changes are expected to occur with emissions changes from the renewable fuel volumes required by RFS2. The air quality modeling results also include changes in deposition of nitrogen and sulfur which are expected to occur with emissions changes from the renewable fuel volumes required by RFS2.

This section describes current ambient levels of ozone, PM, air toxics, and nitrogen and sulfur deposition and presents the projected ambient levels resulting from the increased use of renewable fuels. Note that the projected results for PM are impacted by the error in the $PM_{2.5}$ locomotive inventory (Section 3.4.1.3) and therefore we do not present the modeling results for specific localized $PM_{2.5}$ impacts.

3.4.2.1.1 Particulate Matter ($PM_{2.5}$ and PM_{10})

As described in Section 3.5, PM causes adverse health effects, and the EPA has set national ambient air quality standards (NAAQS) to protect against those health effects. In this section we present information on current and model-projected future PM levels.

3.4.2.1.1.1 Current Levels of PM

Figures 3.4-2 and 3.4-3 show a snapshot of annual and 24-hour $PM_{2.5}$ concentrations in 2007. There are two U.S. National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$: an annual standard (15 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$). In 2007, the highest annual average $PM_{2.5}$ concentrations were in California, Arizona, Alabama, and Pennsylvania and the highest 24-hour $PM_{2.5}$ concentrations were in California, Idaho, and Utah.

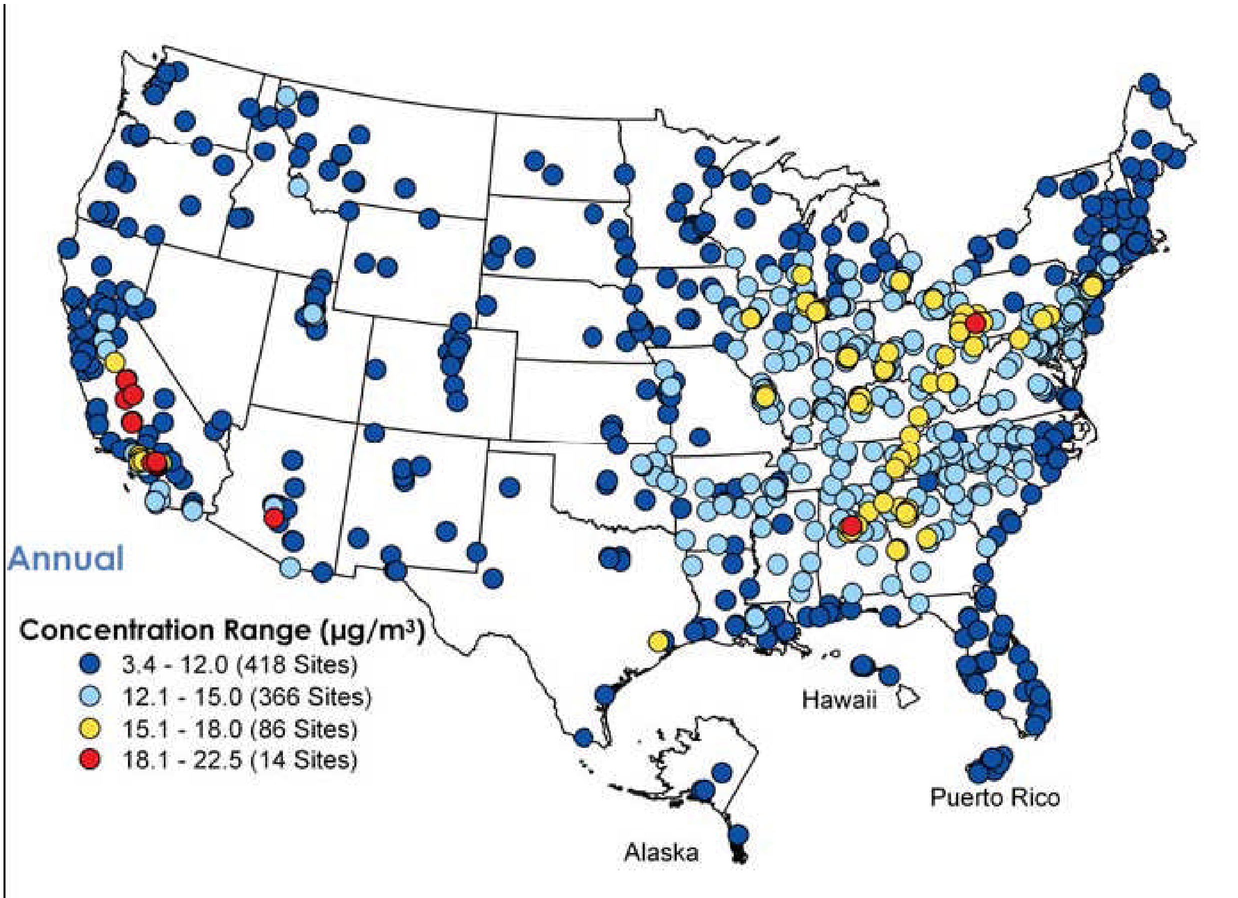

Figure 3.4-2. Annual Average $PM_{2.5}$ Concentrations in $\mu g/m^3$ for 2007 (from 2008 Air Trends Report)

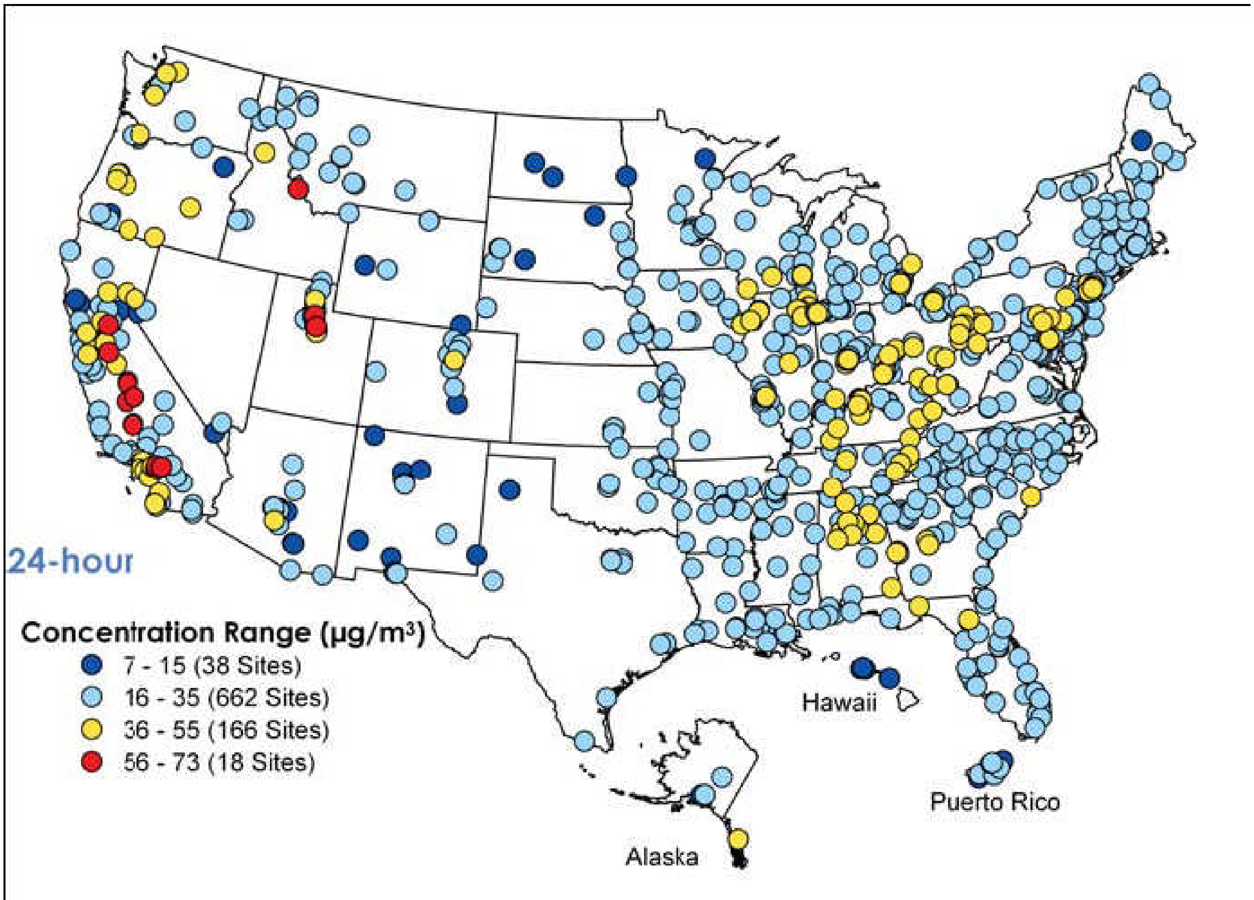

Figure 3.4-3. 24-hour (98th percentile 24- hour concentrations) $PM_{2.5}$ Concentrations in $\mu g/m^3$ for 2007 (from 2008 Air Trends Report)

The most recent revisions to the PM standards were in 1997 and 2006. In 2005, the U.S. EPA designated nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 19844, April 14, 2005).[202] As of January 6, 2010, approximately 88 million people live in the 39 areas that are designated as nonattainment for the 1997 $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS). These $PM_{2.5}$ nonattainment areas are comprised of 208 full or partial counties. Nonattainment areas for the 1997 $PM_{2.5}$ NAAQS are pictured in Figure 3.4-4. On October 8, 2009, the EPA issued final nonattainment area designations for the 2006 24-hour $PM_{2.5}$ NAAQS (74 FR 58688, November 13, 2009). These designations include 31 areas composed of 120 full or partial counties with a population of over 70 million. Nonattainment areas for the 2006 $PM_{2.5}$ NAAQS are pictured in Figure 3.4-5. In total, there are 54 $PM_{2.5}$ nonattainment areas composed of 245 counties with a population of 101 million people.

[202] A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard.

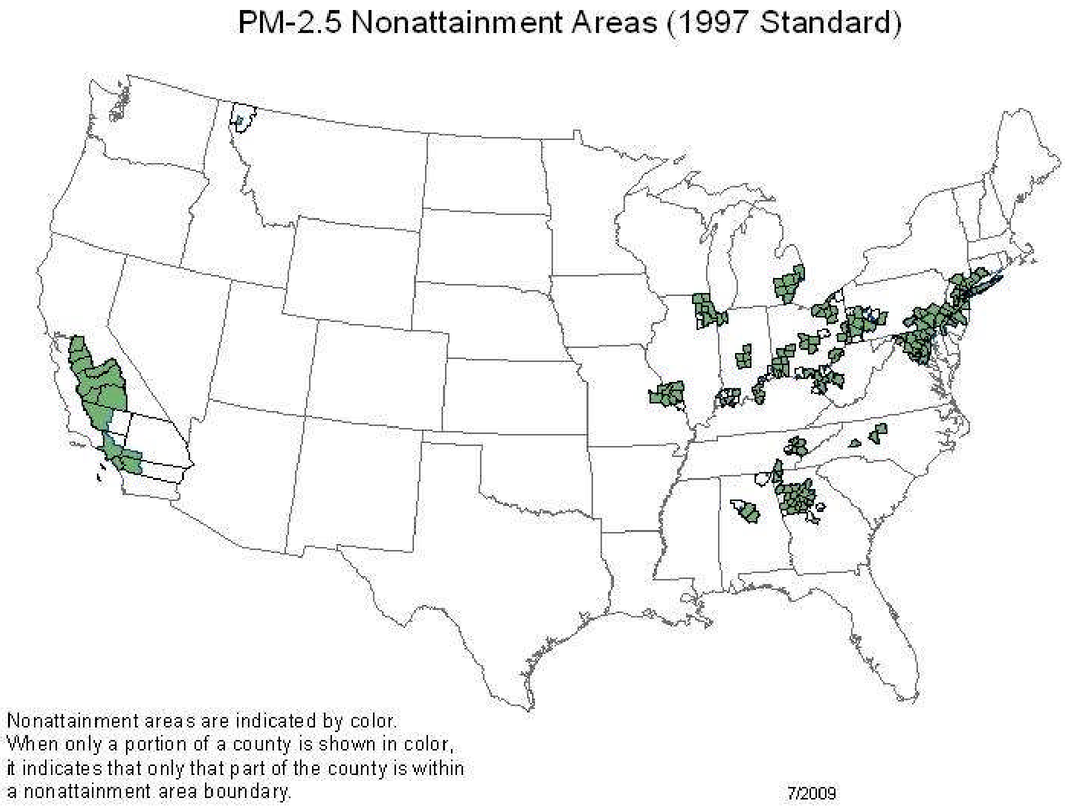

Figure 3.4-4. 1997 $PM_{2.5}$ Nonattainment Areas

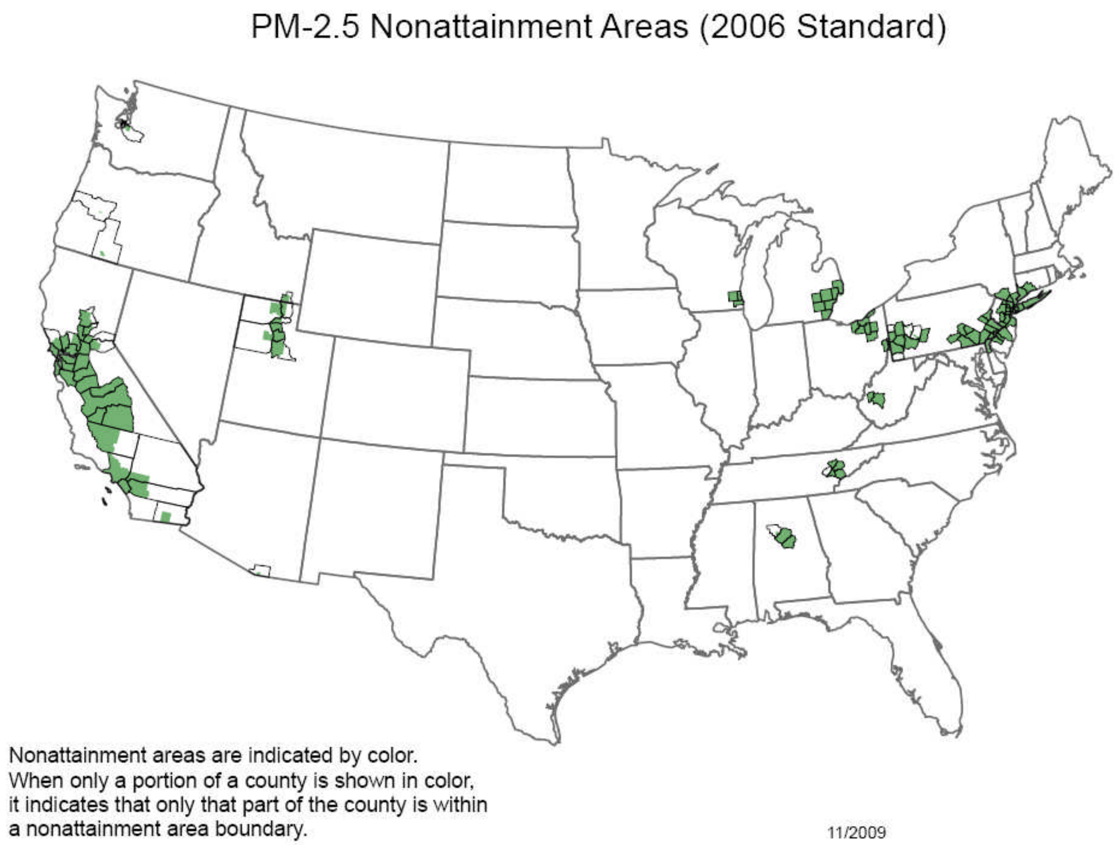

Figure 3.4-5. 2006 $PM_{2.5}$ Nonattainment Areas

As of January 6, 2010, approximately 26 million people live in the 47 areas that are designated as nonattainment for the PM_{10} NAAQS. There are 40 full or partial counties that make up the PM_{10} nonattainment areas. Nonattainment areas for the PM_{10} NAAQS are pictured in Figure 3.4-6.

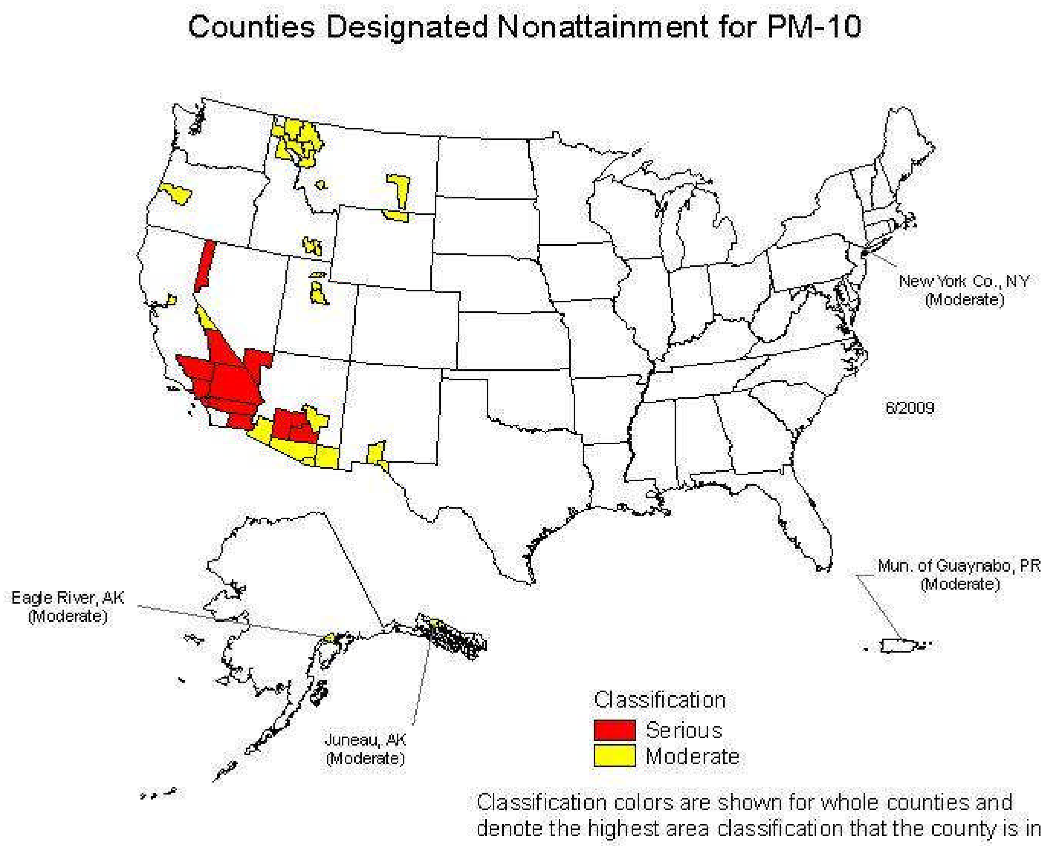

Figure 3.4-6. PM_{10} Nonattainment Areas

3.4.2.1.1.2 Projected Levels of $PM_{2.5}$

Generally, our modeling indicates that the required renewable fuel volumes will reduce $PM_{2.5}$ concentrations in some areas of the country and increase $PM_{2.5}$ concentrations in other areas. In the following sections we describe projected $PM_{2.5}$ levels in the future, with and without the required renewable fuel volumes. Information on the air quality modeling methodology is contained in Section 3.4.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD) in the docket for this rule.

3.4.2.1.1.2.1 Projected $PM_{2.5}$ Levels without RFS2 Volumes

EPA has already adopted many mobile source emission control programs that are expected to reduce ambient PM levels. These control programs include the New Marine

Compression-Ignition Engines at or Above 30 Liters per Cylinder rule,[203] the Marine Spark-Ignition and Small Spark-Ignition Engine rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Compression-Ignition Engine Rule (73 FR 25098, May 6, 2008), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, Feb. 10, 2000). As a result of these programs, the number of areas that fail to meet the $PM_{2.5}$ NAAQS in the future is expected to decrease. However, even with the implementation of all current state and federal regulations, there are projected to be U.S. counties violating the $PM_{2.5}$ NAAQS well into the future.

Recent air quality modeling for the "Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder" rule projects that in 2020, at least 10 counties with a population of almost 25 million may not attain the 1997 annual $PM_{2.5}$ standard of 15 $\mu g/m^3$ and 47 counties with a population of over 53 million may not attain the 2006 24-hour $PM_{2.5}$ standard of 35 $\mu g/m^3$.[204] Since the emission changes from the volumes of renewable fuel required by RFS2 will go into effect during the period when some areas are still working to attain the $PM_{2.5}$ NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the $PM_{2.5}$ standard.

3.4.2.1.1.2.2 Projected $PM_{2.5}$ Levels with RFS2 Volumes

This section includes a summary of the results of our modeling of $PM_{2.5}$ air quality impacts in the future due to the required renewable fuel volumes. We compare the RFS1 mandate reference case and AEO 2007 reference case scenarios to the RFS2 control scenario. When discussing the projected changes in $PM_{2.5}$ it is important to remember that there are uncertainties and limitations related to the air quality modeling (see Section 3.4.1.3), in large part due to uncertainties in projecting the future types of renewable fuels, the location of their production, and their method of use. Section 3.3 discusses the differences in the air quality modeling inventories and the final rule inventories in more detail.

Changes in ambient $PM_{2.5}$ concentrations due to required renewable fuel volumes are a result of changes to upstream and downstream emission sources, complex chemical reactions (direct emissions and secondary formation), transport and meteorology. As is detailed in Section 3.2, the required renewable fuel volumes impact upstream and tailpipe emissions of primary $PM_{2.5}$ and $PM_{2.5}$ precursors such as NOx and VOCs. Primary PM is emitted directly into the atmosphere and, on a mass basis, is largely carbonaceous in nature. Various studies have shown that mobile sources are a major source of primary PM in urban areas over many portions of the United States.[831,832,833,834,835,836,837] Primary PM that is carbonaceous is also referred to as primary organic aerosol (POA). Secondary PM is formed in the atmosphere from chemical

[203] This rule was signed on December 18, 2009 but has not yet been published in the Federal Register. The signed version of the rule is available at http://epa.gov/otaq/oceanvessels.htm).
[204] US EPA (2009). Final Rule "Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder". This rule was signed on December 18, 2009 but has not yet been published in the Federal Register. The signed version of the rule is available at http://epa.gov/otaq/oceanvessels.htm).

transformations of gases. The forms of secondary PM most impacted by the renewable fuel volumes are nitrates and organics or secondary organic aerosol (SOA).

Due to the error in the PM inventory for locomotives we only present design value changes averaged over all 577 modeled counties, and do not present local impacts. The modeled counties are located across the country and have monitors that allow the calculation of a $PM_{2.5}$ design value. A large majority of the modeled counties will see relatively minor annual average $PM_{2.5}$ design value changes of between -0.05 $\mu g/m^3$ and +0.05 $\mu g/m^3$. On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design values are projected to decrease by 0.002 $\mu g/m^3$ when compared with the RFS1 mandate or AEO reference case.[205] We also looked at changes in daily $PM_{2.5}$ design values. A majority of the modeled counties will see daily $PM_{2.5}$ design value changes of between -0.25 $\mu g/m^3$ and +0.25 $\mu g/m^3$. On a population-weighted basis, the average modeled future-year daily $PM_{2.5}$ design value is projected to decrease by 0.06 $\mu g/m^3$ when compared with the RFS1 mandate reference case or 0.05 $\mu g/m^3$ when compared with the AEO reference case.

The changes in ambient $PM_{2.5}$ described above are likely due to both increased emissions at biofuel production plants and from biofuel transport, and reductions in SOA formation and reduced emissions from gasoline refineries. In addition, decreases in ambient PM are predicted because our modeling inventory assumed large volumes of E85 use and also that E85 usage reduces PM tailpipe emissions. As mentioned previously, these direct PM emission reductions would not occur with final rule inventory assumptions.

3.4.2.1.2 Ozone

As described in Section 3.5, ozone causes adverse health effects, and the EPA has set national ambient air quality standards (NAAQS) to protect against those health effects. In this section, we present information on current and model-projected future ozone levels.

3.4.2.1.2.1 Current Levels of Ozone

Figure 3.4-7 shows a snapshot of ozone concentrations in 2007. The highest ozone concentrations were located in California, Connecticut, Georgia, Massachusetts, North Carolina, and Pennsylvania. Fifty-seven percent of the sites were above 0.075 ppm, the level of the 2008 standard.

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[205] Note that the change in annual average $PM_{2.5}$ for design values differs from the change in national population-weighted annual average $PM_{2.5}$ discussed in Sections I and VIII of the preamble and Chapter 5 of the RIA. National population-weighted annual average $PM_{2.5}$ with respect to health impacts is based on modeling data across all populated grid cells rather than just those counties with monitors. We find that there is a small increase in national population-weighted annual average $PM_{2.5}$ across all populated grid cells in the air quality modeling domain.

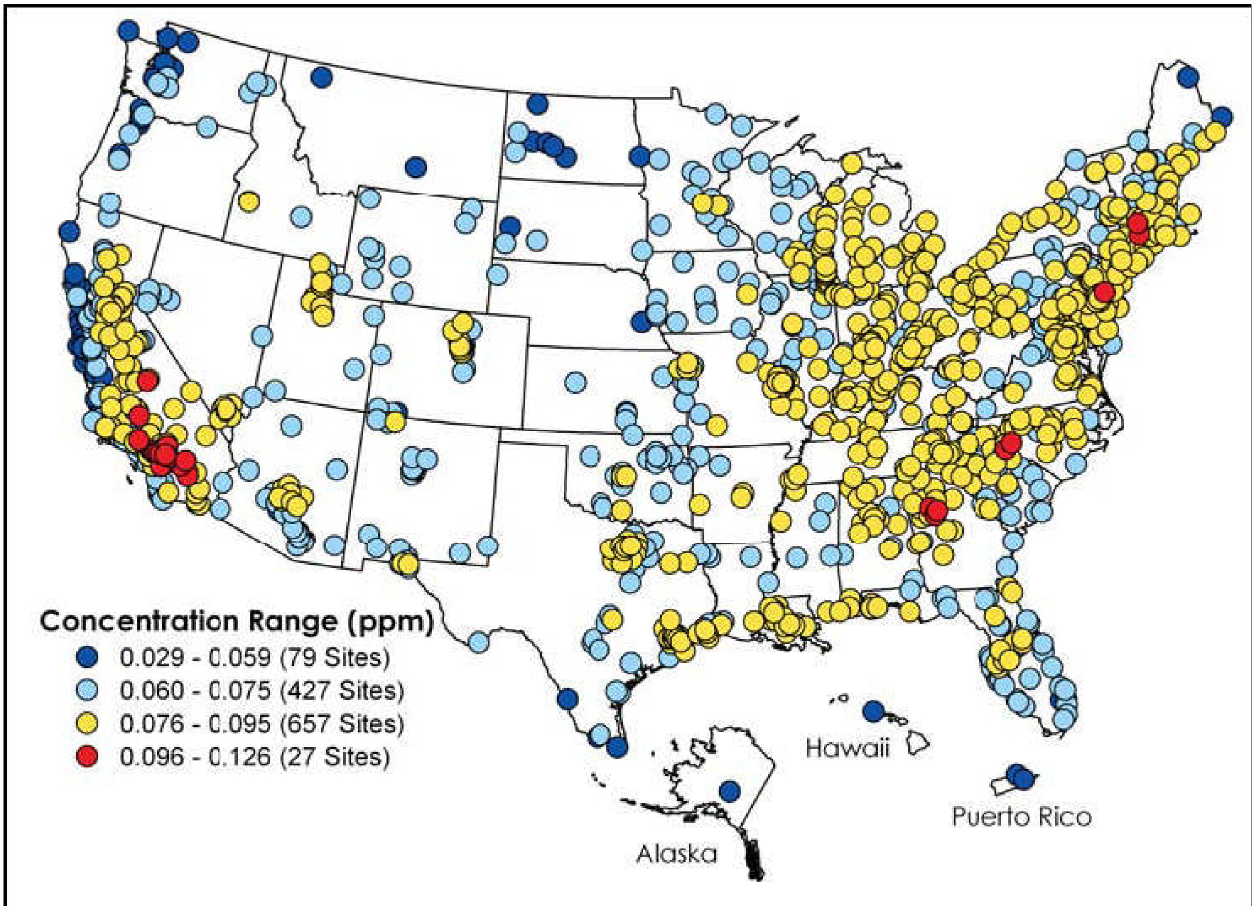


Figure 3.4-7. Ozone Concentrations (fourth highest daily maximum 8-hour concentration) in ppm for 2007 (from 2008 Air Trends Report)

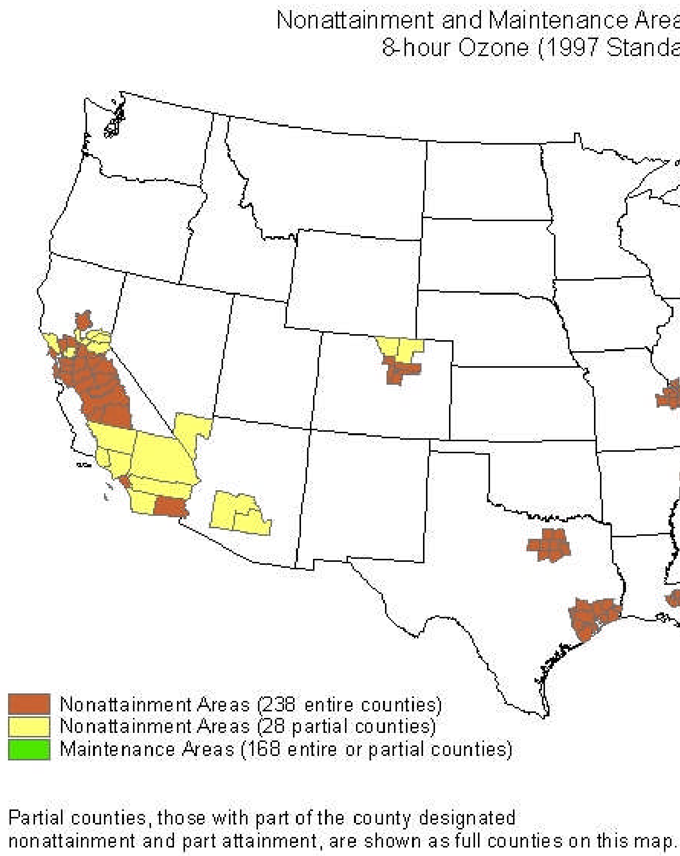


Figure 3.4-8. 1997 Ozone Nonattainment Areas

The primary and secondary national ambient air quality standards (NAAQS) for ozone are 8-hour standards set at 0.075 ppm. The most recent revision to these standards was in 2008; the previous 8-hour ozone standards, set in 1997, had been set at 0.08 ppm. In 2004, the U.S. EPA designated nonattainment areas for the 1997 8-hour ozone NAAQS (69 FR 23858, April 30, 2004). As of January 6, 2010, there are 51 8-hour ozone nonattainment areas for the 1997 ozone NAAQS composed of 266 full or partial counties with a total population of over 122 million. Figure 3.4-8 presents the 1997 NAAQS ozone nonattainment areas. On January 6, 2010, EPA proposed to reconsider the 2008 ozone NAAQS to ensure they are sufficiently protective of public health and the environment. EPA intends to complete the reconsideration by August 31, 2010. If, as a result of the reconsideration, EPA determines that the 2008 ozone standards are not supported by the scientific record and promulgates different ozone standards, the new 2010 ozone standards would replace the 2008 ozone standards and the requirement to designate areas for the replaced 2008 standards would no longer apply. Because of the significant uncertainty the reconsideration proposal creates regarding the continued applicability of the 2008 ozone NAAQS, EPA has extended the deadline for designating areas for the 2008 NAAQS by 1 year. If EPA promulgates new ozone standards in 2010, EPA intends to accelerate the designations process for the primary standard so that the designations would be effective in August 2011.

Table 3.4-1 provides an estimate, based on 2005-07 air quality data, of the counties with design values greater than the 2008 ozone NAAQS.

Table 3.4-1.
Counties with Design Values Greater Than the 2008 Ozone NAAQS Based on 2005-2007 Air Quality Data

	NUMBER OF COUNTIES	POPULATION[a]
1997 Ozone Standard: counties within the 51 areas currently designated as nonattainment (as of 1/6/10)	266	122,343, 799
2008 Ozone Standard: additional counties that would not meet the 2008 NAAQS[b]	227	41,285,262
Total	493	163,629,061

Notes:
[a] Population numbers are from 2000 census data.
[b] Area designations for the 2008 ozone NAAQS have not yet been made. Nonattainment for the 2008 Ozone NAAQS would be based on three years of air quality data from later years. Also, the county numbers in the table include only the counties with monitors violating the 2008 Ozone NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

3.4.2.1.2.2 Projected Levels of Ozone

Achieving the required renewable fuel volumes by 2022 is projected to adversely impact ozone air quality over much of the U.S. However, ozone air quality improvements are projected in a few highly-populated areas which currently have poor air quality. In the following sections we describe projected ozone levels in the future resulting from the increased use of renewable fuels. Information on the air quality modeling methodology is contained in Section 3.4.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD) in the docket for this rule.

3.4.2.1.2.2.1 Projected Ozone Levels without RFS2 Volumes

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder rule,[206] the Marine Spark-Ignition and Small Spark-Ignition Engine rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), the Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001). As a result of these programs, 8-hour ozone levels are expected to improve in the future.

[206] This rule was signed on December 18, 2009 but has not yet been published in the Federal Register. The signed version of the rule is available at http://epa.gov/otaq/oceanvessels.htm).

The baseline air quality modeling projects that in 2022, with all current controls in effect but excluding the emissions changes expected to occur as a result of the required renewable fuel volumes, at least 7 counties, with a projected population of over 22 million people, may not attain the 1997 8-hour ozone standard of 0.08 ppm [and] at least 25 counties, with a projected population of nearly 41 million people, may not attain the 2008 8-hour ozone standard of 75 ppb. This modeling supports the conclusion that there are a number of counties across the U.S. projected to experience ozone concentrations at or above the ozone NAAQS into the future. Since the emission changes from the required renewable fuel volumes go into effect during the period when some areas are still working to attain the ozone NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the ozone standard. In the following section we discuss projected nonattainment areas and how they compare to the areas which are projected to experience either ozone reductions or ozone increases from the required renewable fuel volumes.

3.4.2.1.2.2.2 Projected Ozone Levels with RFS2 Volumes

This section summarizes the results of our modeling of ozone air quality impacts in the future due to required renewable fuel volumes. Specifically, we compare the RFS1 mandate and AEO 2007 reference case scenarios to the RFS2 control scenario.[207] Our modeling indicates that the required renewable fuel volumes will increase ozone design value concentrations in many areas of the country and decrease ozone design value concentrations in a small number of areas. Figures 3.4-9 and 3.4-10 present the changes in 8-hour ozone design value concentration in 2022 when the RFS2 control scenario is compared to the RFS1 mandate reference case and the AEO 2007 reference case respectively.

[207] We used a different speciation profile for E10 gasoline headspace emissions in the EISA control case than was used for the RFS1 and AEO 2007 reference cases. This inconsistency is described in Section 3.4.1.3.

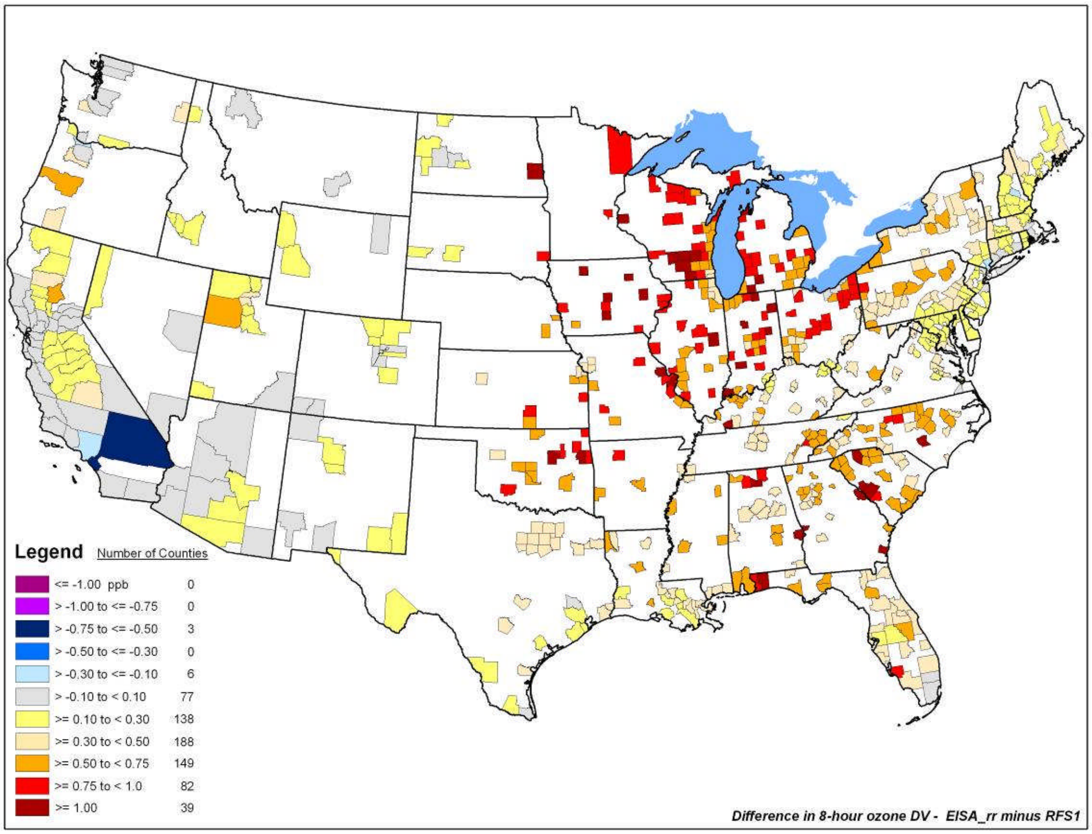


Figure 3.4-9. Projected Change in 2022 8-hour Ozone Design Values Between the RFS2 Control Scenario and RFS1 Mandate Reference Case Scenario

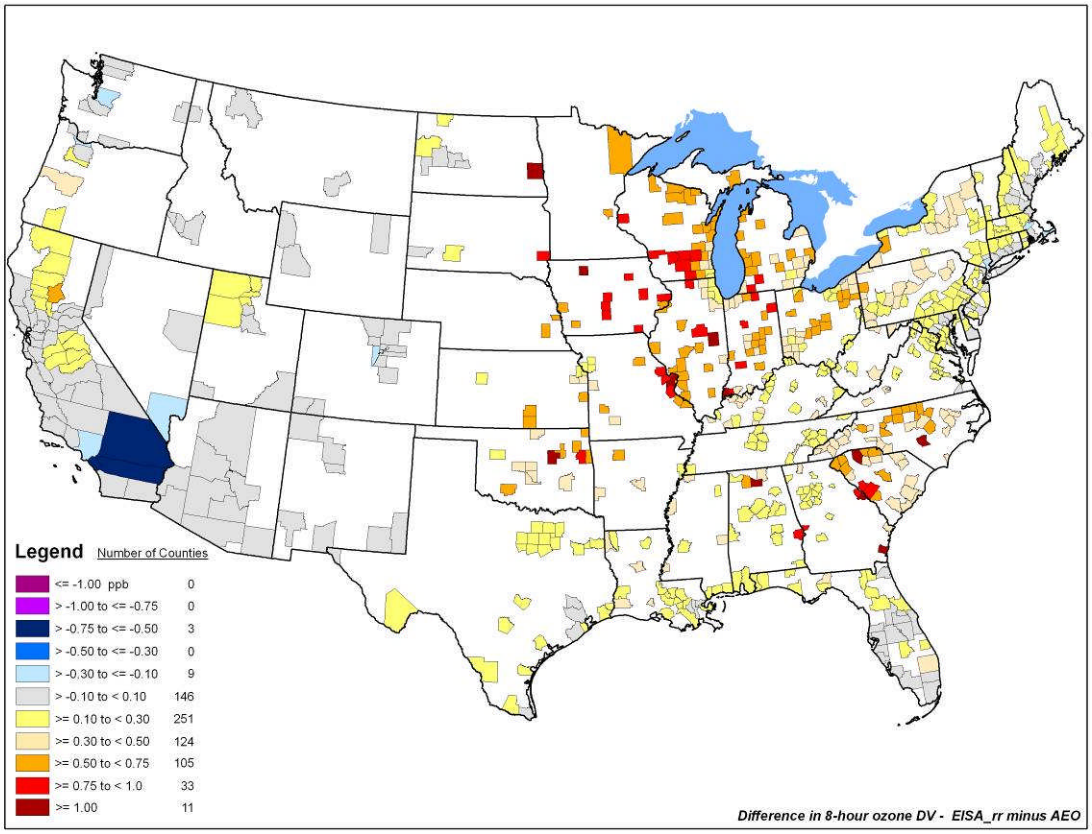


Figure 3.4-10. Projected Change in 2022 8-hour Ozone Design Values Between the RFS2 Control Scenario and AEO 2007 Reference Case Scenario

As can be seen in Figure 3.4-9 and 3.4-10 most counties with modeled data, especially those in the Midwest, see increases in their ozone design values. The majority of these design value increases are less than 0.5 ppb. However, there are some counties that will see 8-hour ozone design value increases above 0.5 ppb; these counties are mainly in the eastern U.S. The maximum projected increase in an 8-hour ozone design value is in Morgan County, Alabama, 1.56 ppb and 1.27 ppb when compared with the RFS1 mandate and AEO 2007 reference cases respectively. There are also some counties that are projected to see 8-hour ozone design value decreases. The counties with ozone design value decreases greater than 0.5 ppb are in Southern California. The maximum decrease projected in an 8-hour ozone design value is in Riverside, CA, 0.66 ppb and 0.60 ppb when compared with the RFS1 mandate and AEO 2007 reference cases respectively.

There are 26 counties, mainly in California, that are projected to have 8-hour ozone design values above the 2008 NAAQS in 2022 with the required renewable fuel volumes in place. Table 3.4-2 below presents the changes in design values for these counties when comparing the RFS2 control scenario with the RFS1 mandate and AEO 2007 reference case scenarios.

Table 3.4-2.
Change in Ozone Design Values (ppb) for Counties Projected to be Above the 2008 Ozone NAAQS in 2022

	RFS2 control - RFS1 mandate	RFS2 control – AEO 2007
San Bernardino County, California	-0.58	-0.53
Riverside County, California	-0.66	-0.60
Los Angeles County, California	-0.16	-0.16
Kern County, California	0.02	-0.02
Tulare County, California	0.34	0.07
Harris County, Texas	0.12	0.05
Fresno County, California	0.11	0.08
Brazoria County, Texas	0.18	0.09
Suffolk County, New York	-0.09	-0.05
East Baton Rouge County, Louisiana	0.39	0.27
Sacramento County, California	0.04	0.04
Orange County, California	-0.57	-0.52
Calaveras County, California	0.15	0.14
Nevada County, California	0.07	0.06
El Dorado County, California	0.05	0.04
Harford County, Maryland	0.23	0.03
Ventura County, California	-0.01	-0.03
Fairfield County, Connecticut	-0.08	-0.08
Placer County, California	0.05	0.04
San Diego County, California	0.25	0.19
Merced County, California	-0.10	-0.09
Westchester County, New York	0.35	0.23
Kenosha County, Wisconsin	-0.11	-0.11
Philadelphia County, Pennsylvania	0.19	0.12
New Haven County, Connecticut	0.92	0.68

Table 3.4-3 shows the average change in 2022 8-hour ozone design values for: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the 2008 ozone standard, (3) counties with 2005 baseline design values that did not exceed the 2008 standard, but were within 10% of it, (4) counties with 2022 design values that exceeded the 2008 ozone standard, and (5) counties with 2022 design values that did not exceed the standard, but were within 10% of it. Counties within 10% of the standard are intended to reflect counties that meet the standard, but will likely benefit from help in maintaining that status in the face of growth. Many of these statistics show an increase in ozone design values in 2022, more often when compared with the RFS1 case, but the magnitude of the increase varies and there are some statistics which show a decrease in 8-hour ozone design values. On a population-weighted basis, the average modeled future-year 8-hour ozone design values are projected to increase by 0.28 ppb in 2022 when compared with the RFS1 mandate reference case and increase by 0.16 ppb when compared with the AEO 2007 reference case. On a population-weighted basis

those counties that are projected to be above the 2008 ozone standard in 2022 will see decreases of 0.14 when compared with the RFS1 mandate reference and 0.15 ppb when compared with the AEO 2007 reference case scenario.

Table 3.4-3.
Average Change in Projected Future Year 8-hour Ozone Design Value as a Result of the Required Renewable Fuel Volumes

AVERAGE[a]	NUMBER OF US COUNTIES	2020 POPULATION[b]	CHANGE IN 2022 DESIGN VALUE (PPB) RFS2-RFS1	CHANGE IN 2022 DESIGN VALUE (PPB) RFS2-AEO 2007
All	678	238,378,342	0.46	0.30
All, population-weighted	678	238,378,342	0.28	0.16
Counties whose 2005 base year is violating the 2008 8-hour ozone standard	389	174,967,297	0.44	0.28
Counties whose 2005 base year is violating the 2008 8-hour ozone standard, population-weighted	389	174,967,297	0.26	0.14
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard	208	43,172,228	0.52	0.36
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted	215	45,008,435	0.35	0.22
Counties whose 2022 RFS2 control case is violating the 2008 8-hour ozone standard	26	41,017,324	0.04	0.00
Counties whose 2022 RFS2 control case is violating the 2008 8-hour ozone standard, population-weighted	26	41,017,324	-0.14	-0.15
Counties whose 2022 RFS2 control case is within 10% of the 2008 8-hour ozone standard	110	61,618,519	0.34	0.22
Counties whose 2022 RFS2 control case is within 10% of the 2008 8-hour ozone standard, population-weighted	110	61,618,519	0.31	0.19

Notes:
[a] Averages are over counties with 2005 modeled design values
b Population numbers based on 2000 census data

Ground-level ozone pollution is formed by the reaction of VOCs and NOx in the atmosphere in the presence of heat and sunlight. The science of ozone formation, transport, and accumulation is complex.[838] The projected ozone increases in some areas and decreases in other areas which are seen in the air quality modeling for this final rule are likely a result of the emissions changes due to the increased volumes of renewable fuels combined with the photochemistry involved, the different background concentrations of VOCs and NOx in different areas of the country, and the different meteorological conditions in different areas of the country. When VOC levels are relatively high, relatively small amounts of NOx enable ozone to form rapidly. Under these conditions VOC reductions have little effect on ozone and while NOx reductions are highly effective in reducing ozone, NOx increases lead to increases in ozone. Such conditions are called "NOx-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NOx-limited. Rural areas are usually NOx-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. The ozone increases seen in the southeastern U.S. and many of the other rural areas are likely due to the fact that those areas are NOx-limited and this final rule is projected to increase NOx and decrease VOCs. A recent review article looking at ethanol in gasoline indicates that increasing usage of E10 fuels, when compared with E0 fuels, can increase NOx emissions and thereby increase ozone concentrations (see Section 3.4.3.3).[839]

When NOx levels are relatively high and VOC levels relatively low, NOx forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NOx reductions can actually increase local ozone under certain circumstances. In the air quality modeling done for this final rule, the ozone decreases seen in southern California and some of the other urban areas, like Cleveland and Miami, are likely due to the fact that those areas are VOC-limited areas and they are projected to see decreases in VOCs and increases in NOx due to this final rule.

As mentioned in Section 3.3, the inventories used for the air quality modeling differ from those being presented in this final rule, and as mentioned in Section 3.4.1.3, there are uncertainties and limitations related to the air quality modeling. When looking at the changes in projected ozone the most important uncertainty has to do with the fact that the modeled inventory assumes increases in NOx for vehicles using E10 fuel. These NOx increases contribute to the ozone increases in NOx-limited areas and the ozone decreases in VOC-limited areas.

3.4.2.1.3 Air Toxics

3.4.2.1.3.1 Current Levels of Air Toxics

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[840] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in U.S. EPA's recent Mobile Source Air Toxics Rule.[841] In order to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern, U. S. EPA conducts the National-Scale Air Toxics Assessment (NATA). The most recent NATA was conducted for calendar year 2002, and was released in June 2009.[842] NATA for 2002 includes four steps:

1) Compiling a national emissions inventory of air toxics emissions from outdoor sources

2) Estimating ambient concentrations of air toxics across the United States

3) Estimating population exposures across the United States

4) Characterizing potential public health risk due to inhalation of air toxics including both cancer and noncancer effects

Figures 3-4.11 and 3-4.12 depict estimated county-level carcinogenic risk and noncancer respiratory hazard from the assessment. The respiratory hazard is dominated by a single pollutant, acrolein.

According to NATA for 2002, mobile sources were responsible for 47 percent of outdoor toxic emissions, over 50 percent of the cancer risk, and over 80 percent of the noncancer hazard.[843,208] Benzene is the largest contributor to cancer risk of all 124 pollutants quantitatively assessed in the 2002 NATA, and mobile sources were responsible for 59 percent of benzene emissions in 2002. Over the years, EPA has implemented a number of mobile source and fuel controls which have resulted in VOC reductions, which also reduced benzene and other air toxic emissions.

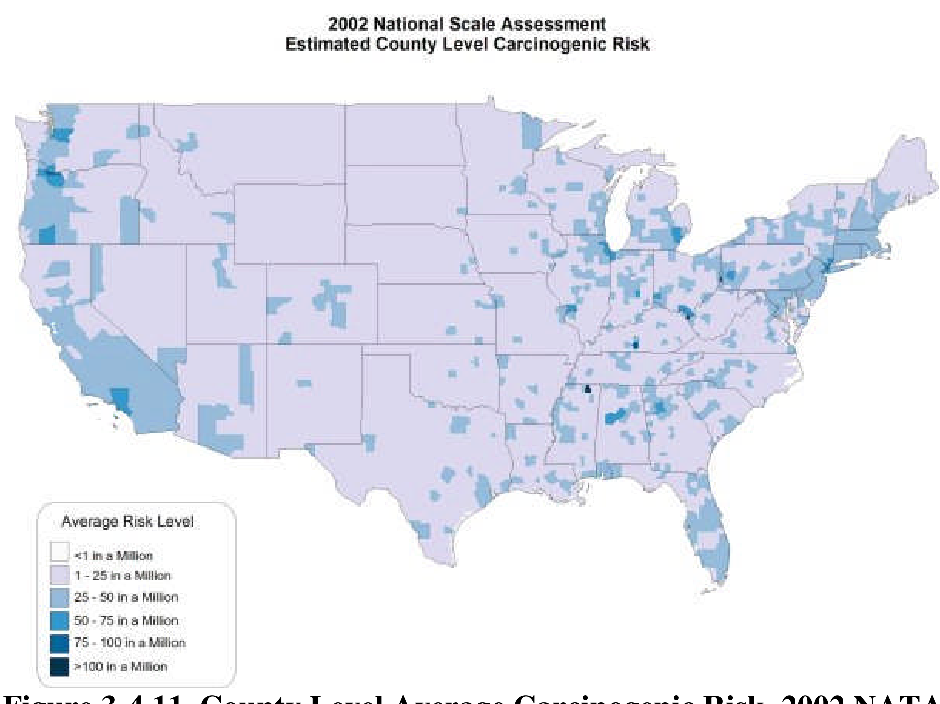


Figure 3-4.11. County Level Average Carcinogenic Risk, 2002 NATA.

[208] NATA relies on a Guassian plume model, Assessment System for Population Exposure Nationwide (ASPEN), to estimate toxic air pollutant concentrations. Projected air toxics concentrations presented in this rule were modeled with CMAQ 4.7, which has only recently been updated to include air toxics.

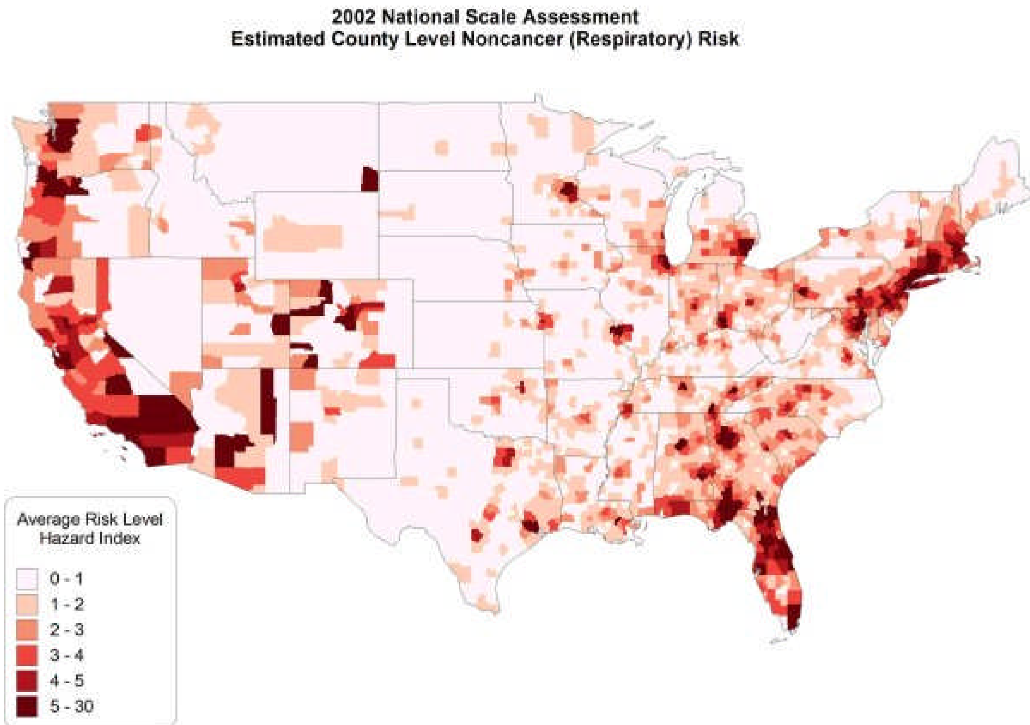


Figure 3-4.12. County Level Average Noncancer Hazard Index, 2002 NATA.

3.4.2.1.3.2 Projected Levels of Air Toxics

In the following sections, we describe results of our modeling of air toxics levels in the future with the renewable fuel volumes required by this action. Although a large number of compounds which are considered air toxics could be impacted by increases in renewable fuel volumes, we focused on those which were identified as national and regional-scale cancer and noncancer risk drivers in the 2002 NATA[844] and were also likely to be significantly impacted by the renewable fuel volumes required by RFS2. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Ethanol impacts were also included in our analyses because of health concerns (Section 3.4.5) and its role as an acetaldehyde precursor. Information on the air quality modeling methodology is contained in Section 3.4.1.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD) in the docket for this rule.

It should be noted that EPA has adopted many mobile source emission control programs that are expected to reduce ambient air toxics levels. These control programs include the Heavy-duty Onboard Diagnostic Rule (74 FR 8310, February 24, 2009), Small SI and Marine SI Engine Rule (73 FR 59034, October 8, 2008), Locomotive and Commercial Marine Rule (73 FR 25098, May 6, 2008), Mobile Source Air Toxics Rule (72 FR 8428, February 26, 2007), Clean Air Nonroad Diesel Rule (69 FR 38957, June 29, 2004), Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, Feb. 10, 2000). As a result of these programs, the ambient concentration of air toxics in the future is expected to decrease. The reference case and control case scenarios include these controls.

This section summarizes the results of our modeling of ambient air toxics impacts in the future from the renewable fuel volumes required by RFS2. Specifically, we compare the RFS1 mandate and AEO 2007 reference scenarios to the RFS2 control scenario for 2022 (see Section 3.3 for more information on the scenarios).[209] Our modeling indicates that, while there are some localized impacts, the renewable fuel volumes required by RFS2 have relatively little impact on national average ambient concentrations of the modeled air toxics. An exception is increased ambient concentrations of ethanol. Because overall impacts are small, we concluded that assessing exposure to ambient concentrations and conducting a quantitative risk assessment of air toxic impacts was not warranted. However, we did develop population metrics, including the population living in areas with increases or decreases in concentrations of various magnitudes. We also estimated aggregated populations above and below reference concentrations for noncancer effects.

Our discussion of the air quality modeling for air toxics primarily focuses on impacts of the renewable fuel volumes required by RFS2 in reference to the RFS1 mandate for 2022; this comparison has a greater difference in projected ethanol volumes between the reference and the control case than a comparison using the AEO 2007 reference case. Except where specifically discussed below, air quality modeling results of the RFS2 control case in comparison with the AEO 2007 reference case are presented in Appendix 3.A of this RIA.

Acetaldehyde

Our air quality modeling does not show substantial overall nationwide impacts on ambient concentrations of acetaldehyde as a result of the renewable fuel volumes required by this rule. Annual percent changes in ambient concentrations of acetaldehyde are less than 1% for most of the country (Figure 3.4-13). Several urban areas show decreases in ambient acetaldehyde concentrations ranging from 1 to 10%, and some rural areas associated with new ethanol plants show increases in ambient acetaldehyde concentrations ranging from 1 to 10% with RFS2. Annual absolute changes in ambient concentrations of acetaldehyde are generally less than 0.1 $\mu g/m^3$ (Figure 3.4-14). However, as discussed below, there are considerable limitations and uncertainties in our assessment of impacts of the renewable fuel volumes required by this rule on ambient concentrations of acetaldehyde.

[209] We used a different speciation profile for E10 gasoline headspace emissions in the RFS2 control case than was used for the RFS1 and AEO reference cases. This inconsistency is described in Section 3.4.1.3.

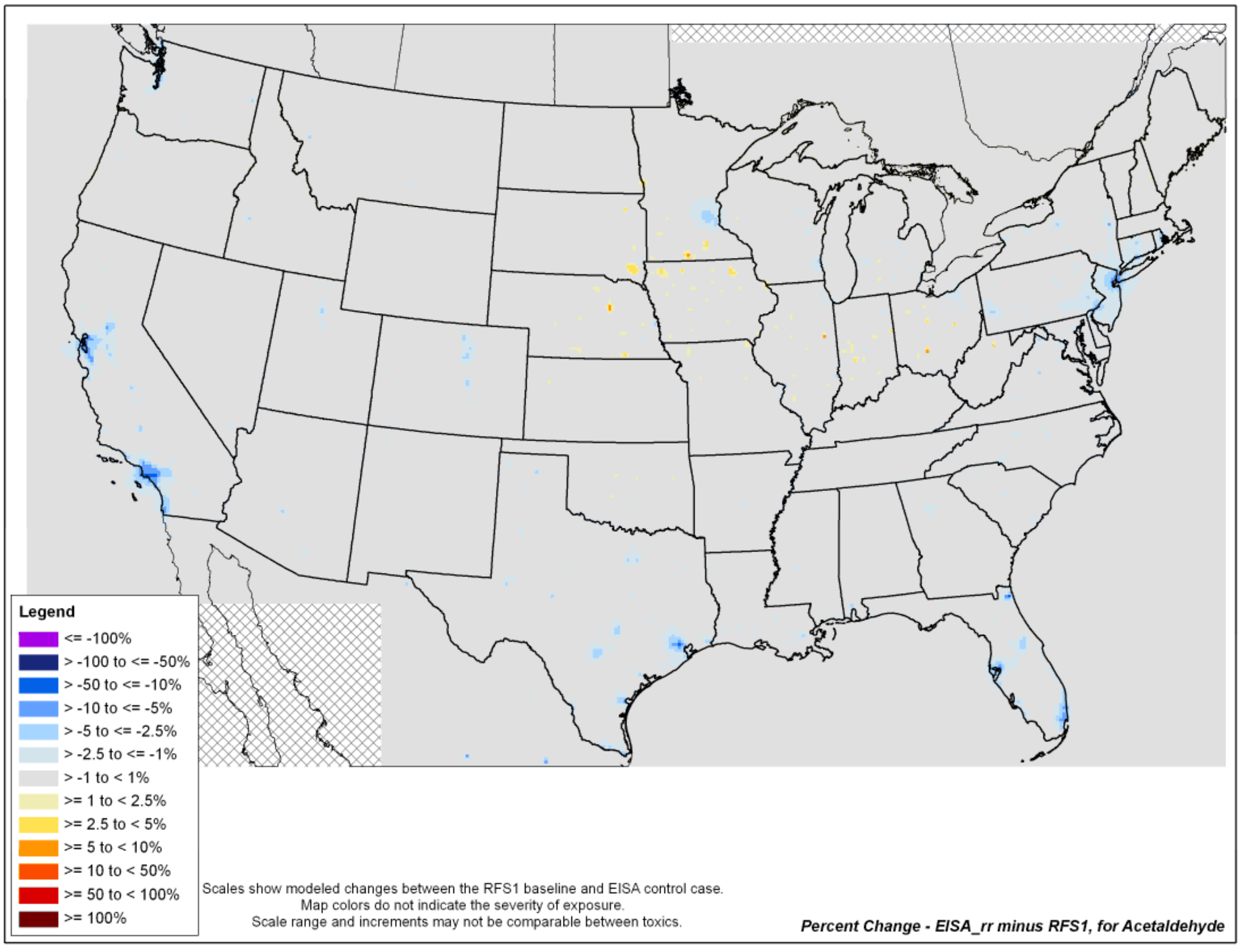


Figure 3.4-13. Acetaldehyde Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

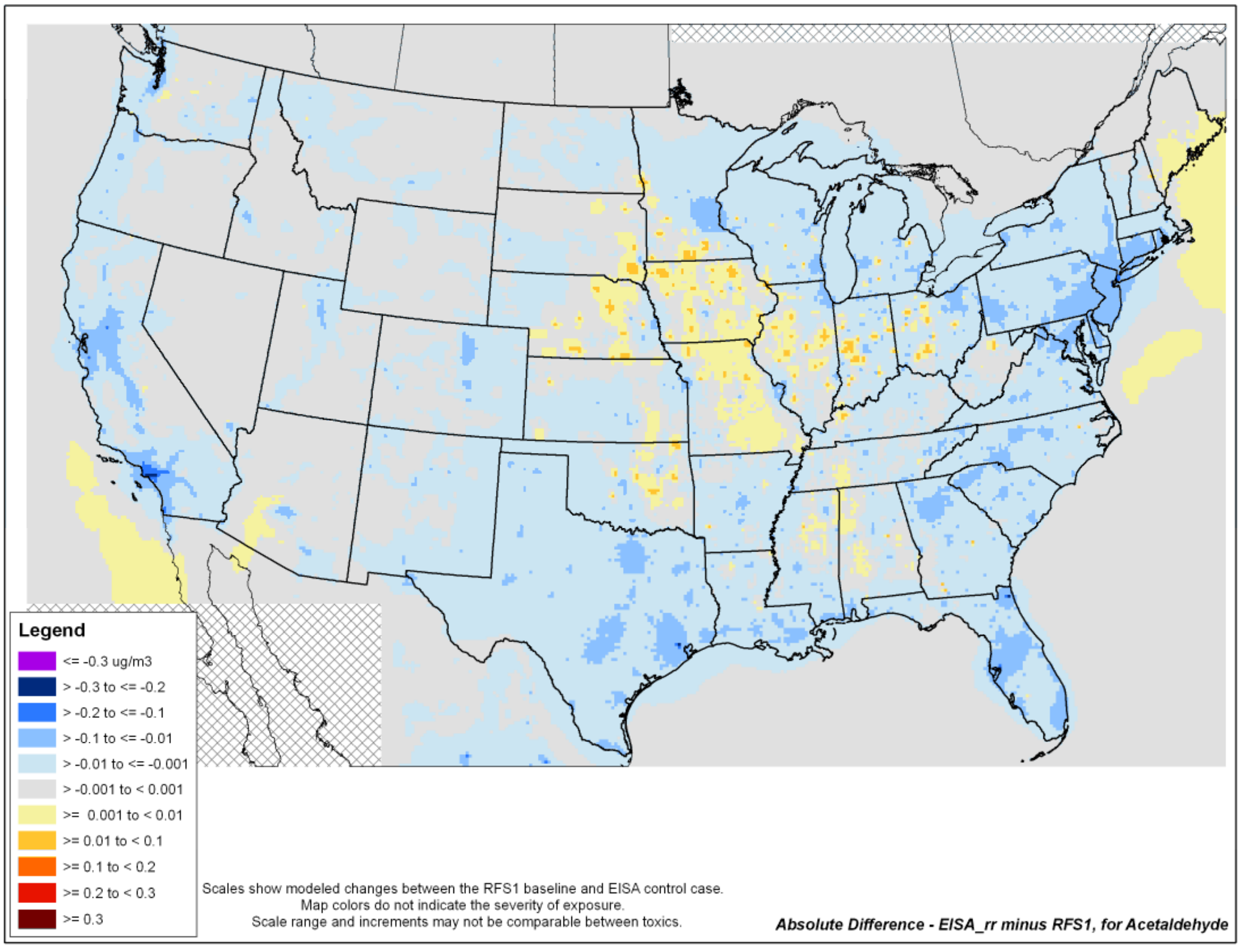


Figure 3.4-14. Acetaldehyde Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 ($\mu g/m^3$)

As noted above, the results show that the largest increases in ambient acetaldehyde concentrations with RFS2 volumes occur in areas associated with new ethanol plants. This result is due to an increase in emissions of primary acetaldehyde and precursor emissions from ethanol plants not included in the RFS1 baseline scenario. Locations for projected corn ethanol plants emissions were based on existing or planned plants, whereas cellulosic ethanol plants were projected based on available feedstocks. Details on how this was done are described in Section 1.8 of the RIA.[845] As discussed in Section 3.4.1.3, the location of these localized increases is limited by uncertainties in the placement of the new plants.

Significant increases in ambient acetaldehyde might be expected based on the significant increases in primary acetaldehyde and ethanol emissions (18% and 16% for the primary case relative to RFS1, nationally, as described in Section 3.2). However, the chemical formation of acetaldehyde is complex; most ambient acetaldehyde is formed from secondary photochemical reactions of numerous precursor compounds, and many photochemical mechanisms are responsible for this process (see Section 3.4.1.2 and 3.4.1.3). As discussed in more detail in Section 3.4.3.1, some previous U.S. monitoring studies have suggested an insignificant or small impact of increased use of ethanol in fuel on ambient acetaldehyde.[846,847,848] These studies suggest that increases in direct emissions of acetaldehyde are offset by decreases in the secondary formation of acetaldehyde. Other past studies have shown increases in ambient acetaldehyde with increased use of ethanol in fuel, although factors such as differences in vehicle fleet, lack of RVP control, exclusion of upstream impacts, and differences in the levels of other compounds in the ambient air may limit the ability of these studies to inform expected impacts on ambient air quality (Section 3.4.3.1). Given the conflicting results among past studies and the limitations of our analysis as discussed in the following paragraphs, considerable additional work is needed to address the impacts of the renewable fuel volumes required by this rule on ambient concentrations of acetaldehyde.

The comparison of the RFS1 mandate reference case with the RFS2 control case for summer and winter shows decreases in ambient acetaldehyde concentrations in urban areas (Figures 3.4-13 and 3.4-14). Decreases are less pronounced in winter when there is less secondary formation of acetaldehyde (Figures 3.4-15 and 3.4-16). A key reason for the decrease in urban areas is reductions in certain acetaldehyde precursors, primarily alkenes (olefins). These reductions are due to differences in the E0 gasoline headspace speciation profiles used for the control case and the reference cases, as discussed in Section 3.4.1.3. Headspace profiles are used to speciate hydrocarbon emissions from gasoline storage, gasoline distribution, and gas cans. The differences between cases arose when EPA noticed that the headspace profiles used in the reference case scenarios exhibited a reduction in alkene levels going from E0 to E10 that was not consistent with what one would expect as a result of increased ethanol use. In these cases, the E0 gasoline headspace profile has 13% of the VOC as alkenes and the E10 profile has an alkene content of 4%.

To address this issue, EPA adjusted the E0 headspace profile based on the assumption that the emissions have an alkene content of 4%, consistent with the percent alkene content of the E10 headspace profile because a 13% alkene content is much higher than typically seen in fuel surveys and one expects the headspace from E0 and E10 to be similar.[849] However, due to time constraints, we were not able to make this improvement for the reference cases. Thus, alkene levels associated with E0 use are lower in the control case than the reference cases, leading to a reduction in secondarily formed acetaldehyde.

To determine the potential impact of this inconsistency, EPA conducted a sensitivity analysis of the RFS1 mandate reference case for the Eastern U.S. modeling domain.[210] This sensitivity analysis was conducted for a single month, July, and compared results with the control case for the following two cases:

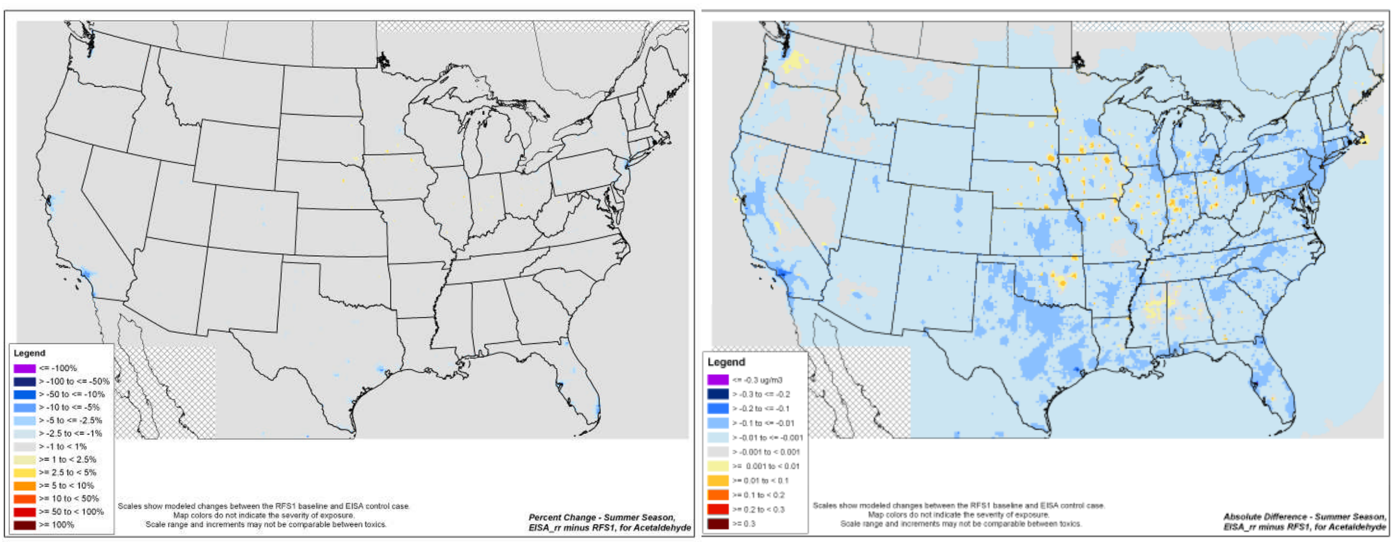
1) RFS1 case with no change in alkene levels between headspace profiles for E0 and E10 (i.e., adjusted E0 profile)

2) RFS1 case with higher alkene levels for E0 headspace profile

[210] Details of the sensitivity run are discussed in the AQ modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161).

The results of the sensitivity analysis showed that acetaldehyde levels were significantly higher for the comparison between Case 1 and the control case than for the comparison between Case 2 and the control case. The sensitivity analysis thus confirmed that the decrease in these acetaldehyde precursors between the reference cases and the control case E0 headspace profile is driving the decrease in ambient concentrations of acetaldehyde in urban areas. Thus, while the air quality modeling results presented in this RIA suggest impacts of increased renewable fuel use on ambient acetaldehyde are not substantial and there may be decreases in urban areas, there is considerable uncertainty associated with these results. In fact, if the reference cases were rerun with revised E0 headspace profiles, some of the observed decreases could become increases. Additional research is underway to address these uncertainties, e.g., measurement of representative fuels to create better headspace speciation profiles (Section 3.4.1.3) and improvements in other speciation profiles based on additional results from the EPAct emissions test program.[211]

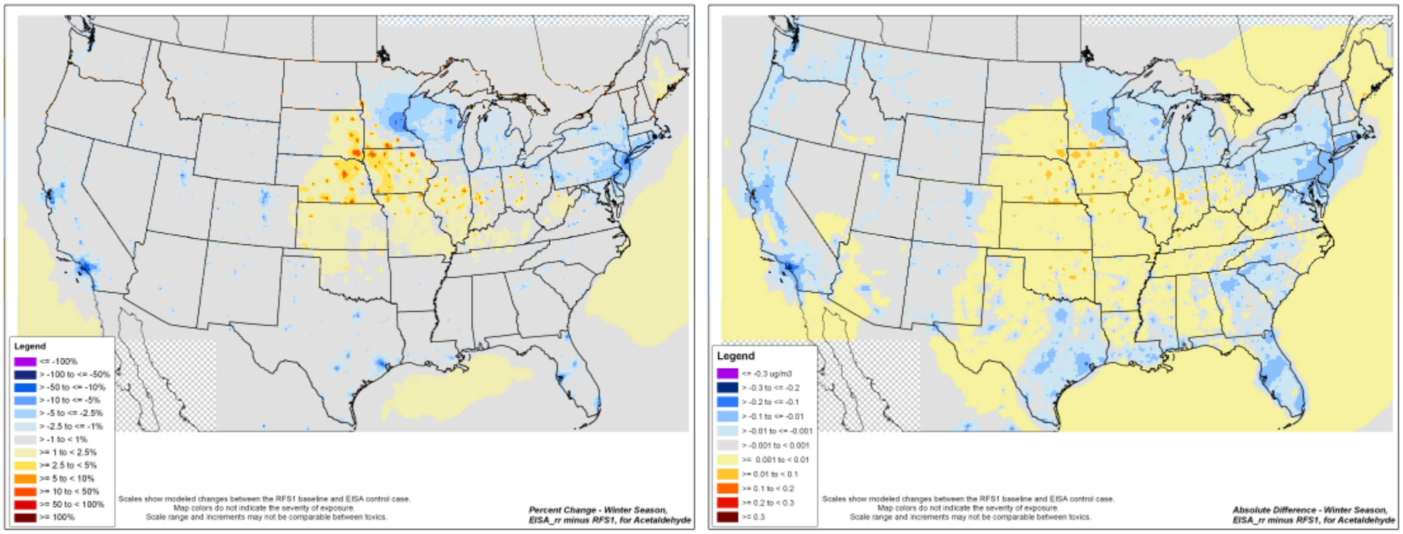
It should also be noted (see Section 3.3 above) that we modeled the "more sensitive" emission inventory case similar to that presented in the NPRM which assumed that use of E10 would lead to increases in NO_x emissions for later model year vehicles. Increases in NOx may result in more acetyl peroxy radical forming PAN rather than acetaldehyde. Recent EPA testing results, which have been included in the FRM scenarios, do not show these increases in NO_x for later model year vehicles.[850] Our air quality modeling results may therefore underestimate the impacts of the renewable fuel volumes required by RFS2 on ambient concentrations of acetaldehyde.



a **b**

211 EPAct Phase I, II, and III Testing: Comprehensive Gasoline Light-Duty Exhaust Fuel Effects Test Program to Cover Multiple Fuel Properties. EPA Contract: EPC-07-028EPA. Southwest Research Institute, San Antonio, TX. Phase III of the EPAct emission test program is scheduled for completion in 2010.

Figure 3.4-15. Summer Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a **b**

Figure 3.4-16. Winter Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)

Formaldehyde

Our air quality modeling results do not show substantial impacts on ambient concentrations of formaldehyde from the renewable fuel volumes required by this rule. As shown in Figure 3.4-17, most of the U.S. experiences a 1% or less change in ambient formaldehyde concentrations. Decreases in ambient formaldehyde concentrations range between 1 and 5% in a few urban areas. Increases range between 1 and 2.5% in some rural areas associated with new ethanol plants; this result is due to increases in emissions of primary formaldehyde and formaldehyde precursors from the new ethanol plants. As discussed above, uncertainties in the placement of new ethanol plants limit the model's projected location of associated emission increases (Section 3.4.1.3). Figure 3.4-18 shows that absolute changes in ambient concentrations of formaldehyde are generally less than 0.1 μg/m³.

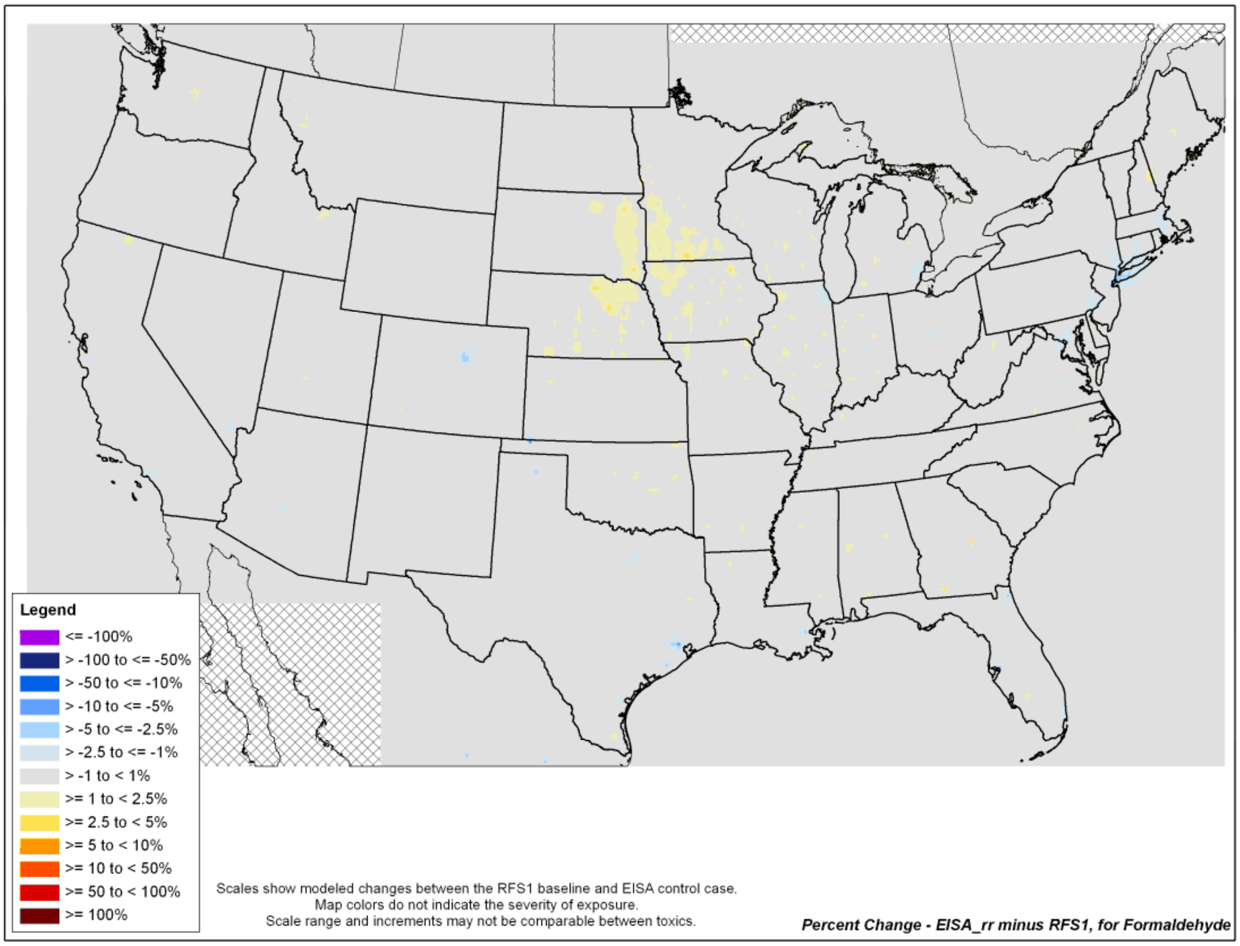


Figure 3.4-17. Formaldehyde Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

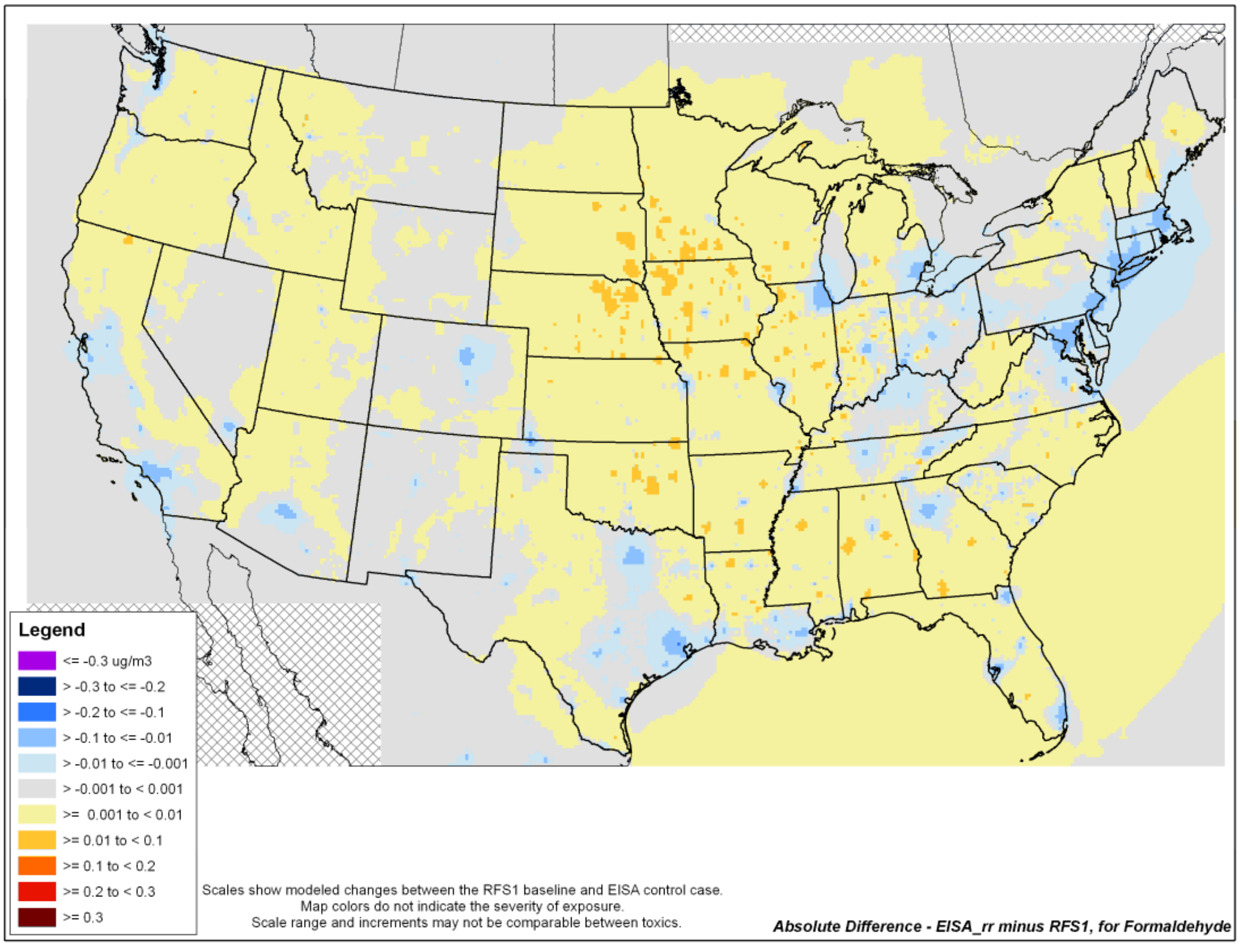


Figure 3.4-18. Formaldehyde Annual Percent Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 ($\mu g/m^3$)

Ethanol

Our modeling projects that the renewable fuel volumes required by this rule will lead to significant nationwide increases in ambient ethanol concentrations. Increases ranging between 10 to 50% are seen across most of the country (Figure 3.4-19). The largest increases (more than 100%) occur in urban areas with high amounts of onroad emissions and in rural areas associated with new ethanol plants. Absolute increases in ambient ethanol concentrations are above 1.0 ppb in some urban areas (Figure 3.4-20). The location of these localized increases is limited by uncertainties in the placement of the new plants, as discussed in Section 3.4.1.3.

It should be noted here that these increases are overestimated because the speciated profile combination used for modeling nonroad emissions was misapplied. While sensitivity analyses suggest that the impact of this error was negligible for other pollutants, it resulted in overestimates of ethanol impacts by more than 10% across much of the modeling domain. For a detailed discussion, please refer to the emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2005-0161).

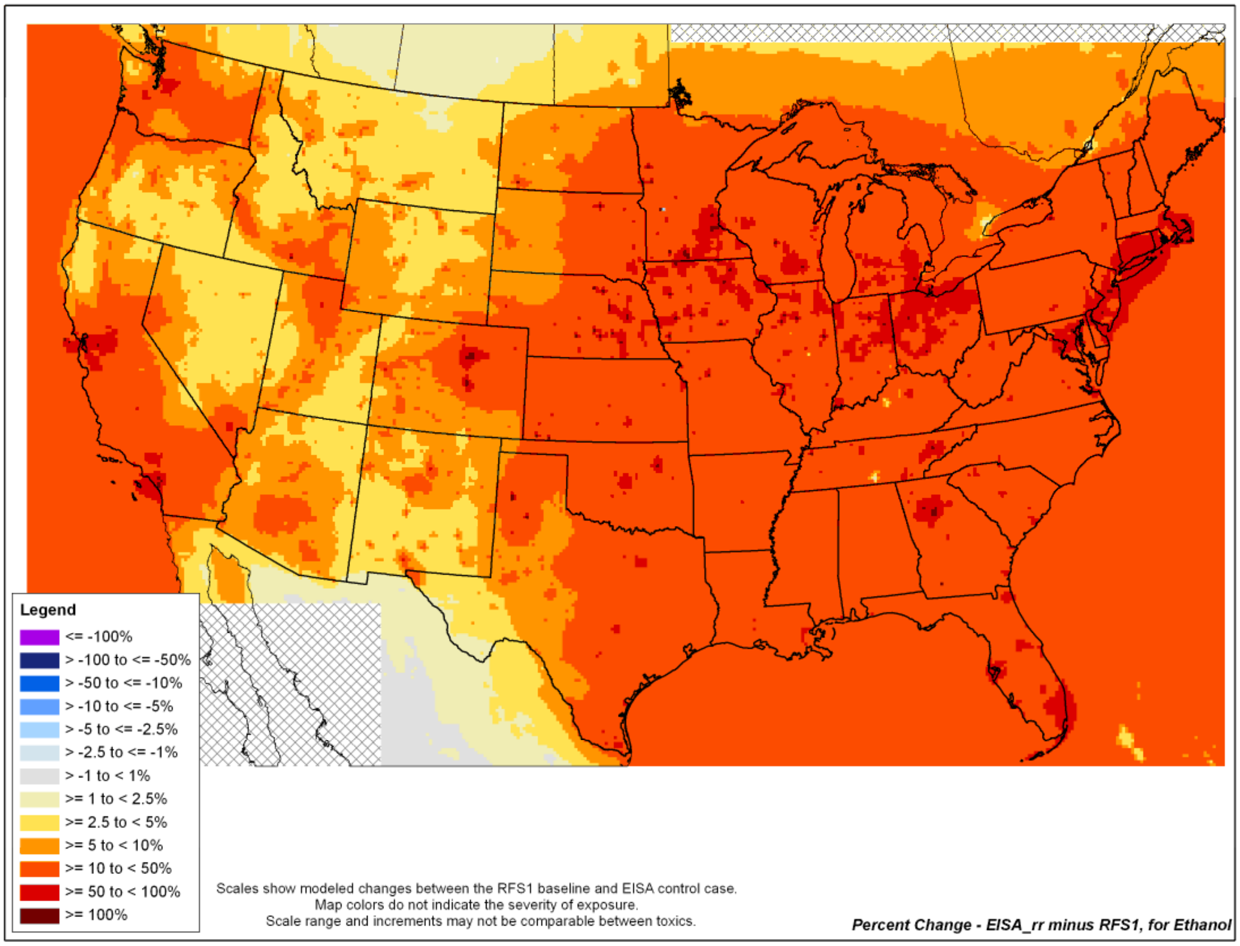


Figure 3.4-19. Ethanol Annual Percent Changes Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

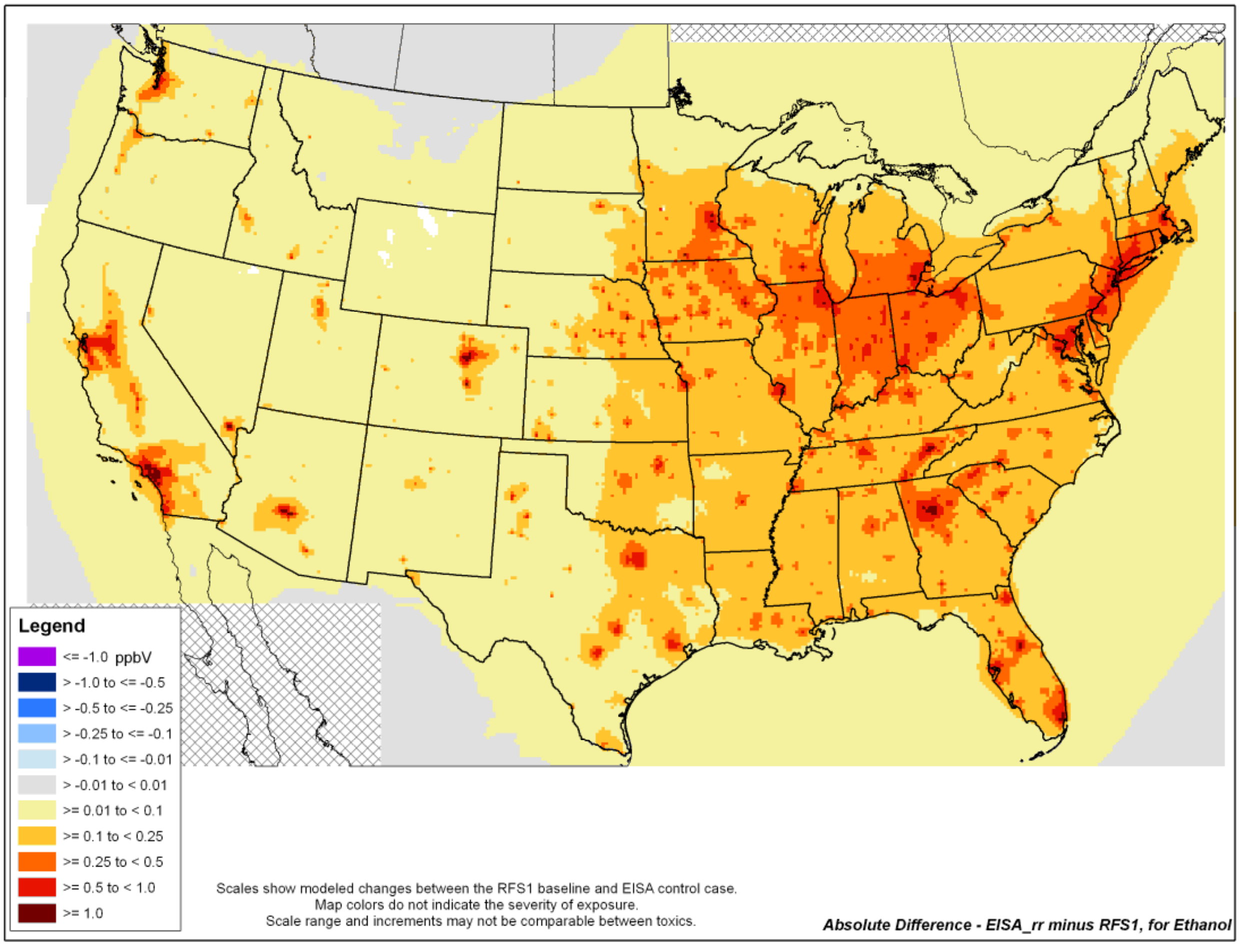


Figure 3.4-20. Ethanol Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (ppb)

Benzene

Our modeling projects that the renewable fuel volumes required by this rule will lead to small nationwide decreases in ambient benzene concentrations. As shown in Figure 3.4-21, decreases in ambient benzene concentrations range between 1 and 10% across most of the country and can be higher in a few urban areas. Absolute changes in ambient concentrations of benzene show reductions up to 0.2 $\mu g/m^3$ (Figure 3.4-22).

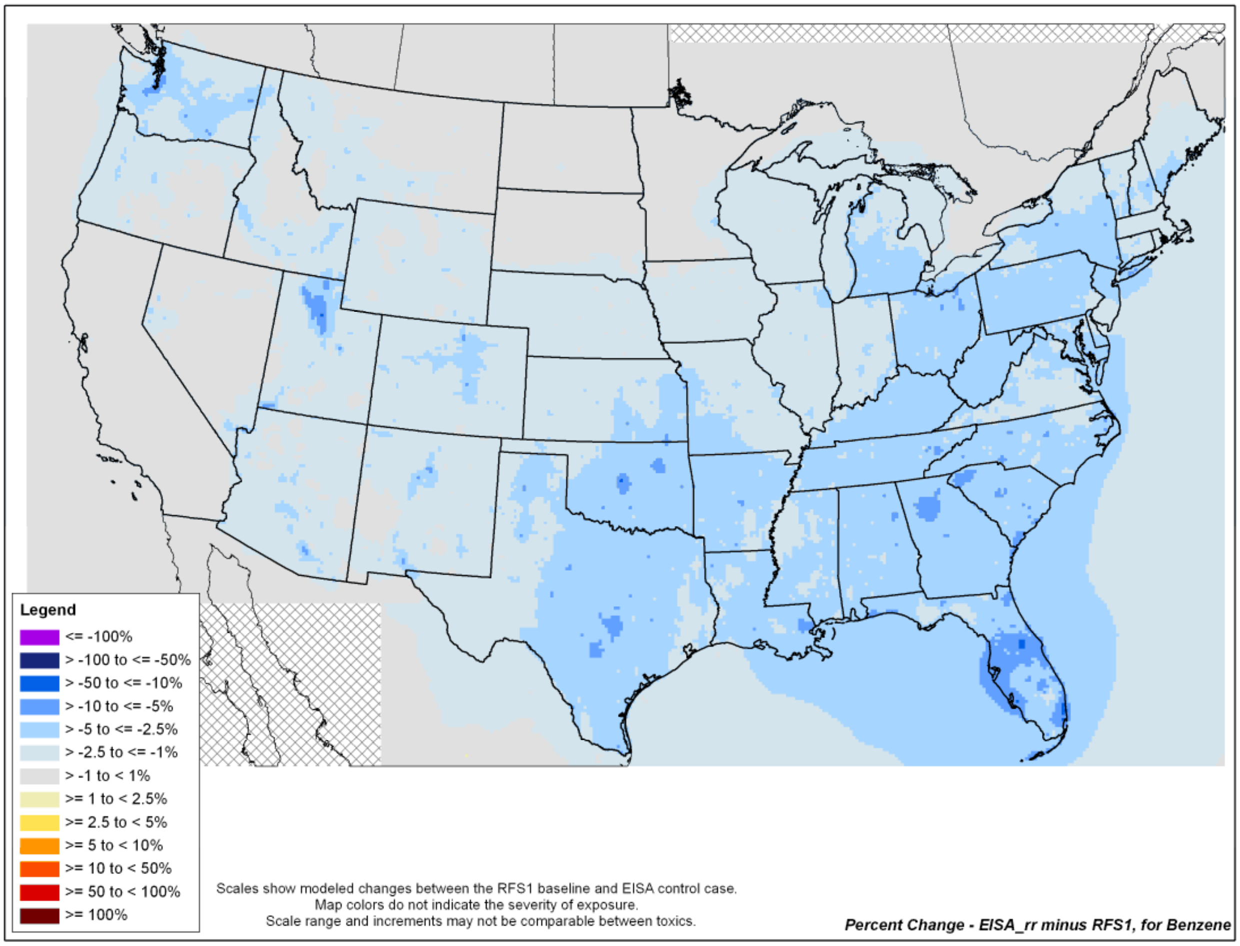


Figure 3.4-21. Benzene Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

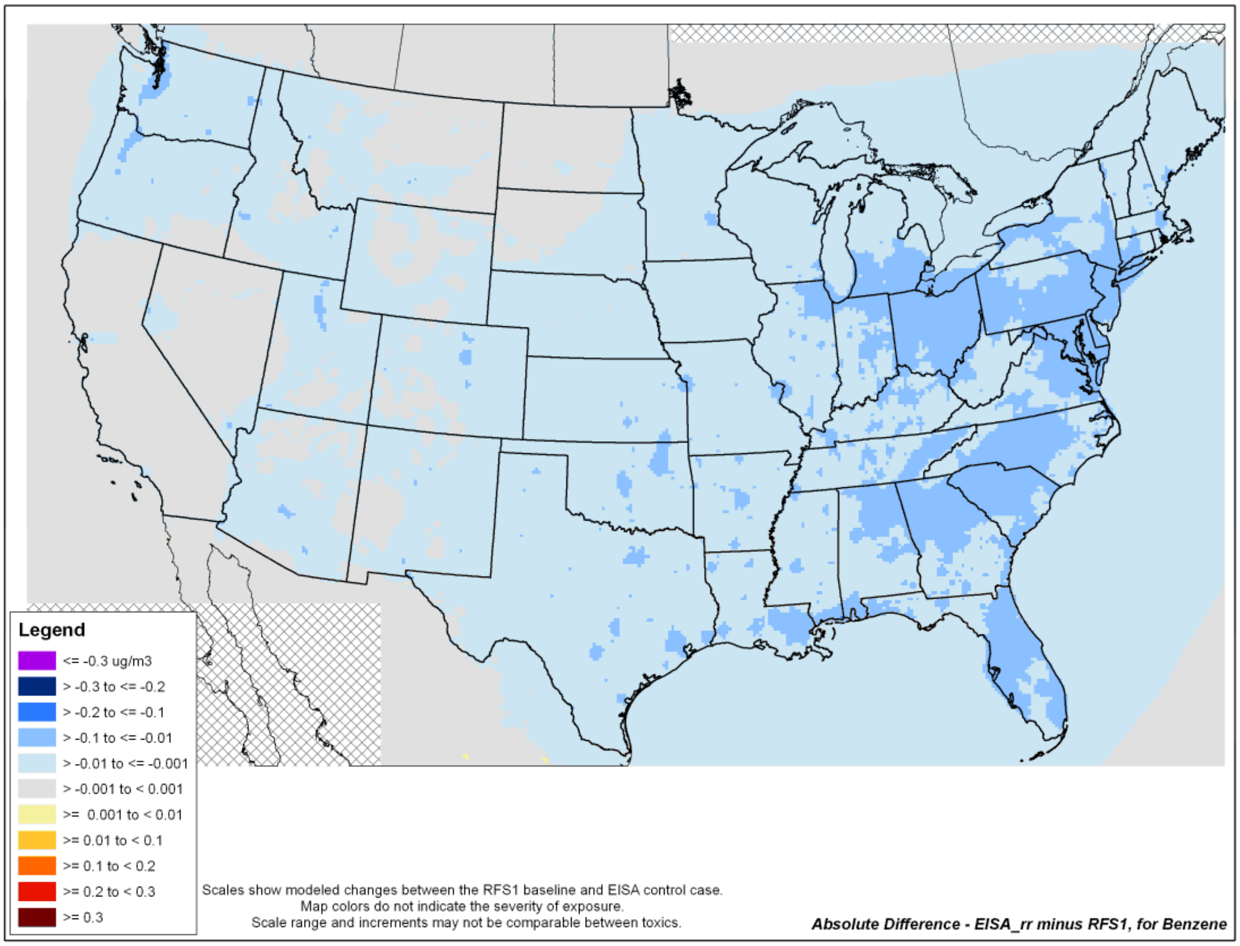


Figure 3.4-22. Benzene Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 ($\mu g/m^3$)

1,3-Butadiene

The results of our air quality modeling show small increases and decreases in ambient concentrations of 1,3-butadiene in parts of the U.S. as a result of the renewable fuel volumes required this rule. Generally, decreases occur in some southern areas of the country and increases occur in some northern areas and areas with high altitudes (Figure 3.4-23). Percent changes in 1,3-butadiene concentrations are over 50% in several areas; but the changes in absolute concentrations of ambient 1,3-butadiene are generally less than 0.005 $\mu g/m^3$ (Figure 3.4-24). Annual increases in ambient concentrations of 1,3-butadiene are driven by wintertime rather than summertime changes (Figures 3.4-25 and 3.4-26). These increases appear in rural areas with cold winters and low ambient levels but high contributions of emissions from snowmobiles, and a major reason for this modeled increase may be deficiencies in available emissions test data used to estimate snowmobile 1,3-butadiene emission inventories. These data were based on tests using only three engines, which showed significantly higher 1,3-butadiene emissions with 10% ethanol. However, they may not have been representative of real-world response of snowmobile engines to ethanol.

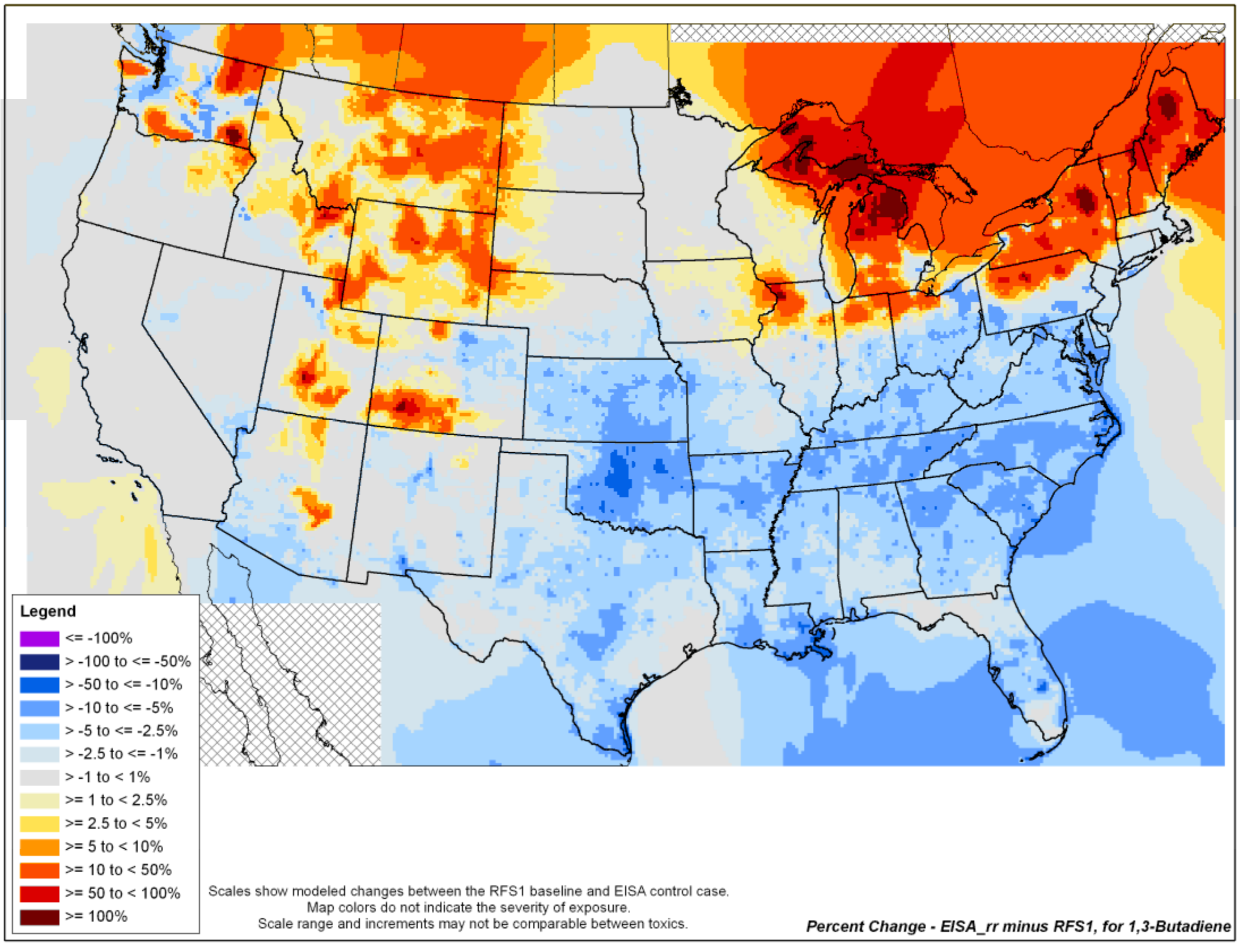


Figure 3.4-23. 1,3-Butadiene Annual Percent Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

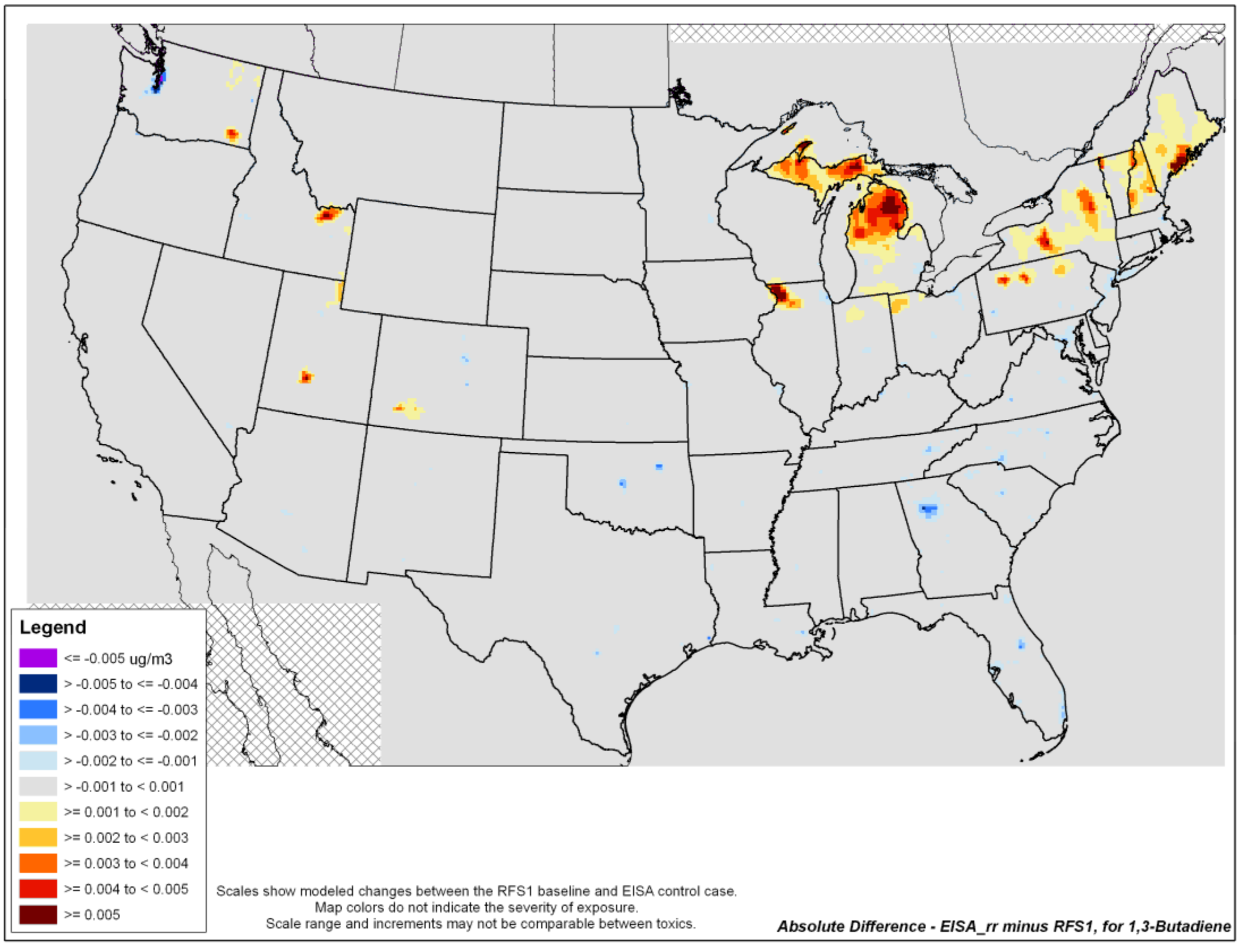
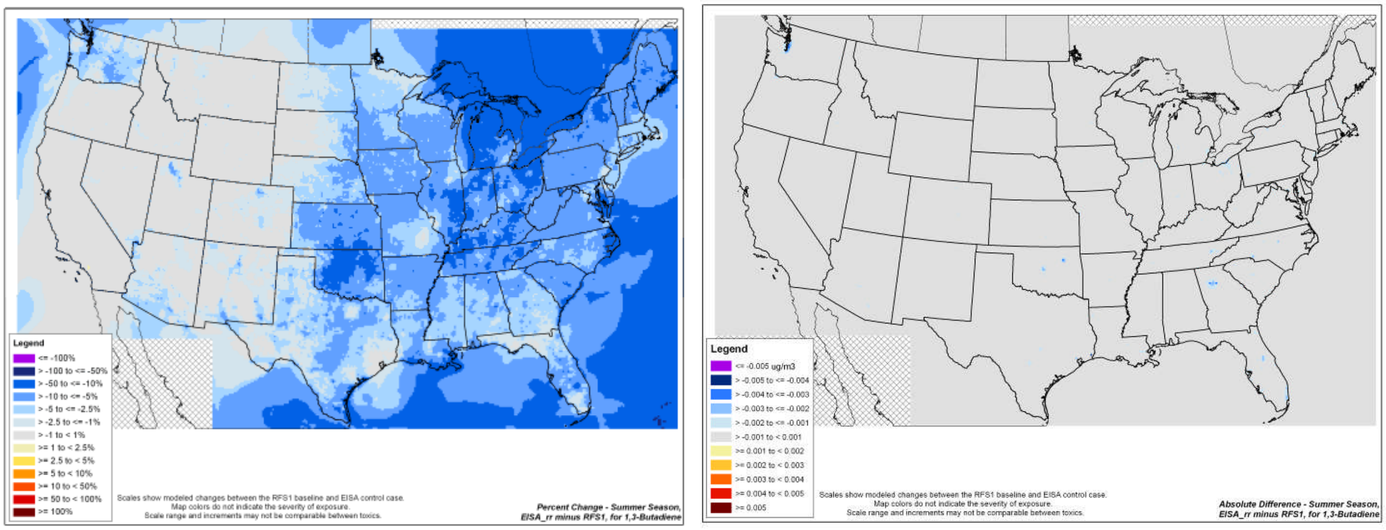
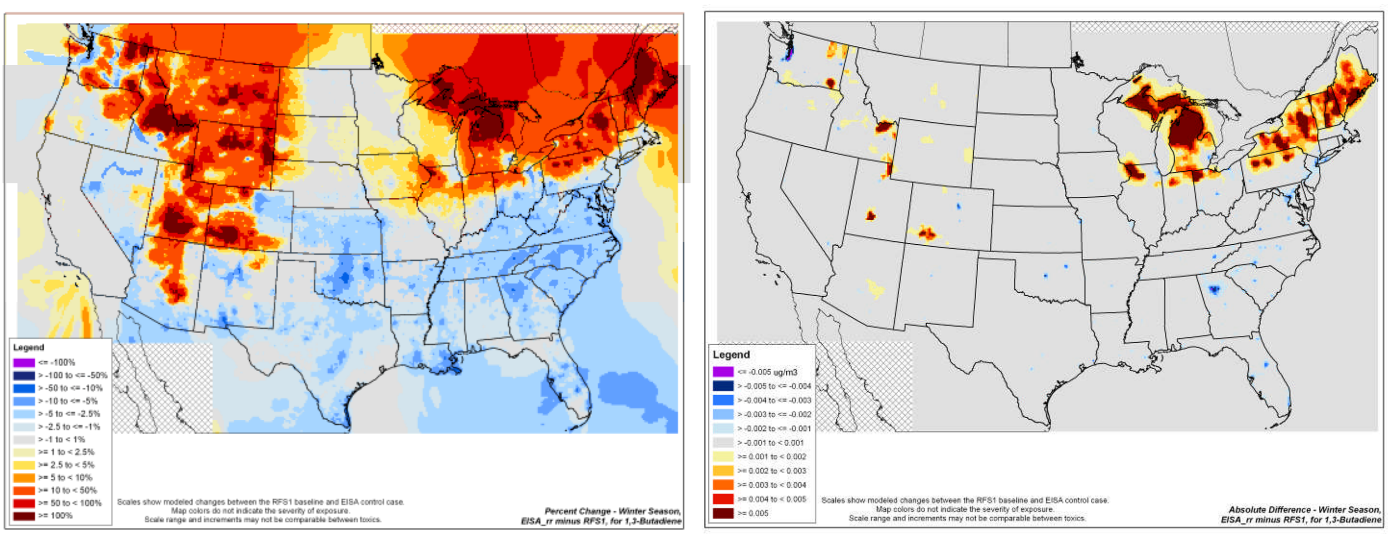


Figure 3.4-24. 1,3-Butadiene Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 (μg/m³)



a **b**

Figure 3.4-25. Summer Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a **b**

Figure 3.4-26. Winter Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)

Acrolein

Our air quality modeling shows small regional increases and decreases in ambient concentrations of acrolein as a result of the renewable fuel volumes required by this rule. As shown in Figure 3.4-27, decreases in acrolein concentrations occur in some eastern and southern parts of the U.S. and increases occur in some northern areas and areas associated with new ethanol plants. Figure 3.4-28 indicates that changes in absolute ambient concentrations of acrolein are between ± 0.001 $\mu g/m^3$ with the exception of the increases associated with new ethanol plants. These increases can be up to and above 0.005 $\mu g/m^3$ with percent changes above 50% and are due to increases in emissions of acrolein from the new plants. As discussed in Section 3.4.1.3, uncertainties in the placement of new ethanol plants limit the model's projected location of associated emission increases. Ambient acrolein increases in upper Michigan, Canada, the Northeast, and the Rocky Mountain region are driven by wintertime changes (Figures 3.4-29 and 3.4-30), and occur in the same areas of the country that have wintertime rather than summertime increases in ambient 1,3-butadiene. 1,3-butadiene is a precursor to acrolein, and these increases are likely associated with the same emission inventory issues in areas of high snowmobile usage seen for 1,3-butadiene, as described above.

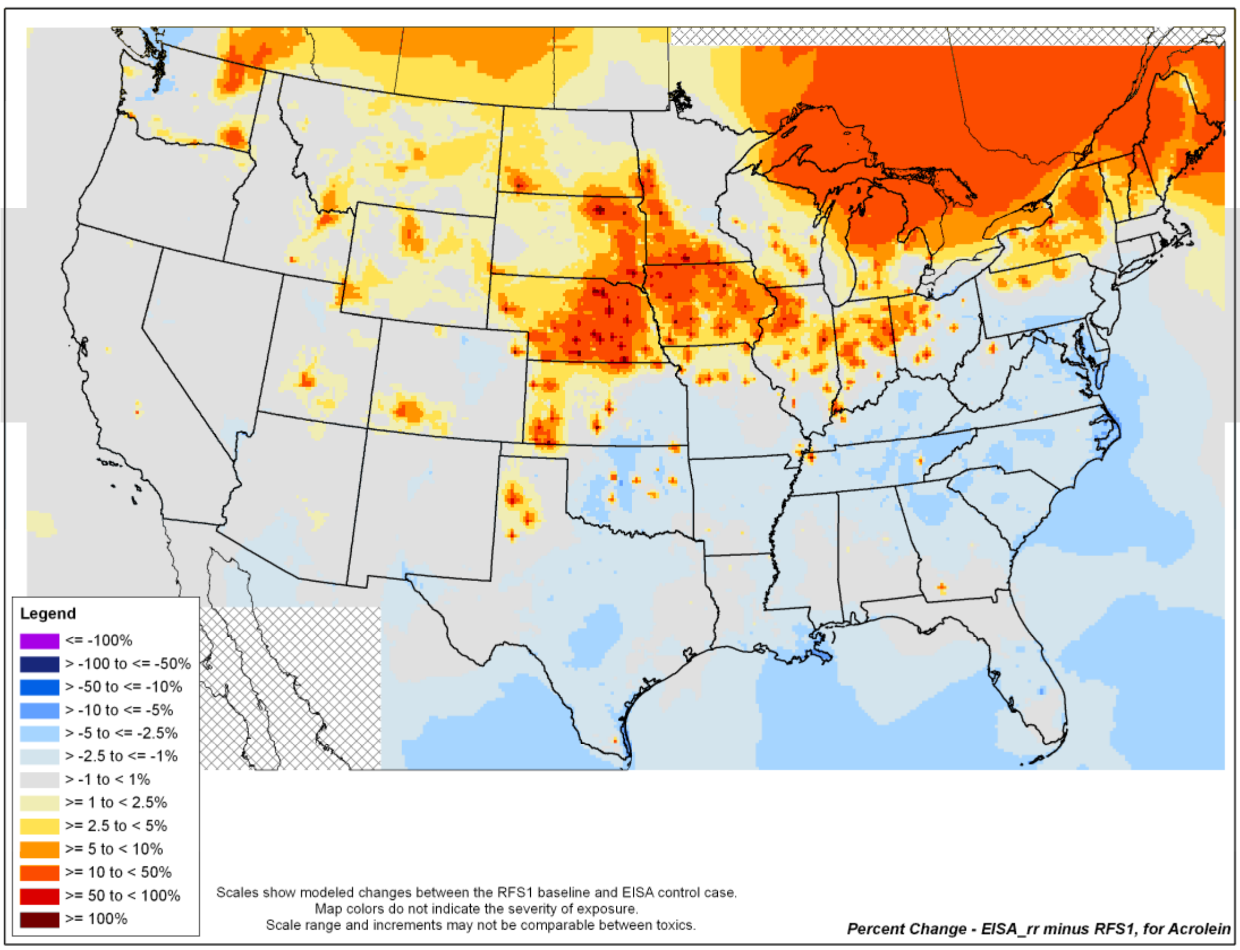


Figure 3.4-27. Acrolein Annual Percent Changes Change in Concentration Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

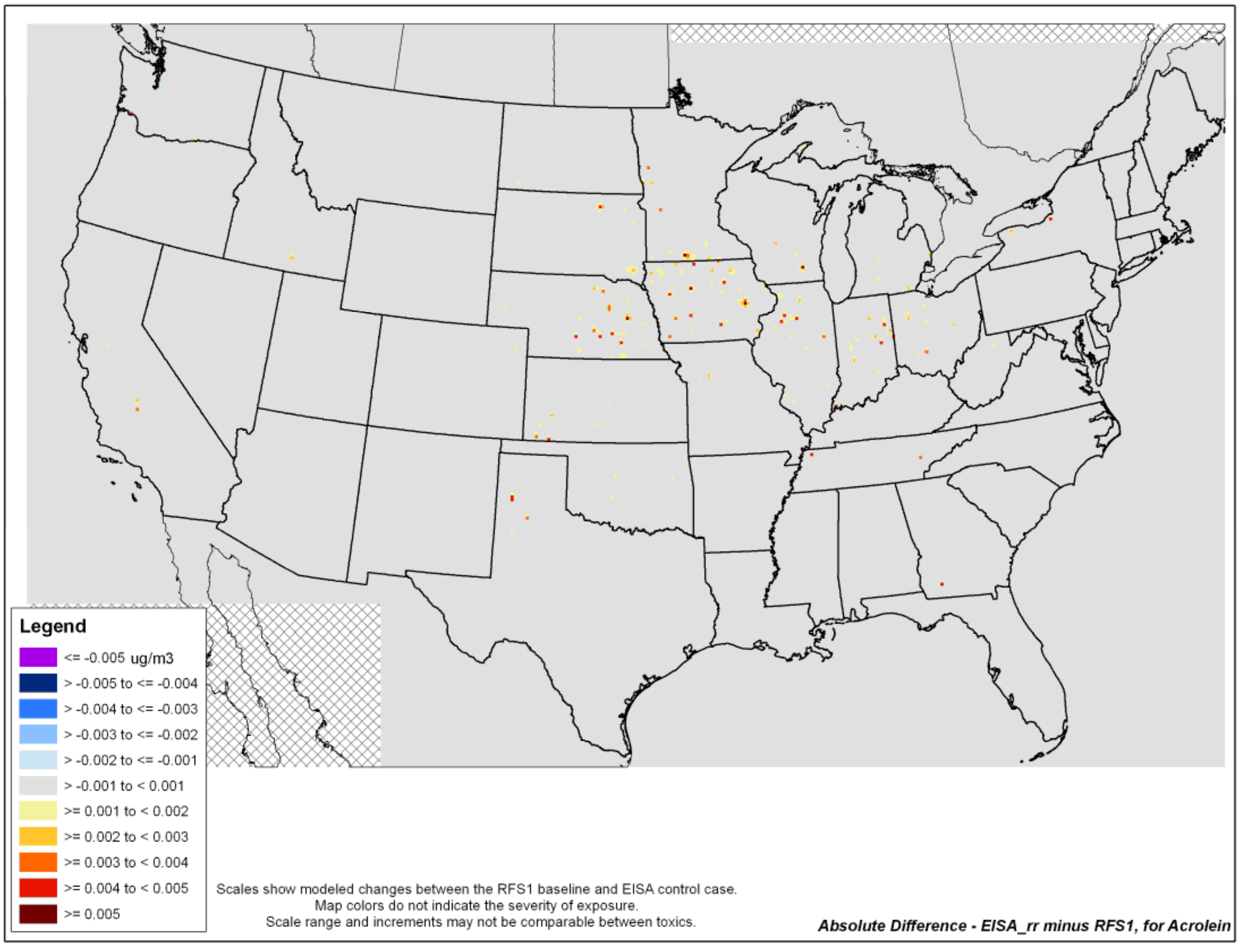
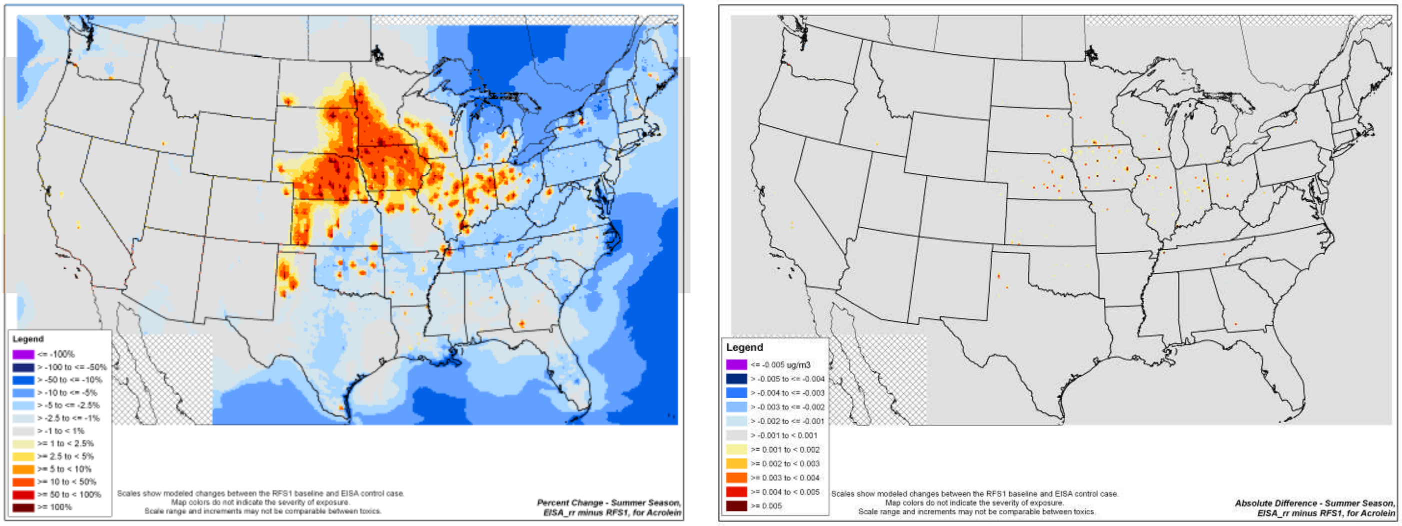
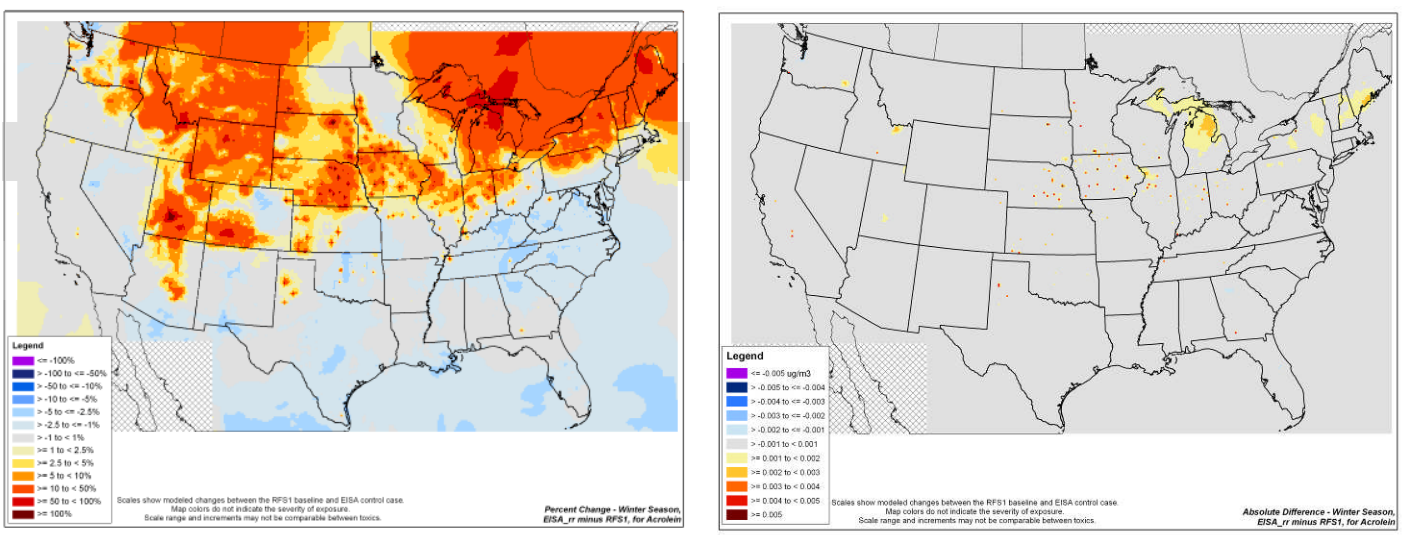


Figure 3.4-28. Acrolein Annual Absolute Changes in Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022 ($\mu g/m^3$)



a **b**

Figure 3.4-29. Summer Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)



a **b**

Figure 3.4-30. Winter Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (a) Percent Changes and (b) Absolute Changes (μg/m³)

Population Metrics

To assess the impact of projected changes in air quality with increased renewable fuel use, we developed population metrics that show population experiencing increases and decreases in annual ambient concentrations across the modeled air toxics. Figure 3.4-31 below illustrates the number of people impacted by changes of various magnitudes in annual ambient concentrations with the renewable fuel volumes required by RFS2 in 2022, as compared to the RFS1 mandate reference case. For ambient concentrations of ethanol, over 98% of the population (334,730,202 people) experiences an increase greater than or equal to 10%. For the other modeled air toxics, more than 90% of the population (greater than 305,658,000 people) will experience a change in ambient concentration of ±1%. For acrolein, 9.9% of the population (33,354,866 people) will live in areas with an increase in ambient concentrations ranging from 1 to 50%; 0.13% (439,535 people) of the population experiences an increase greater than 50%. For 1,3-butadiene, 5.9% of the population (20,171,533 people) experiences a 1 to 50% increase in ambient concentrations, and 0.33% (1,135,806 people) of the population experiences an increase greater than 50%. The percentage of the population living in areas with increases in ambient concentrations of acetaldehyde and formaldehyde are as follows: 0.30% of the population (1,007,009 people) experiences acetaldehyde increases between 1 and 10%, and 0.48% of the population (1,642,944 people) experiences formaldehyde increases between 1 and 2.5%.

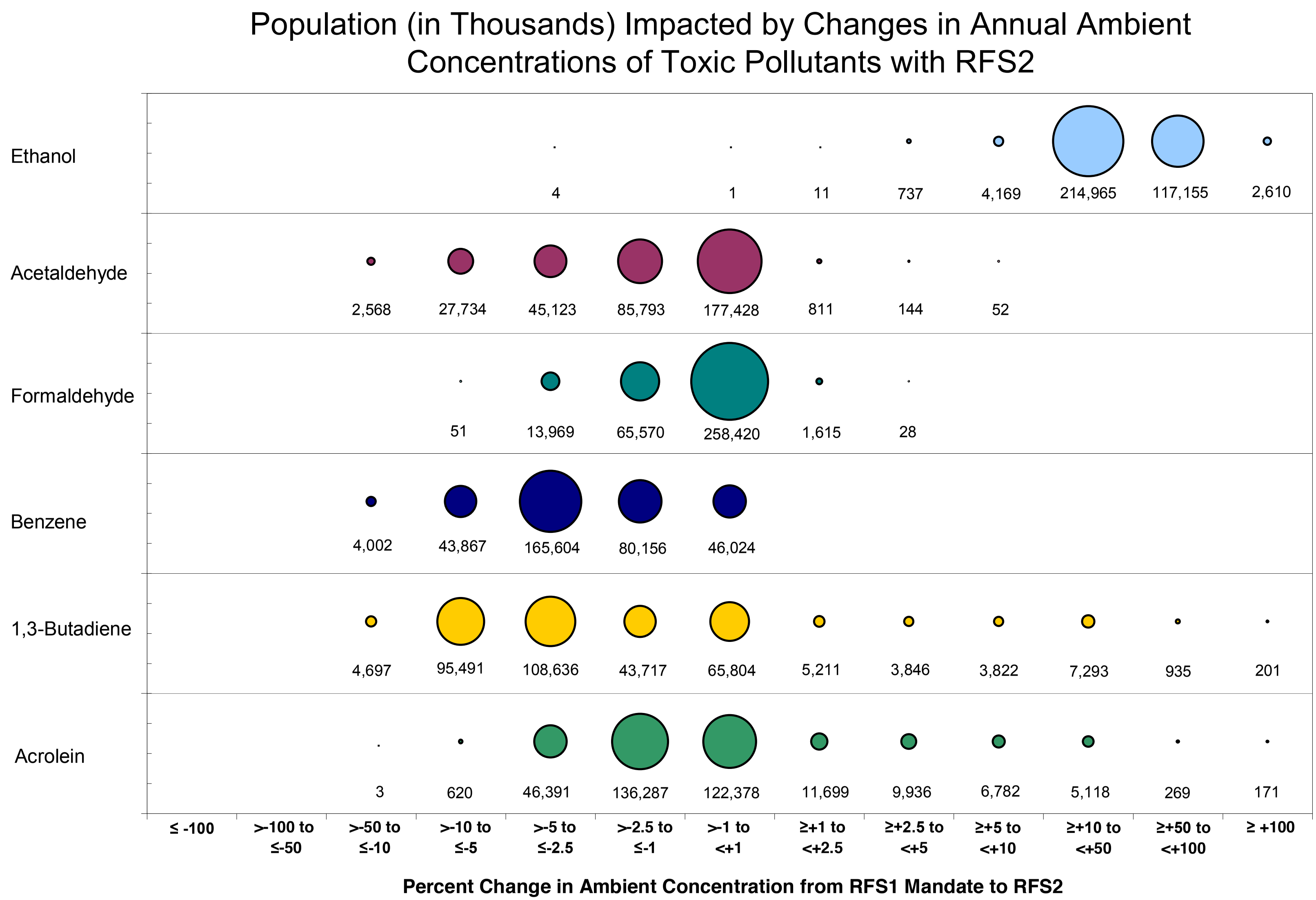


Figure 3.4-31. Number of People Impacted by Changes in Annual Ambient Concentrations or Toxic Pollutants by Percent Change Brackets, RFS 1 Mandate Reference Case Compared to the RFS2 Control Case

The population exposed to average ambient concentrations of air toxics above and below reference concentrations for noncancer health effects in 2022 is presented for the two reference cases in Table 3.4-4 below. Reference concentration (RfC) values presented in this table are the same as those used in the 2002 NATA.[851] At present, no RfC exists for ethanol; EPA is conducting an IRIS assessment for this air toxic. The RfC is an estimate, with uncertainty spanning perhaps an order of magnitude, of an inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risks of deleterious effects during a lifetime. Exposures to levels above the RfC do not necessarily suggest a likelihood of adverse health effects, because many RfCs incorporate protective assumptions in the face of uncertainty. Exposures above the RfC can best be interpreted as indicating that a potential exists for adverse health effects. In addition, average population exposures could be lower or higher than the modeled ambient concentrations.

Table 3.4-4 shows that population-weighted nationwide annual average concentrations for the modeled air toxics are below the RfC values for both the RFS1 reference case and the AEO 2007 reference case. However, the population-weighted nationwide annual average for acrolein is very close to the RfC. Table 3.4-4 also shows the national population that is exposed to ambient concentrations above and below the RfC for the modeled air toxics. In both reference cases, over 94 million people are exposed to ambient concentrations above the RfC for acrolein but the national population is exposed to ambient concentrations below the RfC for acetaldehyde, benzene, 1,3-butadiene, and formaldehyde.

Table 3.4-4. Populations Exposed to Ambient Concentrations of Air Toxics above and below Reference Concentrations for Noncancer Health Effects in 2022 without RFS2

	CAS No.	**Population-weighted Concentration (Nationwide Annual Average in $\mu g/m^3$)**		**RfC ($\mu g/m^3$)**	**National Population above RfC (Annual Average)**		**National Population below RfC (Annual Average)**	
		RFS1 Mandate	AEO 2007		RFS1 Mandate	AEO 2007	RFS1 Mandate	AEO 2007
Acetaldehyde	75070	1.618	1.613	9	0	0	339,652,451	339,652,451
Acrolein	107028	0.018	0.017	0.02	95,059,422	94,087,145	244,593,029	245,565,306
Benzene	71432	0.535	0.527	30	0	0	339,652,451	339,652,451
1,3-Butadiene	106990	0.023	0.023	2	0	0	339,652,451	339,652,451
Ethanol[a]	64175	1.039	1.112	-	-	-	-	-
Formaldehyde	50000	1.558	1.555	9.8	0	0	339,652,451	339,652,451

Table 3.4-5 shows changes in the population exposed to average ambient concentrations of air toxics above and below reference concentrations for noncancer health effects in 2022 that are projected to occur with increased renewable fuel use as required by RFS2. Differences in population-weighted annual average concentrations between the RFS2 control case and the RFS1 mandate reference case are small, and ethanol is the only compound shown to increase with RFS2 fuel volumes. Table 3.4-5 also shows that the renewable fuel volumes required by RFS2 do not result in any increases in the number of people exposed to ambient concentrations above

the RfC values. The results indicate there may be a reduction in the number of people exposed to ambient concentrations of acrolein with RFS2 fuel volumes.

Table 3.4-5. Populations Exposed to Ambient Concentrations of Air Toxics above and below Reference Concentrations for Noncancer Health Effects in 2022 with RFS2

	CAS No.	Population-weighted Concentration (Annual Average in $\mu g/m^3$)			National Population above RfC (Annual Average)		
		RFS2	RFS1 Mandate	Diff.	RFS2	RFS1 Mandate	Diff.
Acetaldehyde	75070	1.590	1.618	-0.028	0	0	0
Acrolein	107028	0.017	0.018	-0.001	92,452,143	95,059,422	-2,607,279
Benzene	71432	0.520	0.535	-0.015	0	0	0
1,3-Butadiene	106990	0.022	0.023	-0.001	0	0	0
Ethanol	64175	1.521	1.039	0.482	-	-	-
Formaldehyde	50000	1.549	1.558	-0.009	0	0	0

3.4.2.2 Deposition of Nitrogen and Sulfur

3.4.2.2.1 Current Levels of Nitrogen and Sulfur Deposition

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 17 years although many areas continue to be negatively impacted by deposition. Deposition of inorganic nitrogen and sulfur species routinely measured in the U.S. between 2004 and 2006 were as high as 9.6 kilograms of nitrogen per hectare per year (kg N/ha/yr) and 21.3 kilograms of sulfur per hectare per year (kg S/ha/yr). Figures 3.4-32 and 3.4-33 show that annual total deposition (the sum of wet and dry deposition) decreased between 1989-1999 and 2004-2006 due to sulfur and NO_X controls on power plants, motor vehicles and fuels in the U.S. The data show that reductions were more substantial for sulfur compounds than for nitrogen compounds. These numbers are generated by the U.S. national monitoring network and they likely underestimate nitrogen deposition because neither ammonia nor organic nitrogen is measured. In the eastern U.S., where data are most abundant, total sulfur deposition decreased by about 36 % between 1990 and 2005, while total nitrogen deposition decreased by 19% over the same time frame.[852]

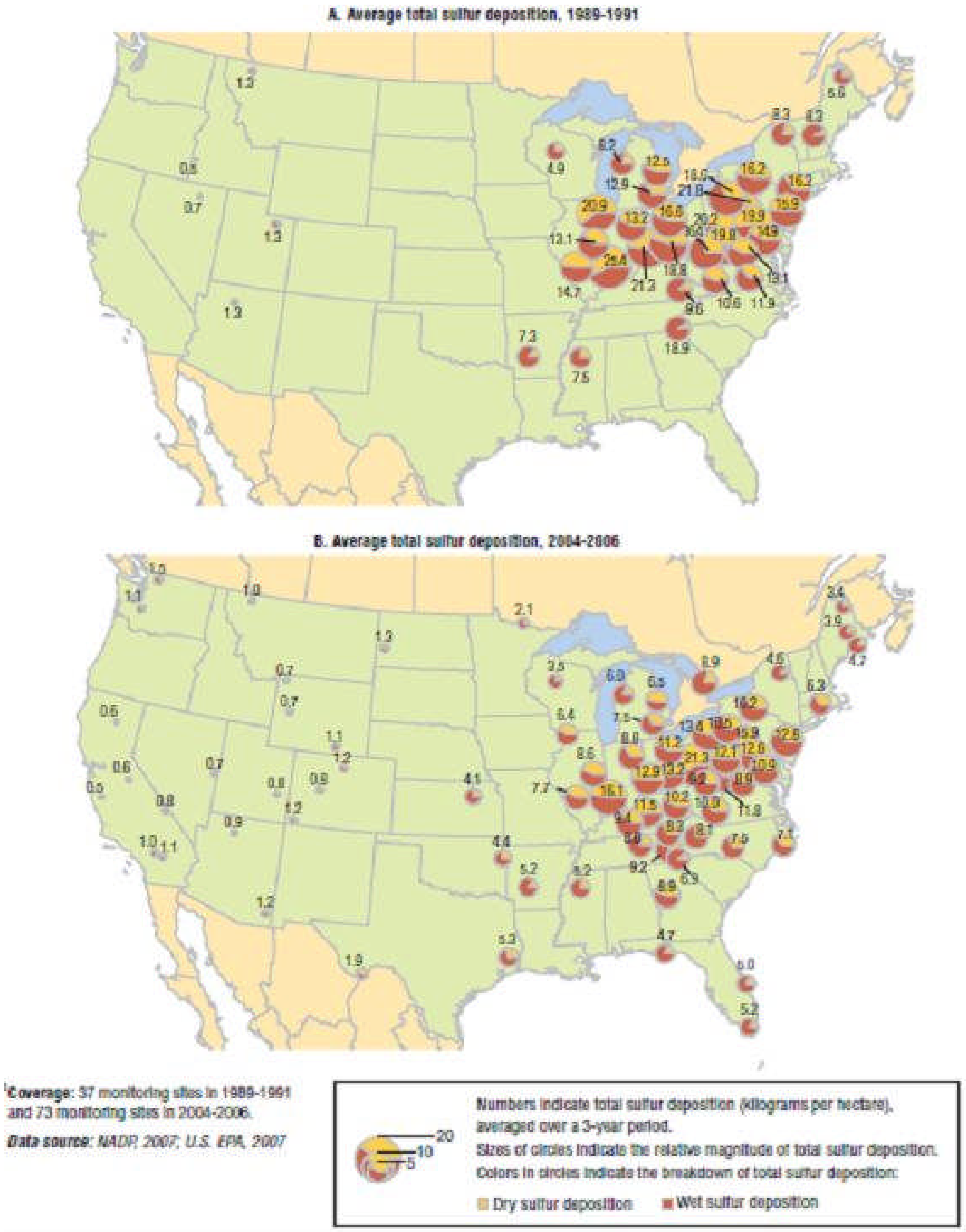


Figure 3.4-32. Total Sulfur Deposition in the Contiguous U.S., 1989-1991 and 2004 -2006

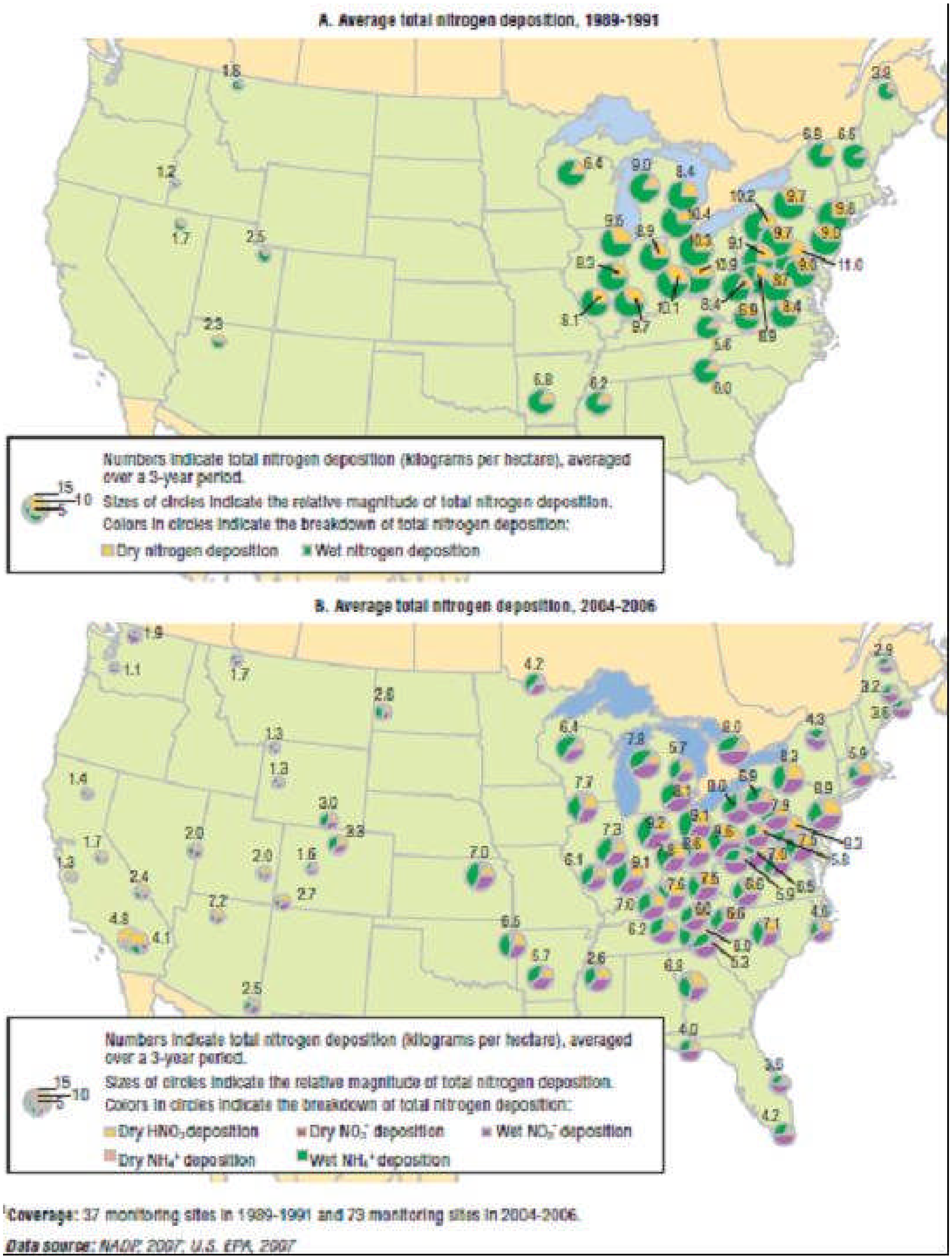


Figure 3.4-33. Total Nitrogen Deposition in the Contiguous U.S., 1989-1991 and 2004-2006

3.4.2.2.2 Projected Levels of Nitrogen and Sulfur Deposition

Our air quality modeling does not show substantial overall nationwide impacts on the annual total sulfur and nitrogen deposition occurring across the U.S. as a result of increased renewable fuel volumes required by this rule. Figure 3.4-34 shows that when compared to the RFS1 mandate reference case, the RFS2 renewable fuel volumes will result in nearly the entire eastern half of the United States seeing nitrogen deposition increases ranging from 0.5% to more than 2%. The largest increases will occur in the states of Illinois, Michigan, Indiana, Wisconsin, and Missouri, with large portions of each of these states seeing nitrogen deposition increases of more than 2%. The Pacific Northwest will also experience increases in nitrogen of 0.5% to more than 2%. Figure 3.4-35 shows that when compared to the AEO 2007 reference case, the changes in nitrogen deposition as a result of the RFS2 renewable fuel volumes are more limited. The eastern half of the United States will still see nitrogen deposition increases ranging from 0.5% to more than 2%; however, the size of the area with these changes will be smaller. Increases of more than 2% will primarily occur only in Illinois, Indiana, Michigan, and Missouri. Fewer areas in the Pacific Northwest will have increases in nitrogen deposition when compared to the AEO 2007 reference case. In both the RFS1 mandate and AEO 2007 reference cases the Mountain West and Southwest will see only minimal changes in nitrogen deposition, ranging from decreases of less than 0.5% to increases of less than 0.5%. A few areas in Minnesota and western Kansas would experience reductions of nitrogen up to 2%.

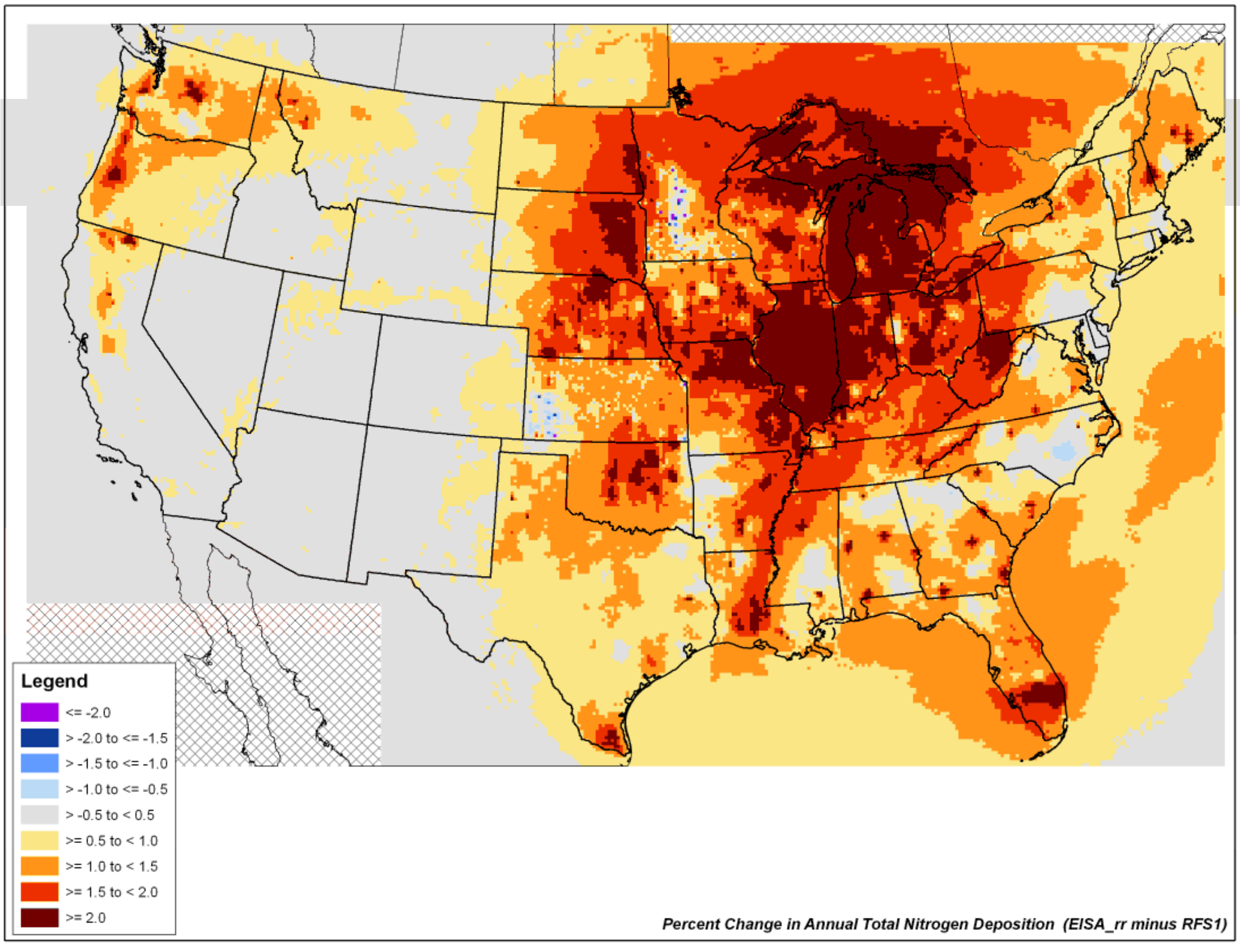


Figure 3.4-34. Percent Change in Annual Total Sulfur over the U.S. Modeling Domain Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022

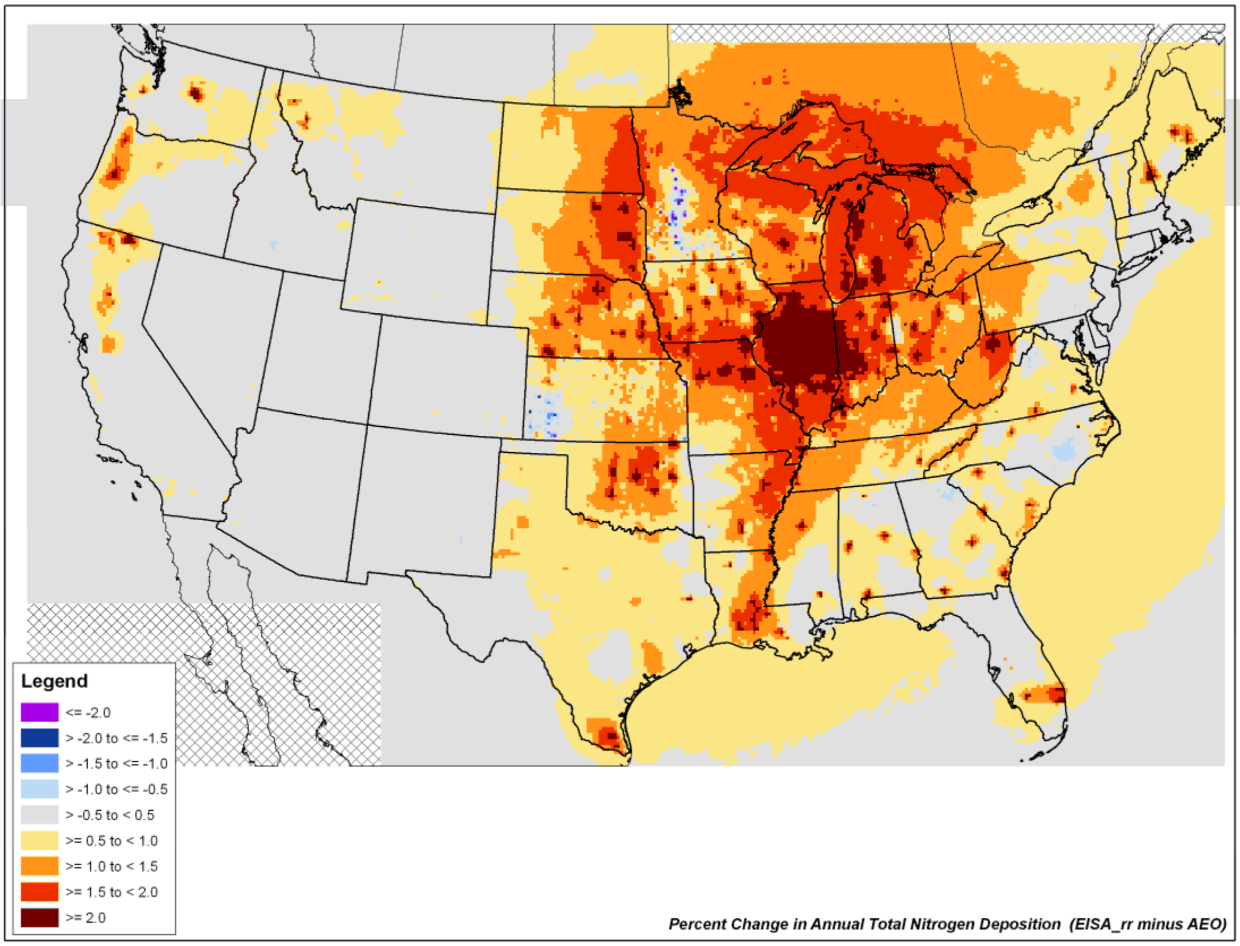


Figure 3.4-35. Percent Change in Annual Total Nitrogen over the U.S. Modeling Domain Between the AEO Reference Case and the RFS2 Control Case in 2022

For sulfur deposition, Figure 3.4-36 shows that when compared to the RFS1 mandate reference case, the RFS2 renewable fuel volumes will result in annual percent increases in the Midwest ranging from 1% to more than 4%. Some rural areas in the west, likely associated with new ethanol plants, will also have increases in sulfur deposition ranging from 1% to more than 4% as a result of the RFS2 renewable fuel volumes. Figure 3.4-37 shows that when compared to the AEO 2007 reference case, the changes are more limited. The Midwest will still have sulfur deposition increases ranging from 1% to more than 4%, but the size of the area with these changes will be smaller. The Pacific Northwest has minimal areas with increases in sulfur deposition when compared to the AEO 2007 reference case. When compared to both the RFS1 mandate and 2007 reference cases, areas along the Gulf Coast in Louisiana and Texas will experience decreases in sulfur deposition of 2% to more than 4%. The remainder of the country will see only minimal changes in sulfur deposition, ranging from decreases of less than 1% to increases of less than 1%.

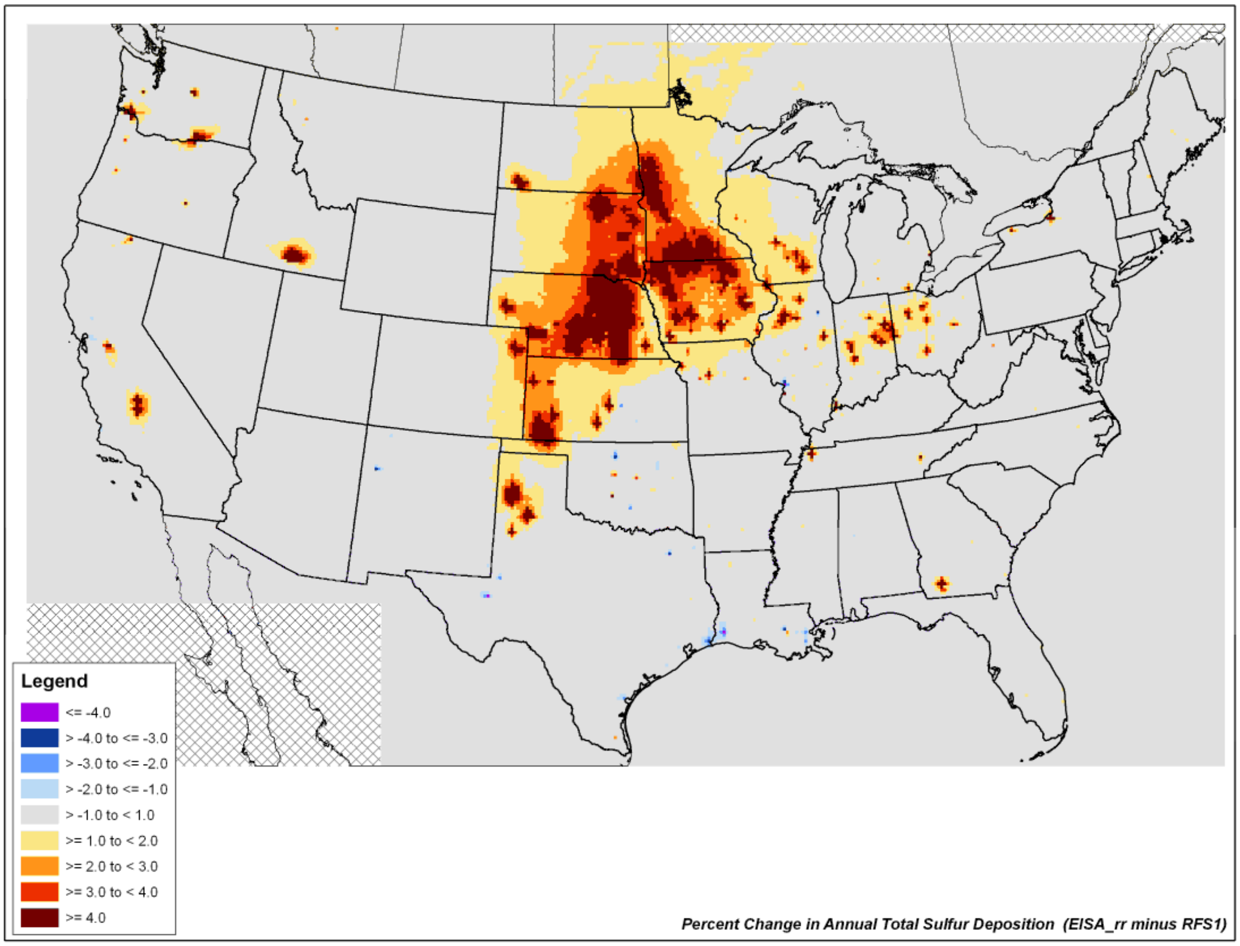


Figure 3.4-36. Percent Change in Annual Total Sulfur over the U.S. Modeling Domain Between the RFS1 Mandate Reference Case and the RFS2 Case in 2022

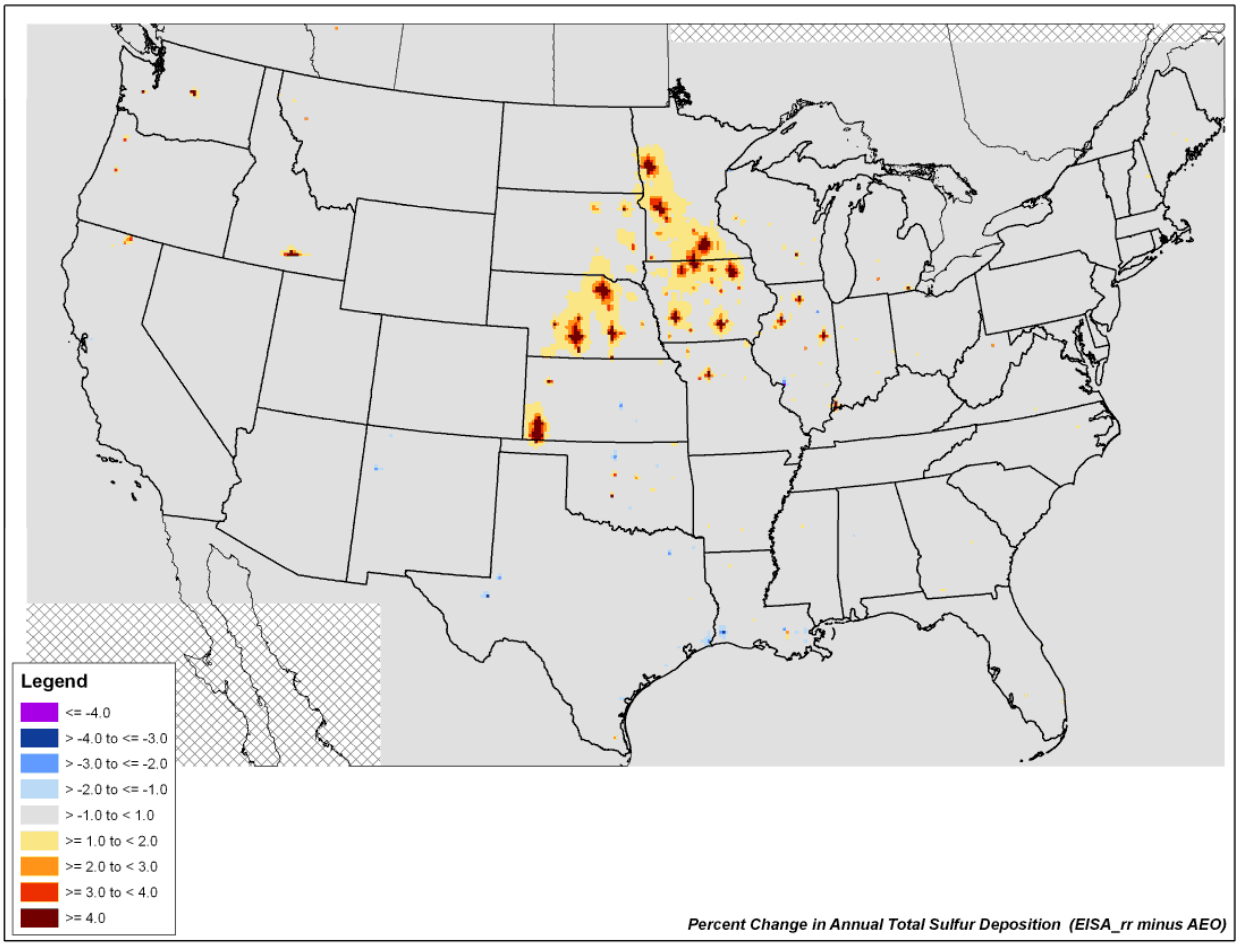


Figure 3.4-37. Percent Change in Annual Total Sulfur over the U.S. Modeling Domain Between the AEO Reference Case and the RFS2 Case in 2022

3.4.3 Ambient Monitoring and Modeling Studies of Ethanol's Impacts on Air Quality

A number of ambient monitoring and modeling studies in the U.S. and abroad have quantified the relative concentrations of ethanol emissions and the potential air quality impacts of using ethanol in fuels. This section summarizes the main results of these studies and is not meant to be a comprehensive examination of this work.

3.4.3.1 U.S. Studies

In 1986, Colorado adopted the first state-wide regulation in the country that required the use of oxygenated fuels in winter time months to reduce carbon monoxide (CO) emissions. From the time the regulation was first adopted, the fuels used quickly shifted from methyl tertiary butyl ether (MTBE) and gasoline to largely ethanol-blended fuels. By the winter of 1996-1997, nearly all of the fuel was blended with ethanol at 10% by volume. The effect of using oxygenated fuels on formaldehyde and acetaldehyde concentrations was monitored by ambient air quality measurements from the winter of 1987-1988 (95% of fuel blended with

MTBE) through the winter of 1996-1997 (nearly all fuel blended with ethanol). Analysis of the data by Anderson et al. showed no clear effect on ambient concentrations of formaldehyde and acetaldehyde through ten winters of oxygenated fuels use.[853,854] Furthermore, Anderson et al. reported that the concentrations of formaldehyde and acetaldehyde during the winter of 1995-1996 when nearly all of the fuel was blended with ethanol were not significantly different from those measured during the winter of 1988-1989 when 95% of the fuel was blended with MTBE. It was hypothesized that the photochemical production and destruction of these compounds suppressed the emissions effect. They concluded that mobile source emissions are the major photochemical sources and sinks for both compounds.[855] Anderson et al. supported this conclusion by citing the work of Altshuller, which showed that most acetaldehyde production comes from alkenes.[856, 857, 858]

Albuquerque, NM is another location that mandated the use of oxygenates in the wintertime to reduce CO emissions. A field study was conducted in Albuquerque to determine the atmospheric impacts of the use of ethanol fuels.[859,860] Atmospheric concentrations of ozone, NO_x, CO, PAN, aldehydes, and organic acids were measured in the summer of 1993, before the use of ethanol fuels, and in the winters of 1994 and 1995, during the use of 10% ethanol fuel (>99%). There were no data for pre-ethanol winter conditions. Results showed increased levels of PAN and an increase in acetaldehyde in one winter, but a decrease in the other. Seasonal differences were not considered. The authors noted that the daytime temperatures were fairly comparable for the summer and winter study periods so it appeared that the significantly higher winter values, despite the much lower photochemical reactivity in winter, were primarily due to local production of PAN. For acetaldehyde, winter values were about twice as high as the summer values. These acetaldehyde levels anti-correlated with PAN levels, indicating a primary source of aldehydes in the winter.

Grosjean et al (2002) conducted monitoring studies in various California cities and measured daily maximum PAN concentrations ranging from 0.2 to 6.9 ppb.[861] Peroxypropionyl nitrate (PPN, a compound similar to PAN) concentrations were measured at lower levels and ranged from 0.33-1.04 ppb. This study concluded that aromatics and alkene compounds are responsible for significant PAN formation with ethanol and acetaldehyde having a minor role. A modeling analysis using the Urban Airshed Model (UAM), was performed by the California Air Resources Board in 1999.[862] Acetaldehyde and ethanol concentrations in 2003, relative to an MTBE baseline, were estimated to increase for 3.5% by weight ethanol-blended gasoline by 4% and 72%, respectively. There was no significant impact on PAN formation. Benzene increased 1%, formaldehyde increased 2 to 4%, butadiene decreased about 2%, and NO_2 (0 to 1%) and peroxypropionyl nitrate (PPN) were essentially unchanged. It should be noted that the chemical mechanism used in this modeling is a previous version of the mechanism used in the modeling for this rule, so comparability of results are limited.

Another air quality modeling study by Jacobson et al. investigated the projected impacts of widespread usage of E85 in Los Angeles and the US in 2020.[863] Overall results showed increases in acetaldehyde and formaldehyde and decreases in 1,3-butadiene and benzene in Los Angeles and the U.S. Sources of acetaldehyde included direct emissions and to a larger degree photooxidation of unburned ethanol. Results of this modeling study also showed increases in unburned ethanol, PAN, and ozone for a future E85 scenario. The results of Jacobson et al.

study differ from the results of our air quality modeling analysis for a number of reasons. First, the scenario modeled in Jacobson et al. study would result in much larger volumes of ethanol in the fuel supply than mandated under EISA (and much greater than could feasibly be produced). This study also did not include upstream impacts from fuel distribution. As discussed elsewhere (Section 3.4.1.3), VOC speciation data used for gasoline storage and distribution and gas cans result in reduction of some acetaldehyde precursor emissions. Finally, the modeled scenario includes large reductions in NO_x emissions. In contrast, we modeled the “more sensitive” emission inventory case where NO_x emissions increased with greater use of E10 fuel. Increases in NO_X, may result in more acetyl peroxy radical forming PAN rather than acetaldehyde. The U.S. monitoring studies discussed here are largely winter studies and the lack of summer studies makes it difficult to quantify the magnitude of air quality impacts of ethanol fuel usage over the entire year.

3.4.3.2 Brazilian Studies

The following studies investigate changes in ambient concentrations of several air pollutants that result from the use of ethanol fuels in Brazil. These studies are not directly relevant to the U.S. due to differences such as vehicles (including less stringent emission standards), fuels, and climate. However, these studies do provide useful information on potential directional changes in pollutant levels with widespread ethanol use.

Brazil is the first country in the world where a nationwide, large-scale alcohol fuel program has been implemented. In 1997, approximately 4 million automobiles ran on neat ethanol and approximately nine million automobiles ran on a 22% ethanol-blended gasoline mixture.[864] It should be noted that Brazilian ethanol blended gasoline does not have RVP controls like U. S. blends.

In Salvador, Bahia, Brazil, ambient levels of formaldehyde and acetaldehyde and their relationship with vehicular fleet composition were evaluated.[865] The measured concentrations for formaldehyde and acetaldehyde ranged from 0.20 to 88 parts per billion by volume (ppbv) and from 0.40 to 93 ppbv, respectively. The ratio of formaldehyde to acetaldehyde revealed the relationship of vehicular fleet composition to ambient levels. In locations where ethanol-fueled vehicular emissions dominated, the ratio decreased, versus locations where diesel-fueled vehicles dominated. Sampling in rural areas showed no relationship between formaldehyde and acetaldehyde.

Acetaldehyde and formaldehyde concentrations were measured in the winter of 1999 in Sao Paulo, Brazil.[866] Ambient levels of these carbonyls were similar. Higher average mixing ratios of acetaldehyde and formaldehyde were found in the morning (18.9 and 17.2 ppbv) than midday (9.5 and 11.8 ppbv) and evening (7.2 and 10.2 ppbv). In the morning, direct emission from vehicles seemed to be the main primary source, whereas at midday and evening these compounds appeared to result mainly from photochemistry.

A survey of volatile organic compounds in areas impacted by heavy traffic, including a tunnel, was obtained for Sao Paulo.[867] Researchers found the ambient air was dominated by ethanol (414 ppbv) with elevated methanol and 1- and 2-propanol. These levels were well above those measurements available for U.S. cities, particularly Los Angeles, CA. The overall data trend also showed levels of C_4-C_9 *n*-aldehydes to be approximately 10 times higher than in Los Angeles. They conclude that the use of alcohol-based fuels is the primary source for these differences since alcohol comprises about 40% of the mobile fuel by volume compared to 3% in Los Angeles. Also, the single-ring aromatic hydrocarbons (2.6 ppbv benzene, 9.0 ppbv toluene, 4.6 ppbv *m,p*-xylene) and the C_4-C_{11} *n*-alkanes were similar or slightly elevated in concentration compared to Los Angeles.

A study in Rio de Janeiro, Brazil some years ago measured and modeled ambient PAN concentrations.[868] The measurements were as high as 5 ppb over a 200 day period, but typically below 1 ppb, at one site; at another site, as high as 3 ppb, but again generally below 1 ppb. Modeling estimates were as high as 3 ppb for PAN and 1 ppb for PPN. This study concluded that with increased use of ethanol in fuels there would be increases in ambient PAN. More recent monitoring studies in Brazil measured daily maximum PAN concentrations ranging from 0.19 to 6.67 ppb.[869] Also, PPN was measured at lower levels of 0.06 to 0.72 ppb. During the 41 days of these measurements, PAN levels accounted for a large fraction of the ambient NO_x. This study concluded that aromatics and alkene compounds are responsible for significant PAN formation with ethanol and acetaldehyde having a minor role.

Speciated ambient carbonyls have also been measured in Rio de Janeiro.[870] The most abundant carbonyls were formaldehyde (9.3 ppb) and acetaldehyde (9.0 ppb). The researchers also examined the ambient acetaldehyde to formaldehyde concentration ratio in Brazilian cities since mid-1980 in the context of changes in Brazil's reliance on ethanol as a vehicle fuel. They showed that this ratio has begun to decrease in recent years due to fleet turnover and decrease in ethanol-fueled vehicles. Ethanol-fueled vehicles are being replaced by lower-emitting newer models that run on a gasoline-ethanol blend.

Using an empirical kinetic modeling approach (EKMA), researchers simulated ozone, formaldehyde, and acetaldehyde concentrations for the urban downtown area of Rio de Janeiro.[871] The simulated ozone peak was in good agreement with monitoring results. Modeling results also showed that acetaldehyde and formaldehyde concentrations were highest in early morning, reaching a maximum which coincided with peak vehicular traffic. Additionally, they confirmed monitoring evidence that the high acetaldehyde to formaldehyde ratios were due to the use of alcohol-based fuels.

These studies modeled and measured ambient concentrations of several compounds that result from the use of ethanol fuels. However, the direct impacts of ethanol fuel usage on air quality in Brazil could not be evaluated since there were no ambient data available prior to the use of ethanol fuel. Notably, these studies did not include ambient measurements of acetaldehyde prior to the use of ethanol fuel, and measured concentrations were much higher than those found in the United States. However, gasolines in Brazil lacked RVP control, resulting in higher evaporative ethanol emissions than would be likely in the U. S., fuel ethanol levels were much higher (neat ethanol or 22% ethanol by volume), and there were significant differences in the vehicle fleet and meteorology. Also, vehicles in Brazil do not meet the same stringent emissions exhaust and evaporative emission standards as vehicles do in the U.S. These factors would all contribute to larger acetaldehyde impacts with ethanol use than expected in the U.S. under the control case evaluated for this rule.

3.4.3.3 Other Studies

A review was conducted on studies that looked at the environmental impacts of E10 and E85 compared to E0.[872] The review article focused on five environmental outcomes including the impact of increased usage of E10 and/or E85 on air pollutant emissions. The review article focuses on studies that are relevant to Australia but includes work done in the US and elsewhere and the results are characterized as being "broad and applicable to most industrialized countries in moderate temperate climates." The author concludes that using E10 fuel instead of E0 fuel provides minimal improvements in air pollutant emissions, specifically E10 causes lower tailpipe CO and particulate emissions but higher acetaldehyde, ethanol and NOx emissions and that there is some evidence of a connection between E10 and higher ground-level ozone concentrations. Since this is a review article it is difficult to compare the modeling for this final rule to the article, however some of the conclusions from the article are useful when interpreting the air quality modeling results.

Some smog chamber studies were recently conducted at EPA[873] with two fuels. These studies were done on headspace vapors which are the hydrocarbon compounds formed by vaporization of hydrocarbon components from gasoline stored in closed (or semi-closed) containers such as fuel storage tanks or tanker trucks. These emissions are different from exhaust emissions which include products of combustion. They are also somewhat different from vehicle evaporative emissions in that the charcoal canister tends to adsorb the higher molecular weight hydrocarbons resulting in emissions of the more volatile fuel components.

The first fuel used in these smog chamber studies was a base gasoline and the second was this gasoline with 10% ethanol added to it (a "splash blend" without any control of fuel volatility). The smog chamber runs were conducted for 24 hours with a target HC/NOx ratio of 10-to-1. The chamber runs with the base gasoline had a higher initial concentration of isopentane compared to the runs with the base gasoline with 10% ethanol. The runs showed that the photoxidation processes of ethanol results in higher levels of acetaldehyde. This photoxidation should also increase acetone levels with the base gasoline which is also observed. The significance of these results is that ethanol does result in increased acetaldehyde formation in smog chamber work. It is important to be able to translate these smog chamber results to actual atmospheric conditions by using such studies to better improve the chemical mechanisms in air quality models to simulate what happens in the atmosphere with other emission components (exhaust, evaporative, other emissions) in actual atmospheric condtions (with meteorology, mixing conditions, temperature, concentrations, and mixing being what they are in the atmosphere).

3.5 Health Effects

In this section we discuss the health and environmental effects associated with particulate matter, ozone, NO_X, SO_X, carbon monoxide and air toxics. The renewable fuel requirements established by the Energy Independence and Security Act (EISA) of 2007 will impact emissions of criteria and air toxic pollutants.

3.5.1 Particulate Matter

3.5.1.1 Background

Particulate matter (PM) is a generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. Since 1987, EPA has delineated that subset of inhalable particles small enough to penetrate to the thoracic region (including the tracheobronchial and alveolar regions) of the respiratory tract (referred to as thoracic particles). Current national ambient air quality standards (NAAQS) use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 μm), and use PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 μm and less than or equal to 10 μm, or $PM_{10-2.5}$). Ultrafine particles are a subset of fine particles, generally less than 100 nanometers (0.1 µm) in aerodynamic diameter.

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles originate from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. In addition, there are also physical, non-chemical reaction mechanisms that contribute to secondary particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from a particle's ability to shift between solid/liquid and gaseous phases, which is influenced by concentration, meteorology, and temperature.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SO_X, NO_X and VOCs) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology and source category. Thus, $PM_{2.5}$ may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.[874]

3.5.1.2 Health Effects of PM

This section provides a summary of the health effects associated with exposure to ambient concentrations of PM.[212] The information in this section is based on the data and conclusions in the PM Air Quality Criteria Document (PM AQCD) and PM Staff Paper prepared

[212] Personal exposure includes contributions from many different types of particles, from many sources, and in many different environments. Total personal exposure to PM includes both ambient and nonambient components; and both components may contribute to adverse health effects.

by the U.S. Environmental Protection Agency (EPA).[213,875,876] We also present additional recent studies published after the cut-off date for the PM AQCD.[877,214] Taken together this information supports the conclusion that exposure to ambient concentrations of PM are associated with adverse health effects.

3.5.1.2.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases,[878] hospitalization and emergency department visits for cardiopulmonary diseases,[879] increased respiratory symptoms,[880] decreased lung function[881] and physiological changes or biomarkers for cardiac changes.[882],[883] In addition, the PM AQCD described a limited body of new evidence from epidemiologic studies for potential relationships between short term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality.[884]

Among the studies of effects associated with short-term exposure to $PM_{2.5}$, several specifically address the contribution of mobile sources to short-term $PM_{2.5}$-related effects on premature mortality. The results from these studies generally indicated that several combustion-related fine particle source-types are likely associated with mortality, including motor vehicle emissions as well as other sources.[885] The analyses incorporate source apportionment tools into short-term exposure studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death rates indicated a relationship between mobile source $PM_{2.5}$ and mortality.[886,887,888,889] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. This study found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient PM_{10} when compared with other sources.[890] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

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[213] The PM NAAQS is currently under review and the EPA is considering all available science on PM health effects, including information which has been published since 2004, in the development of the upcoming PM Integrated Science Assessment Document (ISA). A second draft of the PM ISA was completed in July 2009 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. Comments from the general public have also been requested. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=210586.

[214] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by CASAC and the public, as did the PM AQCD. The provisional assessment found that the "new" studies expand the scientific information and provide important insights on the relationship between PM exposure and health effects of PM. The provisional assessment also found that "new" studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects. Further, the provisional science assessment found that the results reported in the studies did not dramatically diverge from previous findings, and taken in context with the findings of the AQCD, the new information and findings did not materially change any of the broad scientific conclusions regarding the health effects of PM exposure made in the AQCD. However, it is important to note that this assessment was limited to screening, surveying, and preparing a provisional assessment of these studies. For reasons outlined in Section I.C of the preamble for the final PM NAAQS rulemaking in 2006 (see 71 FR 61148-49, October 17, 2006), EPA based its NAAQS decision on the science presented in the 2004 AQCD.

3.5.1.2.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to ambient $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases and lung cancer,[891] and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease.[892] Of specific importance, the PM AQCD also noted that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to the observed ambient PM-related increases in lung cancer incidence and mortality.[893]

The PM AQCD and PM Staff Paper emphasized the results of two long-term epidemiologic studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors – the large air quality data set for PM in the Six Cities Study, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis.[894,895,896,897898,899] These studies indicate that there are positive associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. One analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality from all causes and cardiopulmonary diseases in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[900]

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth.[901] In another recent publication included in the 2006 Provisional Assessment, investigators in southern California reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and a measure of atherosclerosis development in the Los Angeles basin.[902] The study found positive associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis that is an underlying factor in cardiovascular disease.

3.5.1.2.3 Roadway-Related PM Exposure and Health Studies

A recent body of studies examines traffic-related PM exposures and adverse health effects. However, note that the near-road environment is influenced by both gasoline spark-ignition (SI) and diesel vehicles, as well as re-entrained road dust and brake and tire wear. One study was done in North Carolina looking at concentrations of $PM_{2.5}$ inside highway patrol cars and corresponding physiological changes in state troopers driving the cars. The authors report significant elevations in markers of cardiovascular effects (i.e., inflammation, coagulation, and cardiac rhythm) associated with concentrations of $PM_{2.5}$ inside highway patrol cars on North Carolina state highways.[903] Other studies have found associations between traffic-generated particle concentrations at residences and adverse effects, including all-cause mortality, infant respiratory symptoms, and reduced cognitive functional development.[904,905,906,907] There are other pollutants present in the near-roadway environment, including air toxics which are discussed in Section 3.4.5, and it is important to note that current studies do not identify a single pollutant that is most associated with adverse health effects. Additional information on near-roadway health effects can be found in the recent Mobile Source Air Toxics rule (72 FR 8428, February 26, 2007).

3.5.2 Ozone

3.5.2.1 Background

Ground-level ozone pollution is formed by the reaction of VOCs and NO_X in the atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway vehicles and nonroad engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. Ozone can be transported hundreds of miles downwind of precursor emissions, resulting in elevated ozone levels even in areas with low VOC or NO_X emissions.

As mentioned above in Section 3.4.2.1.2, the highest levels of ozone are produced when both VOC and NO_X emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_X enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_X. Under these conditions NO_X reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_X-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X-limited.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO_X, VOC, and ozone, all of which change with time and location. When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited". Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large. Rural areas are usually NO_X-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NO_X-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

3.5.2.2 Health Effects of Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects.[215] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[908,909] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory effects. Cellular-level effects, such as inflammation of lungs, have been documented as well. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[910] People who appear to be more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[911, 912, 913, 914, 915, 916] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[917, 918, 919, 920, 921] Repeated exposure to sufficient concentrations of ozone can also cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could affect premature aging of the lungs and/or the development of chronic respiratory illnesses, such as emphysema and chronic bronchitis.[922, 923, 924, 925]

Children and adults who are outdoors and active during the summer months, such as construction workers, are among those most at risk of elevated ozone exposures.[926] Children and outdoor workers tend to have higher ozone exposure because they typically are active outside, working, playing and exercising, during times of day and seasons (e.g., the summer) when ozone levels are highest.[927] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported statistically significant reductions in lung function in children who are active outdoors.[928, 929, 930, 931, 932, 933, 934, 935] Further, children are more at risk of experiencing health effects from ozone exposure than adults because their respiratory systems are still developing. These individuals (as well as people with respiratory illnesses, such as

[215] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentrations but also by the individuals breathing route and rate.

asthma, especially asthmatic children) can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.[936, 937, 938, 939]

3.5.3 Nitrogen Oxides and Sulfur Oxides

3.5.3.1 Background

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. Nitrogen dioxide (NO_2) is a member of the nitrogen oxide (NO_X) family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. SO_2 and NO_2 can dissolve in water vapor and further oxidize to form sulfuric and nitric acid which react with ammonia to form sulfates and nitrates, both of which are important components of ambient PM. The health effects of ambient PM are discussed in Section 3.5.1.2. NO_X along with non-methane hydrocarbons (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section 3.5.2.2.

3.5.3.2 Health Effects of Sulfur Oxides

Information on the health effects of SO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment for Sulfur Oxides.[216] SO_2 has long been known to cause adverse respiratory health effects, particularly among individuals with asthma. Other potentially sensitive groups include children and the elderly. During periods of elevated ventilation, asthmatics may experience symptomatic bronchoconstriction within minutes of exposure. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. Separately, based on an evaluation of the epidemiologic evidence of associations between short-term exposure to SO_2 and mortality, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

3.5.3.3 Health Effects of Nitrogen Oxides

Information on the health effects of NO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment (ISA) for Nitrogen Oxides.[217] The U.S. EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects

[216] U.S. EPA. (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria (Final Report).* EPA/600/R-08/047F. Washington, DC: U.S. Environmental Protection Agency. Retrieved on March 18, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843

[217] U.S. EPA (2008). *Integrated Science Assessment for Oxides of Nitrogen – Health Criteria (Final Report).* EPA/600/R-08/071. Washington, DC,: U.S.EPA. Retrieved on March 19, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=194645.

including symptoms, emergency department visits, and hospital admissions. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. In addition, small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of asthmatic subjects. Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

Although the weight of evidence supporting a causal relationship is somewhat less certain than that associated with respiratory morbidity, NO_2 has also been linked to other health endpoints. These include all-cause (nonaccidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

3.5.4 Carbon Monoxide

This section summarizes the data and conclusions in the EPA Air Quality Criteria Document for CO (CO Criteria Document), which was published in 2000, regarding the health effects associated with CO exposure.[218,940] Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood's capacity to carry oxygen to organs and tissues.[941,942] Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Although there are effective compensatory increases in blood flow to the brain, at some concentrations of COHb somewhere above 20 percent, these compensations fail to maintain sufficient oxygen delivery, and metabolism declines.[943] The subsequent hypoxia in brain tissue then produces behavioral effects, including decrements in continuous performance and reaction time.[944]

Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects.[945] Persons with heart disease are especially sensitive to CO poisoning and may experience chest pain if they breathe the gas while exercising.[946] Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals,

[218] The CO NAAQS is currently under review and the EPA is considering all available science on CO health effects, including information which has been published since 2000, in the development of the upcoming CO Integrated Science Assessment Document (ISA). A second draft of the CO ISA was completed in September 2009 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=213229.

impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks.[947]

Several epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases). Several studies in the United States and Canada have also reported an association between ambient CO exposures and frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association between ambient CO exposure and mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the CO Criteria Document review process and noted the possibility that the average ambient CO levels used as exposure indices in the epidemiology studies may be surrogates for ambient air mixes impacted by combustion sources and/or other constituent toxic components of such mixes. More research will be needed to better clarify CO's role.[948]

3.5.5 Health Effects of Air Toxics

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to air toxics.[949] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. These compounds, except acetaldehyde, were identified as national or regional risk drivers in the 2002 National-scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources.

According to NATA for 2002, mobile sources were responsible for 47 percent of outdoor toxic emissions, over 50 percent of the cancer risk, and over 80 percent of the noncancer hazard. Benzene is the largest contributor to cancer risk of all 124 pollutants quantitatively assessed in the 2002 NATA and mobile sources were responsible for 59 percent of benzene emissions in 2002. In 2007, EPA finalized vehicle and fuel controls that address this public health risk; it will reduce total emissions of mobile source air toxics by 330,000 tons in 2030, including 61,000 tons of benzene.[950]

Noncancer health effects can result from chronic,[219] subchronic,[220] or acute[221] inhalation exposures to air toxics, and include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems. According to the 2002 NATA, nearly the entire U.S. population was exposed to an average concentration of air toxics that has the potential for adverse noncancer respiratory health effects. This will continue to be the case in 2030, even though toxics concentrations will be lower. Mobile sources were

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[219] Chronic exposure is defined in the glossary of the Integrated Risk Information (IRIS) database (http://www.epa.gov/iris) as repeated exposure by the oral, dermal, or inhalation route for more than approximately 10% of the life span in humans (more than approximately 90 days to 2 years in typically used laboratory animal species).
[220] Defined in the IRIS database as exposure to a substance spanning approximately 10% of the lifetime of an organism.
[221] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

responsible for over 80 percent of the noncancer (respiratory) risk from outdoor air toxics in 2002. The majority of this risk was from exposure to acrolein. The confidence in the RfC for acrolein is medium and confidence in NATA estimates of population noncancer hazard from ambient exposure to this pollutant is low.[951,952]

The NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. These limitations and uncertainties are discussed on the 2002 NATA website.[953] Even so, this modeling framework is very useful in identifying air toxic pollutants and sources of greatest concern, setting regulatory priorities, and informing the decision making process.

3.5.5.1 Benzene

The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[954,955,956] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[957,958]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[959,960] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[961,962] In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[963,964,965,966] EPA's IRIS program has not yet evaluated these new data.

3.5.5.2 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[967,968] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[969,970] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[971]

3.5.5.3 Ethanol

EPA is conducting an assessment of the cancer and noncancer effects of exposure to ethanol, a compound which is not currently listed in EPA's IRIS. A description of these effects to the extent that information is available will be presented, as required by Section 1505 of EPAct, in a Report to Congress on public health, air quality and water resource impacts of fuel additives. We expect to release that report in 2010.

Extensive data are available regarding adverse health effects associated with the ingestion of ethanol while data on inhalation exposure effects are sparse. As part of the IRIS assessment, pharmacokinetic models are being evaluated as a means of extrapolating across species (animal to human) and across exposure routes (oral to inhalation) to better characterize the health hazards and dose-response relationships for low levels of ethanol exposure in the environment.

The IARC has classified "alcoholic beverages" as carcinogenic to humans based on sufficient evidence that malignant tumors of the mouth, pharynx, larynx, esophagus, and liver are causally related to the consumption of alcoholic beverages.[972] The U.S. DHHS in the 11th Report on Carcinogens also identified "alcoholic beverages" as a known human carcinogen (they have not evaluated the cancer risks specifically from exposure to ethanol), with evidence for cancer of the mouth, pharynx, larynx, esophagus, liver and breast.[973] There are no studies reporting carcinogenic effects from inhalation of ethanol. EPA is currently evaluating the available human and animal cancer data to identify which cancer type(s) are the most relevant to an assessment of risk to humans from a low-level oral and inhalation exposure to ethanol.

Noncancer health effects data are available from animal studies as well as epidemiologic studies. The epidemiologic data are obtained from studies of alcoholic beverage consumption. Effects include neurological impairment, developmental effects, cardiovascular effects, immune system depression, and effects on the liver, pancreas and reproductive system.[974] There is evidence that children prenatally exposed via mothers' ingestion of alcoholic beverages during pregnancy are at increased risk of hyperactivity and attention deficits, impaired motor coordination, a lack of regulation of social behavior or poor psychosocial functioning, and deficits in cognition, mathematical ability, verbal fluency, and spatial memory.[975,976,977,978,979,980,981,982] In some people, genetic factors influencing the metabolism of ethanol can lead to differences in internal levels of ethanol and may render some subpopulations more susceptible to risks from the effects of ethanol.

3.5.5.4 Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[983] EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[984,985] In an analysis of the lymphohematopoietic cancer mortality from an extended follow-up of these workers, NCI confirmed an association between lymphohematopoietic cancer risk and peak exposures.[986] A recent National Institute of

Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[987] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[988]

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[989,990,991] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. However, it should be noted that recent research published by EPA indicates that when two-stage modeling assumptions are varied, resulting dose-response estimates can vary by several orders of magnitude.[992,993,994,995] These findings are not supportive of interpreting the CIIT model results as providing a conservative (health protective) estimate of human risk.[996] EPA research also examined the contribution of the two-stage modeling for formaldehyde towards characterizing the relative weights of key events in the mode-of-action of a carcinogen. For example, the model-based inference in the published CIIT study that formaldehyde's direct mutagenic action is not relevant to the compound's tumorigenicity was found not to hold under variations of modeling assumptions.[997]

Based on the developments of the last decade, in 2004, the working group of the IARC concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals - a higher classification than previous IARC evaluations. After reviewing the currently available epidemiological evidence, the IARC (2006) characterized the human evidence for formaldehyde carcinogenicity as "sufficient," based upon the data on nasopharyngeal cancers; the epidemiologic evidence on leukemia was characterized as "strong."[998] EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation – including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.[999,1000]

3.5.5.5 Acetaldehyde

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[1001] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group

2B) by the IARC.[1002,1003] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[1004] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[1005,1006] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[1007] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

3.5.5.6 Acrolein

EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[1008] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[1009]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[1010] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[1011] Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms.[1012] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[1013] Acute exposure effects in animal studies report bronchial hyper-responsiveness.[1014] In a recent study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease by comparison to non-diseased mice which also showed decreases in respiratory rate.[1015] Based on these animal data and demonstration of similar effects in humans (i.e., reduction in respiratory rate), individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

3.5.6.7 Peroxyacetyl nitrate (PAN)

PAN has not been evaluated by EPA's IRIS program. Information regarding the potential carcinogenicity of PAN is limited. As noted in the EPA air quality criteria document for ozone and related photochemical oxidants, cytogenetic studies indicate that PAN is not a potent mutagen, clastogen (a compound that can cause breaks in chromosomes), or DNA-damaging agent in mammalian cells either in vivo or in vitro. Some studies suggest that PAN may be a weak bacterial mutagen at high concentrations much higher than exist in present urban atmospheres.[1016]

Effects of ground-level smog causing intense eye irritation have been attributed to photochemical oxidants, including PAN.[1017] Animal toxicological information on the inhalation effects of the non-ozone oxidants has been limited to a few studies on PAN. Acute exposure to levels of PAN can cause changes in lung morphology, behavioral modifications, weight loss, and susceptibility to pulmonary infections. Human exposure studies indicate minor pulmonary function effects at high PAN concentrations, but large inter-individual variability precludes definitive conclusions.[1018]

3.5.6.8 Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[1019] The draft reassessment completed external peer review.[1020] Based on external peer review comments received, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[1021] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[1022] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[1023]

3.5.6.9 N-Hexane

N-Hexane is associated with polyneuropathy in humans. Effects observed in rodents include nasal lesions as well as neurotoxic effects. EPA has developed a reference concentration of 700 $\mu g/m^3$ from a study of peripheral neuropathy.[1024] There is inadequate data to assess its carcinogenic potential.

3.5.6.10 Pesticides

There are potential toxicity concerns with volatilization of pesticide active ingredients,[1025] in addition to concerns with contamination of foods and drinking water. Furthermore, raising acreage under corn production may increase the quantity of pesticide products in use. As the domestic corn supply grows between the years of 2005 and 2022, the percentage of corn used for ethanol production in the US is expected to increase, though the agricultural impacts of this shifting of crop production domestically are anticipated to be small. Whether there is the potential for adverse human health effects from any increase in pesticide use associated with increased corn production domestically warrants further assessment. Additional information on pesticides and health effects is included in Section 6.1 of this RIA.

3.5.6.11 Other Air Toxics

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles will be affected by today's proposed action. Mobile source air toxic compounds that will potentially be impacted include ethylbenzene, polycyclic organic matter, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[1026]

3.6 Environmental Effects

In this section we discuss some of the environmental effects of PM and its precursors, such as visibility impairment, atmospheric deposition, and materials damage and soiling. We also discuss environmental effects associated with the presence of ozone in the ambient air, such as impacts on plants, including trees, agronomic crops and urban ornamentals.

3.6.1 Visibility Degradation

Emissions from LD vehicles contribute to poor visibility in the U.S. through their primary $PM_{2.5}$ and secondary $PM_{2.5}$ precursor emissions. These airborne particles degrade visibility by scattering and absorbing light. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

The U.S. Government places special emphasis on protecting visibility in national parks and wilderness areas. Section 169 of the Clean Air Act requires the U.S. Government to address existing visibility impairment and future visibility impairment in the national parks exceeding 6,000 acres, and wilderness areas exceeding 5,000 acres, which are categorized as mandatory class I federal areas (62 FR 38680, July 18, 1997).[222] Figure 3.6-1 shows the location of the 156 mandatory class I federal areas.

3.6.1.1 Visibility Monitoring

In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., the U.S. EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network was originally established at 20 sites, but it has now been expanded to 110 sites that represent all but one of the 156 mandatory class I federal areas across the country (see Figure3.6-1). This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of Protected Visual Environments).

IMPROVE provides direct measurement of fine particles that contribute to visibility impairment. The IMPROVE network employs aerosol measurements at all sites, and optical and

[222] These areas are defined in section 162 of the Act as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

scene measurements at some of the sites. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon, soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency, with adjustment for the relative humidity. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. Optical measurements are used to directly measure light extinction or its components. Such measurements are taken principally with either a transmissometer, which measures total light extinction, or a nephelometer, which measures particle scattering (the largest human-caused component of total extinction). Scene characteristics are typically recorded three times daily with 35 millimeter photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Directly measured light extinction is used under the IMPROVE protocol to cross check that the aerosol-derived light extinction levels are reasonable in establishing current visibility conditions. Aerosol-derived light extinction is used to document spatial and temporal trends and to determine how proposed changes in atmospheric constituents would affect future visibility conditions.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. The rural East generally has higher levels of impairment than remote sites in the West, with the exception of urban-influenced sites such as San Gorgonio Wilderness (CA) and Point Reyes National Seashore (CA), which have annual average levels comparable to certain sites in the Northeast. Regional differences are illustrated by Figures 4-39a and 4-39b in the Air Quality Criteria Document for Particulate Matter, which show that, for Class I areas, visibility levels on the 20% haziest days in the West are about equal to levels on the 20% best days in the East.[1027]

Higher visibility impairment levels in the East are due to generally higher concentrations of anthropogenic fine particles, particularly sulfates, and higher average relative humidity levels. In fact, sulfates account for 60-86% of the haziness in eastern sites.[1028] Aerosol light extinction due to sulfate on the 20% haziest days is significantly larger in eastern Class I areas as compared to western areas (Figures 4-40a and 4-40b in the Air Quality Criteria Document for Particulate Matter).[1029] With the exception of remote sites in the northwestern U.S., visibility is typically worse in the summer months. This is particularly true in the Appalachian region, where average light extinction in the summer exceeds the annual average by 40%.[1030]

3.6.1.2 Addressing Visibility in the U.S.

The U.S. EPA is pursuing a two-part strategy to address visibility. First, to address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which act in conjunction with the establishment of a regional haze program. In setting this secondary standard, EPA has concluded that $PM_{2.5}$ causes adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. Second, section 169 of the Clean Air Act provides additional authority to address existing visibility impairment and prevent future visibility impairment in the 156 mandatory Class I federal areas

(62 FR 38680-81, July 18, 1997). In July 1999, the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory Class I federal areas. Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory Class I federal areas.[223]

Figure 3.6-1: Mandatory Class I Areas in the U.S.

3.6.2 Particulate Matter Deposition

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominately from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). Reflecting this fact, the PM AQCD concludes that regardless of size fractions, particles containing nitrates and sulfates have the greatest potential for widespread environmental significance, while effects are also related to other chemical constituents found in ambient PM, such as trace metals and organics. The following characterizations of the nature of

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223 As mentioned above, the EPA recently amended the PM NAAQS, making the secondary NAAQS equal, in all respects, to the primary standards for both $PM_{2.5}$ and PM_{10}, (71 FR 61144, Oct. 17, 2006). In February 2009, the D.C. Circuit Court remanded the secondary standards for fine particles, based on EPA's failure to adequately explain why setting the secondary PM2.5 NAAQS equivalent to the primary standards provided the required protection for public welfare including protection from visibility impairment.

these welfare effects are based on the information contained in the PM AQCD and PM Staff Paper.[1031,1032]

3.6.2.1 Deposition of Nitrogen and Sulfur

Nitrogen and sulfur interactions in the environment are highly complex. Both are essential, and sometimes limiting, nutrients needed for growth and productivity. Excesses of nitrogen or sulfur can lead to acidification, nutrient enrichment, and eutrophication.[1033]

The process of acidification affects both freshwater aquatic and terrestrial ecosystems. Acid deposition causes acidification of sensitive surface waters. The effects of acid deposition on aquatic systems depend largely upon the ability of the ecosystem to neutralize the additional acid. As acidity increases, aluminum leached from soils and sediments, flows into lakes and streams and can be toxic to both terrestrial and aquatic biota. The lower pH concentrations and higher aluminum levels resulting from acidification make it difficult for some fish and other aquatic organisms to survive, grow, and reproduce. Research on effects of acid deposition on forest ecosystems has come to focus increasingly on the biogeochemical processes that affect uptake, retention, and cycling of nutrients within these ecosystems. Decreases in available base cations from soils are at least partly attributable to acid deposition. Base cation depletion is a cause for concern because of the role these ions play in acid neutralization and, because calcium, magnesium and potassium are essential nutrients for plant growth and physiology. Changes in the relative proportions of these nutrients, especially in comparison with aluminum concentrations, have been associated with declining forest health.

At current ambient levels, risks to vegetation from short-term exposures to dry deposited particulate nitrate or sulfate are low. However, when found in acid or acidifying deposition, such particles do have the potential to cause direct leaf injury. Specifically, the responses of forest trees to acid precipitation (rain, snow) include accelerated weathering of leaf cuticular surfaces, increased permeability of leaf surfaces to toxic materials, water, and disease agents; increased leaching of nutrients from foliage; and altered reproductive processes—all which serve to weaken trees so that they are more susceptible to other stresses (e.g., extreme weather, pests, pathogens). Acid deposition with levels of acidity associated with the leaf effects described above are currently found in some locations in the eastern U.S.[1034] Even higher concentrations of acidity can be present in occult depositions (e.g., fog, mist or clouds) which more frequently impacts higher elevations. Thus, the risk of leaf injury occurring from acid deposition in some areas of the eastern U.S. is high. Nitrogen deposition has also been shown to impact ecosystems in the western U.S. A study conducted in the Columbia River Gorge National Scenic Area (CRGNSA), located along a portion of the Oregon/Washington border, indicates that lichen communities in the CRGNSA have shifted to a higher proportion of nitrophilous species and the nitrogen content of lichen tissue is elevated.[1035] Lichens are sensitive indicators of nitrogen deposition effects to terrestrial ecosystems and the lichen studies in the Columbia River Gorge clearly show that ecological effects from air pollution are occurring.

Some of the most significant detrimental effects associated with excess nitrogen deposition are those associated with a syndrome known as nitrogen saturation. These effects include: (1) decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly above background and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) fluctuation of ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms.[1036]

In the U.S. numerous forests now show severe symptoms of nitrogen saturation. These forests include: the northern hardwoods and mixed conifer forests in the Adirondack and Catskill Mountains of New York; the red spruce forests at Whitetop Mountain, Virginia, and Great Smoky Mountains National Park, North Carolina; mixed hardwood watersheds at Fernow Experimental Forest in West Virginia; American beech forests in Great Smoky Mountains National Park, Tennessee; mixed conifer forests and chaparral watersheds in southern California and the southwestern Sierra Nevada in Central California; the alpine tundra/subalpine conifer forests of the Colorado Front Range; and red alder forests in the Cascade Mountains in Washington.

Excess nutrient inputs into aquatic ecosystems (i.e. streams, rivers, lakes, estuaries or oceans) either from direct atmospheric deposition, surface runoff, or leaching from nitrogen saturated soils into ground or surface waters can contribute to conditions of severe water oxygen depletion; eutrophication and algae blooms; altered fish distributions, catches, and physiological states; loss of biodiversity; habitat degradation; and increases in the incidence of disease.

Atmospheric deposition of nitrogen is a significant source of total nitrogen to many estuaries in the United States. The amount of nitrogen entering estuaries that is ultimately attributable to atmospheric deposition is not well-defined. On an annual basis, atmospheric nitrogen deposition may contribute significantly to the total nitrogen load, depending on the size and location of the watershed. In addition, episodic nitrogen inputs, which may be ecologically important, may play a more important role than indicated by the annual average concentrations. Estuaries in the U.S. that suffer from nitrogen enrichment often experience a condition known as eutrophication. Symptoms of eutrophication include changes in the dominant species of phytoplankton, low levels of oxygen in the water column, fish and shellfish kills, outbreaks of toxic alga, and other population changes which can cascade throughout the food web. In addition, increased phytoplankton growth in the water column and on surfaces can attenuate light causing declines in submerged aquatic vegetation, which serves as an important habitat for many estuarine fish and shellfish species.

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation’s fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. According to a NOAA report, more than half of the nation’s estuaries have moderate to high expressions of at least one of these symptoms – an indication that eutrophication is well developed in more than half of U.S. estuaries.[1037]

3.6.2.2 Materials Damage and Soiling

The effects of the deposition of atmospheric pollution, including ambient PM, on materials are related to both physical damage and impaired aesthetic qualities. The deposition of PM (especially sulfates and nitrates) can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Only chemically active fine particles or hygroscopic coarse particles contribute to these physical effects. In addition, the deposition of ambient PM can reduce the aesthetic appeal of buildings and culturally important articles through soiling. Particles consisting primarily of carbonaceous compounds cause soiling of commonly used building materials and culturally important items such as statues and works of art.

3.6.3 Impacts of Ozone on Vegetation

The Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant".[1038] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake."[1039] Once sufficient levels of ozone (a highly reactive substance), or its reaction products, reaches the interior of plant cells, it can inhibit or damage essential cellular components and functions, including enzyme activities, lipids, and cellular membranes, disrupting the plant's osmotic (i.e., water) balance and energy utilization patterns.[1040,1041] This damage is commonly manifested as visible foliar injury, such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[1042] If enough tissue becomes damaged from these effects, a plant's capacity to fix carbon to form carbohydrates, which are the primary form of energy used by plants, is reduced,[1043] while plant respiration increases. With fewer resources available, the plant reallocates existing resources away from root growth and storage, above ground growth or yield, and reproductive processes, toward leaf repair and maintenance, leading to reduced growth and/or reproduction. Studies have shown that plants stressed in these ways may exhibit a general loss of vigor, which can lead to secondary impacts that modify plants' responses to other environmental factors. Specifically, plants may become more sensitive to other air pollutants, more susceptible to disease, insect attack, harsh weather (e.g., drought, frost) and other environmental stresses. Furthermore, there is evidence that ozone can interfere with the formation of mycorrhiza, essential symbiotic fungi associated with the roots of most terrestrial plants, by reducing the amount of carbon available for transfer from the host to the symbiont.[1044,1045]

This ozone damage may or may not be accompanied by visible injury on leaves, and likewise, visible foliar injury may or may not be a symptom of the other types of plant damage described above. When visible injury is present, it is commonly manifested as chlorotic or necrotic spots, and/or increased leaf senescence (accelerated leaf aging). Because ozone damage can consist of visible injury to leaves, it can also reduce the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on sensitive vegetation. Not all plants, however, are equally sensitive to ozone. Much of the variation in sensitivity between individual plants or whole species is related to the plant's ability to regulate the extent of gas exchange via leaf stomata (e.g., avoidance of ozone uptake through closure of stomata).[1046,1047,1048] Other resistance mechanisms may involve the intercellular production of detoxifying substances. Several biochemical substances capable of detoxifying ozone have been reported to occur in plants, including the antioxidants ascorbate and glutathione. After injuries have occurred, plants may be capable of repairing the damage to a limited extent.[1049]

Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants. The next few paragraphs present additional information on ozone damage to trees, ecosystems, agronomic crops and urban ornamentals.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[1050,1051] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts. Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[1052,1053]

Because plants are at the base of the food web in many ecosystems, changes to the plant community can affect associated organisms and ecosystems (including the suitability of habitats that support threatened or endangered species and below ground organisms living in the root zone). Ozone impacts at the community and ecosystem level vary widely depending upon numerous factors, including concentration and temporal variation of tropospheric ozone, species composition, soil properties and climatic factors.[1054] In most instances, responses to chronic or recurrent exposure in forested ecosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[1055,1056,1057] It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Laboratory and field experiments have also shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the Unites States."[1058] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[1059,1060,1061]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[1062] This is therefore a potentially costly environmental effect. However, in the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative analysis has been conducted.

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition.[1063] In the U.S., ozone in the lower atmosphere is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves.[1064]

In the U.S. this indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. As part of its Phase 3 program, formerly known as Forest Health Monitoring, FIA examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. For this indicator, forest land does not include woodlots and urban trees. Sites are selected using a systematic sampling grid, based on a global sampling design.[1065,1066] At each site that has at least 30 individual plants of at least three ozone-sensitive species and enough open space to ensure that sensitive plants are not protected from ozone exposure by the forest canopy, FIA looks for damage on the foliage of ozone-sensitive forest plant species. Monitoring of ozone injury to plants by the USDA Forest Service has expanded over the last 10 years from monitoring sites in 10 states in 1994 to nearly 1,000 monitoring sites in 41 states in 2002.

3.6.3.1 Recent Ozone Data for the U.S.

There is considerable regional variation in ozone-related visible foliar injury to sensitive plants in the U.S. The U.S. EPA has developed an environmental indicator based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program which examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country (This indicator does not include woodlots and urban trees). Sites are selected using a systematic sampling grid, based on a global sampling design.[1067, 1068] Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest. The data underlying the indictor in Figure 3.6-2 are based on averages of all observations collected in 2002, the latest year for which data are publicly available at the time the study was conducted, and are broken down by U.S. EPA Region. Ozone damage to forest plants is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury (visible foliar injury to highly sensitive or moderately sensitive plants, respectively), and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively.[1069, 1070]

The highest percentages of observed high and severe foliar injury, those which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Mid-Atlantic and Southeast regions. In EPA Region 3 (which comprises the States of Pennsylvania, West Virginia, Virginia, Delaware, Maryland and Washington D.C.), 12% of ozone-sensitive plants showed signs of high or severe foliar damage, and in Regions 2 (States of New York, New Jersey), and 4 (States of North Carolina, South Carolina, Kentucky, Tennessee, Georgia, Florida, Alabama, and Mississippi) the values were 10% and 7%, respectively. The sum of high and severe ozone injury ranged from 2% to 4% in EPA Region 1 (the six New England States), Region 7 (States of Missouri, Iowa, Nebraska and Kansas), and Region 9 (States of California, Nevada, Hawaii and Arizona). The percentage of sites showing some ozone damage was about 45% in each of these EPA Regions.

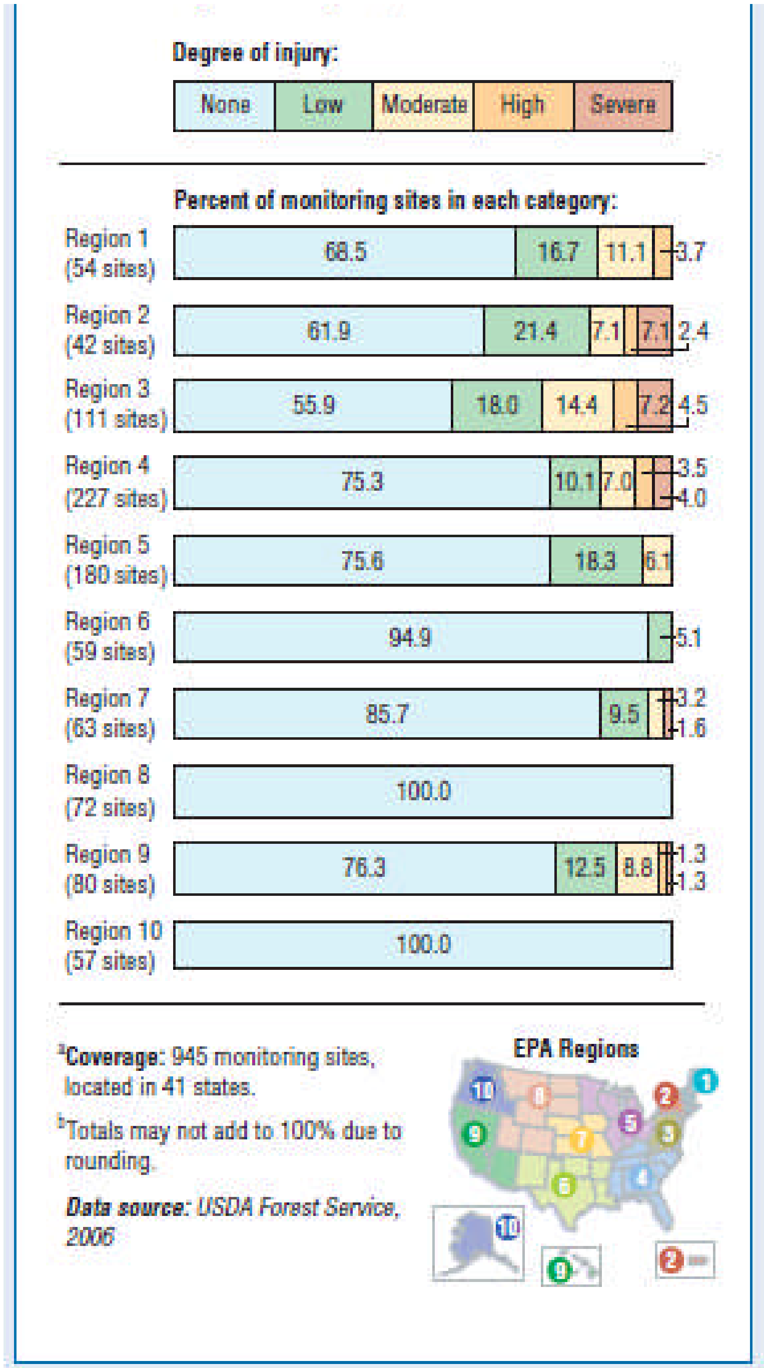


Figure 3.6-2: Ozone Injury to Forest Plants in U.S. by EPA Regions, 2002[ab]

3.6.3.1.1 Indicator Limitations

Field and laboratory studies were reviewed to identify the forest plant species in each region that are highly sensitive to ozone air pollution. Other forest plant species, or even genetic variants of the same species, may not be harmed at ozone levels that cause effects on the selected ozone-sensitive species.

Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among regions of the U.S.

Ozone damage to foliage is considerably reduced under conditions of low soil moisture, but most of the variability in the index (70%) was explained by ozone concentration.[1071] Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury.[1072]

Though FIA has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury. Even though the biosite data have been collected over multiple years, most biosites were not monitored over the entire period, so these data cannot provide more than a baseline for future trends.

3.6.4 Impacts of Ozone on Forest Health

Air pollution can impact the environment and affect ecological systems, leading to changes in the biological community (both in the diversity of species and the health and vigor of individual species). As an example, many studies have shown that ground-level ozone reduces the health of plants including many commercial and ecologically important forest tree species throughout the United States.[1073]

When ozone is present in the air, it can enter the leaves of plants, where it can cause significant cellular damage. Since photosynthesis occurs in cells within leaves, the ability of the plant to produce energy by photosynthesis can be compromised if enough damage occurs to these cells. If enough tissue becomes damaged it can reduce carbon fixation and increase plant respiration, leading to reduced growth and/or reproduction in young and mature trees. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stressors (e.g., harsh weather). Because ozone damage can consist of visible injury to leaves, it also reduces the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affect scenic vistas in protected natural areas.

Assessing the impact of ground-level ozone on forests in the eastern United States involves understanding the risks to sensitive tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risks to particular plants from ground-level ozone, scientists have developed ozone-exposure/tree-response functions by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." Typically, seedlings are used because they are easy to manipulate and measure their growth loss from ozone pollution. The mechanisms of susceptibility to ozone within the leaves of seedlings and mature trees are identical, though the magnitude of the effect may be higher or lower depending on the tree species. [1074]

Some of the common tree species in the United States that are sensitive to ozone are black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera)*, eastern white pine (*Pinus strobus)*. Ozone-exposure/tree-response functions have been developed for each of these tree species, as well as for aspen (*Populus tremuliodes*), and ponderosa pine (*Pinus ponderosa*).

Other common tree species, such as oak (*Quercus* spp.) and hickory (*Carya* spp.), are not nearly as sensitive to ozone. Consequently, with knowledge of the distribution of sensitive species and the level of ozone at particular locations, it is possible to estimate a "biomass loss" for each species across their range.

3.6.5 Environmental Effects of Air Toxics

Fuel combustion emissions contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. PAN is a well-established phytotoxicant causing visible injury to leaves that can appear as metallic glazing on the lower surface of leaves with some leafy vegetables exhibiting particular sensitivity (e.g., spinach, lettuce, chard).[1075,1076,1077] PAN has been demonstrated to inhibit photosynthetic and non-photosynthetic processes in plants and retard the growth of young navel orange trees.[1078,1079] In addition to its oxidizing capability, PAN contributes nitrogen to forests and other vegetation via uptake as well as dry and wet deposition to surfaces. As noted above in Section 3.6.2.1, nitrogen deposition can lead to saturation of terrestrial ecosystems and research is needed to understand the impacts of excess nitrogen deposition experienced in some areas of the country on water quality and ecosystems.[1080]

Volatile organic compounds (VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[1081] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[1082] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (e.g., acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[1083]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[1084,1085,1086] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

Appendix Chapter 3A: Additional Air Toxics Modeling Results

3A.1 Annual Change Ambient Concentration Maps for Air Toxics using the AEO Reference Case

The following section presents maps of annual changes in ambient concentrations of modeled air toxics in 2022 using the AEO 2007 reference case compared to the RFS2 control case.

3A.1.1 Acetaldehyde

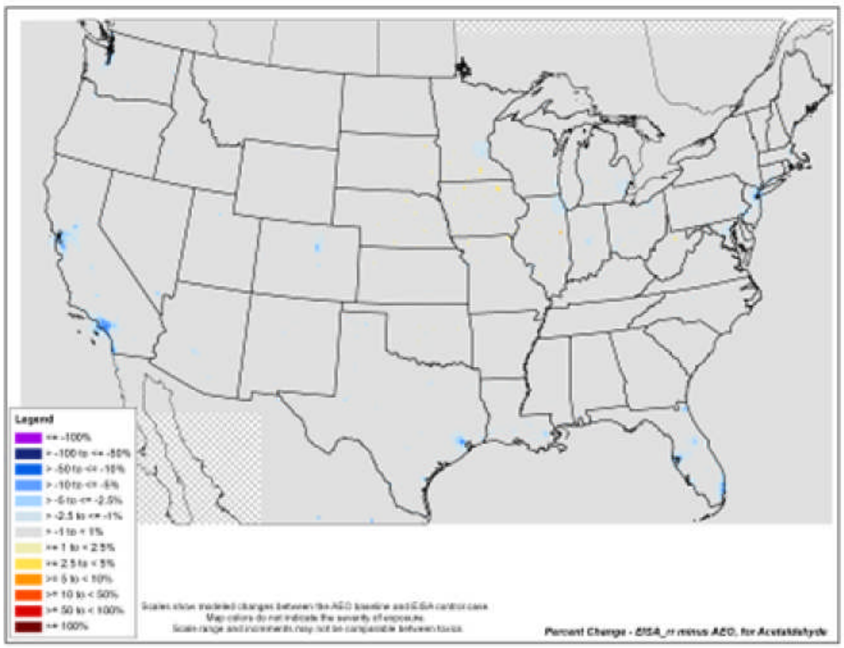


Figure 3A-1. Acetaldehyde Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

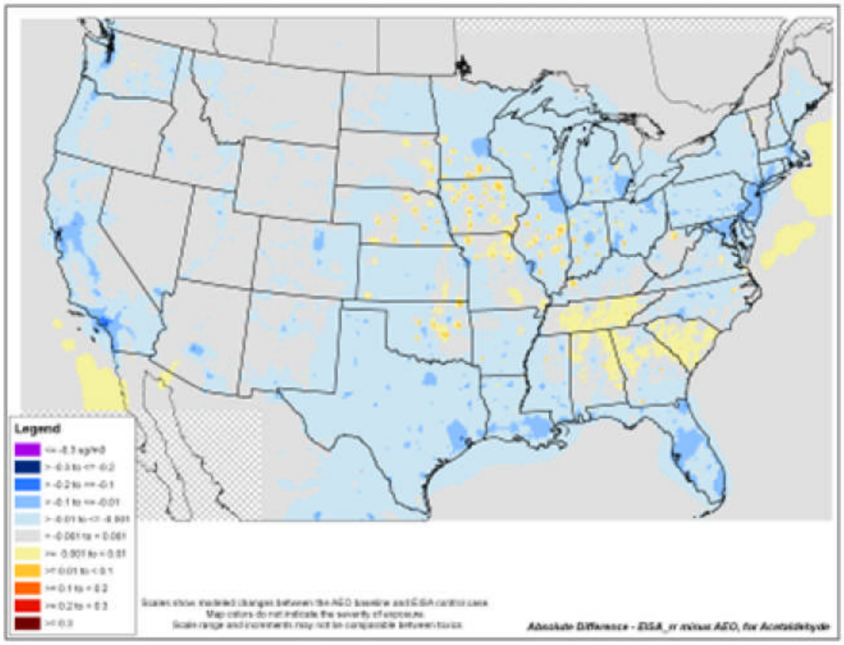


Figure 3A-2. Acetaldehyde Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.1.2 Formaldehyde

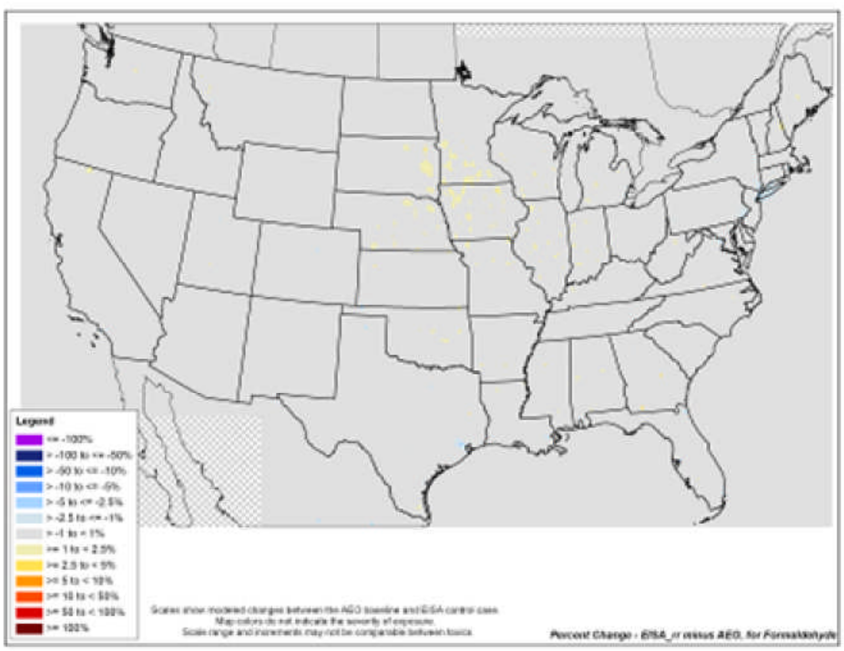


Figure 3A-3. Formaldehyde Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

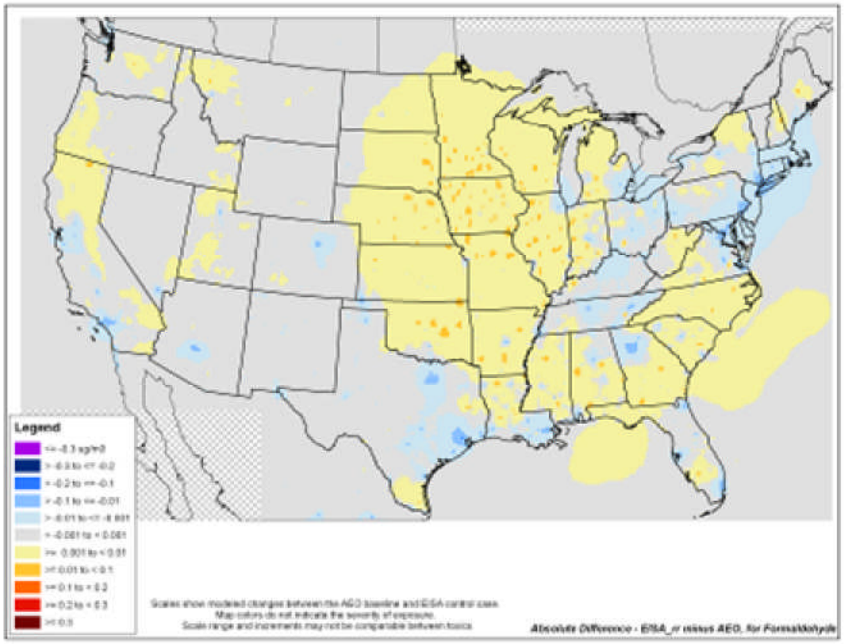


Figure 3A-4. Formaldehyde Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.1.3 Ethanol

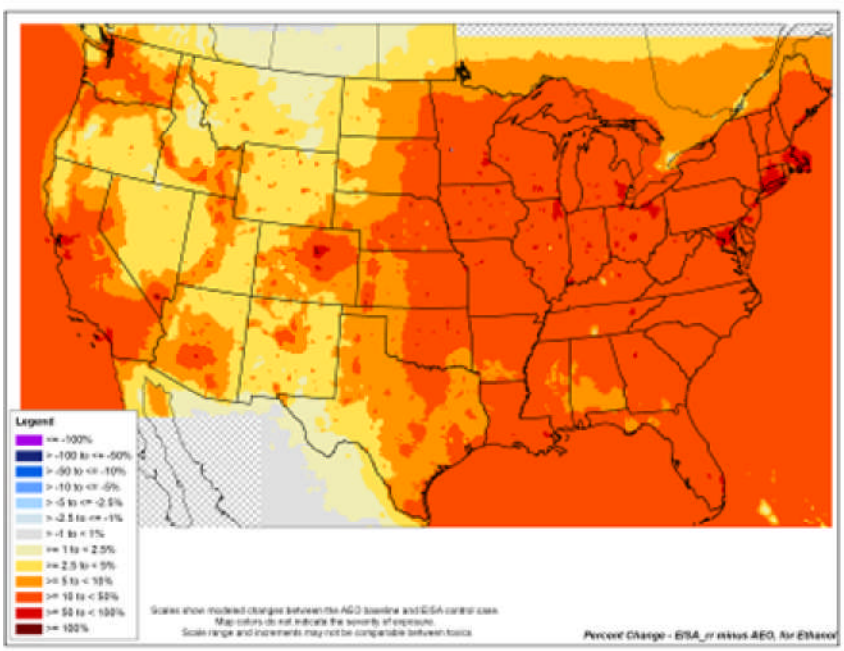


Figure 3A-5. Ethanol Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

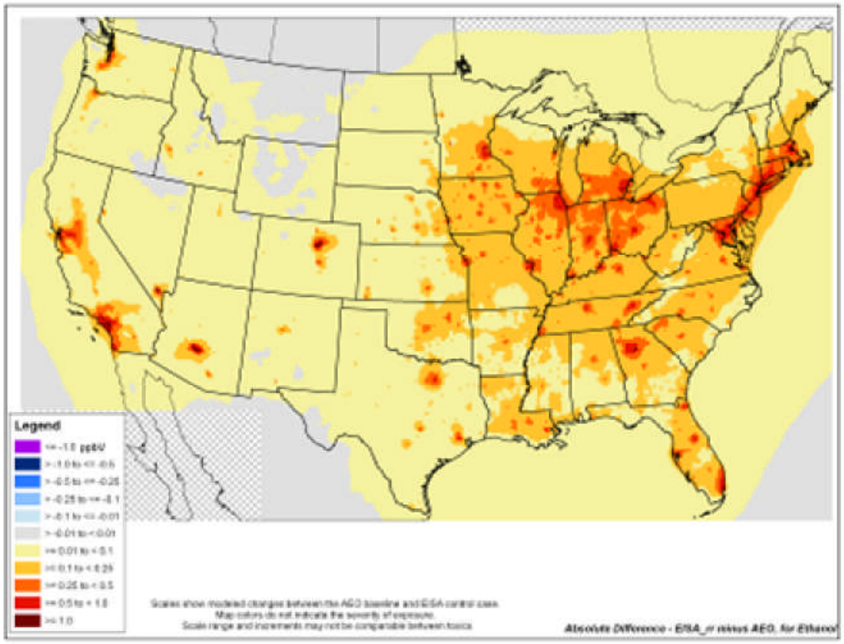


Figure 3A-6. Ethanol Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.1.4 Benzene

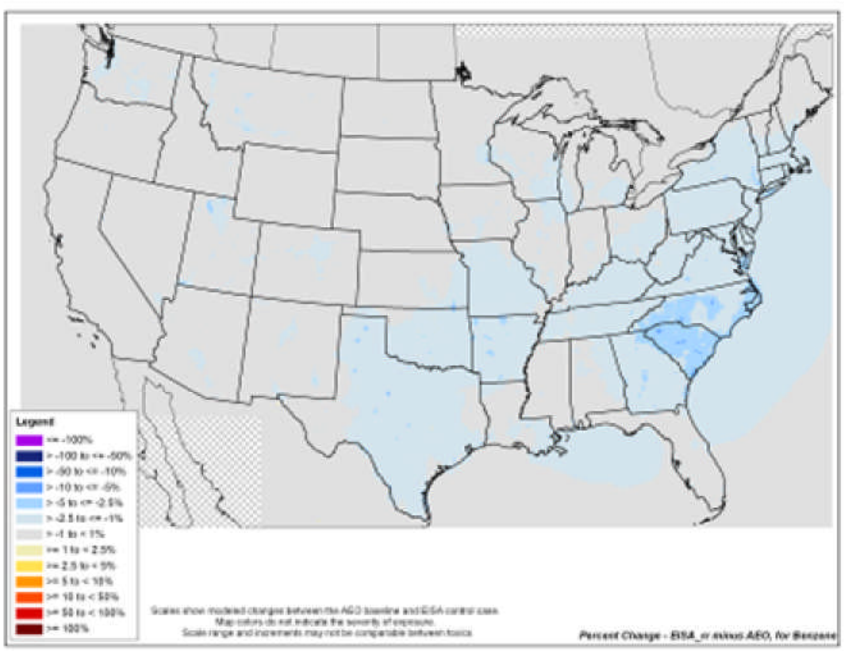


Figure 3A-7. Benzene Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

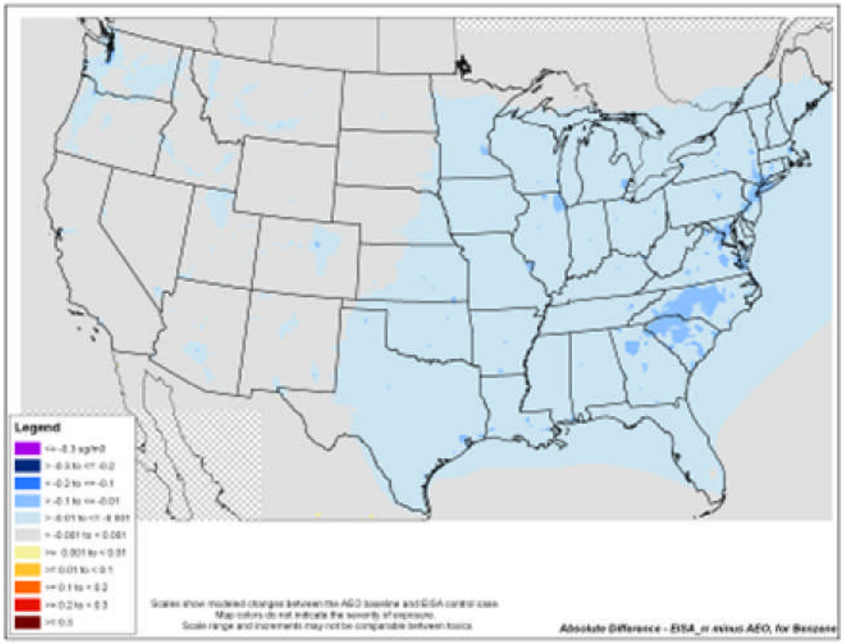


Figure 3A-8. Benzene Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.1.4 1,3-Butadiene

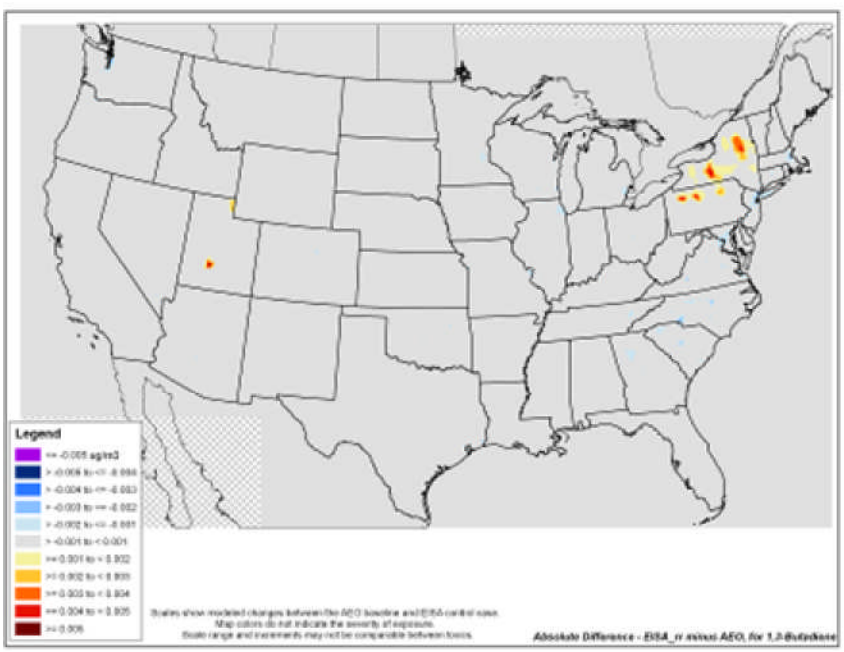


Figure 3A-9. 1,3-Butadiene Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

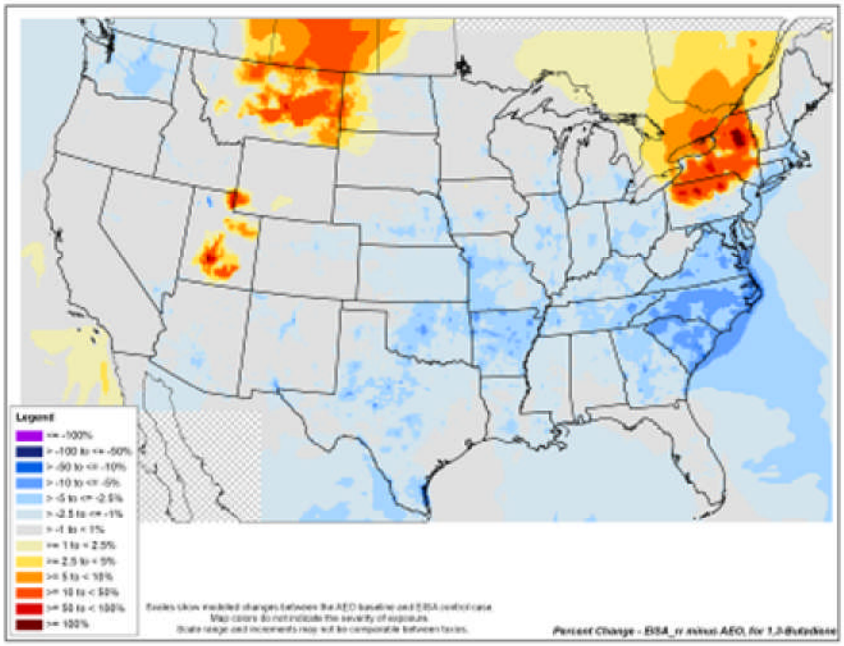


Figure 3A-10. 1,3-Butadiene Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.1.4 Acrolein

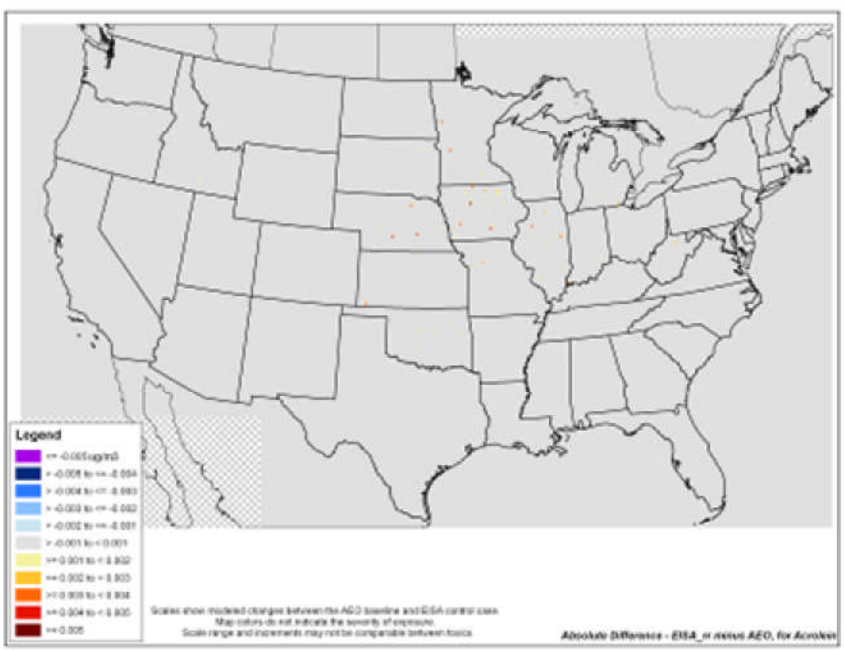


Figure 3A-11. Acrolein Annual Percent Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

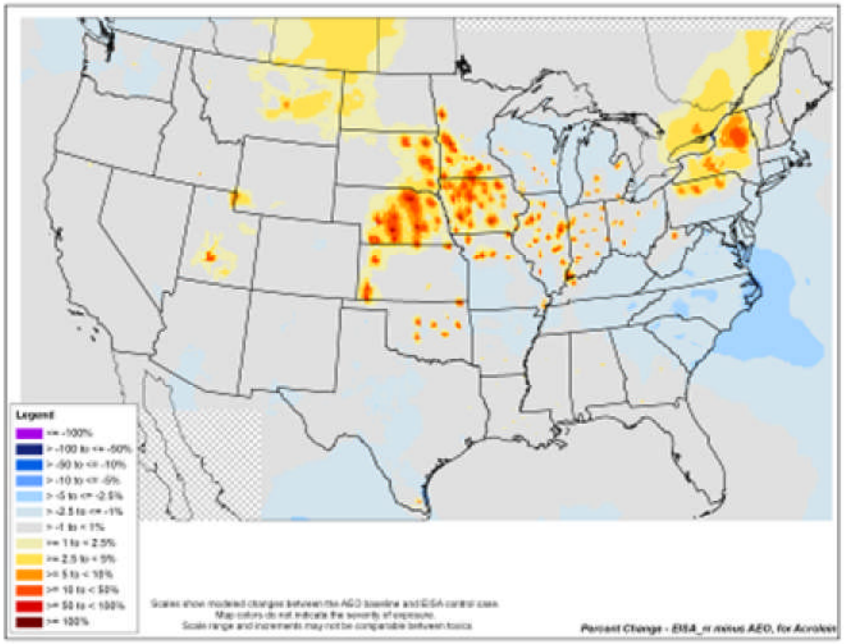


Figure 3A-12. Acrolein Annual Absolute Change in Concentration Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022

3A.2 Seasonal Change Ambient Concentration Maps for Air Toxics using the RFS1 Reference Case

The following section presents maps of seasonal changes in ambient concentrations of modeled air toxics in 2022 using the RFS1 reference case compared to the RFS2 control case.

3A.2.1 Acetaldehyde

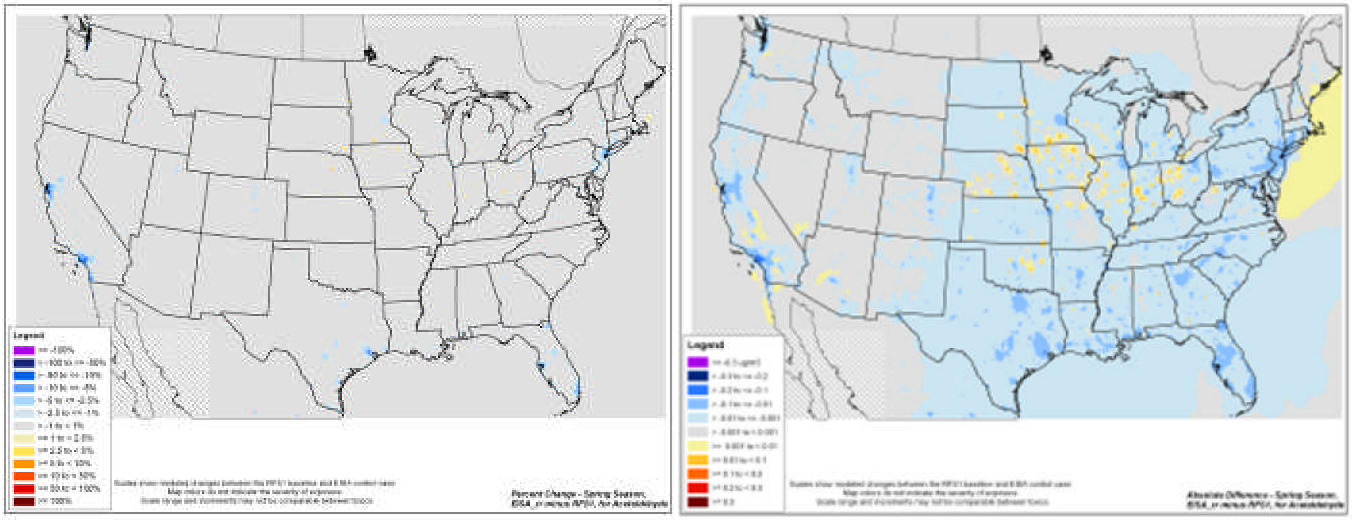


Figure 3A-13. Spring Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

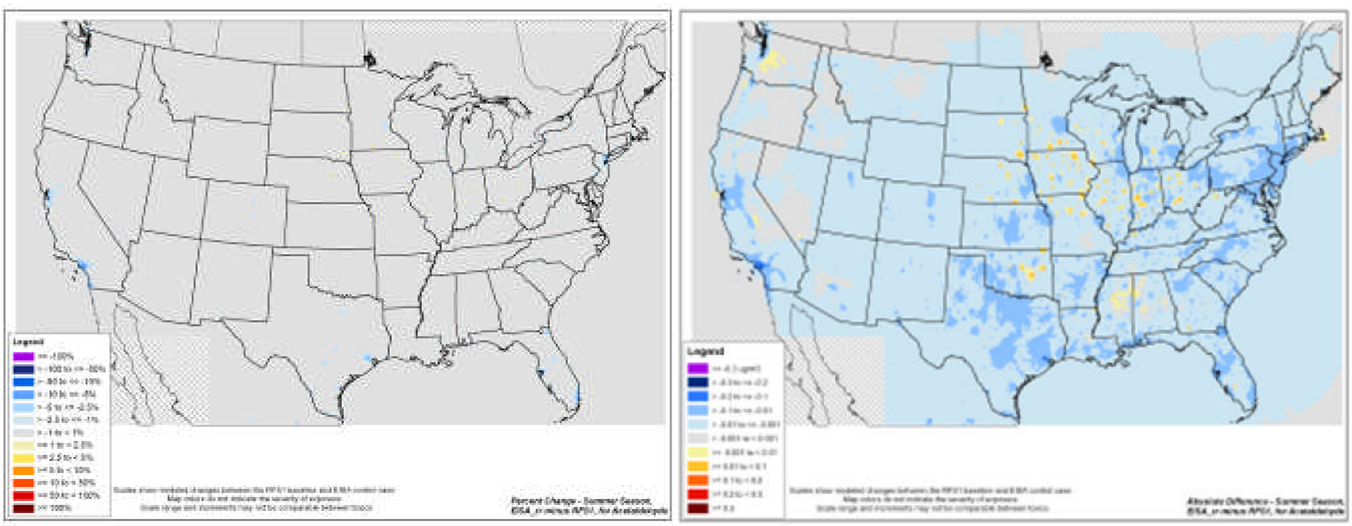


Figure 3A-14. Summer Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

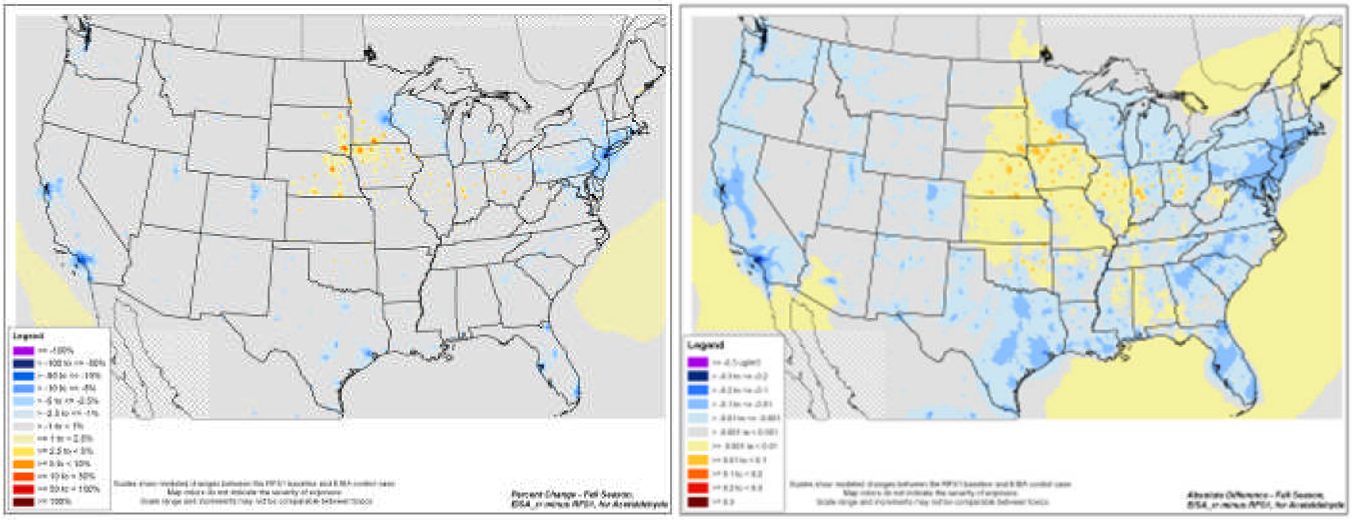


Figure 3A-15. Fall Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

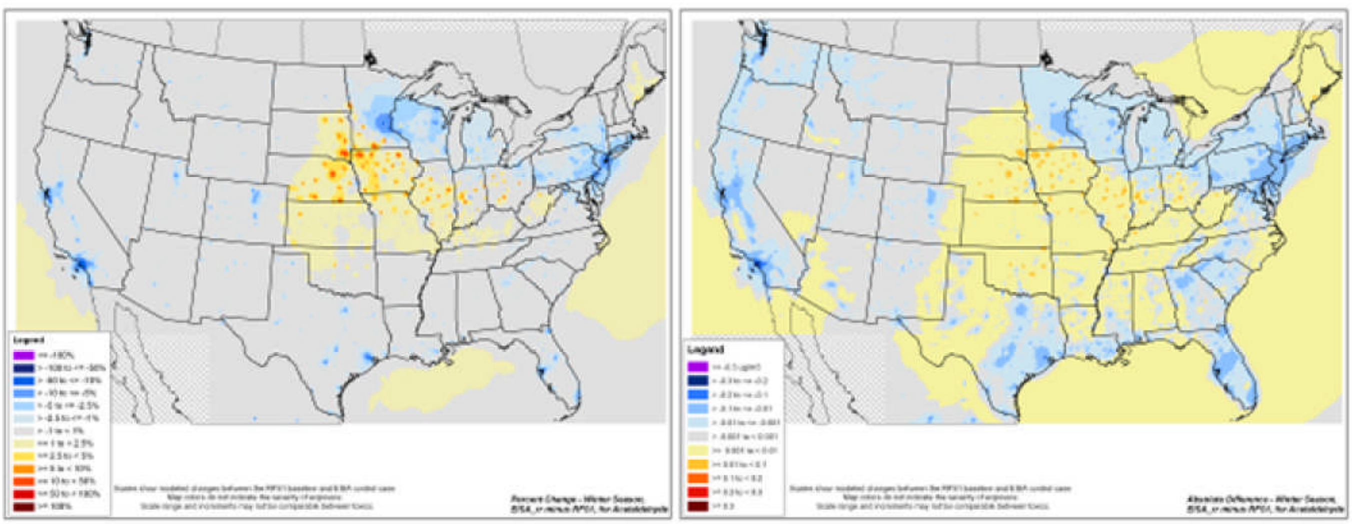


Figure 3A-16. Winter Changes in Acetaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.2.2 Formaldehyde

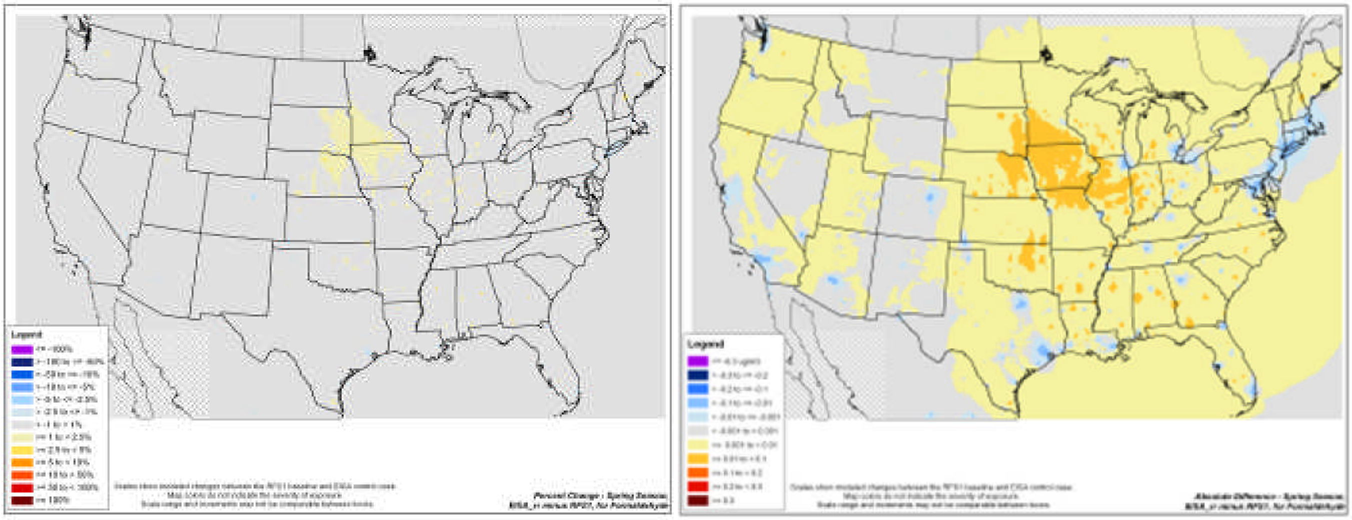


Figure 3A-17. Spring Changes in Formaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

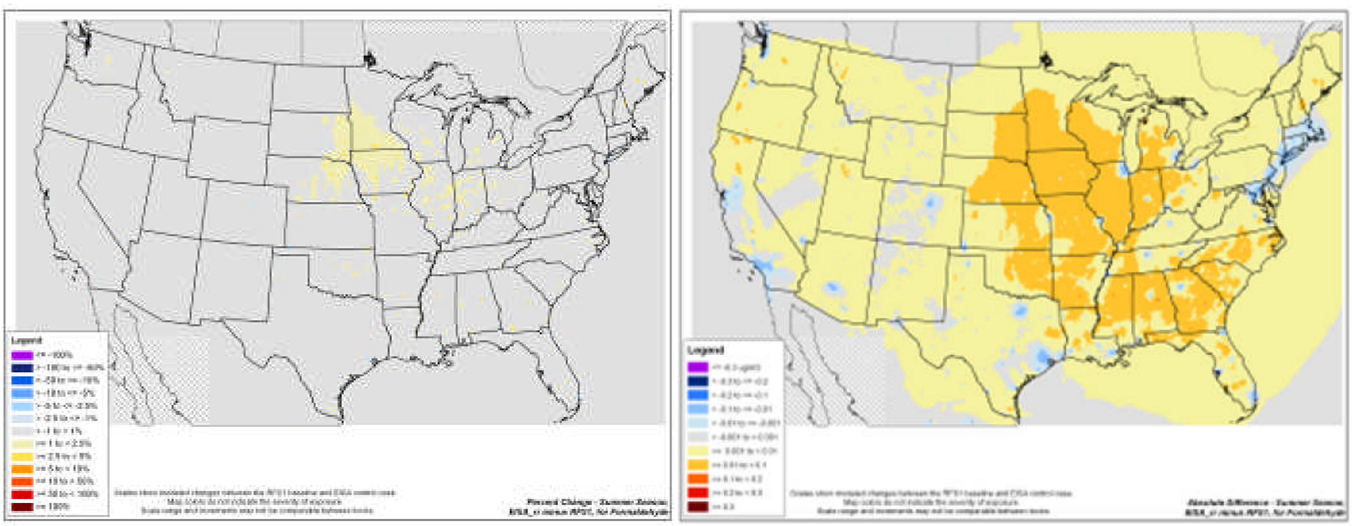


Figure 3A-18. Summer Changes in Formaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

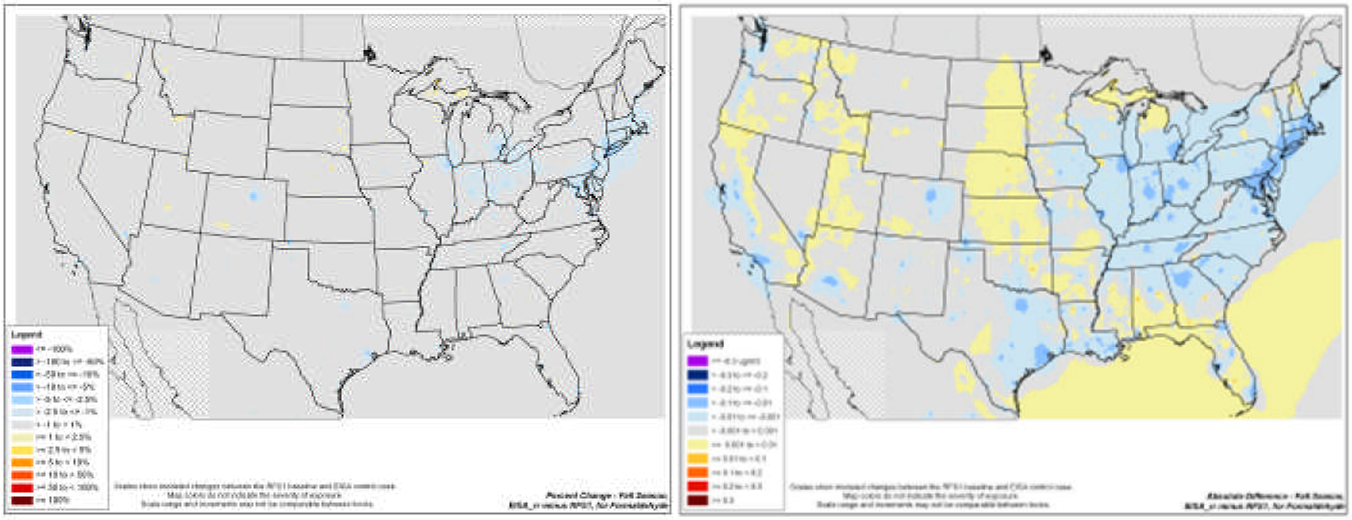


Figure 3A-19. Fall Changes in Formaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

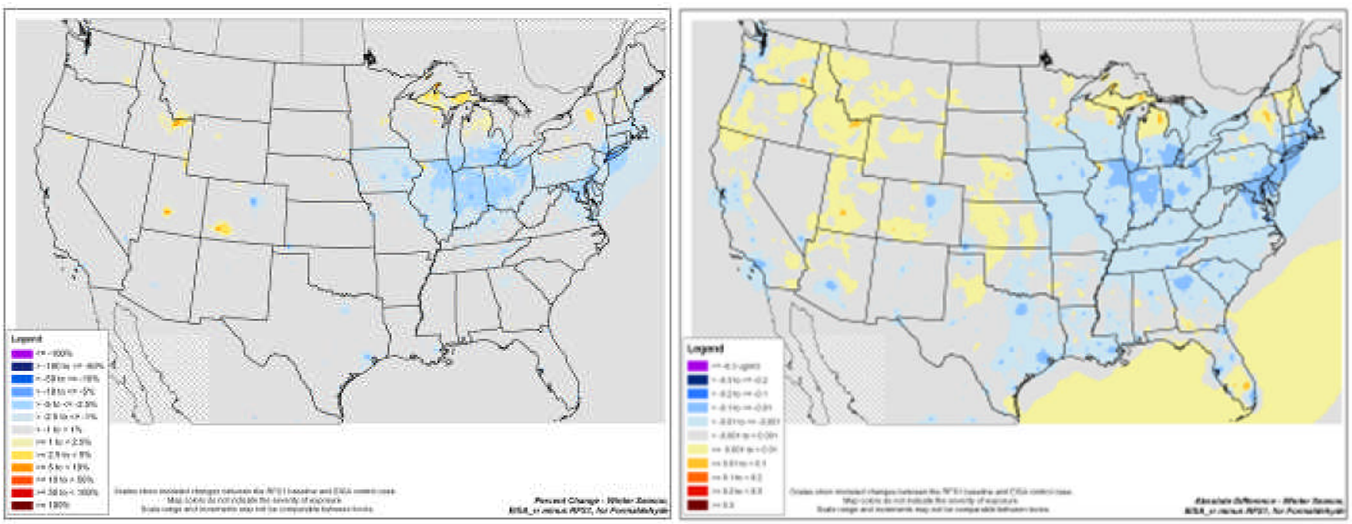


Figure 3A-20. Winter Changes in Formaldehyde Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.2.3 Ethanol

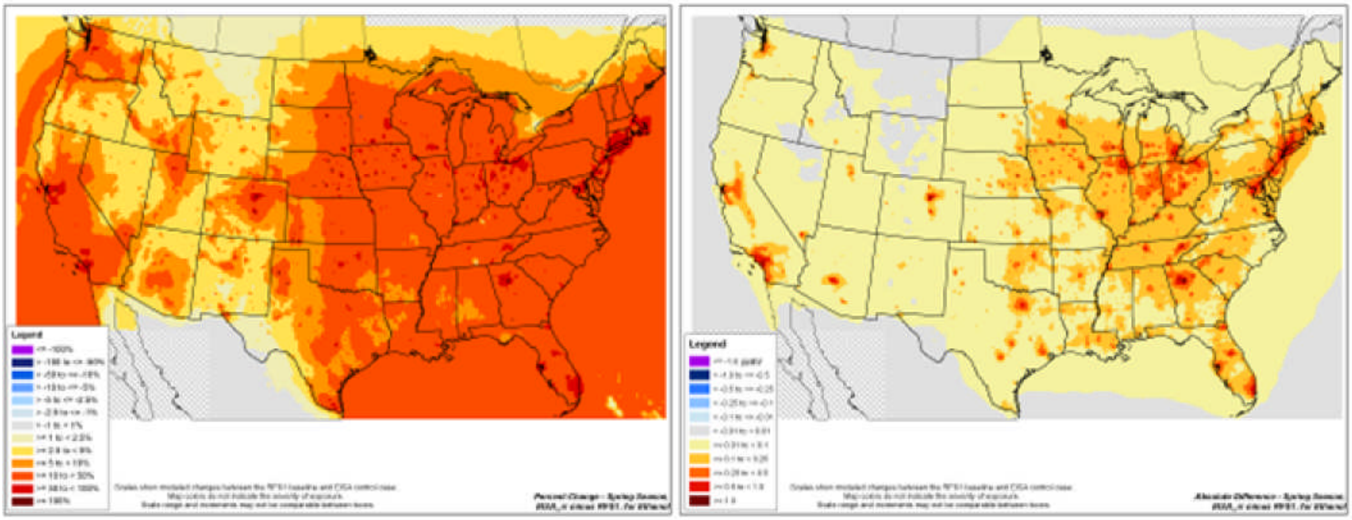


Figure 3A-21. Spring Changes in Ethanol Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

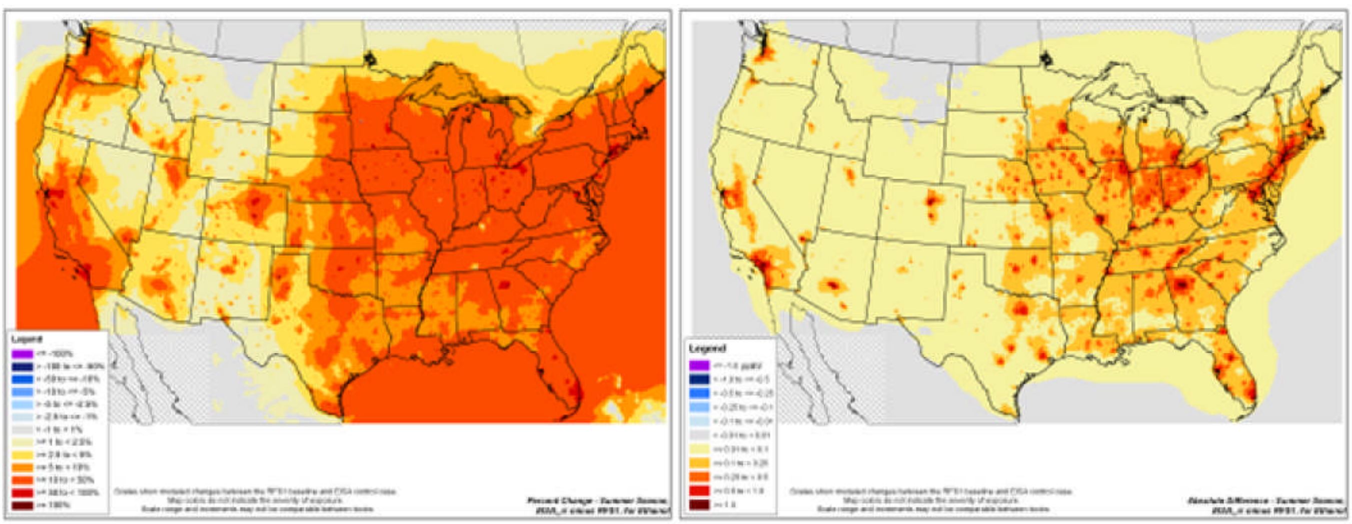


Figure 3A-22. Summer Changes in Ethanol Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

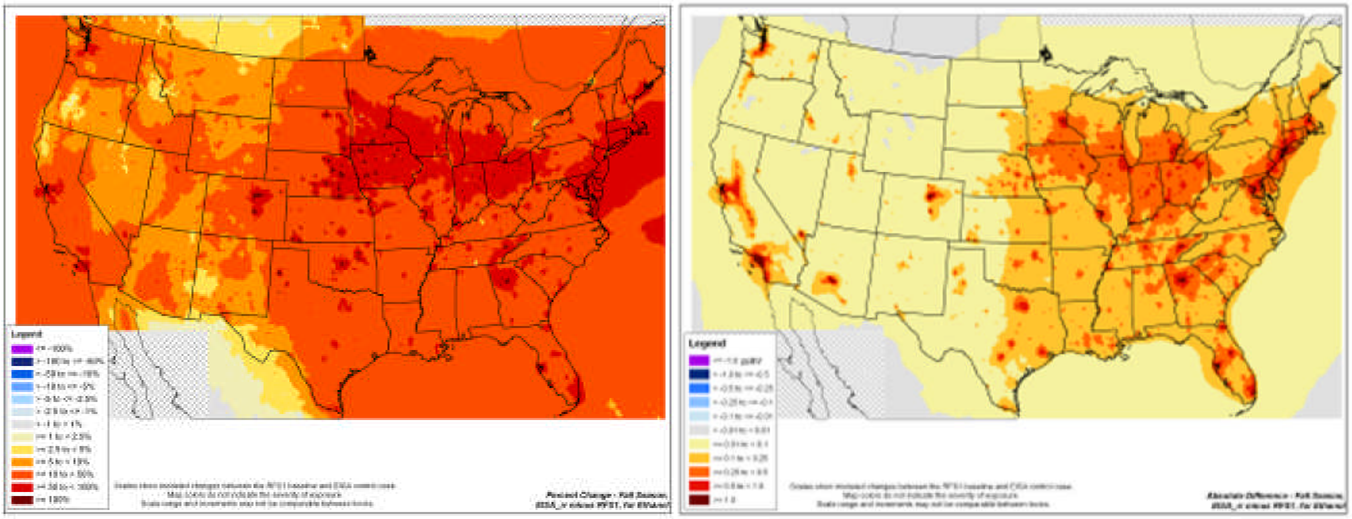


Figure 3A-23. Fall Changes in Ethanol Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

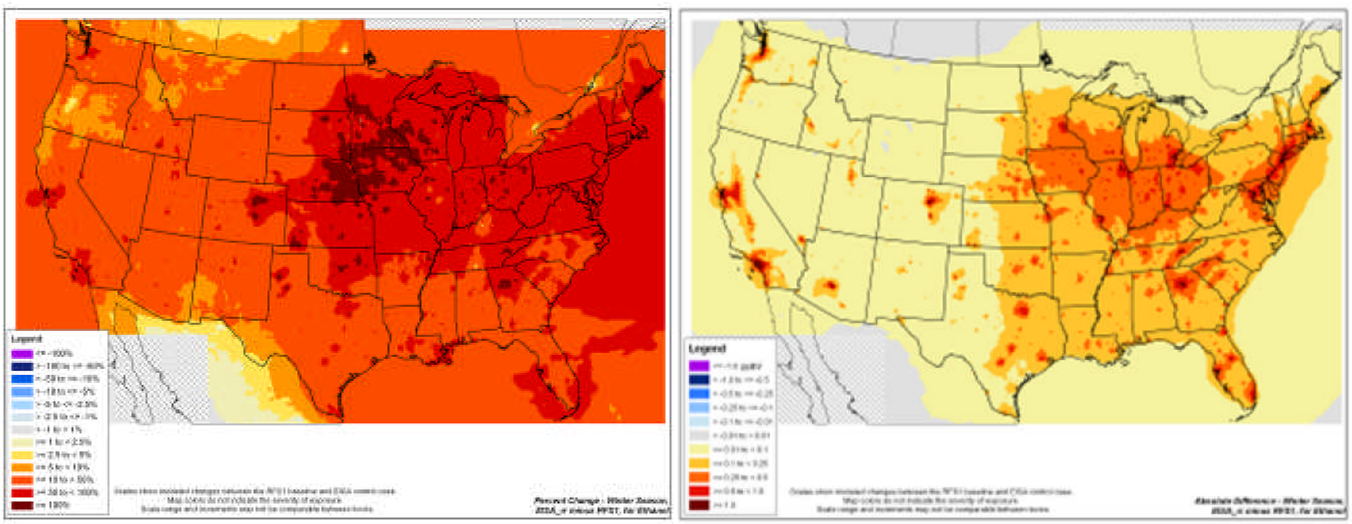


Figure 3A-24. Winter Changes in Ethanol Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.2.4 Benzene

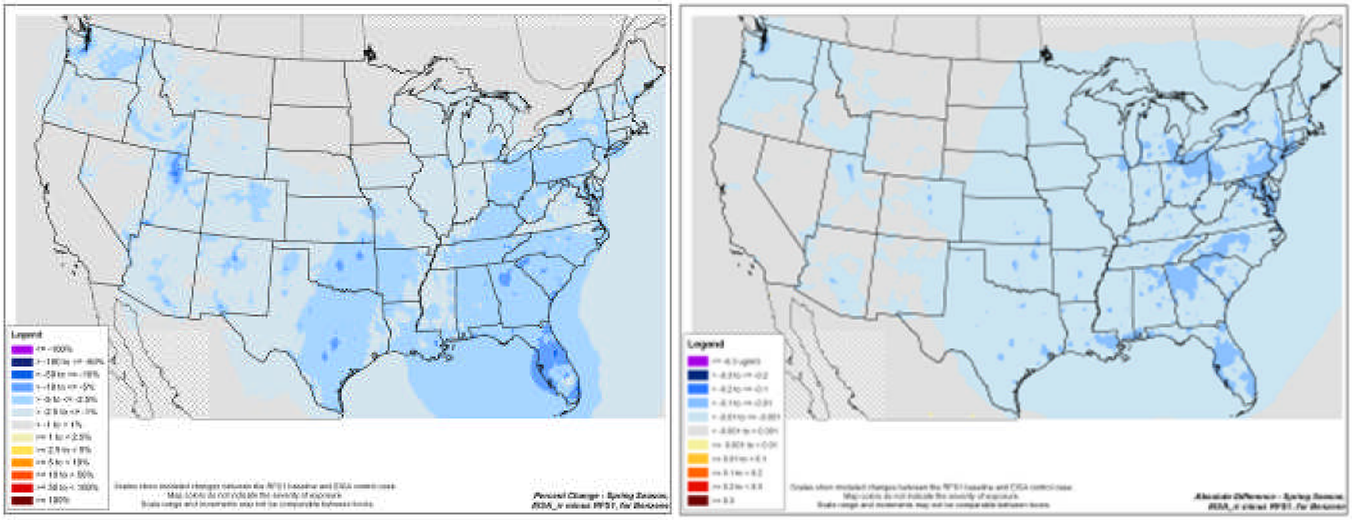


Figure 3A-25. Spring Changes in Benzene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

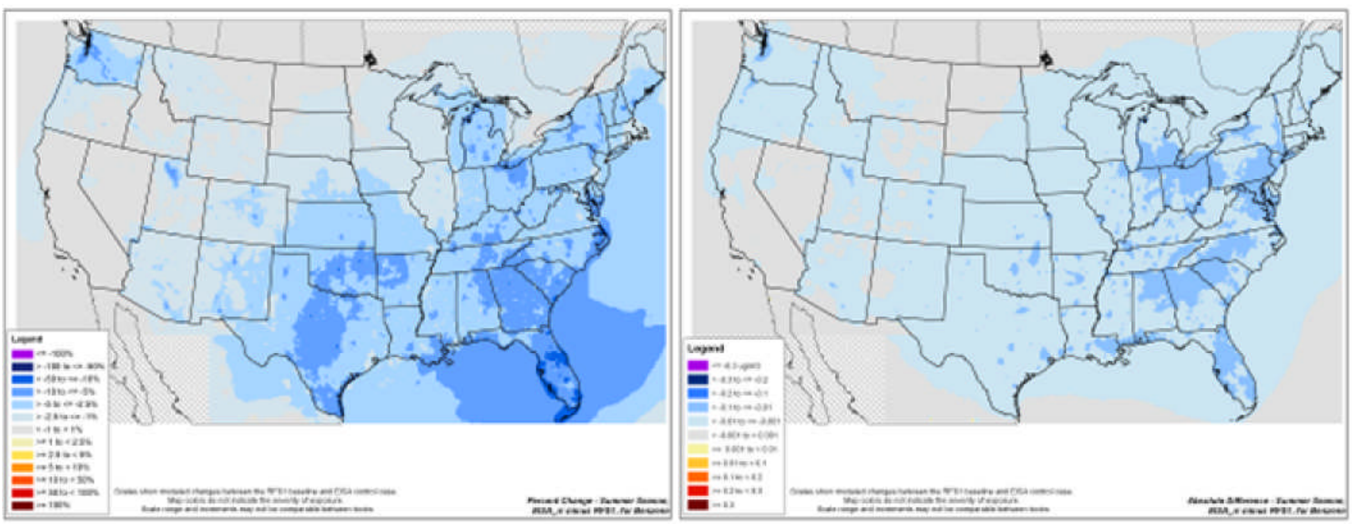


Figure 3A-26. Summer Changes in Benzene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

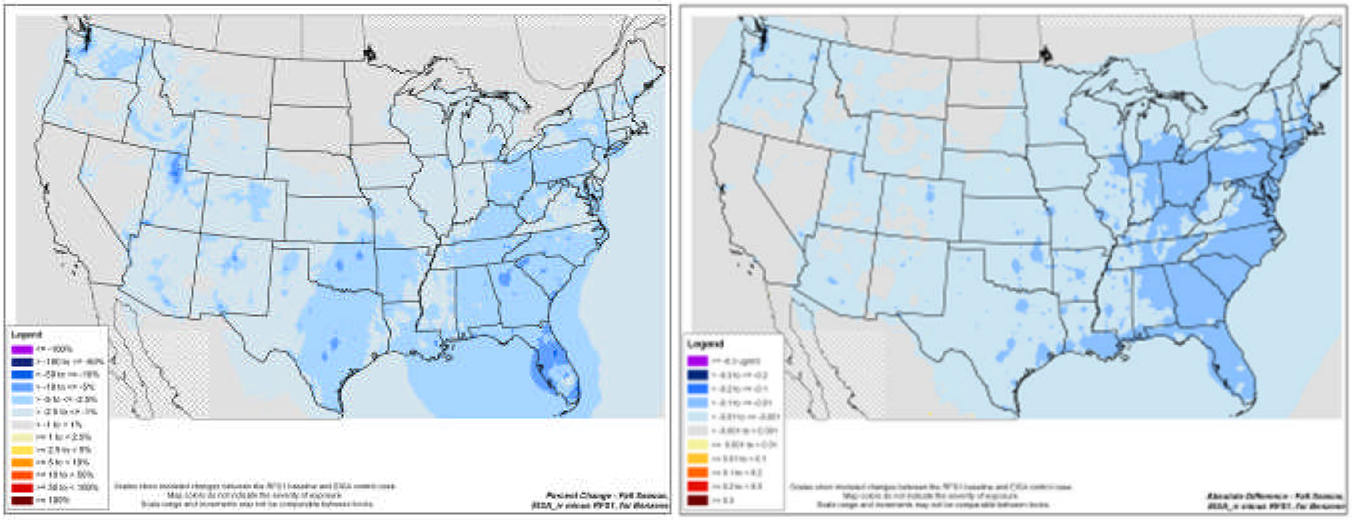


Figure 3A-27. Fall Changes in Benzene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

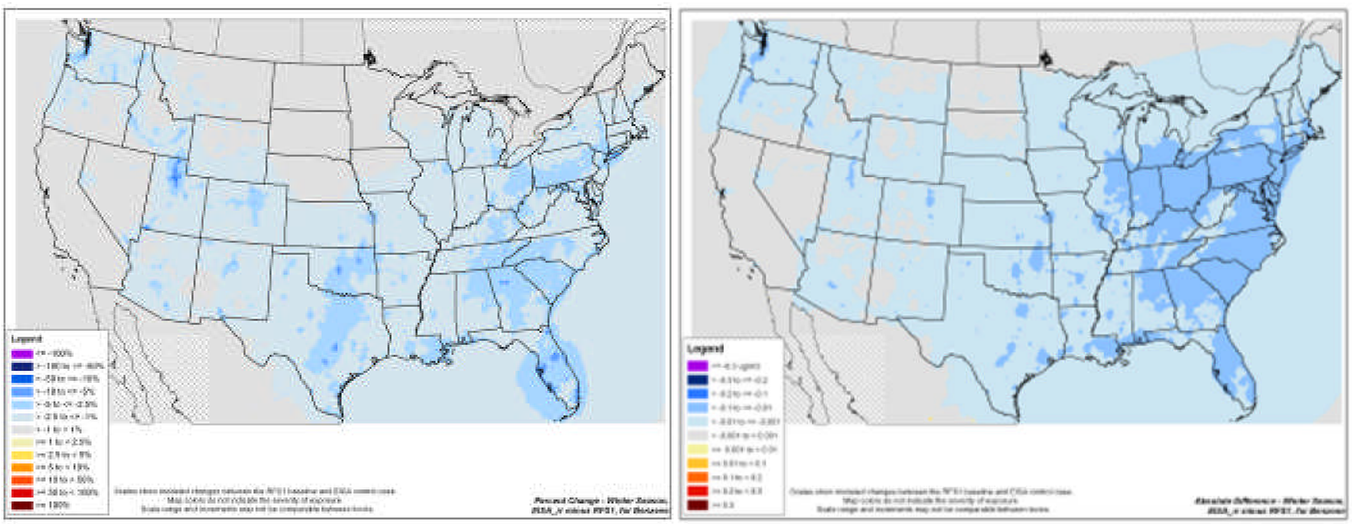


Figure 3A-28. Winter Changes in Benzene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.2.5 1,3-Butadiene

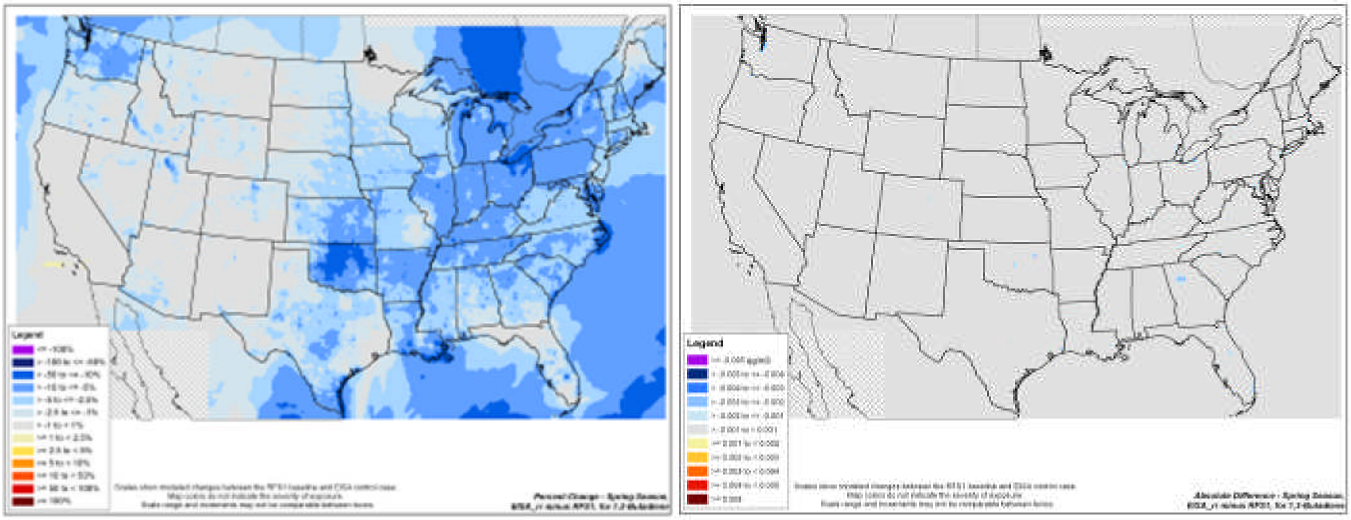


Figure 3A-29. Spring Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

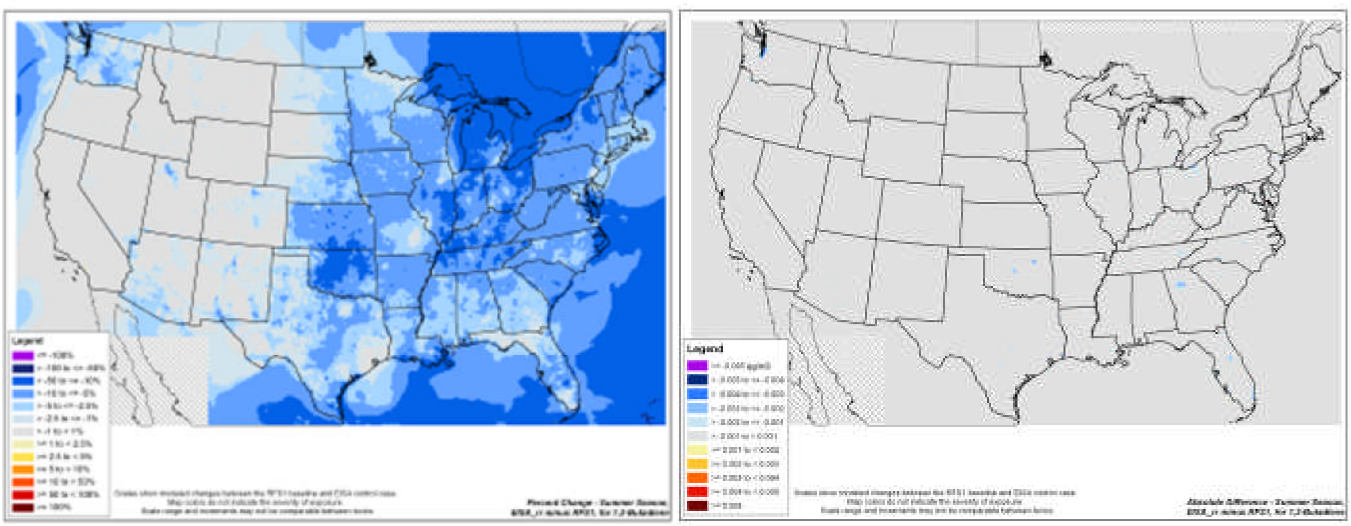


Figure 3A-30. Summer Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

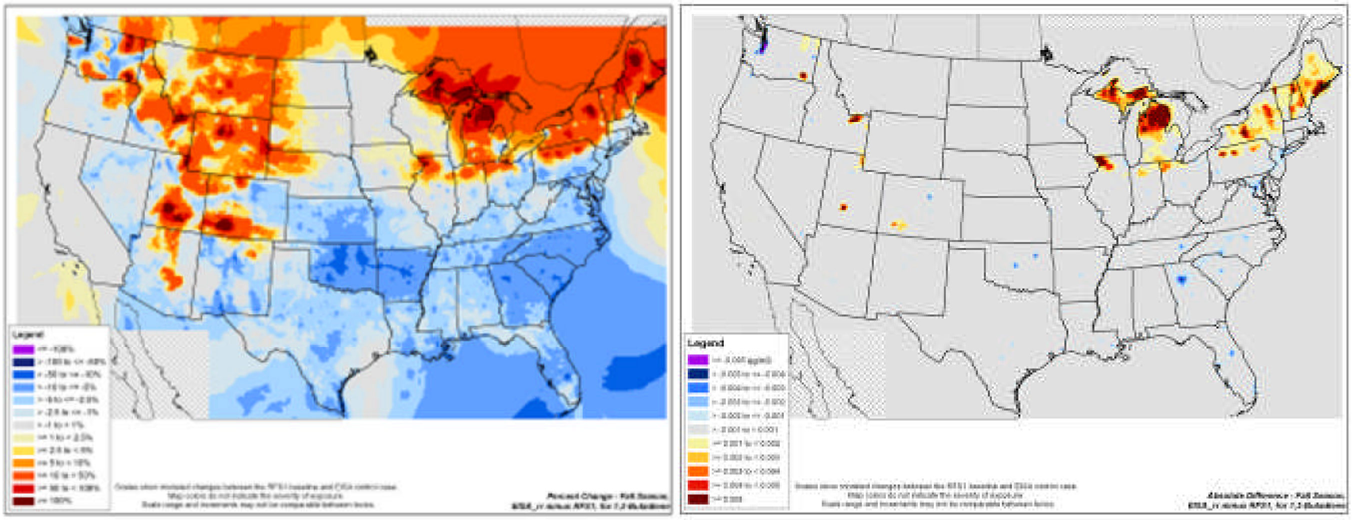


Figure 3A-31. Fall Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

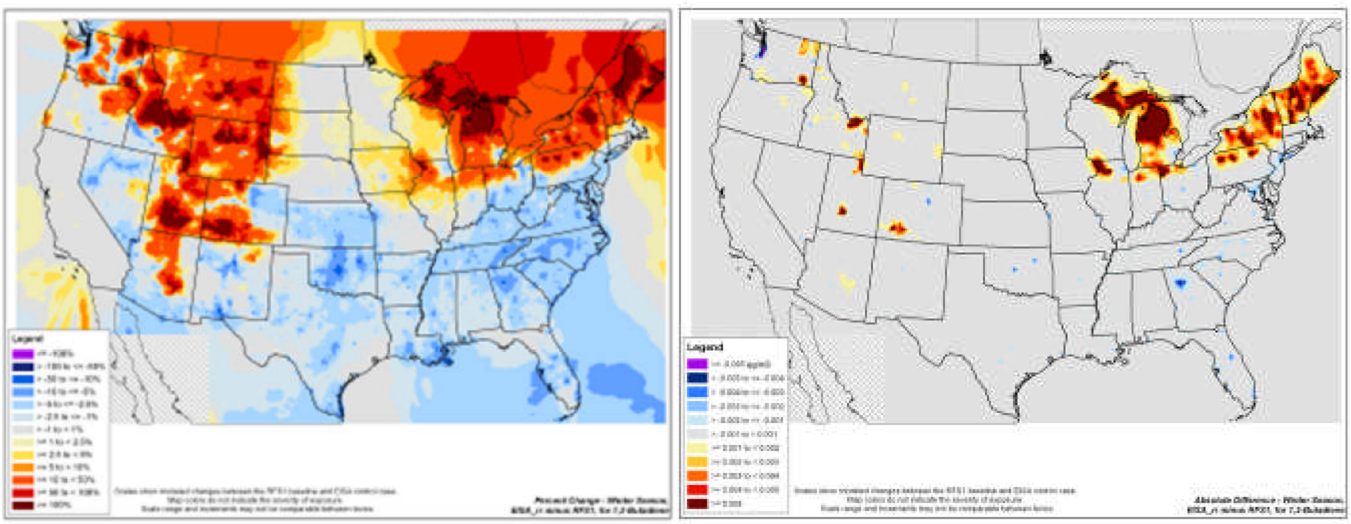


Figure 3A-32. Winter Changes in 1,3-Butadiene Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

3A.2.6 Acrolein

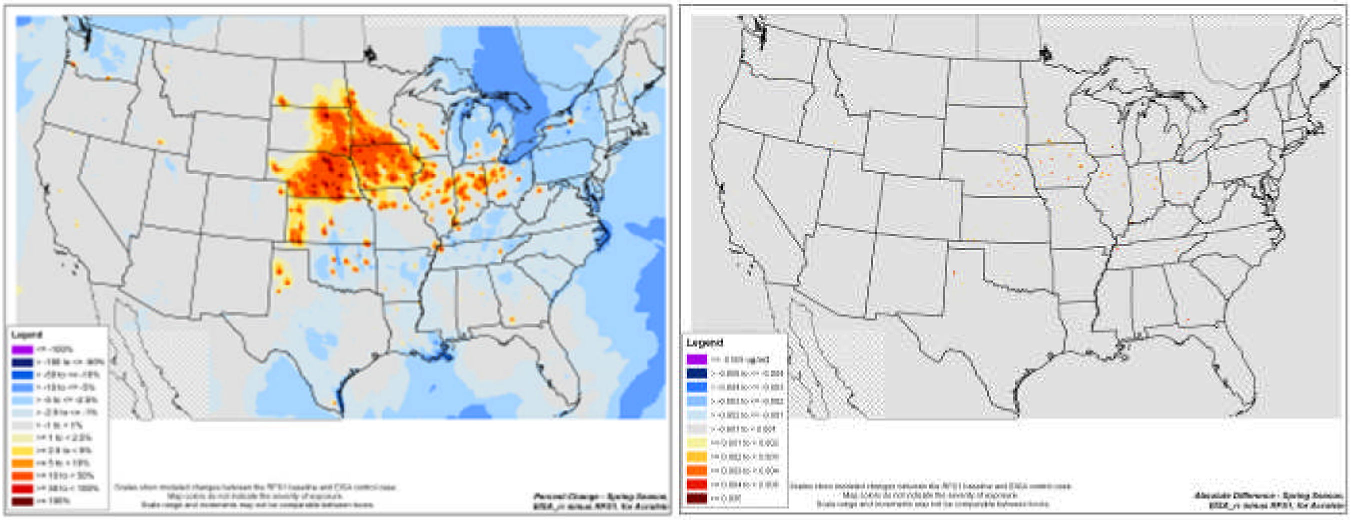


Figure 3A-33. Spring Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

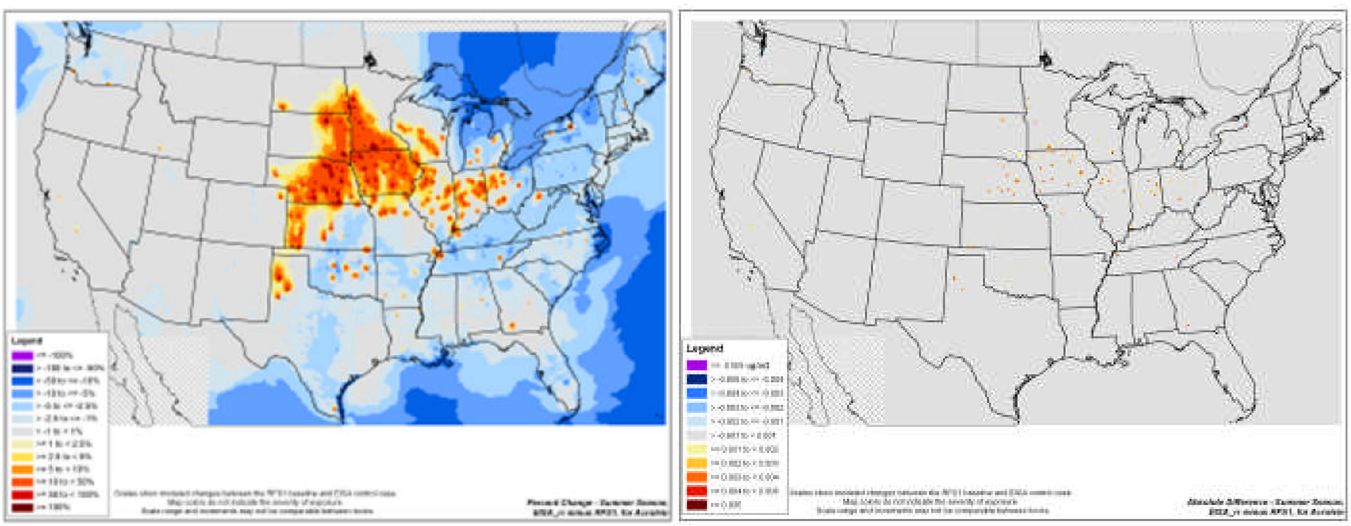


Figure 3A-34. Summer Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

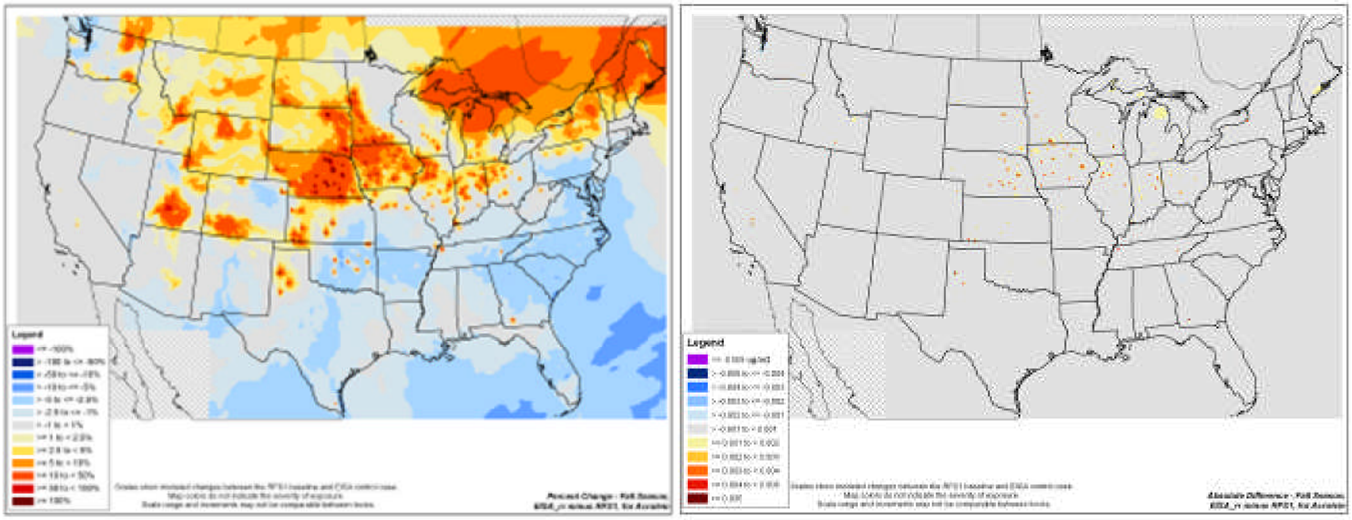


Figure 3A-35. Fall Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

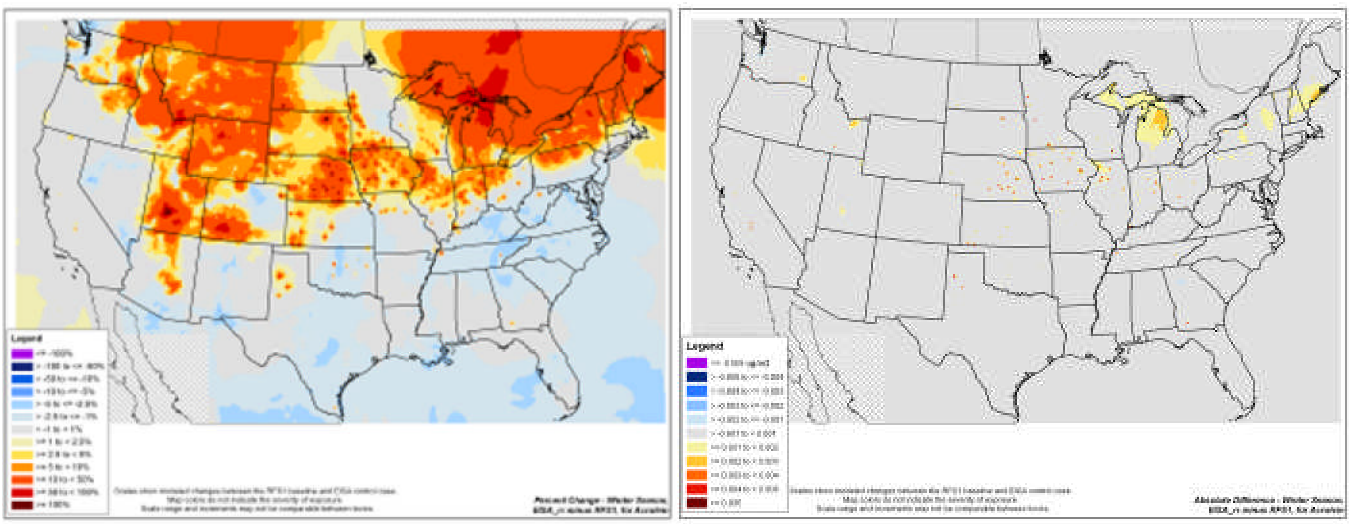


Figure 3A-36. Winter Changes in Acrolein Ambient Concentrations Between the RFS1 Mandate Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.3 Seasonal Change Ambient Concentration Maps for Air Toxics using the AEO Reference Case

The following section presents maps of seasonal changes in ambient concentrations of modeled air toxics in 2022 using the AEO 2007 reference case compared to the RFS2 control case.

3A.3.1 Acetaldehyde

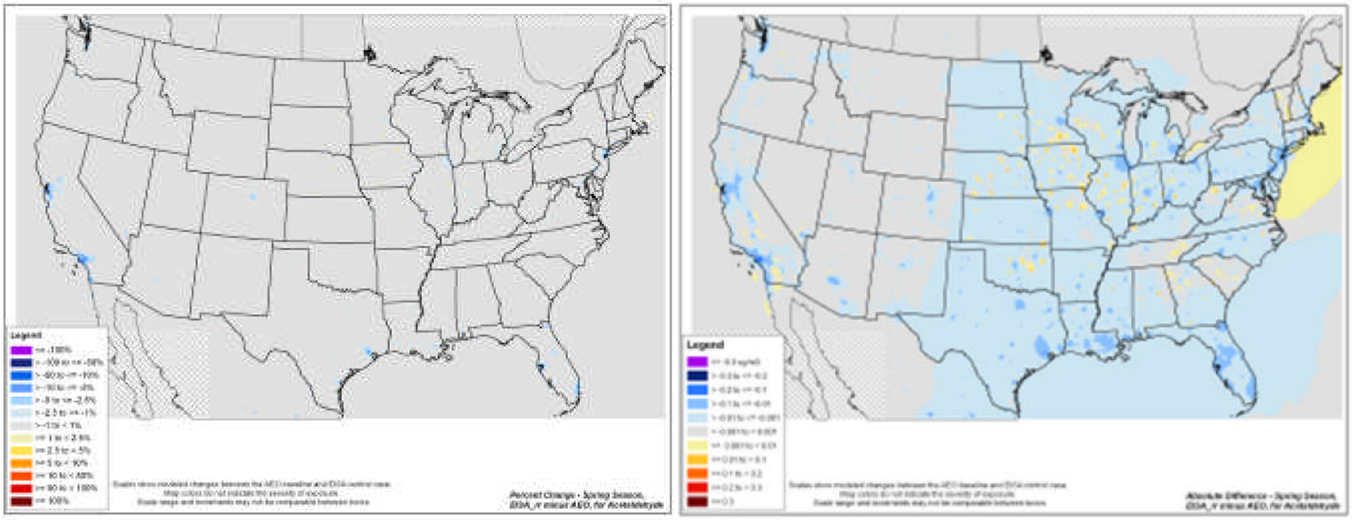


Figure 3A-37. Spring Changes in Acetaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

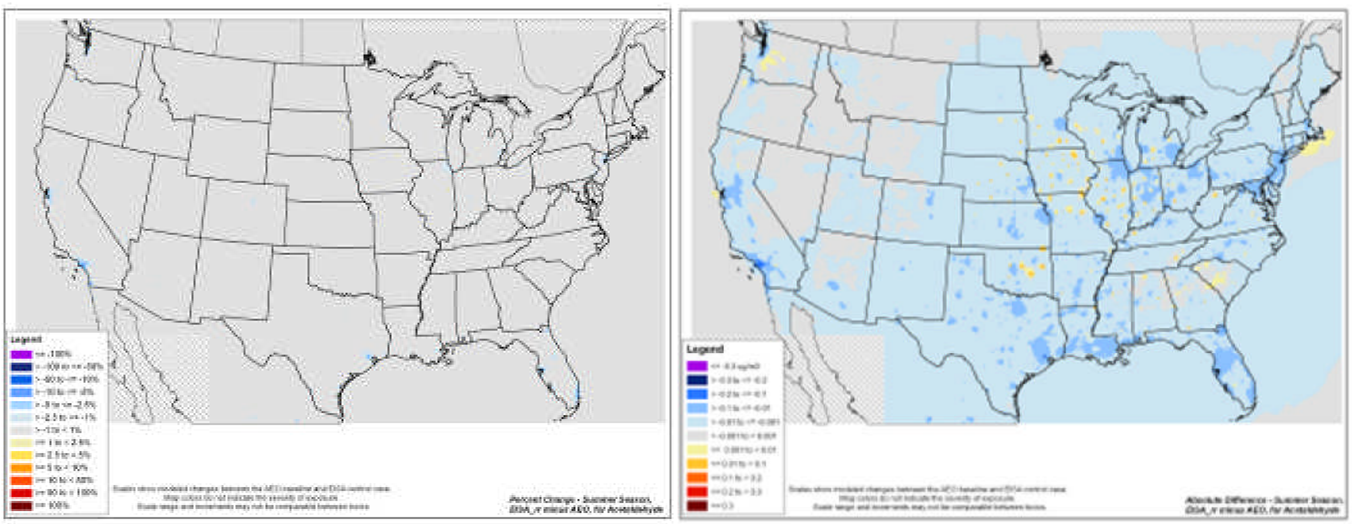


Figure 3A-38. Summer Changes in Acetaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

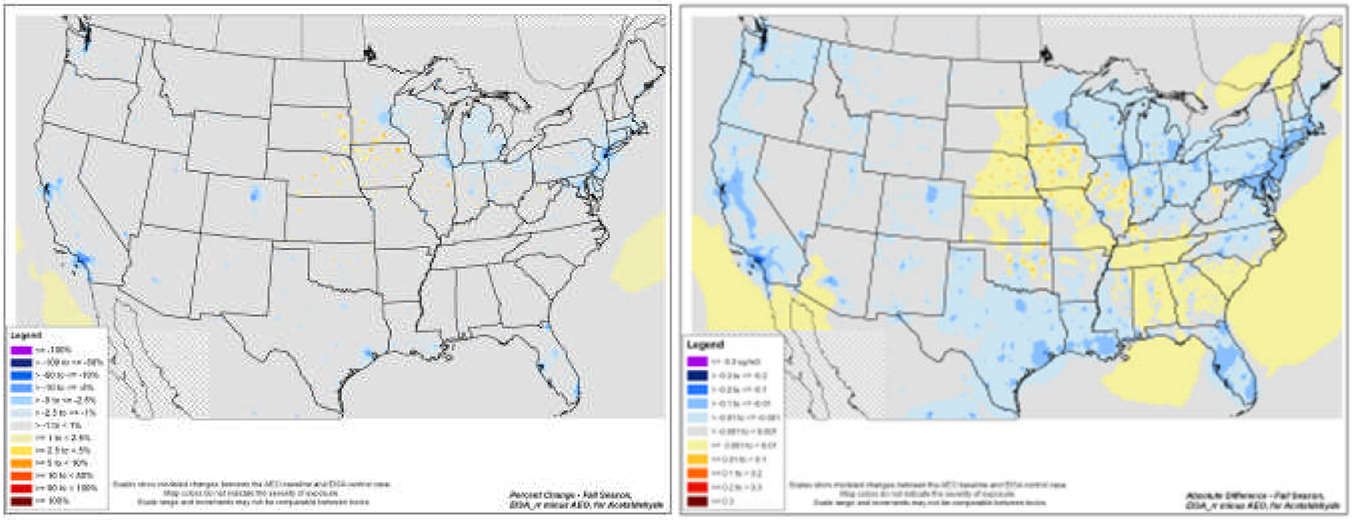


Figure 3A-39. Fall Changes in Acetaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

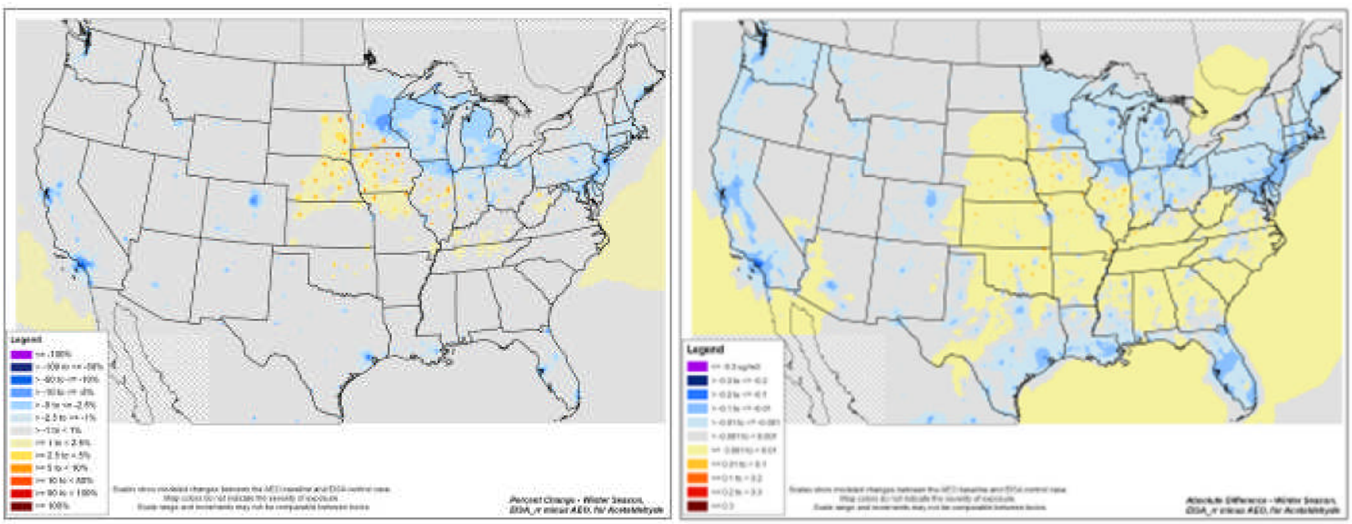


Figure 3A-40. Winter Changes in Acetaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.3.2 Formaldehyde

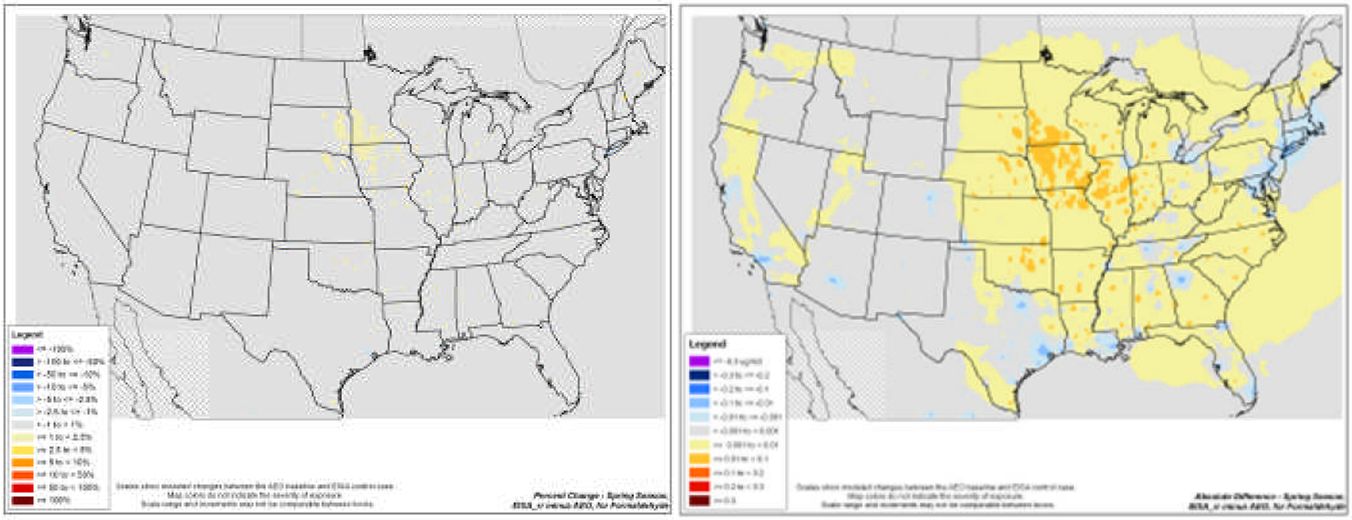


Figure 3A-41. Spring Changes in Formaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

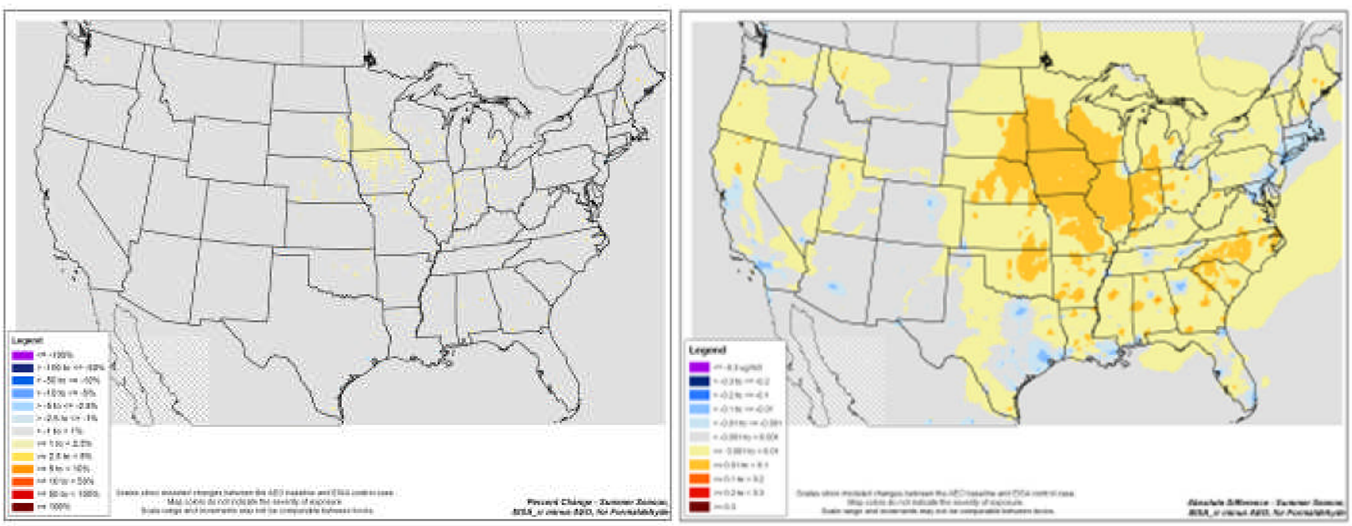


Figure 3A-42. Summer Changes in Formaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m³)

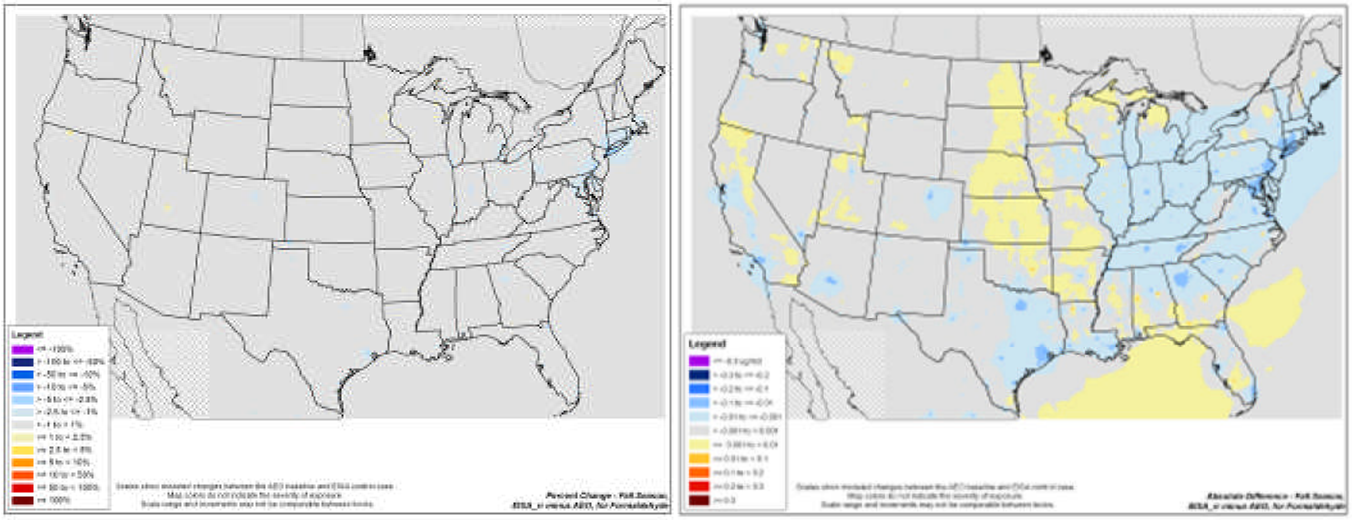


Figure 3A-43. Fall Changes in Formaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

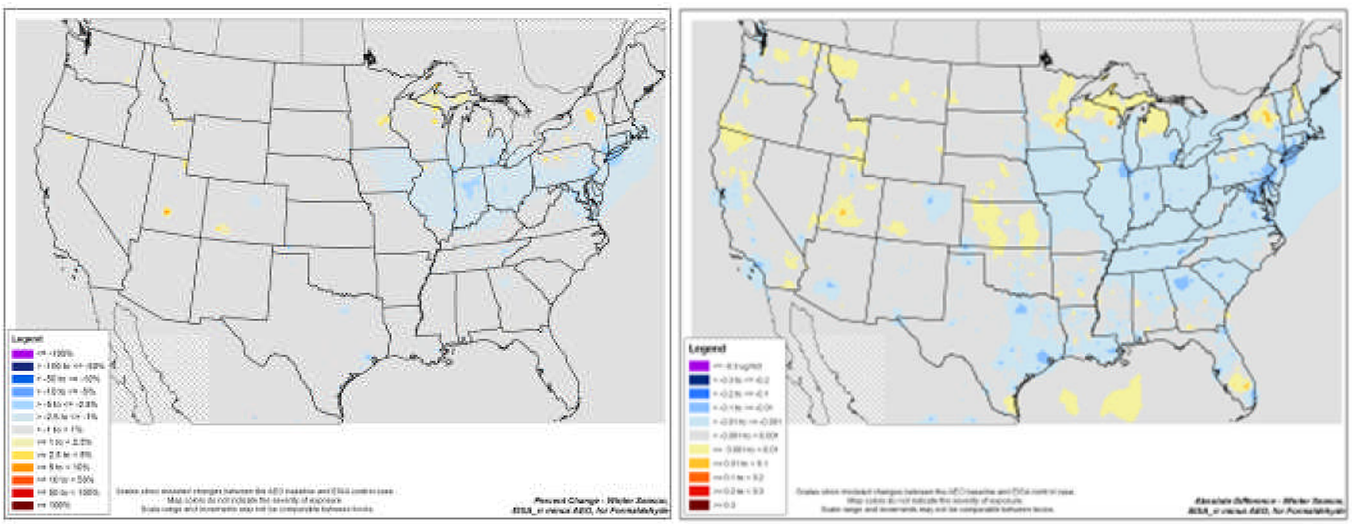


Figure 3A-44. Winter Changes in Formaldehyde Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.3.3 Ethanol

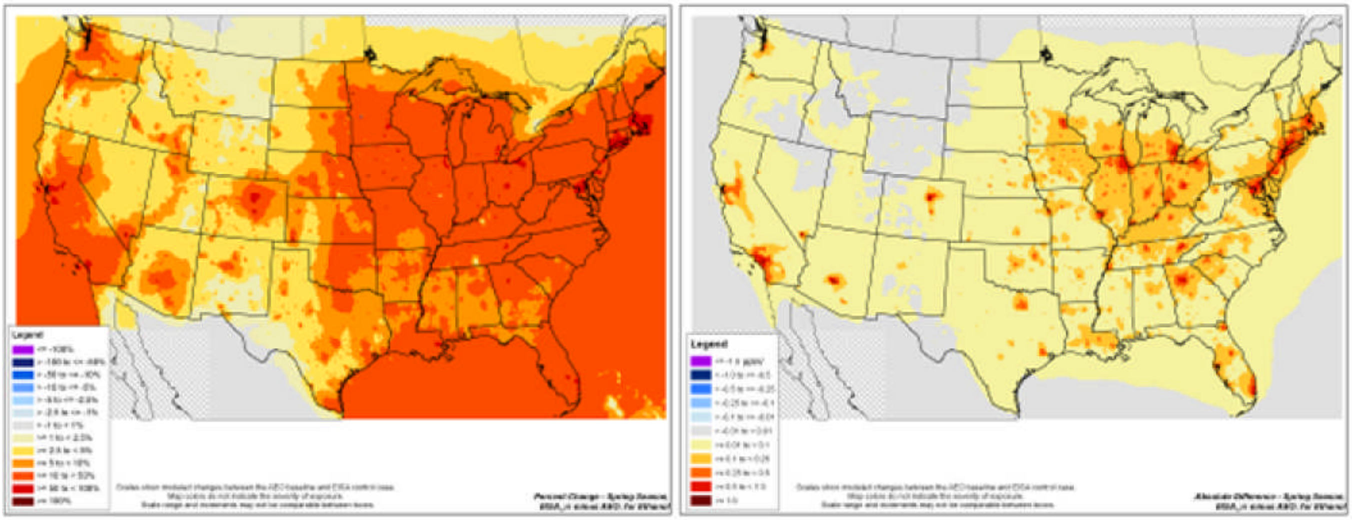


Figure 3A-45. Spring Changes in Ethanol Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

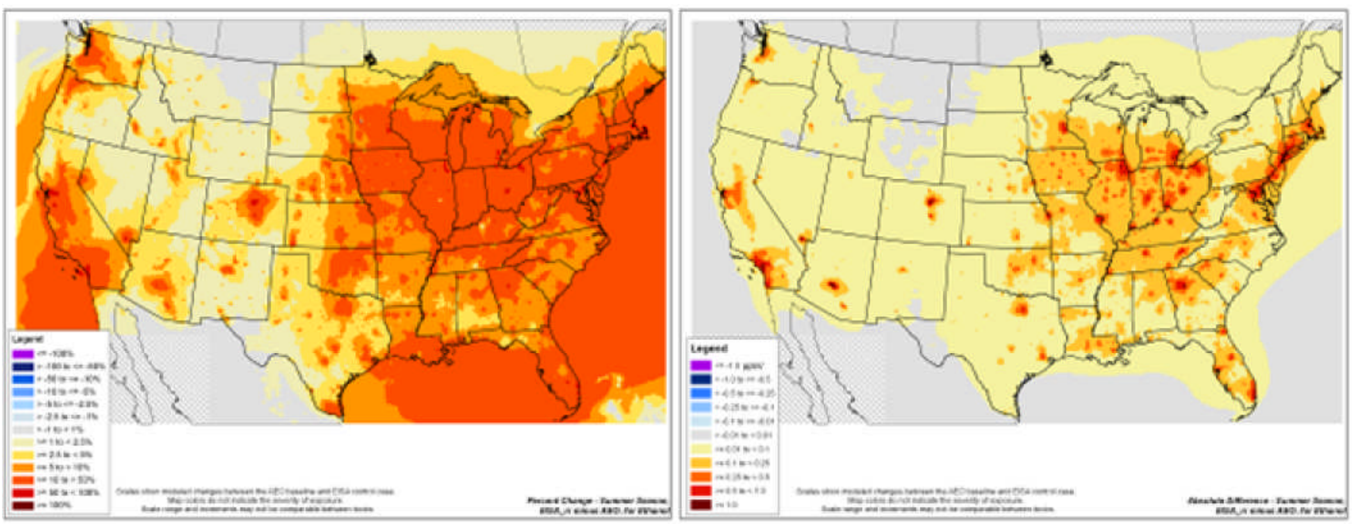


Figure 3A-46. Summer Changes in Ethanol Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

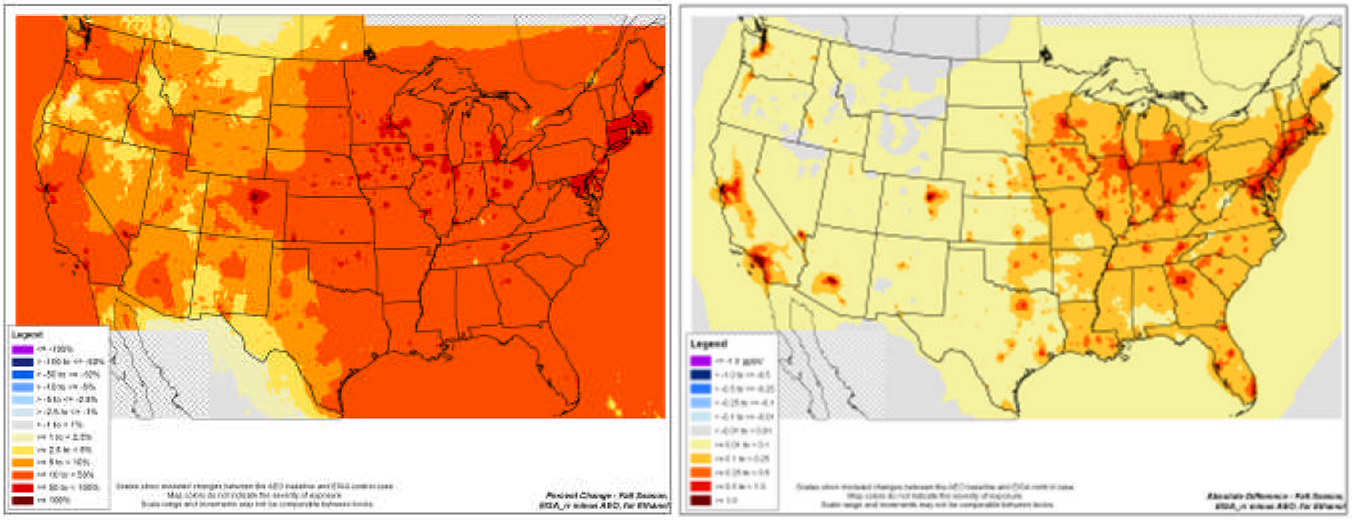


Figure 3A-47. Fall Changes in Ethanol Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

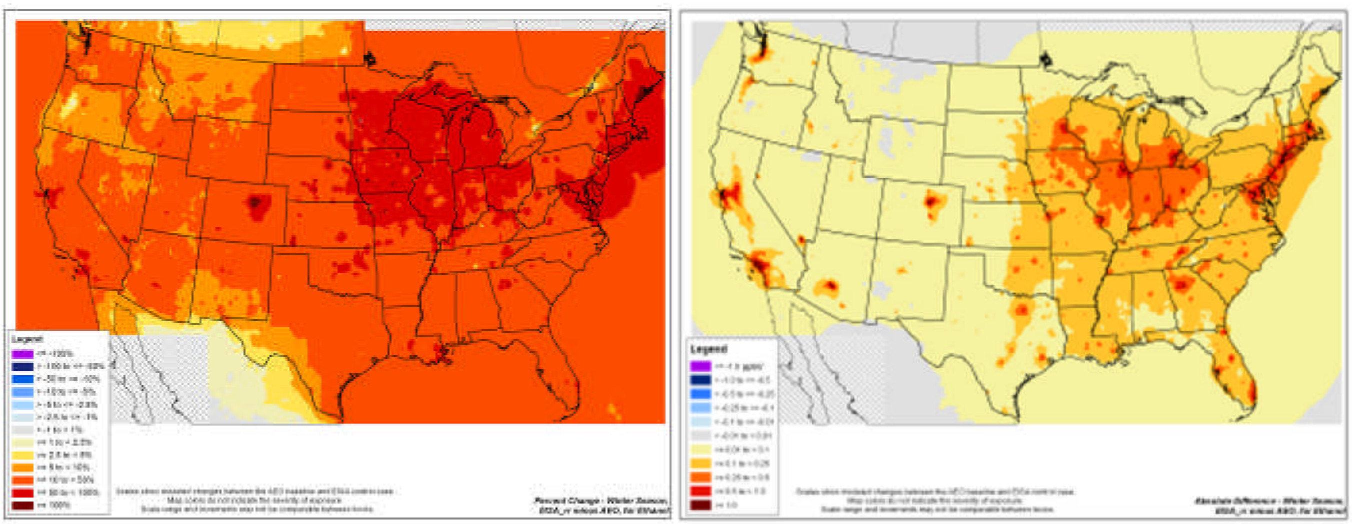


Figure 3A-48. Winter Changes in Ethanol Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.3.4 Benzene

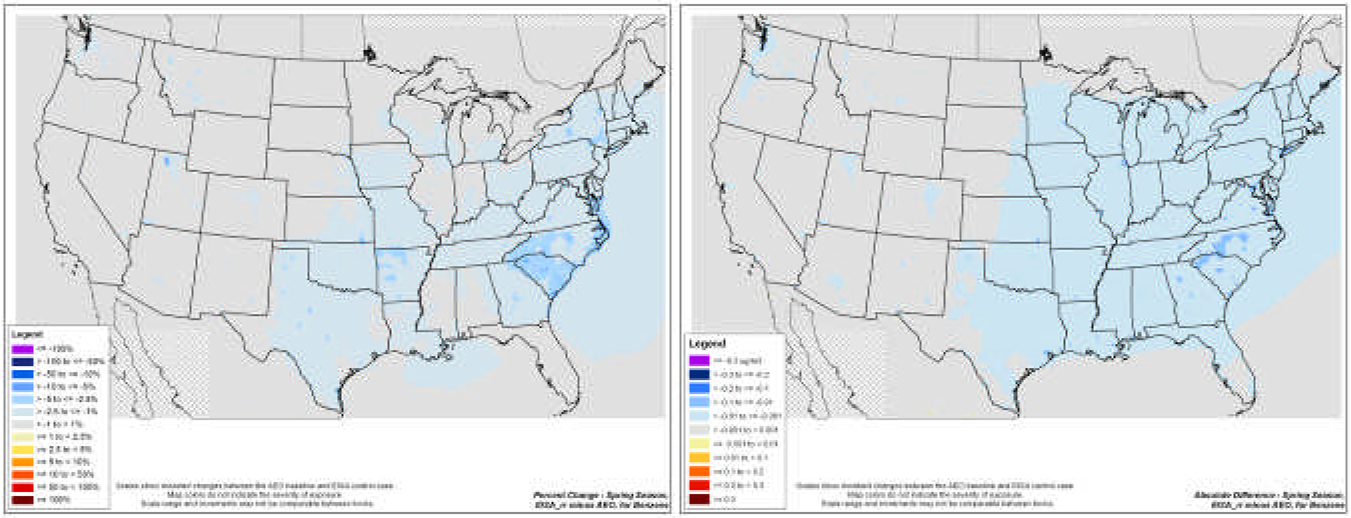


Figure 3A-49. Spring Changes in Benzene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

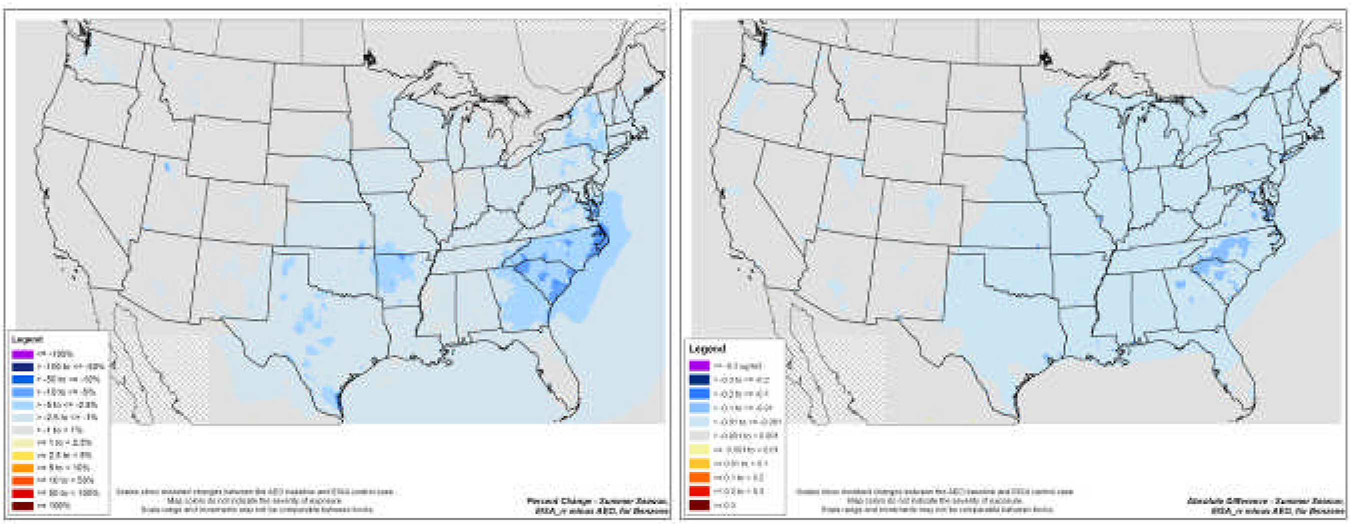


Figure 3A-50. Summer Changes in Benzene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

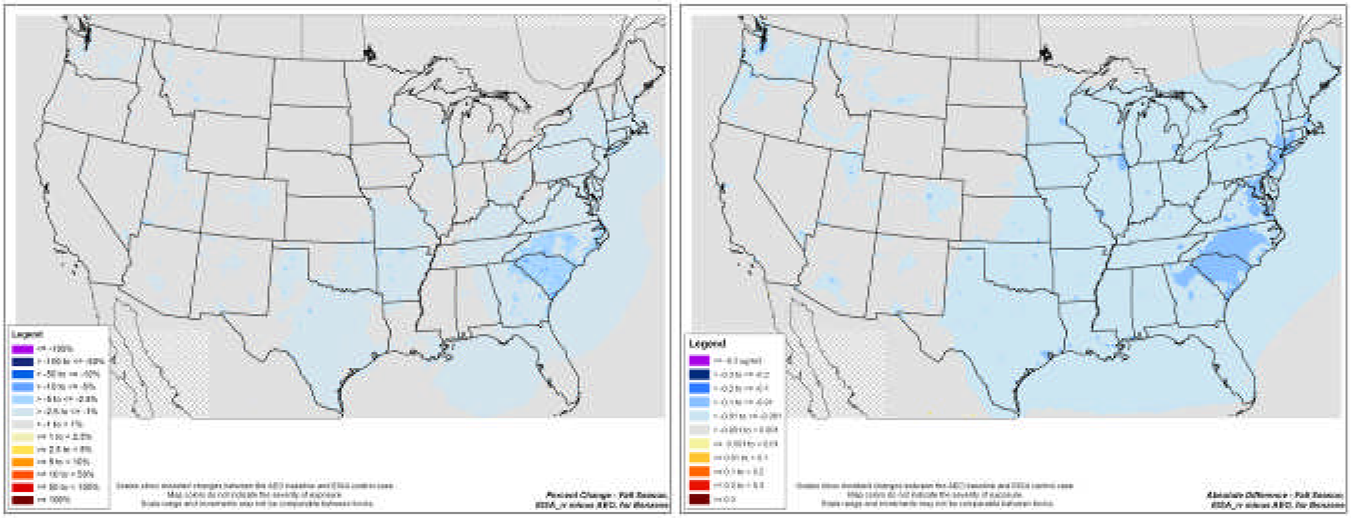


Figure 3A-51. Fall Changes in Benzene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

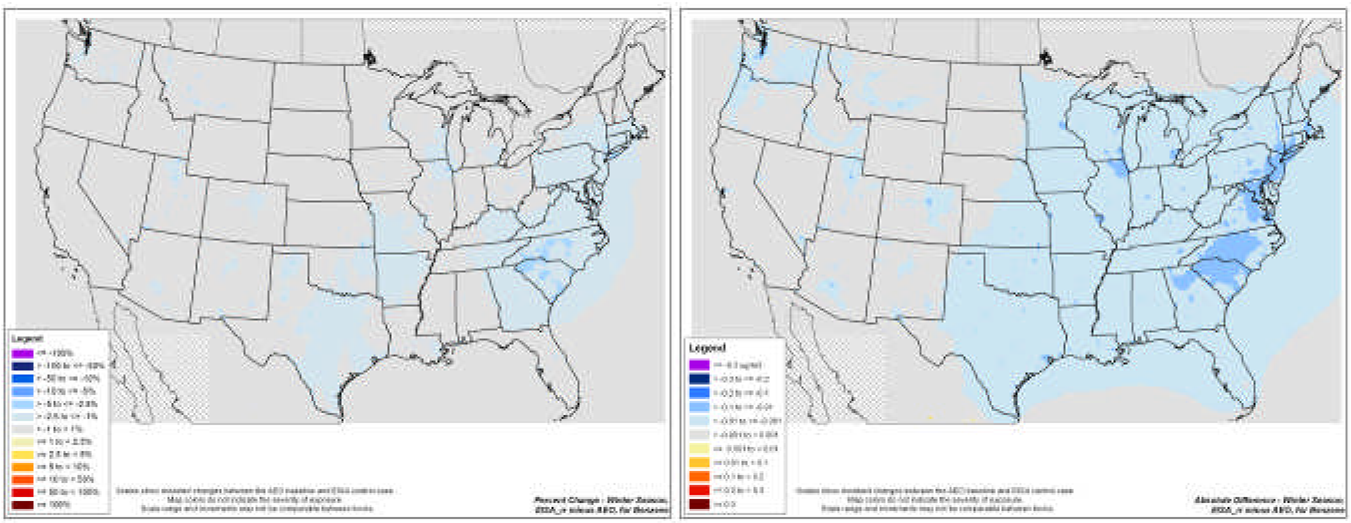


Figure 3A-52. Winter Changes in Benzene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

3A.3.5 1,3-Butadiene

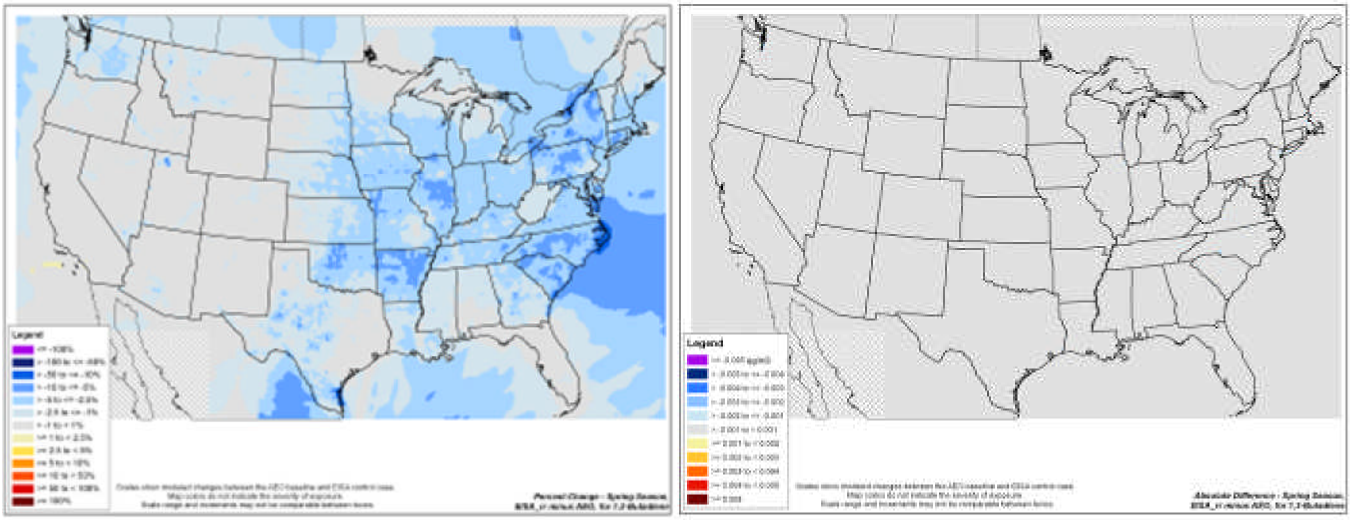


Figure 3A-53. Spring Changes in 1,3-Butadiene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

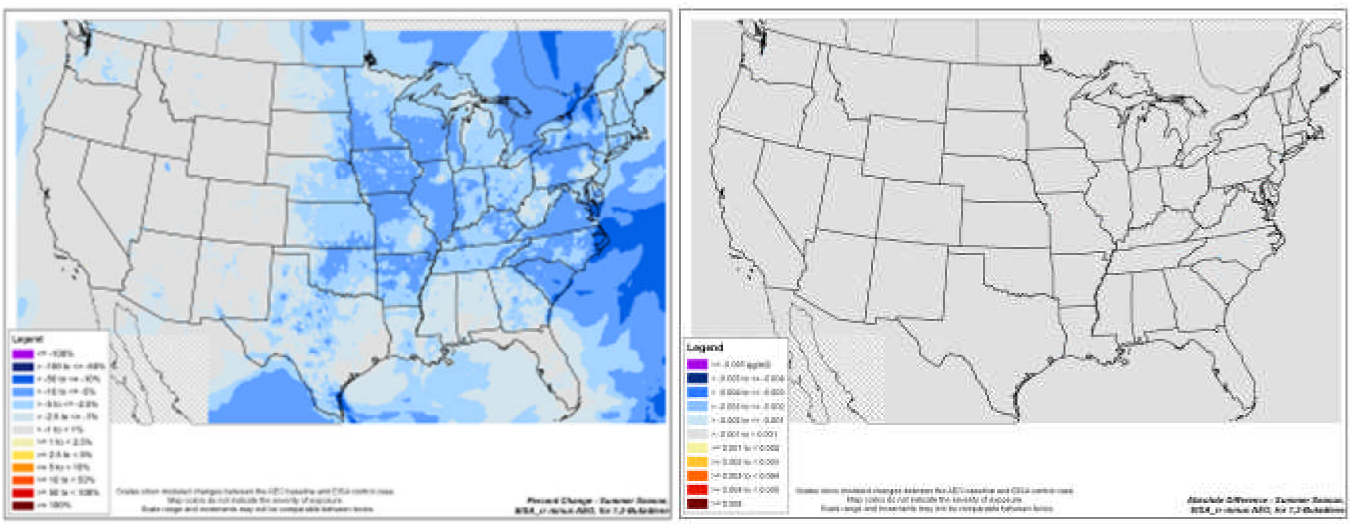


Figure 3A-54. Summer Changes in 1,3-Butadiene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes (μg/m^3)

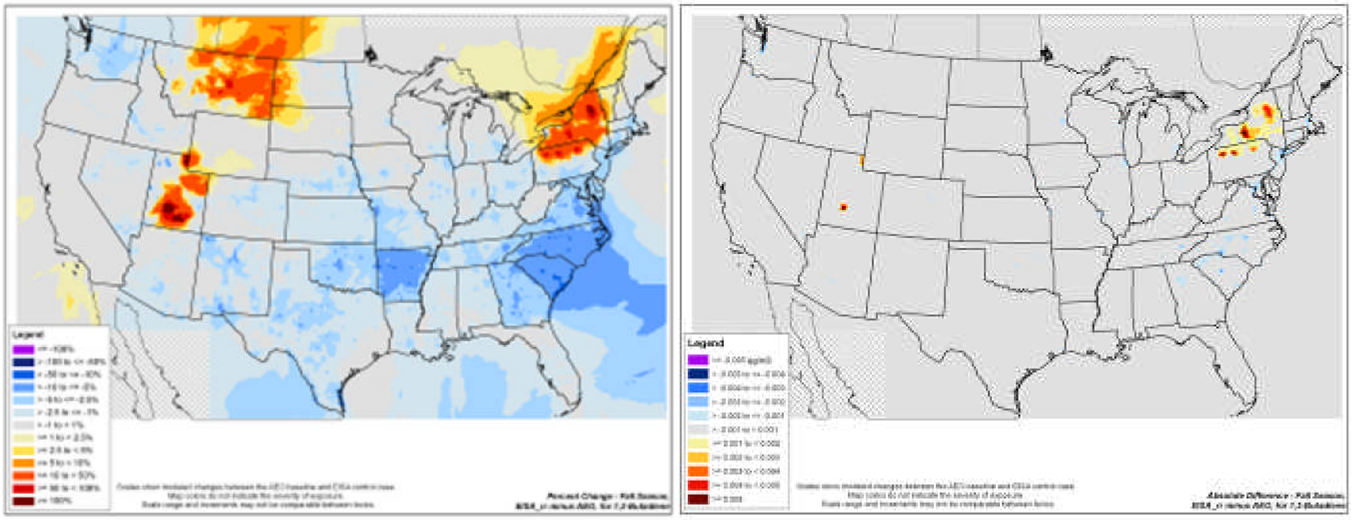


Figure 3A-55. Fall Changes in 1,3-Butadiene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

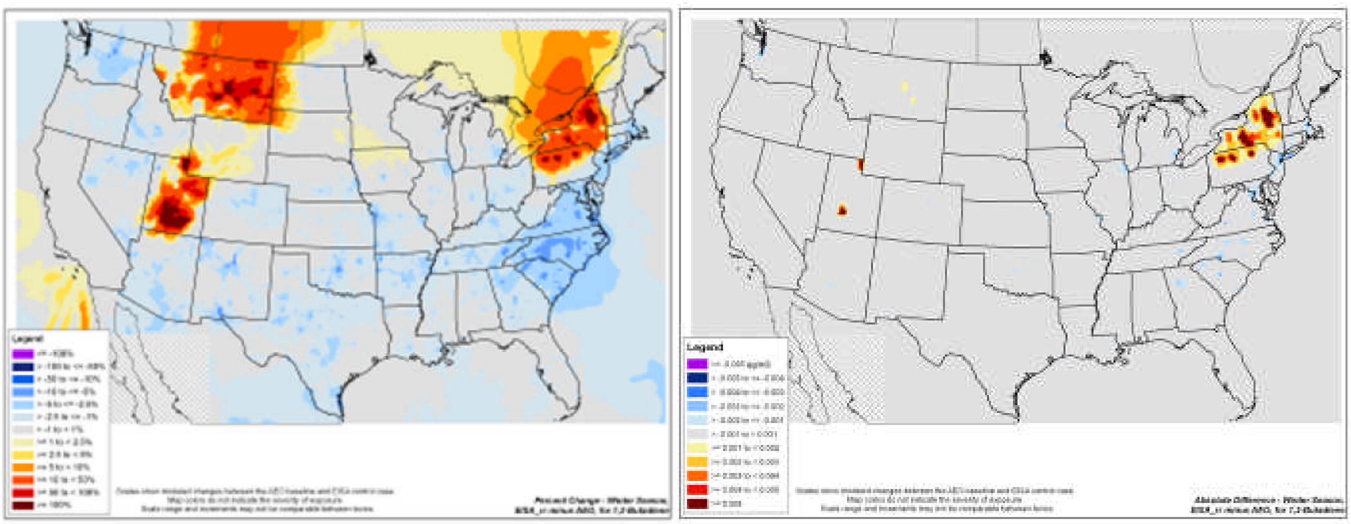


Figure 3A-56. Winter Changes in 1,3-Butadiene Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.3.6 Acrolein

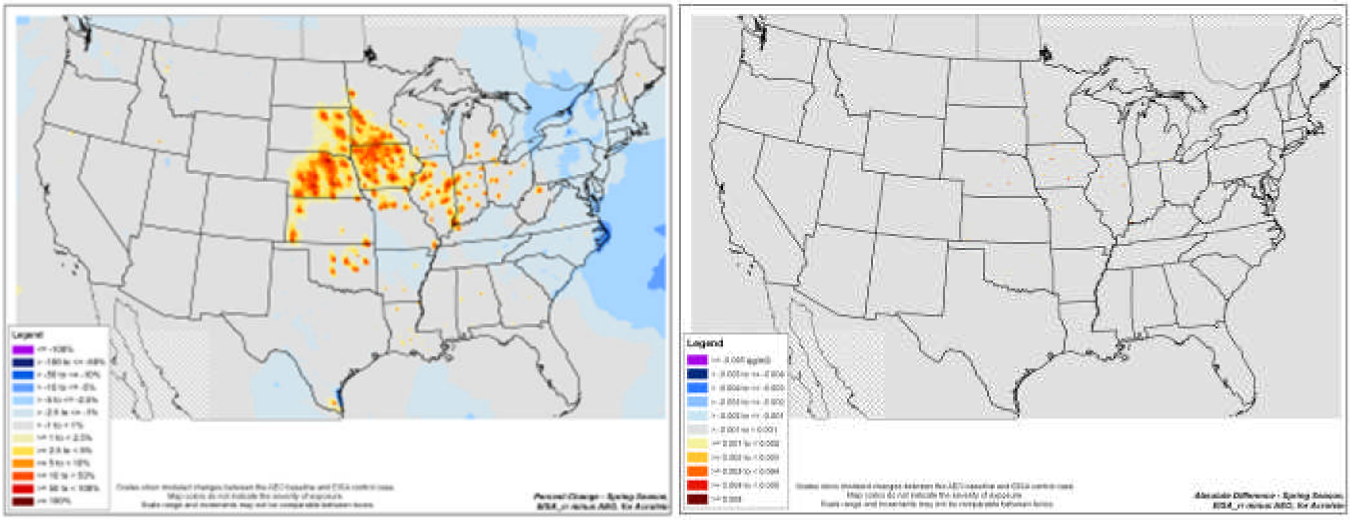


Figure 3A-57. Spring Changes in Acrolein Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

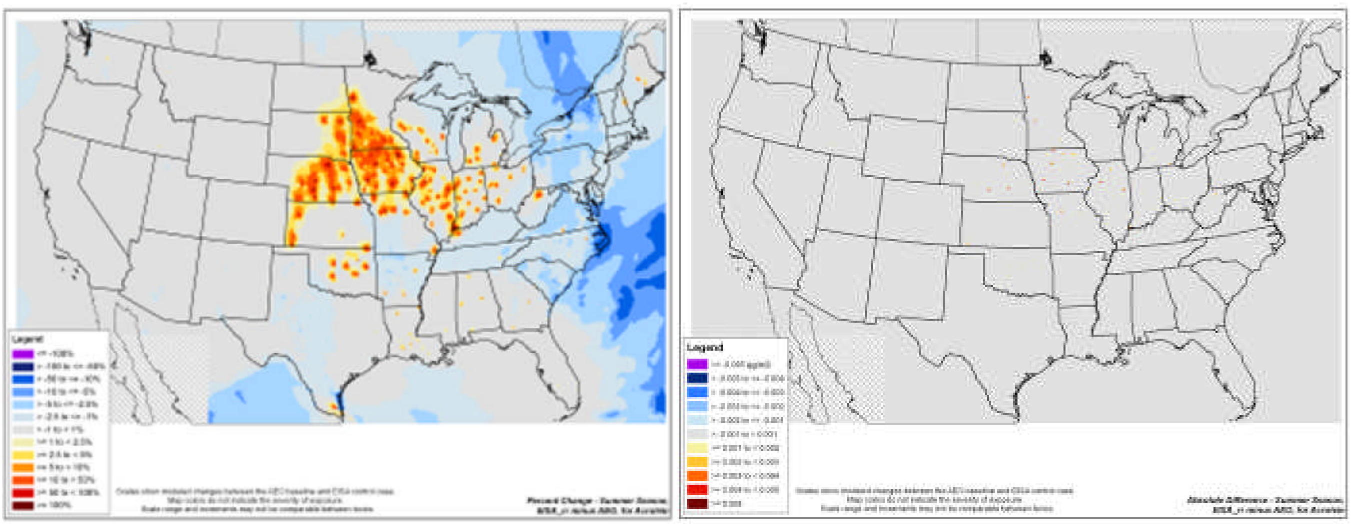


Figure 3A-58. Summer Changes in Acrolein Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

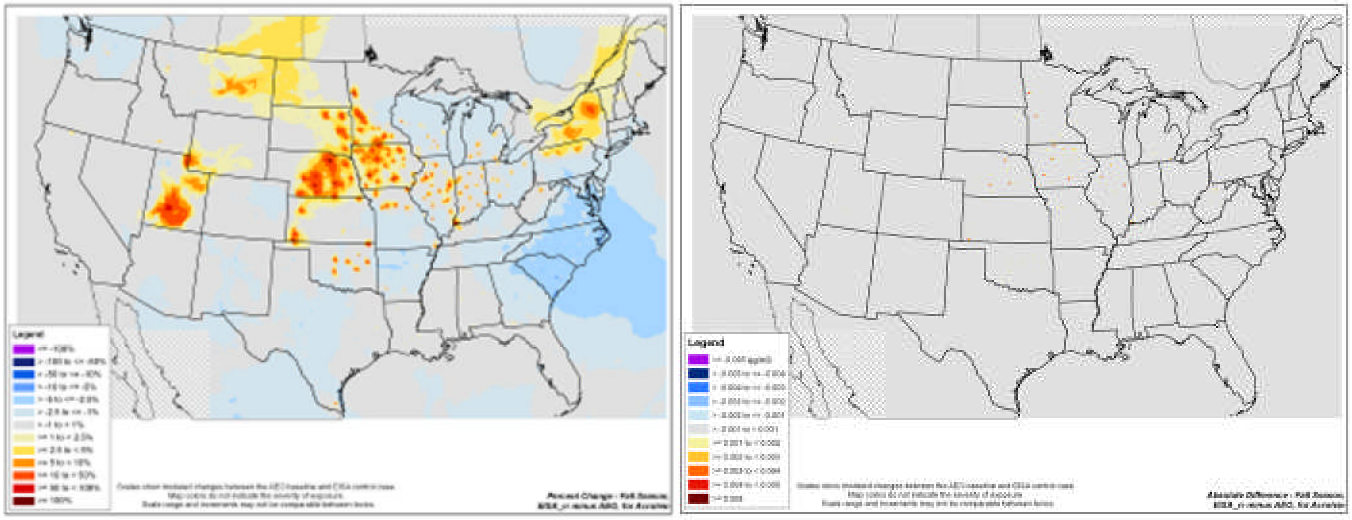


Figure 3A-59. Fall Changes in Acrolein Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

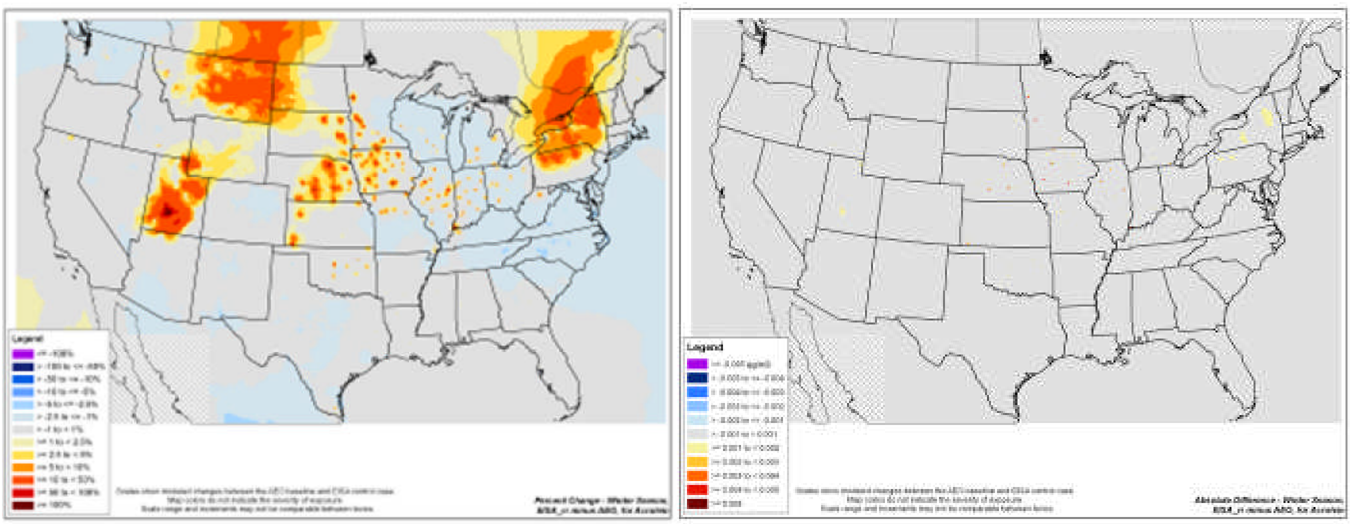


Figure 3A-60. Winter Changes in Acrolein Ambient Concentrations Between the AEO 2007 Reference Case and the RFS2 Control Case in 2022: (left) Percent Changes and (right) Absolute Changes ($\mu g/m^3$)

3A.4 Air Toxics Population Metrics using the AEO Reference Case

The following section presents population metrics for the modeled air toxics in 2022 using the AEO 2007 reference case compared to the RFS2 control case including the estimated aggregated populations above and below reference concentrations for noncancer effects, and population living in areas with increases or decreases in concentrations of various magnitudes.

Table 3A-1.
Populations Exposed to Ambient Concentrations of Air Toxics above and below Reference Concentrations for Noncancer Health Effects in 2022 with RFS2

	CAS No.	Population-weighted Concentration (Annual Average in $\mu g/m^3$)			National Population above RfC (Annual Average)		
		RFS2	AEO 2007	Diff.	RFS2	AEO 2007	Diff.
Acetaldehyde	75070	1.590	1.613	-0.023	0	0	0
Acrolein	107028	0.017	0.017	-0.0001	92,452,143	94,087,145	-1,635,002
Benzene	71432	0.520	0.527	-0.007	0	0	0
1,3-Butadiene	106990	0.022	0.023	-0.208	0	0	0
Ethanol	64175	1.521	1.112	0.409	-	-	-
Formaldehyde	50000	1.549	1.555	-0.006	0	0	0

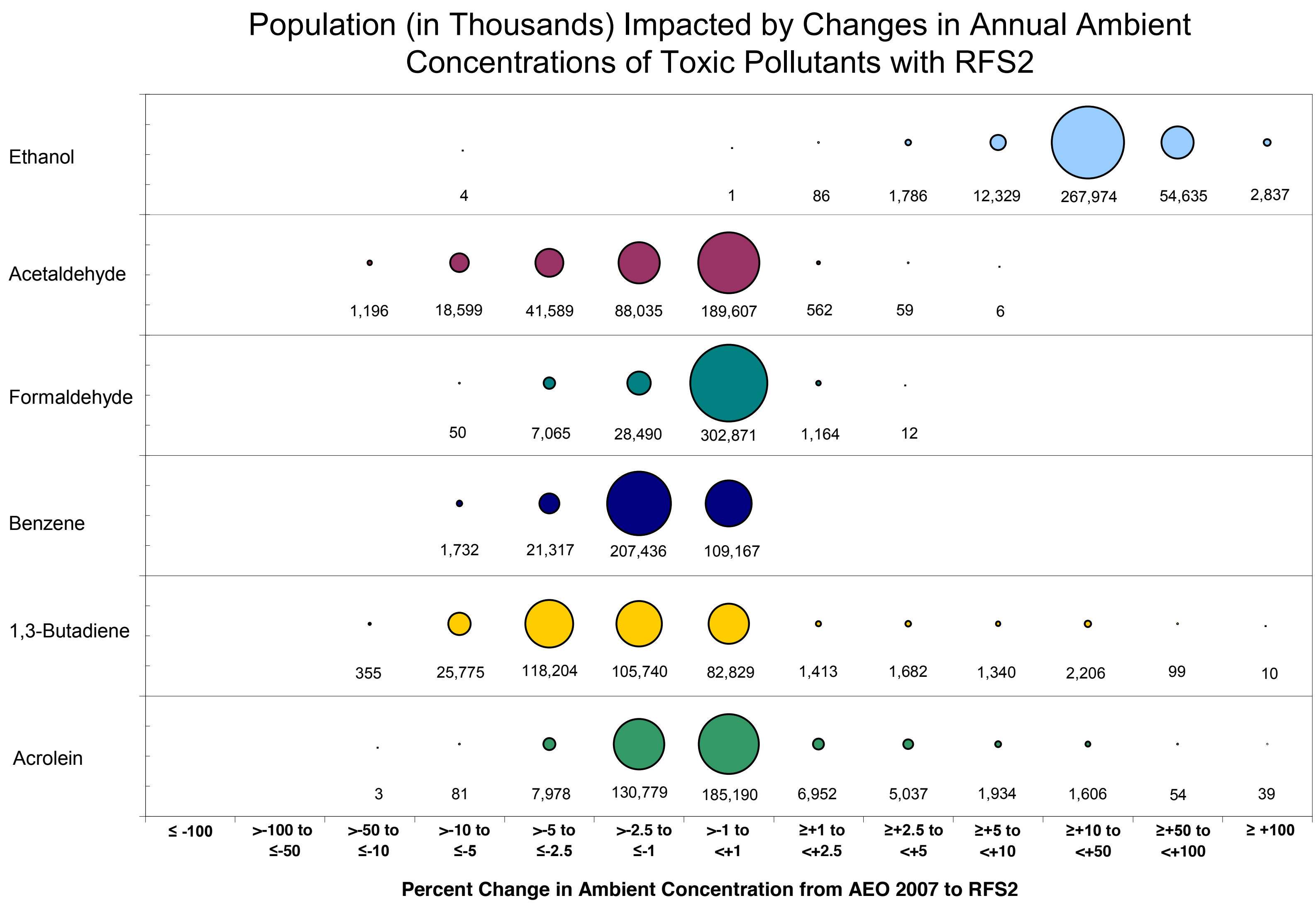


Figure 3A-61. Number of People Impacted by Changes in Annual Ambient Concentrations or Toxic Pollutants by Percent Change Brackets, AEO 2007 Reference Case Compared to the RFS2 Control Case

Chapter 4: Impacts on Cost of Renewable Fuels, Gasoline, and Diesel

4.1 Renewable Fuel Production Costs

4.1.1 Ethanol Production Costs

4.1.1.1 Corn Ethanol

Corn ethanol costs for our work were estimated using a model developed by USDA that was documented in a peer-reviewed journal paper on cost modeling of the dry-grind corn ethanol process.[1087] The USDA model considers a 40 MMgal/yr corn plant producing ethanol with a primary co-product of distillers dried grains with solubles (DDGS). The ethanol yield used in the model is 2.76 gallons per bushel with 2.0% gasoline denaturant. The model is based on work done in chemical process simulation software to generate equipment sizes, stream flowrates, and material and energy balances. These results can then be put together with feedstock, energy, and equipment cost information in a spreadsheet format to generate a per-gallon cost estimate.

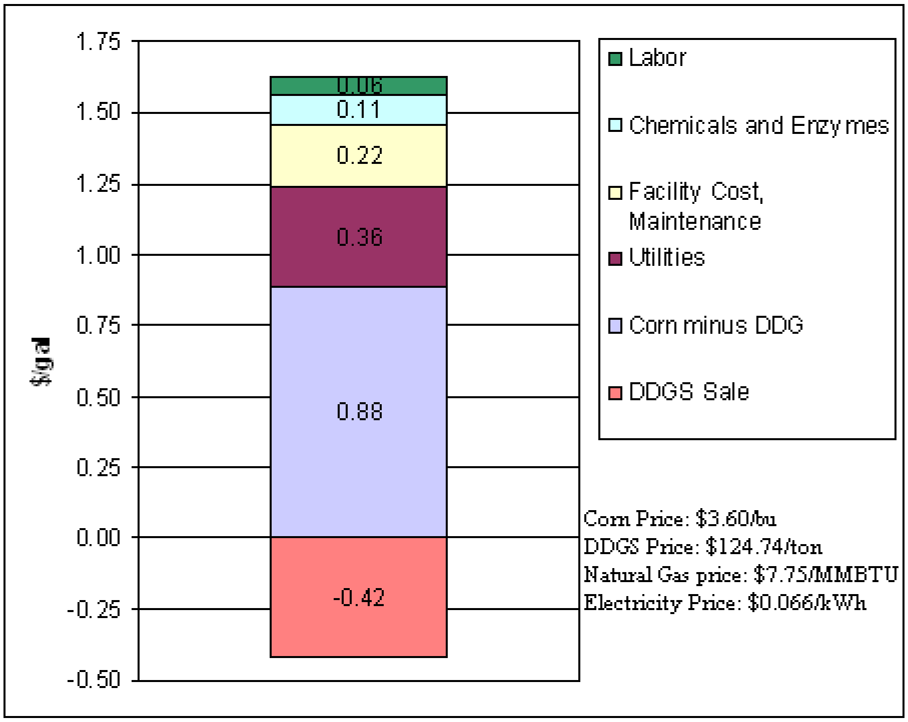
For our primary case scenario, we used corn prices of $3.60/bu in 2022 with corresponding DDGS prices of $124.74/ton (all 2007$). These estimates are taken from agricultural economics modeling work done for this proposal using the Forestry and Agricultural Sector Optimization Model. Energy prices also play a significant role in the cost of ethanol production. For this we relied on the AEO 2009 report for projections of energy costs in 2022 and intermediate years of interest. According to the AEO 2009 updated report the relevant costs are as follows: $7.75 per MMBTU natural gas, $2.57 per MMBTU coal, $30.32 per MMBTU gasoline (~$3.49 per gallon), and $19.31 per MMBTU electricity ($0.066 per kWh). All of these prices are in 2007 dollars.

Using the USDA models and the feedstock and energy prices mentioned above we were able to generate a per gallon cost of ethanol production from a dry mill plant that produces dry DGS, uses natural gas as it's primary fuel source, and utilized no advanced technologies. We did, however, assume that by 2022 the combination of process improvements and more efficient boilers and motors allow the plant described here to produce ethanol with an energy input of 28,660 BTU natural gas per gallon and 2,251 BTU of electricity per gallon. These energy use values are described in more detail in Section 1.5.1.3. The only modification that was made to the USDA model, other than updating the energy and feedstock costs in line with our 2022 projections, was to change the energy demand of the plant to match our projections[224]. The projected cost of ethanol production from this modified USDA model was $1.63 per gallon. For this scenario corn feedstock minus DDGS sale credit represents about 54% of the final per-gallon cost, while utilities, facility, chemical and enzymes, and labor comprise about 22%, 13%, 7%, and 4%, respectively. Figure 4.1-1 shows the cost breakdown for production of a gallon of ethanol. Note that this production model does not account for the cost to ship the DDGS. Those costs are external and are expected to increase the price of DDGS the further an end user is located from the plant. While we do not expect this to be the average cost of ethanol production

[224] An Excel spreadsheet showing a summary of the outputs of this model and the modifications that were made has been placed in the docket (EPA-HQ-OAR-2005-0161- 2726).

in 2022 it serves as a baseline cost to which the cost impacts of different types of fuel used for primary process energy, new technologies, and DGS drying will be applied below.

Figure 4.1-1.
Cost Breakdown of Natural Gas Dry Mill Corn Ethanol Production (2007$).



The price of energy can vary greatly depending on the source of the energy. We expect, therefore, that the cost of ethanol production would also vary depending on whether the production facility uses natural gas, coal, or biomass as its primary thermal energy source. In order to determine the impact that different fuel sources had on the cost of ethanol production in 2022 we first had to project how much of the corn ethanol industry will use each fuel type in 2022. For these projections we relied on our own current industry characterization as well as projections made by Steffen Mueller of the University of Illinois at Chicago. The resulting mix of primary fuel type used in the corn ethanol industry is shown in Table 4.1-1 below.

Table 4.1-1.
Breakdown of fuel types used in estimating production cost of corn ethanol

	Fuel Type				**Total by Plant Type**
Plant Type	**Biomass**	**Coal**	**Natural Gas**	**Biogas**	**All Fuels**
Coal/Biomass Boiler	11%	0%	-	-	11%
Coal/Biomass Boiler + CHP	10%	4%	-	-	14%
Natural Gas Boiler	-	-	49%	14%	63%
Natural Gas Boiler + CHP	-	-	12%	-	12%
Total by Fuel Type	21%	4%	61%	14%	100%

To determine per-gallon cost impact of coal, biomass, and biogas as a process energy source we relied on the modeling work done by the USDA. The USDA modeled dry mill corn ethanol plants using both natural gas and coal as a primary energy source. Their models take into account the differences in capital costs that result from the differences in materials handling and boiler types necessary to use gaseous and solid fuels. We assumed that on average, coal and biomass combustion systems would have the same capital cost due to similarities in feed, ash handling, and emission controls; the same argument can be made for use of biogas combustion relative to natural gas combustion (excluding the digesters or other source). Table 4.1-2 shows the impact that different primary fuel sources have on the overall cost per gallon of corn ethanol production. The overall impact of using different fuel types is very small, less than $0.01 per gallon. Thus, a change in process fuel type has very little impact on the projected future cost of corn ethanol.

Table 4.1-2.
Breakdown of cost impacts by fuel type used in estimating production cost of corn ethanol

	Fuel Type				**Total by Plant Type**
Plant Type	**Biomass [a]**	**Coal**	**Natural Gas**	**Biogas [b]**	**All Fuels**
Coal/Biomass Boiler	+$0.009	+$0.009	-	-	-
Coal/Biomass Boiler + CHP	-$0.021	-$0.021	-	-	-
Natural Gas Boiler	-	-	baseline	+$0.00	-
Natural Gas Boiler + CHP	-	-	-$0.032	-	-
Total by Fuel Type	**-**	**-**	**-**	**-**	**$-0.006**

Table 4.1-2 shows that for our cost analysis we made the assumption that biomass firing has the same overall cost impact on ethanol production as coal firing. One reason for this is that our analysis of biomass feedstock costs suggests a range of $72 per ton in future years which is comparable to the cost of coal supplied to non-electric-power industries after transportation is included.[1088] Wood and stover biomass has on average approximately 85% of the energy content of coal on a mass basis, varying by type of biomass and coal, again suggesting that they are comparable on an energy per mass basis.[1089] Nevertheless, we still project that biomass will displace some coal in the future. If biomass transportation and storage costs are small it is

plausible that some ethanol producers near biomass sources (such as the Midwest and Southeast) may have a cost incentive to transition from coal to biomass for process heat. In addition, ethanol plant owners may want to improve their greenhouse gas performance to increase capacity.

Similarly, for our cost analysis we made the assumption that biogas combustion for process heat would have the same cost impact on ethanol production as natural gas combustion. Use of biogas is somewhat different from biomass in that it would require some capital investment for on-site anaerobic digesters and related feedstock and gas handling equipment. However, we anticipate the digester feedstock itself would have very low or no cost, thus it is reasonable to assume that the ongoing operating costs besides capital would be considerably less than purchasing natural gas. As with biomass combustion, most plants utilizing biogas would take advantage of situations such as co-location with feedlots or MSW facilities where suitable biomass resources are available.

Another factor that we expect to have a significant impact on the cost of ethanol production in 2022 is the development and adoption of new technologies. There are several new technologies currently available or under development that reduce the energy requirements of ethanol production facilities. These include more efficient boilers, motors and turbines, raw starch hydrolysis, corn fractionation, corn oil extraction, and ethanol membrane dehydration. These technologies, and their impact on the projected average energy usage of an ethanol plant in 2022, are discussed in section 1.5.1.3. In addition to reducing cost by decreasing an ethanol plant's energy demand, two of these technologies, corn fractionation and corn oil extraction, produce new co-product streams that also have an impact on the cost of ethanol production. We have adjusted the USDA cost model to reflect the impact that reduced energy usage of ethanol plants in 2022 and new co-products have on the average cost of ethanol production[225]. The impact of these technologies is outlined in Tables 4.1-3 and 4.1-4 below.

Table 4.1-3.
New Technology Impacts on Corn Ethanol Cost

	Capital Cost (40MMGY)	Capital Charge (per gallon)	Operating cost change	New co-product profit	Additional Profit
More Efficient Boilers, etc.	None (included in baseline)	N/A	N/A	N/A	$0.00
Raw Starch Hydrolysis	$0	$0.00	-$0.066	N/A	$0.066
Corn Fractionation	$14,000,000	$0.016	-$0.003	$0.106	$0.093
Corn Oil Extraction	$5,100,000	$0.019	-$0.037	$0.060	$0.079
Membrane Separation	$1,500,000	$0.006	-$0.070	N/A	$0.064

[225] As an example, the spreadsheet with adjusted values for corn oil extraction has been placed in the docket (EPA-HQ-OAR-2005-0161-2727).

Table 4.1-4.
Breakdown of cost impacts by technology for estimating production cost of corn ethanol

Technology	Percent of Plants Adopting Technology	Cost Impact (Change from Baseline)	Weighted Cost Impact
More Efficient Boilers/Motors/Turbines	100%	Included in Baseline	$0.00
Raw Starch Hydrolysis	22%	-$0.066	-$0.015
Corn Fractionation	20%	-$0.093	-$0.019
Corn Oil Extraction	70%	-$0.079	-$0.055
Membrane Separation	5%	-$0.064	-$0.003
Total	N/A	N/A	-$0.092

Whether or not the distillers grains and solubles (DGS) are dried also has an impact on the cost of ethanol production. Drying the DGS is an energy intensive process and results in a significant increase energy usages as well as cost. The advantages of dry DGS are reduced transportation costs and a product that is less susceptible to spoilage, and can therefore be sold to a much wider market. If the DGS can be sold wet, the cost of ethanol production can be reduced by $0.083 per gallon. A 2007 survey of ethanol producers indicated that 37% of DGS were being sold wet. We anticipate that this percentage of wet DGS will remain constant in 2022. The net cost impact of selling 37% of the DGS wet is an average cost reduction of $0.031 per gallon.

The effect of plant scaling on production cost can be estimated by applying an engineering scaling factor to all plant equipment. In past rulemakings involving modifications to refineries we have used a material scaling factor of 0.65. This factor is applied as an exponent to the ratio of the new size to the original size, the result of which is then multiplied by the original capital cost. The fact that this figure is less than 1.0 reflects the per-unit or per-gallon savings that is often realized when processes are scaled up. However, there is information suggesting that a general factor may be considerably higher for ethanol plants. A factor of 0.84 was put forth in a recent publication on dry mill ethanol production.[1090] Using this larger factor, we find that the change in per-gallon production cost due to economies of scale is very small over the range of typical plant sizes, on the order of $0.02 between 40 and 100 MMgal/yr. Thus, in computing production costs for this rulemaking we chose to ignore effects of any changes average plant size. A recent study has also indicated that the co-location of corn and cellulosic ethanol plants may result in reductions of the cost of production for both the corn and cellulosic ethanol[1091]. We have not been able to incorporate these findings into our evaluation due to time constraints; however we do not expect that they would have a large impact on the overall cost of corn ethanol production.

In order to generate a cost estimate for the production of corn ethanol in the year 2022 the cost impact of each of these factors, primary fuel type, advanced technologies, and DGS drying, were applied to the baseline cost produced by the USDA model. When each of these cost reduction have been applied to the baseline cost, the result is a projected cost of production for corn ethanol of $1.50 per gallon in 2022. As with the energy and input costs, this production cost is also in 2007 dollars. We believe this number is an accurate projection of the cost of ethanol in 2022 based on the best available information. For a summary of the cost analysis, including the baseline cost and all the adjustments, see Table 4.1-5 below.

Table 4.1-5.
Average Ethanol Cost of Production in 2022

Baseline Cost of Production (Natural Gas, no new technologies, 100% dry DGS)	$1.627/gal
Fuel Type Cost Impact	-$0.006/gal
New Technology Cost Impact	-$0.092/gal
DGS Drying Cost Impact	-$0.031/gal
Average Cost of Ethanol Production (2022)	$1.499/gal

4.1.1.2 Cellulosic Ethanol

4.1.1.2.1 Feedstock Costs

In order to allow for an accurate estimate of the cost of production for cellulosic biofuels in 2022 we must first determine the cost of the cellulosic feedstocks. We relied on the Forest and Agriculture Sector Optimization Model (FASOM) to project the roadside cost of agricultural residues, energy crops, and wood residues for 2022. For more details on the FASOM model see Chapter 5 of the RIA. FASOM does not model MSW costs. We therefore relied on conversations with companies who intend to use MSW as a renewable fuel feedstock, as well as our own analysis of the necessary steps required to acquire appropriate feedstock streams from MSW to help inform our feedstock cost estimates. In order to validate the reasonableness of the FASOM cost estimates we also conducted an internal assessment of the potential agricultural residue, energy crop, wood residue, and MSW feedstock systems. The description of this analysis is discussed in Section 4.1.1.2.2.

To each of these roadside costs we added the cost of transportation and secondary storage where appropriate using a tool we developed for this purpose. The framework of this tool is discussed in Section 1.3.3 and a more detailed discussion of the assumptions and equations used in this tool can be found below. Table 4.1-6 shows a summary of the individual roadside costs for each of the feedstock sources, as well as average costs for storage and transport and grinding of the materials. A weighted average cost, based on the percentage of the overall feedstock supply each of the categories is expected to represent according to the FASOM model, is also given.

Table 4.1-6.
Summary of Cellulosic Feedstock Costs

<table>
<tr><th>Ag Residue</th><th>Switchgrass</th><th>Forest Residue</th><th>MSW</th></tr>
<tr><td>36% of Total Feedstock</td><td>49% of total Feedstock</td><td>1% of Total Feedstock</td><td>15% of Total Feedstock</td></tr>
<tr><td>Mowing, Raking, Baling, Hauling, Nutrients and Farmer Payment $34.49/ton</td><td>Land Rent, Mowing, Raking, Baling, Hauling, Nutrients and Farmer Payment $40.85/ton</td><td>Harvesting, Hauling to Forest Edge, $20.79/ton</td><td>Sorting, Contaminant Removal, Tipping Fees Avoided $15/ton</td></tr>
<tr><td colspan="4">Hauling to Secondary Storage, Secondary Storage, Hauling to Plant
$21.53/ton (average)</td></tr>
<tr><td colspan="4">Grinding
$11/ton</td></tr>
<tr><td colspan="4">Total
$67.42/ton</td></tr>
</table>

Crop Residue Costs

The FASOM agricultural econometric model described in Chapter 5 estimated the roadside price for corn stover, which we used to be representative of all agricultural residues. The FASOM model accounted for harvesting, shredding, raking, baling and hauling the corn stover to the farm edge, and replenishing the soil with nutrients. It predicts a roadside price of $34.49 per dry ton in 2022 for corn residue. In order to validate FASOM's cost estimate we also performed an analysis of a possible agricultural residue harvest system. We based our analysis on a Purdue University study of the logistics of corn stover storage and transportation. Our analysis, described in Section 4.1.1.2.2, predicts a roadside cost for corn stover ranging from $44.97 to $46.20 per dry ton, depending on the size of the farms from which the stover is harvested. The FASOM cost is approximately $10 per ton lower than the price calculated in our analysis. While this is a significant price difference it is in the same vicinity as the FASOM estimate, and it is not unreasonable to expect that advances in technology and changes in harvesting practice for corn stover and other agricultural residues will significantly reduce the cost for these feedstocks. For all of the biofuel production cost analysis work, the FASOM price was used as the projected price of agricultural residue. To this roadside cost was added the cost of transportation and secondary storage as calculated by the tool discussed in Section 1.3. A detailed description of our analysis of a likely agricultural residue harvest system using existing machinery can be found below.

Energy Crops

The FASOM model predicts a roadside cost for switchgrass and similar energy crops of $40.85 per dry ton in 2022. While this costs is higher than the cost of agricultural residues the delivered cost of energy crops is expected to be slightly lower because of the lower transportation and secondary storage costs associated with the higher production density of energy crops. The $40.85 per dry ton roadside cost has been used in our cost analysis of biofuel production, with appropriate transportation and storage costs added using the tool described in Section 1.3. See Table 4.1-6 for a summary of the expected delivered costs of various feedstocks.

Wood Residue

The FASOM model estimates costs for two different types of wood residues, hardwood logging residue ($21.16 per dry ton) and softwood logging residue ($18.37 per dry ton). We decided to use $19.77 per dry ton, an average of these two prices, as the roadside cost of wood residue for our analysis of biofuel production costs. Despite the low roadside cost of wood residues, FASOM predicts that few biofuels production facilities (less than 1%) will use wood residues. We believe that the reason for this is that the high transportation costs for wood residue in the FASOM model cause the delivered cost of wood residue to be relatively high. The FASOM model allowed biofuel producers to use only one type of feedstock (wood residue, agricultural residue, energy crops, or MSW). Therefore, in order for a facility to use wood residues, the entire feedstock supply must come from wood residues. Logging operations are less likely to be concentrated in a small area than other potential feedstock supply systems such as agricultural residues or energy crops. The result is that in order to supply a 100 million gallon per year biofuel production plant (the size specified in the FASOM model) with sufficient feedstock from wood residues the residues must be transported long distances. In most cases these high transportation costs outweighed the low roadside costs despite the fact that no secondary storage will be required for wood residues. If this assumption were relaxed and the FASOM model allowed biofuel production facilities to use locally available wood residues in combination with other feedstocks such as agricultural residues, energy crops, or MSW, we believe that much more wood residues would be selected for biofuel production. At this point, however, it is not clear whether biofuel production facilities would require uniform feedstock or be able to process a diverse feedstock stream. This uncertainty was one of the factors in our decision to use the FASOM estimates for our cost analysis work.

Municipal Solid Waste

Unlike the other three sources of cellulosic feedstock, the FASOM model does not predict a roadside cost for MSW. We therefore relied on our own analysis, together with input from the Office of Solid Waste and conversations with companies who intend to use MSW as a feedstock for producing biofuels. One of the biggest costs associated with using MSW as a biofuel feedstock is the cost to sort the waste material. Some materials, such as metals and contaminated materials, must be removed so that they do not interfere with the biofuel production process. Other materials, such as paper or plastics, may also be separated due to their value as recovered materials or in order to increase the renewability content of the resulting fuel.

The Office of Solid Waste has estimated that sorting costs will likely be $20 - $30 per ton. In addition to sorting costs, the biofuel producer would also have to pay for the transportation and disposal of unusable material. These costs may be relatively high due to the nature of this contaminated material. Offsetting these costs would be tipping fees received by the biofuel producer, which we estimate would be in the $30 per ton range.

In addition to our own analyses presented in Section 4.1.1.2.2, we also contacted companies that intend to use MSW as a feedstock for biofuel production. In confidential conversations these companies indicated that they believed that MSW would be available, at least initially, at close to zero net cost, after accounting for the receipt of tipping fees and the sale of recoverable materials. One company told us that whether the MSW was sorted or unsorted was not expected to make much of a difference from a cost perspective, as they expected that the higher tipping fees received for unsorted MSW and the money received from the sale of the recovered materials would pay for the cost of sorting. We believe that while these costs may be accurate, they are likely only representative of the cheapest and most readily available sources of MSW. It is likely that as more biofuel producers seek to use MSW as a feedstock, the cost of this feedstock source will increase. Competition from waste to energy companies may be another driver for the cost increase of MSW. Taking all this into account, we have conservatively estimated that the average cost of MSW will be $15 per dry ton in 2022. While this is an admittedly conservative estimate, MSW remains the cheapest source of feedstock for the production of biofuels. More details of our cost assessment for MSW can be found below.

4.1.1.2.2 EPA Internal Assessment of Potential Roadside Cellulosic Feedstock Costs

While the FASOM model provides an estimate for the roadside costs of agricultural residue, energy crops, and wood residue, we were also interested in performing our own internal assessment of the potential roadside cost of these feedstocks. This assessment served as a second estimate for the costs of these feedstocks, and allowed us to verify the costs generated by FASOM. They also allowed us to have a better understanding of the costs of each of the steps in the harvest process. In each of these cases we found that our own assessments matched reasonably well with the roadside costs reported by FASOM. Our internal assessment of the roadside costs of crop residue, energy crops, wood residue, and MSW is shown in detail in the following sections.

Crop Residue

We could have used any of the crop residues as an example feedstock in the following discussion, since similar logistics apply to all of them. We chose to use corn stover, e.g., the stalks, leaves, and cobs that remain following grain harvest, since it is likely to represent a significant portion of cellulosic feedstocks in the future. Since there is no equipment specifically designed to harvest corn, the system we describe below uses combines, mowers, rakes, balers, and bale haulers already in use for harvesting hay or straw. Differences in stalk or stem diameter and density, bale density, moisture content, machine field speeds and efficiencies are a few things that make it relatively more difficult to harvest stover than hay or straw. One of the main concerns is that the density of the large stover bales, whether round or rectangular, can be as little as one-half that of similar dimension hay bales, which usually translates into higher transportation costs.[1092]

Most biomass feedstocks must be harvested, stored, and transported to a processing facility before they can be converted into ethanol. At present, there are no commercial sized cellulosic ethanol plants in the U.S. Likewise, there are no commercially proven, fully-integrated feedstock supply systems dedicated to providing any of the crop residues or other feedstocks to ethanol facilities of any size. We emphasize 'integrated feedstock supply systems' because logistically the delivery of a feedstock to a processing facility will require the planning, executing, and controlling of several different, closely integrated operations, e.g., feedstock harvesting, gathering, storing, and moving by road and rail. Apart from the large numbers and wide variety of equipment, these operations will require professional and technical support services and personnel such as office space, staff, and office equipment such as computers and printers. Also, engineers, light- and heavy-duty equipment operators, vehicle maintenance personnel and repair and storage facilities for tractors, rakes, balers, loaders, and trucks and trailers, as well as transportation infrastructure planning and management.

Ordinarily, to determine the operational sufficiency and efficiency of such a system, we would 'analyze' it. We would first break it down into its component parts or essential features and then study them, e.g., how much they cost, and how and/or whether they operate efficiently within the 'system.' However, no such system currently exists. Therefore, we 'synthesized' a feedstock supply system in order to analyze it. We used a Purdue University, School of Industrial Engineering simulation study of corn stover logistics from satellite storage to an ethanol plant, to set up our feedstock harvesting and gathering operation. Purdue's notional cellulosic ethanol plant was to be constructed next to an actual existing corn grain plant in northern Indiana. They used discrete event simulation software and GIS tools to study the transportation logistics associated with supplying the conversion facility directly from satellite storage. They identified 785,200 available acres out of 848,453 potential acres, on 2,052 actual farms, of 200-, 400-, or 800-acres, in 12 northern Indiana counties within 50-miles of the production facility (they disregarded fields or farms of less than 200-acres). We reproduced their original table as Table. 4.1-7.

Table 4.1-7.
Feedstock Availability at Various Distances From South Bend, IN

				Average Farm Size						
Average Distance	County	Actual Acres	Cumulative Acres	200	400	800	Available Acres	Cumulative Acres	bales/ day	bales/day /farm set
					Acres					
12	St Joseph	69	69	74	51	35	63	63	4,956	4,956
25	Elkhart	150	219	90	47	23	55	118	4,328	10,257
	Marshall			110	52	41	76	194	5,928	
30	La Porte	113	332	113	73	70	108	302	8,453	8,453
35	Starke	60	392	34	39	41	55	357	4,328	4,328
40	Kosciusko	93	485	108	66	43	82	439	6,461	6,461
45	Lagrange	132	617	53	47	20	45	485	3,560	9,049
	Fulton			86	66	43	70	555	5,489	
50	Porter	225	842	76	59	34	66	621	5,175	18,224
	Noble			115	47	21	59	679	4,595	
	Pulaski			39	72	64	108	787	8,453	
		842		998	619	435	787		61,726	61,728

We initially assumed that the stover had been harvested (square bales), gathered, field-transported, and stored at seven-satellite storage areas located near the corn fields.[1093] However, upon further study, we determined the counties that Purdue combined into each of the farm sets, weren't anywhere near each other. In reality, it would have been far too costly to gather all the bales from the Porter, Noble, and Pulaski counties into one site, because these three counties are actually separated by other counties. Rather than try to construct seven satellite storage sites, we constructed a site at the center of each county. This was done in order to estimate the cost to collect the bales from all the fields in each county. We determined that the distance from the center of each of the Porter, Noble, and Pulaski counties, as well as the other two so-called farm-sets, to the ethanol plant was about equal, so regardless of whether we treat them as single sites, the transport costs for the bales to the ethanol plant will be the same. We 'synthesized' the feedstock system to harvest, gather, field transport, and store stover bales at the 11-notional satellite storage units rather than the seven farm-set units used in the Purdue transportation model (our study was not done in conjunction with the Purdue study; rather we used their information/data as the basis from which to synthesize our notional operation). The format we chose to analyze was to shred, rake, square-bale, gather, field-side, and then load and haul the bales to satellite storage; then, as needed, haul the bales to the processing plant.

Rather than guess at how such a system should look and function, we carefully studied several similar systems that were put forward by various agricultural and biological experts.[1094, 1095, 1096, 1097, 1098, 1099, 1100, 1101, 1102] We used the American Society of Agricultural and Biological Engineers (ASABE), 2007 Standards, Engineering Practices, and Data as the primary source for our equipment capital and operating cost estimates. It has a machinery management section, ASE EP496.3, FEB2006, devoted to providing helpful information in making management decisions involving machine power requirements, capacities, cost, selection, and replacement, as well section ASAE D497.5 FEB2006, with data which includes representative values of farm machinery operating parameters, to aid managers, planners, and designers in estimating the performance of field machines. These data are intended for use with ASAE EP496 (some data are also presented in equation form for easier use with computers, etc.).[1103] We used these sections along with other examples by other experts to estimate the machinery capital and operating costs for our analysis.[1104, 1105, 1106, 1107, 1108] We were able to get some machinery purchase prices from vendors whose identities are confidential. We reduced the equipment listed price by 10% to determine the purchase price, a standard industry estimating practice. Otherwise, most of the data used to calculate machinery costs were generated with equations and appropriate data from the ASABE 2007 Standards. We used the equipment, list and purchase prices, along with their power and size estimates, with the suggested data and equations, mentioned previously, to calculate the lifetime hours and years, annual use, field efficiency, salvage value, fuel and oil use and cost (we obtained vendor quotes for oil cost), capital charge, repairs, insurance, housing, taxes, and labor. We compared our data, where appropriate, with the USDA 2006 Price Summary, published July 2007.[1109] We also compared our results with those generated by the experts we listed earlier in this paragraph.

The Purdue study was based on supplying a 100-million gallon per year ethanol production facility, which they assumed would convert the stover-to-ethanol at 72-gallons per ton; they assumed that 2-dry tons corn stover could be harvested per acre, as did we. We used National Agricultural Statistical Service (NASS) data to determine the actual corn grain yield in 2005 (the data year for the Purdue study) for the counties studied in the simulation. We determined how much corn each county produced and from that how much stover was produced, 2,455,000 tons or 3.12 dry tons per acre, with an assumed harvest index (HI) of 1:1 (see Table. 4.1.1.2.2.)[1110] HI is based on the assumption that, for a single corn plant, half of the above ground dry matter is made up of stover and the other half is made up of grain. This is a fairly common assumption, although more than one group of researchers has found that this 1:1 ratio may not be the most accurate under some conditions. When considering above ground dry matter before and after full grain physiological maturation, they found that a stover to grain ratio of 0.8 to 1 may be more realistic especially when grain moisture is between 18 and 31 percent.[1111]

Table 4.1-8.
NASS Indiana Data and Purdue Data Comparison

USDA-NASS – Counties in State of Indiana - 2005					Purdue Model Year – 2005				
	Planted	Harvested	Grain Yield	Grain Production	Model	Available Acres	Prorated Grain Production	Wet Tons Stover	Dry Tons Stover
County	acres x 10^3	acres x 10^3	bu/ acre	bu x 10^6	acres x 10^3	acres x 10^3	bu x 10^6	x 10^3	x 10^3
St Joseph	71	70	147	10.2	69	65	9.5	266	225
Elkhart	60	53	142	7.6	150	52	7.4	206	174
Marshall	94	89	150	13.4	0	87	13.1	366	309
La Porte	117	112	137	15.3	113	104	14.2	398	336
Starke	61	60	137	8.2	60	56	7.7	214	181
Kosciusko	102	100	149	14.9	93	93	13.8	386	326
Lagrange	55	51	113	5.8	132	45	5.0	141	119
Fulton	90	89	159	14.1	0	78	12.3	345	291
Porter	68	67	137	9.2	225	61	8.4	234	198
Noble	65	62	142	8.8	0	57	8.0	225	190
Pulaski	103	101	152	15.3	0	92	13.9	390	330
		855			842	787		3,172	2,455

However, a professor of agricultural engineering at the University of Wisconsin found that several researchers, going back to 1973 reported a grain mass fraction of 45% to 55% of total corn crop DM yield. On average, the variations seem to confirm the common rule of thumb of one unit mass of stover for a unit mass of grain. However, differences among harvesting methods, stages of maturity, and harvest dates can no doubt lead to much of the variation the researchers found in this estimate. His research indicates that the ratio of grain dry mass to total mass increased from about 38% in late August to about 59% in mid-October, during a recent harvest. Therefore, the stover to total ratio declined from 62% to 41%. During the typical harvest period in the Upper Midwest when grain moisture is between 20% and 30%, the ratio of stover to total dry mass was less than 45% and averaged 43%. These results are similar to those found by others.[1112] Mainly, because we have no information upon which to base a reason to use something different, we chose to use the 1:1 ratio for corn stover to corn grain. We also assumed 56-lbs per wet bushel (15.5% moisture) and 47.3-lbs per dry bushel, for the corn grain, to make our stover yield calculations.[1113] Table 4.1-9 summarizes the general operating parameters for our study.

Table 4.1-9. Operating Parameters

EtOH Operating Year	350-days/yr
On Stream Factor	0.96
Hours per year	8,400-hr/yr
EtOH Production Rate	100,000,000-gal/yr
EtOH Yield	72-gal/dry ton
Feedstock Required	
per year	1,389,000-dry tons/yr
per day	3,970-dry tons/day
Expected Dry Matter Loss	11.8%
Feedstock Harvested	1,574,000-dry tons/yr
Feedstock Yield	2-dry tons/acre
Harvest Period	
Days,	50-days
Hours per Day	16-hr/day
Harvest Hours	800-hr
Format:	Shred/Rake,
	Bale - Lg. Sq. - 3'x4'x8'
	Field Side - Self-Propelled Wagon
	Satellite Storage – Pole Barn on Concrete
	Transport to EtOH Facility – Truck & Trailer

At 72 gallons per dry ton, the processing plant would require 1,389,000 dry tons of stover per year. However, we believe storage and transportation losses can be significant and should be taken into account. If, as stated in the report, they harvested 2-tons per acre, they actually harvested 1,574,000 tons of stover, or 64% of the 2,455,000 tons of available dry stover. The quantity of stover used versus the quantity harvested represents an 11.8% loss.[226] Thus, we assumed that with an 11% loss, we would need to harvest 4,500- dry tons of stover per day, which by the time it reaches the plant will actually equal 3,970-dry tons – the amount required per day at the ethanol plant. During a 350-day production year, 1.574-million tons of stover would have be stored in about 3.5-million, 900-lb bales (Purdue study bale weight), at the various satellite storage areas. For this study, we assumed all the loss took place between the satellite storage areas and the ethanol plant, rather than guess what the losses would be at various points within the harvest/transport scheme.

In the following analysis, we did not account for the extra time or equipment that would be necessary for inevitable break-downs. Nor was time and equipment factored in for driving between fields and for weather delays. Stover suppliers face several, in some cases, difficult problems. At best, the actual harvest period is nearly always too short; winter weather can suddenly set in, which in some cases may completely stop a potential stover or straw harvest. Once the grain is harvested and the stalks are mowed, stover usually must be left in the field for three or four days to dry to below 20% moisture before it's baled, otherwise spoilage or rot as well as spontaneous combustion are possible. If it rains, additional time is required for drying and muddy roads and fields can be badly damaged and the field-soil compacted by the increased

[226] We indicated in a previous section that there may be as little as 25% to 50% stover actually available; however, since we didn't have the computer software and database Purdue used and therefore couldn't rerun the simulation, we chose to use the data we had.

heavy-weight harvest and transport equipment traffic. One expert commented that, "If there's a rainy harvest, you might as well forget about it. Also, the longer the wet material is left in the field, there's more of a chance for microbes to eat away at the hemicellulose."[1114] Delayed baling also raises the chances of dry matter loss. The stover needs to field-dry, so the stover harvest can't actually begin for at least a few days after the grain harvest starts. But, once it begins it can continue until either it's finished or until winter weather stops it.

For reasons that weren't explained in the report, the researchers at Purdue chose 50-days for the harvest period, which at their 16-hr per day schedule, provided a total of 800-hrs to complete the harvest and store the stover. In this harvest format (800-hrs), most of the machinery will be stored for the balance of the year. Crop harvest schedules in the Midwest and upper-Midwest are determined by the length of the growing season, the time of year when the crops are mature enough to harvest, and the time when winter weather sets in. Under ordinary conditions, farmers use their harvesting machinery during just a few weeks each year. During the past few years, as machinery costs have risen, many farmers have turned to custom harvesters, that move into an area and harvest several farms. A farmer must always weigh the differences in the custom rates and what it would cost him to own the equipment and complete the harvest himself, but then store most of the harvesting machinery for the rest of the year. In the South, winters are milder and it's possible to harvest some crops all year long. In such cases, feedstocks could conceivably be harvested and shipped to a conversion facility on an 'as needed' basis; storage costs could be saved and machinery would be used all year long. However, an important factor, when it comes to harvest machinery, is the usable-life of the equipment. The more hours used each year, the more often the machine will need to be replaced. A machine lasts only so many hours, whether it's used 800-hrs per year or 8,000-hours per year. We obviously could have arbitrarily chosen some longer period, but in order to maintain at least some consistency with the Purdue study, we chose to use the 50-day schedule for our study. This short period means we must harvest and store a full year's inventory within a few weeks.

Mow, Shred, Rake: Modern corn combines strip most of the leaves from a corn stalk, but leave up to about half of the stalk standing when they cut it off just below the bottom ear. In the combine, the corn grain is stripped from the cob, and the top part of the stalk, the leaves, and the cobs are subsequently discharged out the spreader at the rear of the machine. According to a group of researchers, at the time of grain harvest, of the total stover dry mass, 16% resides in the cob, 7% in the husk, 16% in the leaves, and 60% in the stalk fractions. Of the stalk dry mass, roughly 45% is found in the bottom one-quarter and 80% in bottom one-half of the stalk. If stover yield is to be maximized, harvesting systems must be developed that allow the bottom half of the stalk to be fully harvested.[1115] We summarized the costs to shred and rake in Table 4.1-10

Table 4.1-10. Corn Stover Shredding & Raking Operation

		Tractor – 245-hp	Flail-Shredder -30'	Tractor 75-hp MFWD	Wheeled V-Rake - 20 ft
Equipment Factors					
Purchase price	$	144,502	28,733	59,383	3,660
Useful life	yrs	11.3	3.1	11.3	15
Discounted Salvage value	$	11,736	0.00	7,861	
Annual use	hr	800	800	800	800
Fixed Costs	$/hr				
Depreciation and interest		25.47	14.51	10.06	1.87
Taxes Insurance Housing (THI)	$/hr	3.97	0.79	1.63	0.10
Total Fixed Costs	$/hr	29.44	15.30	11.69	1.97
Variable Costs					
Repairs and maintenance	$/hr	19.62	14.05	8.06	1.63
Fuel consumption[227]	gal/hr	9.6	8	5.6	
Fuel and lubrication	$/hr	23.82	19.87	13.81	4.27
Operating Interest		1.70	1.21	0.82	0.21
Labor	$/hr	15.91	15.91	15.91	4.00
Total Variable Cost	$/hr	61.05	51.04	38.60	10.11
Total Costs					
Total	$/hr	90.49	66.34	50.29	12.08
Equipment capacity	MT/hr	32.7		13.27	
Total	$/ton	4.80		4.70	

It will likely be necessary to flail-cut or mow the standing-stalks, and then rake and bale the windrows. We estimated that it cost about $4.80 per ton of stover for shredding and about $4.70 per ton for raking.

Bale: As previously discussed, large square bales will likely be the bale-format for this system, although large round bales could be used. There are currently more round balers than square balers in use, mainly because large square balers are more expensive. However, gathering, stacking, and transporting large, round bales is much less efficient. It is difficult to stack round bales more than about three high, since they tend to deform rather badly, during even short storage periods; square bale stacks can be stacked up to five or six bales high, which translates into a more efficient use of storage area as well as more stable stacks that are far less prone to deformation over extended storage periods. Although large round bales tend to weather better out in the open, for the reasons just stated as well as those given in the Purdue report, we used large square bales in this analysis. Table 4.1-11 summarizes the cost of the baling operation, which we estimate to be $10.87 per ton.[1116, 1117]

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[227] We have received comment that it may be inappropriate to assign a fuel usage to both the 245-hp tractor and the flail shredder. We were unable to determine whether this was the case. The impact of not including such fuel would be a decrease in the price per ton cost of $0.61.

Table 4.1-11. Corn Stover Baling Operation

		Tractor - 275-hp	Lg. Sq. Baler - 3' x 4' x 8'
Equipment Factors			
Purchase price	$	147,102	110,723
Useful life	yrs	11.3	3.8
Discounted Salvage value	$	7,553	32,455
Annual use	hr	800	800
Fixed Costs	$/hr		
Depreciation and interest		25.93	36.74
Taxes Insurance Housing (THI)	$/hr	4.05	3.04
Total Fixed Costs	$/hr	29.98	39.78
Variable Costs			
Repairs and maintenance	$/hr	19.98	45.11
Fuel consumption[228]	gal/hr	10	8
Fuel and lubrication	$/hr	24.84	19.87
Operating Interest		1.71	2.38
Labor	$/hr	15.91	10.66
Total Variable Cost	$/hr	62.44	78.02
Total Costs			
Total	$/hr	92.42	117.80
Equipment capacity	DMT/hr	19.4	
Total	$/ton	10.87	

Bale Pick-Up & Field Side: It is important to remove the stover bales from off the fields. Few farmers will tolerate bales left for long periods on their fields, especially if there is a chance spring planting will be negatively affected. Nor do we expect farmers will allow random piles of bales left at field edges, for retrieval over the winter and spring months. Aside from the likelihood that trucks and other equipment would get stuck in muddy roads and fields, thus slowing down deliveries and running up operating costs, farmers would have little tolerance for torn-up roads and fields. This may not be a big problem, if the farmer/grower intends to plow a field in the spring. However, it could be highly problematic for a farmer/grower who “no till” farms and would be forced to repair ruts and holes in fields and roads before spring planting. Apart from this, dry matter losses from bales, left out in the open on dirt, can be as high as 10% to 20%. At harvest time, the bales, regardless of format, must be picked up and hauled either to a satellite storage site for intermediate storage or hauled directly to the processing plant.

Several variables must be taken into account for bale pickup and the field-side haul operation that could easily affect the cost. Because the exact location on a field where a bale lands as it falls from a baler varies according to stover yield and harvest efficiency, there is no easy or accurate method for predicting the exact location of each bale on the field, either relative to each other or to the field edges or entry. The distance between bales and the potential variability in the area, shape, and relative dimensions of each field add to the difficulty of estimating bale pickup costs. If it was possible to somehow tag each bale with GPS coordinates as it fell to the ground, theoretically the coordinates could be used in some type of ‘bale retrieval’ program to optimize the time and pickup distance traveled.[1118, 1119]

[228] We have received comment that it may be inappropriate to assign a fuel usage to both the 275-hp tractor and the baler. We were unable to determine whether this was the case. The impact of not including such fuel would be a decrease in the price per ton cost of $1.06.

For this study, we used the theoretical stover density on the field, the speed and width of the harvester to estimate the distance between bales. We used a spreadsheet with these data to position the bales in a variety of patterns on a notional rectangular 100-acre field. We devised three or four drive-patterns in which the bales could be retrieved, by using simple visual inspection. We calculated the time to pick up the bales using each pattern and the average speed of the self-propelled bale-wagon. There were a few variables for which we couldn't adjust our numbers because we simply had no way of knowing their effect. For example, if the field was furrowed, it seemed that the less time spent driving across the furrows, at, as we assumed a slower speed than could be traveled along the furrows, the more efficient would be the pick up. Table 4.1-12 summarizes the information we used for our calculations.

Table 4.1-12. Bale Pickup and Field-Side

Ft. Between Each Bale	490		
Pickup One 10-Bale Load - Ft/Load	4,901		
Bales/Acre	4.4		
Bales/Load	10		
Tons/Load	4.5		
Loader Speed - mph	7.5		
Field Size - Acres	200	400	800
Number of Loads per Field Size	89	178	356
Bales/Field Size - Total	889	1,778	3,556
Miles Traveled per Load	1.74	2.05	2.51
Tons/Hour	26	22	18
Cost per Ton – Pickup & Field-Side	$2.82	$3.31	$ 4.05

In any case, using our basic assumptions, the time it took to retrieve a 10-bale load didn't vary significantly for any of our plots. Table 4.1-13 presents the operating data for the bale wagon.

Table 4.1-13. Self-Propelled Bale-Wagon

		Bale Wagon
Equipment Factors		
Purchase price	$	153,716
Useful life	yrs	18.1
Discounted Salvage value		6,013
Annual use	hr	800
Fixed Costs	$/hr	
Depreciation and Interest	$/hr	20.70
Taxes Insurance Housing (THI)	$/hr	4.23
Total Fixed Costs	$/hr	24.93
Variable Costs		
Repairs and Maintenance	$/hr	12.96
Fuel Consumption gal/hr		7
Fuel and Lubrication	$/hr	17.39
Operating Interest		1.21
Labor	$/hr	15.91
Total Variable Cost	$/hr	47.47
Total Costs	$/hr	72.40
Total	$/hr	72.40
Equipment capacity	DMT/hr	23
Total	$/ton	3.15

Since the fields were no smaller than 200-acres, we piled the bales at one of the corners, which we assumed as the field-entry. We calculated the cost to haul bales for each of the 200-, 400-, and 800-acre fields. We assumed the 20-ft rake made 148-passes across the 200-acre field; 209-passes across the 400-ft field; and 295-passes across the 800-ft field. We used the number of windrows the rake left to determine the number of passes the baler would make. The baler dropped a bale every 490-ft; to collect a 10-bale load the loader would need to travel 4,900-ft. We estimated that the average distance every bale would need to travel to the corner of the field, e.g., the field entry, would be the distance from the field center to the corner (field-entry); we assumed the fields were square. The loader would need to travel that distance and then return empty, for the next load. Therefore, each loader would travel 4,900-ft to pickup the load, and then an additional 4,174-ft for the 200-acre field; 5,903-ft for the 400-acre field; and 8,348-ft for the 800-acre field to haul to the field edge (corner) and return. We chose to pick up 10-bales per load with a self-propelled bale wagon with an average speed of about 10-mph. We assumed the bales would be picked up, transported, and dumped at the field-edge at a cost of $2.82-per ton for the 200-acre fields; $3.31-per ton for the 400-acre fields; and $4.05-per ton for the 800-acre fields. We weighted the DM hauled for each field size by the total tons recovered from each size, to arrive at 23-weighted dry tons/hr hauled for $3.15-per ton

Haul to Satellite Storage: Theoretically, we could store all the bales at the ethanol plant. If so, we would need to move 3,149,000-bales or about 100-loads per hour for 16 hours each day during the 50-day harvest. It would require 50-stacks, each, eight-bales wide by 5-bales high, by 1,577-bales (12,615-ft.) long, with 51 x 20-ft aprons and isles, between each stack and along two-sides of the entire area, plus a 20-ft apron, across the entire front and rear. The area would total ~33-million square feet or 1.19-square miles.

We stored the bales at satellite facilities near the center of each county. As previously discussed, the Purdue study established 'farm-sets,' but did not describe how they were configured and how bales were to be hauled to each storage site, nor did the study specify exactly where each storage site was. Rather, they only estimated the distance between each storage area and the ethanol plant. The following table summarizes the cost factors used to estimate the costs to haul the bales to satellite storage.

Table 4.1-14.
Haul - Field Side to Satellite Storage

		High-Speed Tractor	Bale Wagon	2-Telescopic Handlers
Equipment Factors				
Purchase price	$	133,865	23,851	130,106
Useful life	yrs	15	15	12.5
Discounted Salvage Value	$	10,782	4,803	6,490
Annual use	hr	800	800	800
Fixed Costs	$/hr			
Depreciation and Interest	$/hr	19.62	3.34	21.48
Taxes Insurance Housing(THI)	$/hr	3.68	0.66	3.58
Total Fixed Costs	$/hr	23.30	4.00	25.06
Variable Costs				
Repairs and Maintenance	$/hr	13.63	1.94	15.90
Fuel Consumption gal/hr		6	0	2
Fuel and Lubrication	$/hr	14.90	0	9.94
Operating Interest	$/hr	1.13	0.09	1.02
Labor	$/hr	15.91	7.95	31.82
Total Variable Cost	$/hr	45.57	9.98	58.68
Total Costs	$/hr	68.87	13.98	83.74
Total	$/hr	166.59		
Equipment capacity	DMT/hr	9.3		
Total	$/ton	17.91		

We assumed that a telescopic loader would load the bales at the field-edges onto 20-bale, 2-axle, 30-ft long wagons, each pulled by a high-speed tractor to the storage area located at the center of each county, where they were unloaded by another telescopic loader and the bales stacked for temporary storage. Several variables make the cost of this operation difficult to estimate. A cursory inspection of the general outline/shape of many of the counties in the study reveals that they are by no means square. However, to make our calculations manageable, we assumed they were in order to determine the average distance each bale would need to be transported to its respective storage area in each county. We estimated that the average distance any load would travel from any position in the counties, e.g., from the furthest to the nearest, would be equal to one-half the distance from the corner of the county to its center. We used the published area of each county, from which we determined the distance from one-corner to the center; that distance equaled the trip to the storage area and the return. We multiplied each by a 30% winding factor (rather than a straight-line drive, this accounts for turns and other meanderings).[1120] We estimated the operation would cost about $17.91 per ton.

Satellite Storage: We assumed each storage unit would consist of a concrete slab with open sides and pole-supported tin roof. Smooth paved surfaces are safer and make work easier. Gravel and dirt do not stick to the bottoms of the bales. If winter (wet, muddy) access is necessary, this cost should be included in the overall costs for storage; particularly from the highway to the stack. Beyond the need to keep the area around the stack accessible and clean, there could be problems with local authorities if trucks leaving the property carry significant quantities of mud onto a public highway. Ordinarily, in an agricultural area a certain amount of mud is expected to be left on highways during wet weather. However, at the truck and trailer volumes we're anticipating, the amount being tracked onto highways and possibly through municipalities, would increase rapidly. We used 1% of construction costs for upkeep, and 2% of the construction cost for the storage unit to cover the cost of access. These are incurred costs within the overall maintenance of stored stacks of biomass. These costs are essentially insignificant in the overall storage costs, are subject to great fluctuations due to weather and equipment availability, and, therefore, were rolled up into a percentage of the overall storage costs of stacked bales. The following table summarizes our storage area construction cost factors and costs.

Table 4.1-15.
Satellite Storage Construction & Maintenance Costs – For Each of 11-Areas

Land Rent ($/acre/yr)	100					
Land Preparation ($/acre)	30,000					
Construction ($/sq ft)	3.75					
Upkeep – 1% of Construction ($/ton)	0.91					
Access – 2% of Construction ($/ton)	1.81					
Depreciation Period (yrs)	12					
	Number of Bales	Bale Storage Area (sq ft)	Bale Storage Area (acres)	Tons Stover per site	Supply days	Total Storage Cost
St Joseph	280,889	2,943,716	67.6	126,400	28.1	$1,123,463
Elkhart	245,333	2,571,093	59.0	110,400	24.5	$981,252
Marshall	336,000	3,521,280	80.8	151,200	33.6	$1,343,889
La Porte	479,111	5,021,084	115.3	215,600	47.9	$1,916,286
Starke	245,333	2,571,093	59.0	110,400	24.5	$981,252
Kosciusko	366,222	3,838,009	88.1	164,800	36.6	$1,464,768
Lagrange	201,778	2,114,631	48.6	90,800	20.2	$807,044
Fulton	311,111	3,260,444	74.8	140,000	31.1	$1,244,342
Porter	293,333	3,074,133	70.6	132,000	29.3	$1,173,236
Noble	260,444	2,729,458	62.7	117,200	26.1	$1,041,692
Pulaski	479,111	5,021,084	115.3	215,600	47.9	$1,916,286
Total				1,574,400	350	$13,993,510
Total Cost						$8.89/ton

With well-paved surfaces, equipment can be maneuvered regardless of weather, and surfaces can be sloped to enhance drainage. We also assumed the bales would be stored in multiple stacks, 8-bales wide and 5-bales high, and long enough to accommodate the number of bales we expect; there would 20-ft aprons along the outside of the stacks and 20-ft isles between stacks for stacking, stack management, and for general and fire safety.[1121] One researcher determined that the economics of scale, in the current situation, did not really apply. The cost for secondary storage would therefore be approximately equal on a per ton basis regardless of the size of the biofuel production facility. Based on the numbers above, we estimated that storage would cost about $8.89 per ton.[1122] We used this as the cost per ton for the satellite storage as well as for storage at the plant.

We used 11-telehandlers at the storage areas. (However, once the harvest is complete the telehandlers being used for loading and unloading bale wagons during the field-side to storage area operation could possibly be pressed into transport – load, unload service (see Table 4.1-15). If so, the cost to use the telehandlers could be reduced from $3.28 to $3.08 per ton.) Plus 11-telehandlers at the plant to load and unload trucks and trailers that deliver the stover from satellite storage to the plant; extra telehandler time at the plant will be used to move feedstock as needed. The following table summarizes the cost associated with the transportation. The following table summarizes the cost associated with the transportation.

Table 4.1-16. Haul From Satellite Storage to Plant

		Class 8 Truck	53-ft Flatbed Trailer	22-Telescopic Handlers
Equipment Factors				
Purchase price	$	103,839	42,173	130,106
Useful life	yrs	20	22	13
Discounted Salvage Value	$	4,025	931	6,490
Annual use	hr	5,600	5,600	800
Fixed Costs	$/hr			
Depreciation and Interest	$/hr	1.91	0.74	236.28
Taxes Insurance Housing(THI)	$/hr	0.41	0.71	39.38
Total Fixed Costs	$/hr	2.31	1.45	275.66
Variable Costs				
Repairs and Maintenance	$/hr	1.13	3.16	174.90
Fuel Consumption gal/hr		9	0	2
Fuel and Lubrication	$/hr	33.95	0	109.34
Operating Interest	$/hr	0.37	0.14	11.22
Labor	$/hr	17.46		350.02
Total Variable Cost	$/hr	52.91	2.31	$645.48
Total Costs	$/hr	55.22	3.76	921.14
Total	$/hr	58.97		921.14
Equipment capacity	DMT/hr	4.5		281
Total, each	$/ton	13.10		3.28
Total	$/ton	16.38		

To transport the bales to the ethanol plant, we calculated the ton-weighted average trip-time to be 4.09 hr. We plan to ship 4,497-tons of stover to the plant on each of the 350-operating days. At 17.5-tons per load, we anticipate there will be about 256-loads per day. Using the 4.09-ton weighted trip time, we estimated that it would require 63-trucks and trailers to haul 4 x 17.5-ton per day. The cost of transportation plus loading and unloading is estimated to be $16.38 per dry ton. The following table summarizes all the costs to harvest, bale, field-side, haul to satellite storage, store, and haul to the plant.

Table 4.1-17.
Ag Residue Cost Summary

Farm-Set Size, acres	200	400	800	Total Tons
Tons per Farm-Set, t	756,439	476,402	341,559	1,574,400
Farmer/Grower $/t	10.00	10.00	10.00	
Nutrient Replace $/t	11.81	11.81	11.81	
Shred $/t	4.80	4.80	4.80	
Rake $/t	4.70	4.70	4.70	
Bale $/t	10.84	10.84	10.84	
Haul – Edge $/t	2.82	3.31	4.05	
Total Farm Edge Cost $/t	**44.97**	**45.46**	**46.20**	
Haul – SS $/t	17.91	17.91	17.91	
Storage $/t	8.89	8.89	8.89	
Haul to Ethanol Plant $/t	16.38	16.38	16.38	
Field to Plant – Total $/t	**43.18**	**43.18**	**43.18**	
Per Farm- Set – Total $/t	88.15	88.64	89.38	
Avg. Total Cost $/t	**88.71**			

We anticipate that by 2022 the industry will improve the efficiency of feedstock delivery and reduce the cost of feedstocks. The current harvest-system is usually referred to as a multipass system: the corn grain is first combined, and then the stover is shredded, raked, baled, and the bales hauled to the field side. Each field-pass adds to the final cost and further compacts the soil; soil compaction is especially critical if the soil is prone to compaction or in no-till situations.[1123] Because the combine-spreader drops the stover on to the ground, not only are fewer cobs collected, but dirt, dirt clods, and other debris, including metal, are inevitably gathered up with the stover by the baler.[1124, 1125] Thus, extra effort and money must be expended to remove the debris before processing can begin, apart from the fact that dry matter is also lost during this operation. In their 2002 study report, NREL included a wash table to remove dirt and grit and had magnets to remove tramp iron, e.g., wire, etc. from the stover.[1126]

According to a few sources, which for reasons of confidentiality, we can't quote, there appears to be active interest in restructuring the system we just described to move the preprocessing (feedstock preparation) forward in the chain, away from the ethanol plant, and closer to the fields. Including the issues highlighted in the previous paragraphs, a major concern has to do with the use of standard hay and forage equipment, for which the overall collection efficiency of stover (ratio of stover collected to the total above-ground stover excluding grain) using flail choppers, rakes, and balers was less than 30%.[1127] Until now, most research has been based on a multi-pass system similar to the one we synthesized.[1128,1129] In addition, the timeliness for collection (weather concerns) and moisture content issues are major problems associated with a multi-pass corn stover harvest.[1130]

The restructuring efforts also include exploring other methods to more efficiently gather the stover that avoids the need to pick it up from the ground, e.g., gather or catch it before it hits the ground.[1131] In one early case, a baler was hitched directly onto a combine, to capture the combine effluent and square-bale it. The problem was that there was a strict need to limit moisture to under 20% if bales are to be stored, plus the extra equipment slowed the grain harvest.[1132] Ideally, the stover harvest system should be capable of harvesting stover at any level of moisture even while the grain is being harvested. All the cobs would be collected, the stover wouldn't touch the ground and a controlled amount of residue would be left to meet any conservation requirements (we believe finding a way to leave the correct amount of residue behind will be difficult, and should be a top priority).

A modification of the system we previously described would be to use a mobile tub grinder that could be towed from one satellite storage area to the next. A telehandler would feed the grinder to directly fill trucks for transport to the production facility. The 'walking floor,' rear-dump, or belly-dump trailers would unload the ground-up stover into silos or tanks at the facility. These silos or tanks could be sized to provide as much feed surge capacity as the facility required to maintain continuous operation.[1133]

Again, ideally, the corn stover harvest should be reduced to a single-pass operation during which the amount of residue left on the field will be less a function of harvest efficiency and more a function of the farmer/grower and the harvesting company being able to determine how much residue must be left to maintain soil health. In reality, most of the equipment doesn't yet exist that could perform some of the operations we will describe. Nevertheless, we believe this reflects some of the forward thinking that is currently taking place. For example, a combine designed specifically for the job must still be constructed. A single-pass harvester would cut the whole stalk a few inches above the soil, leaving some stalk anchored to the ground. It would pull the entire plant, e.g., stalks, leaves, and cobs with grain into the combine, where they are mixed into a single, clean, grain and stover stream. It would then blow the entire stream into tractor-pulled grain-carts that run along-side the harvester. It is important to be able to change full carts for empties without stopping the harvester. As a cart is filled, it is pulled from beneath the discharge tube, as an empty cart is pulled under it. The full cart is hauled to the field side, where the harvested material is unloaded directly into bulk 'walking-floor' semi trailers, for transport to a co-op or depot type elevator/facility. After the biomass stream is unloaded, equipment at the elevator/depot separates the stover from the grain, following which the stover is chopped, dried, and sent to tanks or silos for intermediate storage. Currently, there are no simple methods for drying wet corn stover, other than to let it field-dry. However, if the single-pass harvest is to become a reality, the stover will need to be dried or else stored in much the same way silage is stored.[1134] At harvest, corn grain has a moisture content of 25%, while at the same time, the stover ordinarily ranges from 35% to well over 50% moisture. There have been studies to artificially dry corn stover as well as other biomass types; there will likely be changes to the reported results of these and other studies, but, then we expect advancements and certainly changes in several parts of the feedstock supply system.[1135, 1136, 1137] Given that these changes take place, the stover, would have flowability characteristics similar to small cereal grains, and could be moved by standard grain loading and unloading systems into large corrugated steel bins (silos) for intermediate storage. In this harvest format, the stover is handled by only two machines before it reaches the roadside and never hits the ground. Dry matter losses should be significantly reduced.[1138]

Harvesting, storing, and transporting a denser feedstock should offer significant savings.[1139] Using this and other anticipated improvements, it appears possible that in the out years, e.g., by 2022, corn stover and other residues could be commoditized, much as is the case with grain, and then purchased by a processor on an as-needed basis.

However, commoditization offers its own set of issues, among which are both tangible and non-tangible infrastructures. Although tangible infrastructure with regard to ethanol distribution is discussed in greater detail in Section 4.2, we believe the following comments fit within the context of our preceding information. The impact of both feedstock and finished ethanol on rural road, highway and railroad infrastructure is likely to be even greater than the current and anticipated impact of corn based ethanol. Raw cellulosic feedstocks have lower levels of concentrated fermentable carbohydrates and therefore require a greater mass of feedstock to produce an equivalent level of ethanol. Thus, public and private transportation infrastructure must move a greater volume of feedstock per gallon of ethanol produced. The magnitude of the impact will depend on the field density of feedstocks near the plant and whether feedstock densification will make it possible to ship more dense carbohydrate product to the cellulosic ethanol plant.

Intangible infrastructure is essentially absent for crop residue type cellulosic feedstocks. Intangible infrastructure includes such things as uniform grade and quality standards, market price discovery mechanisms, collateral warehouse receipts, regulatory structure and other marketing institutions. Grain market institutions have been developed and fine-tuned over the past century which provide corn ethanol plants a decided benefit. Daily price information, as well as a wealth of crop condition, and supply and demand information from a variety of public and private sources is available on corn grain. Well known institutions such Uniform Grade and Quality Standards, FGIS, Grain Warehouse Regulations, Collateral Warehouse Receipts, Trade Associations, Non-Recourse Government Commodity Loans, and a set of futures markets that efficiently price grain over time and space are all readily available. This infrastructure is already in place, tested and readily accessible to corn grain ethanol producers. Although not highly visible and frequently taken for granted, it plays a critical role in efficient feedstock pricing, risk management, trading and financing. The cellulosic marketing infrastructure required for similar efficient commercial transactions will need to be established from top to bottom.

Pricing infrastructure is one of the most pressing needs. Large daily volumes of corn and other grains are traded on well established exchanges with a great deal of confidence on the part of buyers and sellers that the other party will perform. Initially, it could be difficult, at best, to develop these infrastructure benefits for crop residues such as corn stover. Cellulosic feedstocks will be starting from a relatively small production base with no pricing institutions in place. There are no existing grades and quality standards to underpin transactions over distance and time. Nor are there any trade rules or established patterns for prompt and efficient settlement of trade disputes between buyers and sellers. The absence of these factors does not mean that they won't develop, but there could be a stressful transition period.

Also, there is no regulatory infrastructure to protect producers who wish to hold inventory after harvest in a public warehouse or handlers warehouse. This kind of infrastructure serves an important role in underpinning warehouse receipts and producer financing by creating a higher and more reliable collateral value for inventory. Nor are there equivalents to the U.S. grain grades and quality standards or Federal Grain Inspection Service. While there are other ways these functions can be provided some type of commodity grades and standards will be necessary to permit trading. Another possibility would be to have the production of cellulosic feedstocks and the production of ethanol vertically integrated in some fashion so that the responsibility for quality is internalized.[1140]

Energy Crops

Energy crops such as switchgrass and miscanthus would be harvested, baled, stored and transported very similar to crop residues. Because energy crops are not currently grown on a commercial scale, and are therefore not harvested, it is difficult to model the costs of harvesting these crops. Given the process for harvesting is likely to resemble the corn stover harvesting system described in our internal analysis of agricultural residue costs, we believe the costs would also be similar. Despite these similarities, there are several key differences that will cause the price of energy crops to differ from that of corn stover and other agricultural residues.

One of the main advantages of growing energy crops is the low nutrient inputs, and therefore low nutrient replacement costs, that are required as compared to traditional crops. Energy crops are also expected to produce higher yields per acre than the harvesting of agricultural residues. This higher density is likely to increase the number of tons of feedstock than can be harvested per hour, while at the same time decreasing the transportation distance between the farms where the feedstock is produced and the biofuel production facility. Both of these factors would further decrease the cost of energy crop production, as labor and transportation costs would be lower and less secondary storage facilities would be required.

Not all of the traits of energy crops would indicate lower costs of production, however. Energy crops will also incur a land rent cost. In the scenario described in our internal analysis for corn stover no land rent cost was charged to the production of corn stover. This is because the stover is assumed to be a secondary crop, and therefore all the land rent charges are assumed to be included in the cost of grain production. Because energy crops will likely be grown as primary crops there will be some land rent cost associated with their production. How big this cost is will vary greatly, depending on where and on what type of land the energy crops are grown. If energy crops are grown on marginal land that is unsuitable for traditional crops, as has been suggested, this cost may be low. In any case, it will be an increase when compared with agricultural residues, which do not have any associated land rent costs[229].

Wood Residue

As we did with agricultural residues, we also examined the costs associated with wood residue harvesting to validate the cost generated with FASOM. Harvest and transport costs for woody biomass in its different forms vary due to tract size, tree species, volumes removed, distance to the wood-using/storage facility, terrain, road condition, and other many other considerations. There is a significant variation in these factors within the United States, so timber harvest and delivery systems must be designed to meet constraints at the local level.

[229] Land rent charges are included in the FASOM estimate of the roadside cost of energy crops.

Harvesting costs also depend on the type of equipment used, season in which the operation occurs, along with a host of other factors. Much of the forest residue is already being harvested by logging operations, or is available from milling operations. However, the smaller branches and smaller trees proposed to be used for biofuel production are not collected for their lumber so they are normally left behind. Thus, this forest residue would simply have to be collected and transported out of the forest, although it would still have to be chipped before transport to the biofuel plant.

In general, most operators in the near future will chip at roadside in the forest, blowing the chips directly into a chip van. When the van is full it will be hauled to an end user's facility and a new van will be moved into position at the chipper. The process might change in the future as baling systems become economically feasible or as roll-off containers are proven as a way to handle logging slash. At present, most of the chipping for biomass production is done in connection with fuel-reduction treatments. This could change if the price of raw biomass increases to a point where it becomes feasible to recover logging residues associated with normal commercial operations. The major problem associated with collecting logging residues and biomass from small trees is handling the material in the forest before it gets to the chipper. Balers and roll-off containers offer some promise to reduce this cost. Whether the material is collected from a fuel-reduction treatment or a commercial logging operation, chips from residues will be dirty and will require screening or some type of filtration at the end-user's facility.[230]

Results from a study in South Georgia show that under the right conditions, a small chipper can be added to a larger operation to obtain additional chip production without adversely impacting roundwood production, and chips can be produced from limbs and tops of harvested trees at costs ranging from $11 per ton and up. Harvesting understory (the layer formed by grasses, shrubs, and small trees under the canopy of larger trees and plants) for use in making fuel chips is about $1 per ton more expensive.

Per ton costs decrease as the volume chipped increases per acre. Some estimates suggest that if no more than 10 loads of roundwood are produced before a load of chips is made, that chipper-modified system could break even. Cost projections suggest that removing only limbs and tops may be marginal in terms of cost since one load of chips is produced for about every 15 loads of roundwood.

The U.S. Forest Service provided us a cost curve for different categories of forest residue, including logging residue, other removals (i.e., clearing trees for new building construction), timberland trimmings (forest fire prevention strategy) and mill residues.[1141] The data was provided to us on a county-by-county basis. The national forest lands are omitted from consideration, and the urban forest residue is not considered here, but in the section discussing MSW. The information was also provided at different price points. The quantities of forest residue are summarized by source type in Tables 4.1-18, 4.1-19 and 4.1-20. To avoid presenting

[230] Personal Communication, Eini C. Lowell, Research Scientist, USDA Forest Service

a huge amount of data, we aggregated the county data by state, and we are presenting the data at specific price points: $30/dry ton, $45/dry ton and $70/dry ton.

Table 4.1-18.
Volume of Wood Residue Available for Producing Biofuel
Biomass Available at $30/ton (dry tons)

	Logging Residue	Other Removals	Timberland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	433,519	7,117	1,896,798
Arizona	8,849	22,436	33,085	1,351	65,721
Arkansas	851,772	385,492	369,083	12,889	1,619,236
California	334,870	0	871,351	65,088	1,271,309
Colorado	9,203	7	0	2,302	11,511
Connecticut	4,195	15,339	10,465	3,949	33,949
Delaware	15,051	12,109	4,918	0	32,077
Florida	535,215	257,704	240,947	2,202	1,036,067
Georgia	1,556,954	496,631	553,627	45,138	2,652,350
Idaho	126,573	0	41,548	6,006	174,126
Illinois	139,101	117,589	115,431	18,523	390,644
Indiana	281,242	52,087	198,112	10,627	542,068
Iowa	56,049	27,580	48,991	159	132,780
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	344,948	55,196	1,246,311
Louisiana	1,317,139	440,293	300,924	30,075	2,088,431
Maine	1,206,438	470	80,314	42,483	1,329,705
Maryland	90,722	415	40,994	17,067	149,197
Massachusetts	35,461	31,043	13,801	0	80,305
Michigan	379,463	122,476	327,640	13,763	843,343
Minnesota	348,807	331,492	132,712	26,878	839,889
Mississippi	1,548,534	355,071	425,344	95,138	2,424,088
Missouri	387,434	265,146	342,077	79,787	1,074,443
Montana	131,335	0	66,592	9,136	207,063
Nebraska	10,572	9,386	11,707	4,971	36,637
Nevada	15	53	0	0	67
New Hampshire	157,321	174	47,802	7,019	212,316
New Jersey	2,959	39	2,288	1,437	6,723
New Mexico	11,929	1,279	25,898	4,902	44,008
New York	367,003	54,671	163,336	27,390	612,400
North Carolina	1,013,165	629,632	560,814	12,811	2,216,422
North Dakota	1,453	7,601	3,822	265	13,141
Ohio	185,398	9,053	83,676	22,600	300,726
Oklahoma	173,869	98,794	53,043	495	326,200
Oregon	760,276	31	527,702	16,316	1,304,326
Pennsylvania	543,663	699	224,978	170,972	940,312
Rhode Island	884	22,860	2,800	389	26,934
South Carolina	714,551	348,289	301,850	1,051	1,365,741
South Dakota	6,972	14,436	2,993	2,294	26,695
Tennessee	316,706	244,920	423,906	187,583	1,173,115
Texas	616,777	218,464	185,718	3,021	1,023,979
Utah	2,973	7	9,909	4,437	17,325
Vermont	104,876	18,652	48,395	0	171,923
Virginia	741,673	406,800	436,870	39,366	1,624,709
Washington	641,144	22	925,479	21,446	1,588,091
West Virginia	488,356	24,714	161,653	118,779	793,502
Wisconsin	568,800	491,132	260,293	60,410	1,380,636
Wyoming	11,343	0	14,050	34,014	59,407
Total	18,530,943	6,165,088	9,485,083	1,295,560	35,476,674

Table 4.1-19.
Tons of Wood Residue Available for Producing Biofuel
Biomass Available at $45/ton (dry tons)

	Logging Residue	Other Removals	Timberland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	506,045	7,117	1,969,324
Arizona	13,566	21,210	34,967	1,351	71,094
Arkansas	851,772	385,492	429,414	12,889	1,679,567
California	583,478	0	949,468	65,088	1,598,034
Colorado	10,056	11	30,619	2,302	42,988
Connecticut	4,301	16,095	10,465	3,949	34,810
Delaware	17,932	14,145	6,700	0	38,777
Florida	535,215	257,704	266,597	2,202	1,061,718
Georgia	1,556,954	496,631	644,295	45,138	2,743,018
Idaho	216,303	0	52,594	6,006	274,902
Illinois	139,153	117,589	115,431	18,523	390,696
Indiana	281,464	52,087	221,845	10,627	566,023
Iowa	56,050	27,607	49,551	159	133,367
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	407,371	55,196	1,308,735
Louisiana	1,317,139	440,293	330,512	30,075	2,118,019
Maine	1,280,511	495	102,442	42,483	1,425,931
Maryland	94,579	421	40,994	17,067	153,060
Massachusetts	39,127	33,191	13,801	0	86,119
Michigan	391,732	128,600	410,302	13,763	944,398
Minnesota	358,518	341,894	159,990	26,878	887,280
Mississippi	1,548,534	355,071	467,935	95,138	2,466,679
Missouri	387,434	265,146	466,082	79,787	1,198,448
Montana	215,597	0	70,775	9,136	295,507
Nebraska	10,710	9,434	11,707	4,971	36,822
Nevada	22	71	0	0	93
New Hampshire	165,519	197	57,566	7,019	230,301
New Jersey	3,184	40	2,423	1,437	7,084
New Mexico	17,239	1,287	26,862	4,902	50,291
New York	384,457	56,552	189,696	27,390	658,094
North Carolina	1,013,165	629,632	668,420	12,811	2,324,028
North Dakota	1,454	7,601	3,822	265	13,142
Ohio	186,022	9,069	88,572	22,600	306,263
Oklahoma	173,869	98,794	62,700	495	335,858
Oregon	1,341,835	34	574,948	16,316	1,933,133
Pennsylvania	1,341,835	34	574,948	170,972	2,087,789
Rhode Island	957	25,039	2,800	389	29,185
South Carolina	714,551	348,289	352,018	1,051	1,415,909
South Dakota	11,872	15,581	3,253	2,294	32,999
Tennessee	316,706	244,920	507,698	187,583	1,256,906
Texas	616,777	218,464	219,187	3,021	1,057,448
Utah	3,758	0	10,786	4,437	18,980
Vermont	108,542	19,182	53,836	0	181,560
Virginia	741,673	406,800	524,372	39,366	1,712,212
Washington	1,067,587	23	981,839	21,446	2,070,895
West Virginia	488,356	24,714	241,184	118,779	873,033
Wisconsin	576,938	499,302	327,027	60,410	1,463,677
Wyoming	18,163	0	18,202	34,014	70,380
Total	20,928,463	6,198,742	11,301,737	1,295,560	39,724,502

Table 4.1-20.
Tons of Wood Residue Available for Producing Biofuels
Biomass available at $70/ton (dry tons)

	Logging Residue	Other Removals	Timberland Thinnings	Unused Mill Residue	Total Quantity
Alabama	1,202,541	253,620	581,654	7,117	2,044,933
Arizona	13,566	24,510	38,678	1,351	78,105
Arkansas	851,772	385,492	492,094	12,889	1,742,247
California	583,478	0	1,000,615	65,088	1,649,181
Colorado	10,056	11	30,619	2,302	42,988
Connecticut	4,301	16,095	10,465	3,949	34,810
Delaware	17,932	14,145	6,700	0	38,777
Florida	535,215	257,704	332,353	2,202	1,127,474
Georgia	1,556,954	496,631	776,911	45,138	2,875,634
Idaho	216,303	0	61,926	6,006	284,235
Illinois	139,153	117,589	115,431	18,523	390,696
Indiana	281,464	52,087	221,845	10,627	566,023
Iowa	56,050	27,607	49,551	159	133,367
Kansas	7,329	44,202	9,676	8,720	69,928
Kentucky	513,989	332,179	463,904	55,196	1,365,268
Louisiana	1,317,139	440,293	375,052	30,075	2,162,559
Maine	1,280,511	495	166,117	42,483	1,489,605
Maryland	94,579	421	40,994	17,067	153,060
Massachusetts	39,127	33,191	13,801	0	86,119
Michigan	391,732	128,600	533,107	13,763	1,067,203
Minnesota	358,518	341,894	200,599	26,878	927,889
Mississippi	1,548,534	355,071	516,598	95,138	2,515,342
Missouri	387,434	265,146	643,929	79,787	1,376,295
Montana	215,597	0	83,023	9,136	307,755
Nebraska	10,710	9,434	11,707	4,971	36,822
Nevada	22	71	0	0	93
New Hampshire	165,519	197	58,098	7,019	230,833
New Jersey	3,184	40	2,423	1,437	7,084
New Mexico	17,239	1,287	32,187	4,902	55,616
New York	384,457	56,552	192,851	27,390	661,249
North Carolina	1,013,165	629,632	800,455	12,811	2,456,063
North Dakota	1,454	7,601	3,822	265	13,142
Ohio	186,022	9,069	88,572	22,600	306,263
Oklahoma	173,869	98,794	81,634	495	354,792
Oregon	1,251,094	34	566,594	16,316	1,834,037
Pennsylvania	546,418	707	340,497	170,972	1,058,594
Rhode Island	957	25,039	2,800	389	29,185
South Carolina	714,551	348,289	395,555	1,051	1,459,446
South Dakota	11,872	15,581	4,129	2,294	33,875
Tennessee	316,706	244,920	516,550	187,583	1,265,759
Texas	616,777	218,464	253,670	3,021	1,091,931
Utah	3,758	7	14,717	4,437	22,918
Vermont	108,542	19,182	71,105	0	198,829
Virginia	741,673	406,800	630,366	39,366	1,818,206
Washington	1,067,587	23	1,029,985	21,446	2,119,041
West Virginia	488,356	24,714	287,639	118,779	919,489
Wisconsin	576,938	499,302	420,775	60,410	1,557,425
Wyoming	18,163	0	21,598	34,014	73,775
Total	20,042,304	6,202,722	12,593,373	1,295,560	40,133,959

The relatively flat supply curve indicates that small changes in the demand for wood residues could have a significant impact on the cost of these residues. This makes predicting an appropriate cost for these residues a difficult task. The FASOM model estimates that 1.67 million dry tons of wood residues will be used in cellulosic biofuel production in 2022. This number is far less than the 35.5 million dry tons of wood residue that the US Forestry service estimates will be available at $30 a ton. This would suggest that the low costs estimated by FASOM ($19.77 per dry ton) are reasonable.

Delivery of woody biomass from the harvesting site to a conversion facility, like delivery of more conventional forest products, accounts for a significant portion of the delivered cost. In fact, transportation of wood fiber (including hauling within the forest) accounts for about 25 to 50 percent of the total delivered costs and highly depends on fuel prices, haul distance, material moisture content, and vehicle capacity and utilization. Also, beyond a certain distance, transportation becomes the limiting factor and the costs become directly proportional to haul distance. We believe Class 8 over-the-road hauling will be used to transport the wood residues from the roadside to the biofuel production facilities. The cost for the transportation of wood residues was determined using the transportation and secondary storage tool presented in Section 1.3 and in further detail below. Because wood residues can be harvested throughout the year and delivered to the biofuel production plant on an as needed basis no secondary storage costs were included.

Municipal Solid Waste

Million of tons of municipal solid waste (MSW) continue to be disposed of in landfills across the country, despite recent large gains in waste reduction and diversion. The biomass fraction of this total stream represents a potentially significant resource for renewable energy (including electricity and biofuels). Because this waste material is already being generated, collected and transported (it would solely need to be transported to a different location), its use is likely to be less expensive than other cellulosic feedstocks. One important difficulty facing those who plan to use MSW fractions for fuel production is that in many places, even today, MSW is a mixture of all types of wastes, including biomaterials such as animal fats and grease, tin, iron, aluminum, and other metals, painted woods, plastics, and glass. Many of these materials can't be used in biochemical and thermochemical ethanol production, and, in fact, would inflate the transportation costs, impede the operations at the biofuel plant and leave an expensive waste stream for biofuel producers.

Thus, accessing sorted MSW would likely be a requirement for firms planning on using MSW for producing cellulosic biofuels. In a confidential conversation, a potential producer who plans to use MSW to produce ethanol indicated that their plant plans are based on the obtaining cellulosic biowaste which has already been sorted at the waste source (e.g., at the curbside, where the refuse hauler picks up waste already sorted by the generating home-owner or business). For example, in a tract of homes, one refuse truck would pick up glass, plastic, and perhaps other types of waste destined for a specific disposal depot, whereas a different truck would follow to pick up wood, paper, and other cellulosic materials to be hauled to a depot that supplies an ethanol plant. However, only a small fraction of the MSW generated today is sorted at the curbside.

Another alternative would be to sort the waste either at a sorting facility, or at the landfill, prior to dumping. There are two prominent options here. The first is that there is no sorting at the waste creation site, the home or business, and thus a single waste stream must be sorted at the facility. This operation would likely be done by hand or by automated equipment at the facility. To do so by hand is very labor intensive and somewhat slower than using an automated system. In most cases the 'by-hand' system produces a slightly cleaner stream, but the high cost of labor usually makes the automated system more cost-effective. Perhaps the best approach for low cost and a clean stream is the combination of hand sorting with automated sorting.

The third option is a combination of the two which requires that there is at least some sorting at the home or business which helps to prevent contamination of the waste material, but then the final sorting occurs downstream at a sorting site, or at the landfill.

We have little data and few estimates for the cost to sort MSW. One estimate from our Office of Solid Waste for a combination of mechanically and manually sorting of a single waste stream downstream of where the waste is generated puts the cost in the $20 to $30 per ton range. There is a risk, though, that the waste stream could still be contaminated and this would increase the cost of both transporting and using this material at the biofuel plant due to the toxic ash produced which would require disposal at a toxic waste facility. If a less contaminated stream is desired it would probably require sorting at the generation site – the home or business - which would likely be more costly since many more people in society would then have to be involved and special trucks would need to be used. Also, widespread participation is difficult when a change in human behavior is required as some may not be so willing to participate. Offering incentives could help to speed the transition to curbside recycling (i.e., charging fee for nonsorted waste, or paying a small amount for sorted tree trimmings and construction and demolition waste). Assuming that curbside sorting is involved, at least in a minor way, total sorting costs might be in the $30 to $40 per ton range.

These sorting costs would be offset by the cost savings for not disposing of the waste material as well as the value of the recovered materials. Most landfills charge tipping fees, the cost to dump a load of waste, a societal cost that would be avoided. In the United States, the national average nominal tipping fee increased fourfold from 1985 to 2000. The real tipping fee almost doubled, up from a national average (in 1997 dollars) of about $12 per ton in 1985 to just over $30 in 2000. Equally important, it is apparent that the tipping fee is much higher in densely populated regions. Statewide averages also varied widely, from $8 a ton in New Mexico to $75 in New Jersey. Tipping fees ranged from $21 to 98 per ton in 2006 for MSW and $18/ton to $120/ton for construction and demolition waste. It is likely that the tipping fees are highest for waste contaminated by toxic materials that require the disposal at Resource Conservation and Recovery Act (RCRA) certified toxic waste sites as opposed to a composting site. However, this same contaminated material would not be desirable to biofuel producers. Presuming that only the noncontaminated cellulosic waste (yard and food wastes, building construction and demolition waste and some paper) is collected as feedstocks for biofuel plants, the handling and tipping fees are likely much lower, in the $30 per ton range.[231]

[231] A much more thorough analysis of tipping fees by waste type is planned for the final rulemaking analysis.

The avoidance of tipping fees, however, is a complex issue since landfills are generally not owned by municipalities anymore. Both large and small municipalities recognized their inability to handle the new and complex solid waste regulations at a reasonable cost. Only 38 out of the 100 largest cities own their own landfills. To deal with the solid waste, large private companies built massive amounts of landfill capacity. The economic incentive is for private landfill operators to fill their landfills with garbage as early as possible to pay off their capital investment (landfill site) quickly. Also, the longer the landfill is operating the greater is its exposure to liability due to leakages and leaching. Furthermore, landfills can more cost-effectively manage the waste as the scale of the landfill is enlarged. As a result, there are fewer landfills and landfill owners, and an expansion of market share by large private waste management firms, thus decreasing the leverage a biofuel producer may have.[232] Hence, MSW-biofuel plants could be opposed by landfill operators. This may also be true in the case of a waste-to-energy (WTE) facility, which burns as much garbage as possible to produce electricity. For sustainable operation, a certain amount of daily waste supply should be guaranteed. A MSW-biofuel plant may therefore be seen as an unwelcome competition to both landfill owners and WTE facilities. This competition may increase the cost of cellulosic biomass to the biofuel producers.

Once the cellulosic biomass has been sorted from the rest of MSW, it would have to be transported to the biofuels plant. Transportation is different for MSW biomass compared to forest and crop residues. Forest and crop residues are collected from forests and farms, which are both rural sites, and transported to the biofuel plant which likely is located at a rural site. The trucks which transport the forest and crop residues are large over-the-road trucks which can average moderate speeds because of the lower amount of traffic that they experience. Conversely, MSW is collected from throughout urban areas and would have to be transported through those urban areas to the plant site. If the cellulosic biomass is being collected at curbside, it would likely be collected in more conventional refuse trucks. If the biofuel plant is nearby, then the refuse trucks could transport the cellulosic biomass directly to the plant. In this case, the refuse trucks would simply be delivering the MSW to the biofuel producer instead of a landfill or waste sorting facility, and therefore would not result in any additional cost to the biofuel producer. If, however, the plant is located far away from where the waste is collected, then the refuse trucks would probably to be offloaded to more conventional over-the-road trucks with sizable trailers to make transport more cost-effective. This would likely be an additional cost charged to the biofuel producer, as the MSW is now being transported farther to be used as a biofuel feedstock instead of disposed of at a local landfill. Because the roadside cost of MSW is significantly lower than the other feedstock sources it may still be cheaper to import MSW from some distance away rather than use an alternative, locally available feedstock.

Cellulosic biomass sourced from MSW is generated year-round. If a steady enough stream of this material is available, then secondary storage would not be necessary, thus avoiding the need to install secondary storage. We assumed that no secondary storage costs would be incurred for MSW-sourced cellulosic biomass. If the MSW is sourced from within the same county as the biofuel plant we have assumed that there is no cost to the biofuel producer for the

[232] Osamu Sakamoto, The Financial Feasibility Analysis of Municipal Solid Waste to Ethanol Conversion, Michigan State University, Plan B Master Research Paper in partial fulfillment of the requirement for the degree of Master of Science, Department of Agricultural Economics, 2004

transportation of the feedstock. If, however, the feedstock comes from a county other than the one in which the biofuel plant is located we assume that the biofuel producer must pay to have the MSW transported in large over-the-road trucks. These assumptions are used for the transportation and secondary storage tool discussed in Section 1.3 and in detail in the following section.

4.1.1.2.3 Transportation and Secondary Storage

For many of the feedstocks such as corn or soy oil, the feedstock costs include the cost for transportation and any storage costs. However, for cellulosic feedstocks, the FASOM model only estimates the feedstock costs at the "farm-side" or "forest side," therefore, it was necessary to estimate the transportation and secondary storage costs for these feedstocks. These transportation and secondary storage cost estimates were ultimately used in the Cellulosic Feedstock Transportation and Storage Cost Tool described in Section 1.3. Each feedstock involves a different set of assumptions for transportation and whether or not secondary storage would be necessary.

Agricultural Residue and Energy Crops

For agricultural residue and energy crops (assumed to be switchgrass), we assume that for most of these feedstocks, that the feedstocks will be transported to secondary storage, stored and then transported from secondary storage to the plant. Since a portion of this feedstock may be harvested close to the plant, we assumed that some of the feedstock would be transported directly to the plant.

For transportation to secondary storage, we used the cost information in Table 4.1-14. The transportation to secondary storage involves loading a trailer with 12 tons of baled cellulosic material, and pulling the trailer to the secondary storage site using a high speed farm tractor. At the secondary storage site, the bales must be offloaded for storage. The loading and unloading of the trailer involves the use of a tele-handler. Total time for loading and unloading is estimated to require 40 minutes of time, or 20 minutes at each site.

For estimating costs, we subdivided the transportation from farm to secondary storage into two different operations. One operation is the loading and offloading of the cellulosic feedstock bales which require the use of the farm tractor, trailer and one tele-handler per tractor/trailer. To estimate these costs we summed the total per-hour costs of these three pieces of equipment (assuming one telehandler instead of two), minus the farm tractor fuel and lube costs since the farm tractor is parked, which sums to $110 per hour. Assuming that these loading and unloading operations require 40 minutes of time for 12 tons of cellulosic feedstock, we derive a cost of $6.14 per ton.

The second operation for the transportation costs to secondary storage involves the actual hauling of the agricultural residue and energy crop cellulosic feedstocks from the farm to the secondary storage site. For this operation, the farm tractor pulls the trailer containing the bales of cellulosic feedstock. We again use the total costs of the farm tractor and trailer, but include the fuel and lube costs since the farm tractor is using fuel pulling the trailer; this totals to $83 per hour. We assume that the farm tractor will average 22 miles per hour hauling the 12 tons of cellulosic feedstock to secondary storage. This results in a cost of $0.64 per ton-mile which accounts for the roundtrip from the farm to the secondary storage facility. Therefore, the total transportation costs per ton of feedstock is $6.14 + $0.64 x D where "D" is the one way distance from farm to secondary storage. Whenever we estimated the distance traveled from the farm to secondary storage, we assumed that the distance would be 1.3 times the most direct route between the two. This assumption makes sense because roads in farming regions of the country are less numerous than in urban areas, and they often require traveling in circuitous routes to reach the desired site. For example to reach a location north and west of a starting location, it may be necessary to travel due north and then due west on two different roads until the desired site is reached. Also, rural roads can be windy which also adds to the travelled distance

The secondary storage costs are accounted for in Table 4.1-15. However, an inherent assumption of that analysis is that the per-ton storage costs are the same $8.89 per ton regardless of the size of the storage facility, which is inconsistent with how construction costs are incurred. To optimize the secondary storage costs with the transportation costs, we scaled the secondary storage costs such that small secondary storage facilities would incur a higher per ton cost than a larger facility. The scaling factor we used is 0.8.[233] The base size for the secondary storage facility is 25,800 tons of cellulosic feedstock which is the size of secondary storage site which matched the costs for another secondary storage cost estimate. The costs scale up and down from the $8.89 per ton value indicated in Table 4.1-15 depending on whether the facilities are smaller or larger facilities. For example, a secondary storage facility which stores 9900 tons of cellulosic feedstock is estimated to cost $10.7 per ton of feedstock stored, while a facility which stores 132,000 tons of cellulosic feedstock is estimated to cost $6.40 per ton of feedstock stored.

Scaling the secondary storage costs was important for conducting an optimization analysis with respect to transportation and secondary storage costs. If secondary storage costs did not vary based on size, then the most efficient means for storing the cellulosic feedstock would be in very small secondary storage facilities located at the farm, which would essentially eliminate transportation costs to the secondary site. However, we feel that such an assumption would not be realistic considering how the construction costs are incurred.

In conducting our optimization analysis, we assumed that denser agricultural residue or energy crop densities would help to lower the transportation and secondary storage costs compared to less dense cellulosic feedstocks. This is logical because the higher the density, the shorter the distance that cellulosic feedstock would have transported to secondary storage facilities and the less numerous and larger the secondary storage facilities could be for the same amount of feedstock. The optimization analysis we conducted considered three different densities for the cellulosic material and these were 1.8, 5.7 and 15 tons per acre. We assumed that 25% of the acres of the land are planted in the area. We then assessed an array of distances from farm to secondary storage sites and secondary storage site capacities consistent with the

[233] The capital cost is estimated using an exponential equation. The equation is as follows: $(Sb/Sa)^e xCa=Cb$, where Sa is the size of reference sized secondary storage site which can hold 25,800 tons of cellulosic feedstock, Sb is the size of the unit for which the cost is desired, e is the exponent, Ca is the cost of the reference secondary storage site, and Cb is the desired cost for the different sized unit. The exponential value "e" used in this equation is 0.8 for secondary storage sites (equation from Peters and Timmerhaus, 1991)

distances. For example, for the 5.7 tons per acre crop density case, one situation we analyzed assumed that the cellulosic feedstock would be transported 7.5 miles to 10 different secondary storage sites each storing 107,000 tons of cellulosic feedstock per site. This example estimated an average transportation to secondary storage and secondary storage cost of $17.63 per ton. Another example for the 5.7 tons per acre crop density case assumed that there would be 60 secondary storage sites each storing 17,900 tons of cellulosic feedstock which would require that, on average, the cellulosic feedstock would need to be transported 3.1 miles to the secondary storage site. This example costs about the same, which is $17.60 per ton of feedstock. However, our optimization analysis estimates that the optimum situation for the 5.7 tons per acre crop density case is 23 secondary storage sites each storing 46,800 tons of cellulosic feedstock. The average transportation distance for this optimum case is 5.0 miles and the average cost for both the transportation to the secondary storage site and the secondary storage cost is $17.20 per ton of cellulosic feedstock.

When conducting this analysis, we realized that for a portion of the feedstock grown closest to the plant, that it would make more sense to build the secondary storage site at or adjacent to the plant to avoid extensive transportation costs moving the feedstock for storage when the plant was nearby. The assumption we made is that for all feedstock grown within the radius equal to the optimal transportation distance to secondary storage, the feedstock would be transported directly to the plant. For example, for the 5.7 tons per acre case, the average transportation distance to secondary storage is 5.0 miles when the costs are optimized. To avoid excessive transportation costs, we assumed that all the feedstock grown within 5.0 miles of the plant would be transported directly to the plant or to storage adjacent to the plant. This assumption for the optimized 5.7 tons per acre case resulted in 14% of the cellulosic feedstock being transported directly to the plant. As the density of the feedstock increases, this assumption resulted in a larger amount of cellulosic feedstock being transported directly to the plant.

Table 4.1-21 summarizes the optimal number and size of secondary storage sites and average transportation distances for transporting the cellulosic feedstock from the farm to the secondary storage sites, and the costs for the optimal situation for each cellulosic feedstock density case. Table 4.1-21 also summarizes our estimate of the percentage of cellulosic feedstock being transported directly to the plant.

Table 4.1-21
Optimal Number of Secondary Storage Sites and
Optimal Transportation Distances to those Sites

Celluosic Feedstock Density (tons/acre)	1.8	5.7	15
Average Transportation Distance (miles)	5.66	4.96	4.36
Number of Secondary Storage Sites	60	23	11
Amount of Cellulosic Feedstock per Secondary Storage Site (tons)	19,400	46,800	88,000
Cost for Storage and Transportation to Secondary Storage Site ($/ton)	19.17	17.20	15.88
Percentage of Cellulosic Transported directly to the Plant	7	14	23
Average Cost including Storage and Transportation to Secondary Storage Site ($/ton)	17.83	14.81	12.30

Our transportation and secondary storage optimization analysis shows that as crop density decreases, there is a corresponding increase in the secondary storage costs and the transportation costs for transporting the cellulosic feedstock from the farm to secondary storage. Low crop density requires an increased number of smaller secondary storage sites, however smaller secondary storage sites are associated with higher per-ton costs. Another advantage of higher density feedstocks is it becomes more likely that more of the cellulosic feedstocks will be taken directly to the plant as opposed to being stored at secondary storage sites, which further helps to reduce the feedstock costs.

For integrating the secondary storage costs and the transportation costs into our model described in Section 1.3, we needed to represent these costs in a form that could be used by the model. Since our model contains crop density information for each crop, we conducted a linear regression of the cellulosic feedstock density values against the average secondary storage cost and transportation to secondary storage costs (bottom row of Table 4.1-21). This regression resulted in the following equation: SSTC = -0.473 x DY +18.90 where "SSTC" equals the secondary storage cost and transportation cost from the farm to secondary storage and "DY" equals the cellulosic feedstock density in the farm field in tons per acre.

Once the cellulosic feedstock is at a secondary storage facility, it must be transported from secondary storage to the plant. This additional transportation step will incur an additional cost. To estimate this transportation cost we used the cost information in Table 4.1-16.

To facilitate these calculations we once again subdivided the cost estimate into two different operations. One operation is the loading and offloading of the cellulosic feedstock bales. For the loading operation, we assumed the use of the truck, flatbed trailer and two tele-handlers. We assumed that two tele-handlers would be used to optimize the time required for loading of 24 tons of cellulosic feedstock. To estimate these costs we summed the total per-hour costs of these three pieces of equipment, minus the truck fuel and lube costs because the truck is parked (using one-eleventh of the costs for 22 tele-handlers), which sums to $109 per hour. We assume that the actual loading operation would require about 30 minutes. However, the over-the-road truck would likely require that a tarp be secured over the bales to as a safety measure for hauling the bales over principal roadways, so we increased the loading time to an hour. For offloading the feedstock, we assumed that the plant would have its own offloading equipment, so we only included the total cost minus fuel and lube for the truck and trailer, which is $25.03 per ton. However, because the truck would also have to be weighed for determining the mass of feedstock being delivered, we increased the total offloading time including weighing of the cellulosic feedstock to 1 ½ hours. Totaling the loading and offloading costs for 24 tons of cellulosic feedstock, we derive a cost of $6.90 per ton.

The second operation is the actual hauling of the cellulosic feedstock from secondary storage to the plant. For this operation, the truck pulls the flatbed trailer containing the bales of cellulosic feedstock. We used the total costs of the truck and flatbed trailer, but include the fuel and lube costs since the truck is pulling the trailer; this totals to $69 per hour. We assume that the truck will average 30 miles per hour hauling the 24 tons of cellulosic feedstock to the plant. Although the over-the-road is capable of much higher speeds compared to the farm tractor which hauled the feedstock to the secondary storage, we assumed that the truck's speed would be limited by driving on dirt roads and smaller county roads and by needing to drive through smaller towns located in rural areas. This results in a cost of $0.17 per ton-mile which accounts for the roundtrip from the secondary storage facility to the plant. Therefore, the total transportation costs per ton of feedstock can be summarized into the following equation: TC = $6.90 + $0.17 x D where "TC" is transportation cost in dollars per ton and "D" is the one-way distance in miles.

We needed to estimate an average distance traveled for the cellulosic feedstock when it is being transported from secondary storage to the plant. The average distance can be estimated by knowing the size of the area from which the cellulosic feedstock is being harvested, such as the entire county. The average distance from each point within the area to the centerpoint of the area (the cellulosic biofuel plant is assumed to be located in the center of the country) is estimated to be 70 percent of the total radius or distance to the outer edge of the area. Another way to understand the 70 percent value, assuming that the area is a circle, is that half the area of the circle is within the area marked by 70% of the circle's total radius while the other half of the radius falls within the last 30% of the circle's radius. This same relationship holds true for a square as well. Therefore, knowing the area of the region from which the cellulosic feedstock is being harvested for processing by a particular plant, we assumed that the average transportation distance is 70% of the total average distance from the centerpoint to the outer edge of the area.

Forest Residue and Municipal Solid Waste

By the nature of how they are produced, MSW and forest residue were assumed to not need secondary storage. MSW is created throughout the year and can be processed and then transported directly to the plant as it is produced. This is true for forest residue as well. Forest material is "stored on the stump" until it is needed. Since the primary uses of forest material is for pulp and paper production and wood products for the building industry, and these uses demand product year-round, the forest residue from these operations are assumed to be made available on the year-round basis as well. Thus for these categories of cellulosic feedstocks, only transportation directly to the plant was assumed.

Another factor that we considered is that MSW already incurs a transportation cost for transporting the MSW to a landfill. Thus, when MSW is being transported to a cellulosic biofuel plant, instead of additional transportation cost being incurred, the MSW would simply be rerouted to a cellulosic biofuel plant and no new transportation cost would be incurred. This assumes that the MSW has been partially or perhaps completely presorted such that the MSW feedstock would simply be rerouted to the cellulosic biofuel plant. However, if sorting still needs to occur, it very well would occur at the landfill and additional transportation costs would be incurred if the cellulosic biofuel plant is not located at the landfill. If the MSW is being transported to a plant located away from the landfill, for example, if the plant were to be located in an adjacent county, then additional transportation costs would be incurred.

For estimating the transportation costs for MSW and forest residue we assumed that the transportation cost methodology for transporting cellulosic feedstock from secondary storage to the cellulosic biofuel plant would apply in this case as well. Thus, the transportation costs per ton of feedstock for forest residue and for intercounty shipments of MSW would be TC = \$6.90 + \$0.17 x D where "TC" is transportation cost in dollars per ton and "D" is the one-way distance in miles.

4.1.1.2.4 Cellulosic Ethanol Production Costs

Two different technologies served as the basis for estimating the costs for converting cellulose into ethanol. One technology relies on the biochemical conversion of the cellulose to ethanol. The second technology converts the cellulose to a syngas and then reacts the syngas to mixed alcohols over a catalyst.

Biochemical Conversion of Cellulose to Ethanol

We contracted with the National Renewable Energy Laboratory (NREL) to estimate the cost to convert corn stover into ethanol for the years 2010, 2015, and 2022. It is of particular importance for the following discussion, to note the following: NREL used the same feedstock mass (772,168 dry tons of corn stover) in all three cases.

For the three cases, NREL assumed the feedstock, 'as-needed,' was hauled to the plant by trucks and trailers from satellite storage, already shredded to the appropriate size for processing, and free of dirt, iron, and other contaminates; in other words – process ready. The transport vehicles were unloaded into surge tanks, large enough to hold feedstock for three days of operation. The pretreatment and hydrolysis reactors are charged from these feed surge tanks.

The following is background information for our discussion of both operating and capital costs, some of which is also included in our brief discussion of the process flow description and capital equipment charges. The first step was to develop a set of process flow diagrams that set the arrangement of the equipment. Based on the desired production volume, these diagrams, were used within an ASPEN Plus4© model to develop complete mass and energy balance. The model consists of 164 unit operation blocks, 457 streams (247 material and 210 heat or work), 63 components, and 82 control blocks.

The overall model is thermodynamically rigorous and uses physical properties for the feedstock and process chemicals included in the ASPEN software as well as property data developed at NREL. The individual unit models are also thermodynamically consistent and can be either rigorous (for example, the simulation of the distillation) or simple. The reactors could be modeled with kinetic expressions, but because of the level of development of the experimental data, they were modeled as experimentally determined conversions of specific reactions. This type of model still satisfies the rigorous mass and energy balance. Other unit operations, such as liquid-solid separations, are typically modeled with fixed solids removal and liquid retention (in the solids stream) data from vendor tests.[234] Using the process flow diagrams and the mass and energy balance information, NREL estimated stream flows and conditions, along with the estimated quantities of raw materials and other process chemicals.

The following table presents NREL's summary of each of the three year's total project investment. For each year's total project investment, NREL provided capital charge, which includes income tax, depreciation, and average return on investment, the cost of raw materials, waste handling charges, and by-product credits.

[234] A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace
National Renewable Energy Laboratory (NREL); L. Montague, A. Slayton, and J. Lukas Harris Group, Seattle, Washington, Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover; June 2002; NREL is a U.S. Department of Energy Laboratory Operated by Midwest Research Institute • Battelle • Bechtel; Contract No. DE-AC36-99-GO10337

Table 4.1-22. Summary of NREL's Capital Charges and Operating Costs

Year Technology	2010		2015		2022	
Plant Size MMgal/yr	56		69		71	
Capital Cost $MM (TPI)	232		220		199	
	$MM/yr	¢/gal	$MM/yr	¢/gal	$MM/yr	¢/gal
Capital Charge 10% after tax ROI	42	75	39	56	35	50
Fixed Costs	9	16	9	12	8	12
Feedstock Cost	84	46	51	35	50	35
Other Raw Matl. Costs	17	30	4	5	16	16
Enzyme Cost	18	32	7	10	5	8
Enzyme Nutrients	8	14	2	3	2	2
Electricity	-6	-10	-7	-9	-12	-16
Waste Disposal	1	2	3	4	1	1
Total Costs	173	205	108	116	105	108

The quantities of all raw material, generated electricity, and produced wastes were determined using the ASPEN mass and energy balance model. These costs include: *Feedstock* – corn stover, *CSL* – purchased corn steep liquor (a nutrient); *Cellulase* – purchased cellulase enzymes; *Other Raw Materials* – sulfuric acid, diammonium phosphate, make-up water, boiler feed water chemicals, cooling water chemicals. Waste Disposal – waste water chemicals, waste water polymers, ash disposal, gypsum disposal. *Electricity* – marketing and distribution of surplus electricity to the grid for credit.

We note that the percent change in total project investment from year to year is not insignificant and reflects improvements in mechanical process efficiencies among other general improvements in the process technology, including the automatic distributed process control system, all of which are off-set to some extent by increases in the real cost of the technology improvements, as well as those of constructions materials. We discuss capital costs following this discussion of operating costs.

The most notable reductions in NREL's operating costs are in the price per dry ton of the corn stover feedstock and in the cost of cellulase enzyme. NREL anticipates significant improvement in the efficiency of these enzymes, especially those that saccharify glucan to glucose and xylose oligomers[235] generated during hydrolysis. They also expect improvement in the yeasts that ferment xylose. According to the 2007 NREL – State of Technology report, they anticipate that as a first step, the relationship between corn stover hydrolysate conditioning and fermentation will be better defined and understood. Commercial cellulase preparations will continue to be analyzed for baseline performance (specific activity), and due to increased research efforts, cellulase function will be better understood, which should lead to efficiency improvements. Integrated testing of whole slurry and recycle options will also be conducted resulting in potential improvements in that area. Last, the efficacy of advanced enzyme preparations (including oligomerases and/or hemicellulases) will continue to be tested in conjunction with alternative pretreatment technologies. NREL expects that the cost of pretreatment will deminish, hydrolysis time will decrease, and the sugar (xylose and glucose) yields will increase.[236]

As the process costs decline over time, the feedstock costs become a larger fraction of the overall costs. We also note that in the following table that the cost of the feedstock makes up 50% of the total cost in 2010; 67% in 2015; and 68% in 2022. The reduction in feedstock cost, from $60 per dry ton in 2010, to $45.90 per dry ton in both 2015 and 2022 also has a significant effect on operating costs. In addition, NREL did not include payments to the farmers/growers nor for soil nutrients (fertilizer, etc.) that were removed with the harvested corn stover. The cost of the cellulase enzyme is the next highest contributor, with percent reductions contributed to total cost that reduced from ~19% in 2010, to 13% in 2015 and 10% in 2022. It should be obvious that any reductions in these costs have significant effects on the total operating cost. The majority of research going forward will be focused on these two items, although some work will be done to reduce the cost of the others. Table 4.1-23 summarizes NREL's operating costs for a biochemical cellulosic ethanol plant.

[235] Xylan polymer chains, with considerably fewer residue numbers in the chain than were in the original xylan polymer; they were broken off the polymer as these short chains rather than as single molecule sugars.
[236] Andy Aden, National Renewable Energy Laboratory, Golden, Colorado, Biochemical Production of Ethanol from Corn Stover: 2007 State of Technology Model, Technical Report NREL/TP-510-43205, Task No. BB07.2410; May 2008

Table 4.1-23.
Percent of the total operating cost for each actual operating cost item

	2010		2015		2022	
	¢/gal	% of Total	¢/gal	% of Total	¢/gal	% of Total
Feedstock	84	50	51	67	50	68
Biomass to Boiler	0.0	0.0	0.0	0.0	0.0	0.0
CSL[a]	14	8	3	4	2	3
Cellulase	32	19	9	13	8	10
Other Raw Matl. Costs	31	18	5	7	16	22
Waste Disposal	2	1	4	5	2	2
Electricity	-10	-6	-9	-12	-16	-22
Fixed Costs	16	10	12	16	12	16
	168		76		72	

[a]Corn steep liquor – provides nutrients for the enzymes.

The following table includes our adjustments to NREL's variable or operating cost data for the three years studied. We note that the two main differences between NREL's and our estimates are in the feedstock costs and in the way we calculate capital charges. We adjusted NREL's capital charges which were calculated using a 10% after tax return on investment, to reflect a 7 percent before tax rate of return, which is the capital cost basis for our cost analyses. We also adjusted the NREL feedstock costs to those that we estimated in Table 4.1-6, which was $67.42 per dry ton. This significant difference between their and our feedstock cost estimates is due to our including payments to farmers/growers plus covering the cost to replace nutrients (fertilizer, etc.) removed at the time the stover was harvested. According to a personal communication, NREL used unpublished data from the Idaho National Laboratory that indicate feedstock costs will be significantly reduced between 2010 and 2015.

Table 4.1-24.
Adjusted Capital Charges and Operating Costs

Year Technology	2010		2015		2022	
Plant Size MMgal/yr	56		69		71	
Capital Cost $MM	232		220		199	
	$MM/yr	¢/gal	$MM/yr	¢/gal	$MM/yr	¢/gal
Capital Cost 7% ROI before taxes	25	46	24	35	22	31
Fixed Costs	9	16	9	12	8	12
Feedstock Cost	52	94	55	75	52	73
Other Raw Matl. Costs	17	30	4	5	16	16
Enzyme Cost	18	32	7	10	5	8
Enzyme Nutrients	8	14	2	3	2	2
Electricity	-6	-10	-7	-9	-12	-16
Waste Disposal	1	2	3	4	1	1
Total Costs	124	224	94	135	90	127

The changes in the minimum ethanol selling prices for the three years studied are partially due to the changes in necessary capital investments. In order to determine capital costs, NREL developed specifications for pieces of equipment that fall within different areas of a biochemical plant. A biochemical plant is divided up into 8 different areas (Area 200 through Area 900). For each equipment specification, they developed individual purchased equipment and installation costs. Vendors supplied installation costs where possible; in other cases installation factors were used. Equipment costs were obtained from vendor quotations when possible, especially for uncommon equipment such as pretreatment reactors. These costs reflect the base case for which the equipment was designed. If process changes were made and the equipment size changed, the equipment is not generally re-costed, in detail. Rather, the cost was adjusted by scaling using the following exponential scaling expression, [New Cost = Original Cost x (New Size/Original Size)^exp]. They also scaled the size of equipment that was known to change linearly with a change in inlet flow. The scaling exponents (exp) were obtained from vendor quotes, or from a standard reference, such as Garrett.[237]

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[237] Garrett, D.E., Chemical Engineering Economics, Van Nostrand Reinhold, New York, 1989

Installation costs were taken primarily from Delta-T, a process consultant's experience. Once the scaled, installed equipment costs (total installed capital costs) were determined, they applied overhead and contingency factors to determine a total plant investment cost. That cost, along with the plant operating expenses (generally developed from the ASPEN model) was used in a discounted cash flow analysis to determine the cost of ethanol production, using a set discount rate. NREL use a discount rate of 10%, whereas we used 7%, a factor generally used in our financial calculations. For this analysis, the minimum ethanol selling price was the primary value used to compare cases.

The total project investment was briefly discussed previously in our summary discussion of operating costs; we used NREL's total project investment for our estimates. The following summarizes the capital expenditures that account for that capital investment.

Area 200: Pretreatment and Hydrolysis. The equipment in this area consists of an assortment of pipe, pumps, tanks, tank-agitators, tank-mixers, coolers, 3-pneumapress filters, as well as three separate process trains, each of which includes a presteamer, a blow tank, and a reactor. The presteamer uses low-pressure steam to heat the feedstock to about 212 ^oF. It discharges the hot, saturated mix into a blow tank that serves as a seal between the presteamer and the hydrolysis reactor. The mix is charged to the reactor and dilute sulfuric acid is added; the reactor operates at 191 psia and 547 ^oF. Most of the hemicellulose, e.g., primarily xylose, mannose, arabinose, and galactose are converted into sugars. Glucan in the hemicellulose and a small portion of the glucan in the cellulose are converted to glucose. These conditions also solubilize some of the lignin in the feedstock and 'expose' the cellulose for subsequent enzymatic hydrolysis, in a downstream section. In addition, acetic acid is liberated from the hemicellulose hydrolysis. Degradation products of pentose sugars (primarily furfural) and hexose sugars (primarily hydroxymethyl furfural (HMF)) are also formed.

Following the pretreatment reactor, the hydrolyzate liquid and solids are flash cooled, which vaporizes a large amount of water, a portion of the acetic acid, and much of the furfural and HMF, which can be toxic to downstream fermentation microorganisms.

In addition to the flash removal of aldehydes, the solids are washed and filter-pressed to remove the liquid portion of the hydrolyzate, which contains sulfuric acid. The liquid is then neutralized to pH 10 with ammonia and held until the gypsum precipitates and is filtered out. The hydrolyzate, which contains the hydrolyzed xylose sugars and some glucose sugars, is mixed back with dilution water and the filter cake, which contains the unhydrolyzed cellulose and is sent to saccharification and co-fermentation (Area 300)

An important issue on an industrial scale is accurate pH control. By pH 11, as much as 30% of the glucose may be lost to HMF and other side reactions. Several factors increase the probability of overshooting pH endpoints during neutralization. The natural buffering capacity of hydrolyzates causes neutralization reactions to be slow. Plus, measurements using pH membrane probes are affected by temperature and the presence of dissolved organic compounds (sugars and lignin).

Since we are handling the same mass of feedstock in each of the modeled years, we don't expect the cost of the equipment for pretreatment and hydrolysis will change much over the 2010-2022 time period. The equipment costs for Area 200 – Pretreatment & Hydrolysis are 2010: $23-million; 2015: $22.7-million; and 2022: $18.9-million. Neutralization and Conditioning costs were separated out from the Pretreatment & Hydrolysis costs, even though the NREL's design report includes both cost centers in Area 200. Neutralization and Conditioning costs are as follows: 2010: $8.4-million; 2015: $9.4-million; and 2022: $7.7-million. The combined cost for Area 200 is as follows: 2010: $31.4-million; 2015: $32.1-million; and 2022: $26.6-million. In total, this area contributed about 23.5% to the total installed capital cost of the project in 2010; about 25.3% in 2015; and 23.2% in 2022

Area 300: Saccharification and Co-Fermentation. The equipment in this area consists of pumps, tanks, tank-agitators, coolers, and heaters. Two different operations take place in this process area — the saccharification of the cellulose to glucose using cellulase enzymes, and the fermentation to ethanol of that glucose plus the xylose and glucose sugars from the dilute acid pretreatment of hemicellulose from Area 200.

Glucan from the cellulose undergoes hydrolysis or saccharification, at about 149 ^{o}F, prior to fermentation. This slightly higher temperature increases enzyme activity and reduces the time and amount of enzyme required for saccharification. Saccharification or cellulase enzymes, purchased from an enzyme manufacturer, and the diluted, detoxified hydrolyzate are continuously added to a train of five 1-million gallon saccharification vessels; residence time is estimated to be 36-hours.

Cellulase enzyme is actually a 'cocktail' of enzymes, comprised of: (1) endoglucanases, which attack randomly along the cellulose fiber to reduce polymer size rapidly; (2) exoglucanases, which attack the ends of cellulose fibers, allowing it to hydrolyze highly crystalline cellulose; and (3) β-glucosidase, which hydrolyzes cellobiose to glucose. Several bacteria and fungi naturally produce these enzymes, including bacteria in ruminant and termite guts and white rot fungus. The most common organism used to produce cellulase industrially is *Trichoderma reesei*. Genencor International and Novozymes Biotech are developing more cost effective cellulase enzymes. DOE is funding this important work, which should improve the economic viability of biomass conversion.

The recombinant *Z. mobilis bacterium* is used as the biocatalyst to ferment glucoses and xyloses to ethanol. Several research institutions are genetically engineering strains, such as *Z. mobilis*, to treat additional sugars and identifying other naturally occurring organisms that metabolize hemicellulosic sugars.

The *Z. mobilis* must be 'grown' in increasingly higher volume stages. Initially, a small amount of saccharified slurry and nutrients are combined in a very small vessel with a seed inoculum, that's been grown in the laboratory. This initial seed batch is used as the inoculum for the next larger size seed batch, and so on. This series of batch scale-ups continues until the last batch is large enough to support the actual production fermentation.

Finally, the seed inoculum, nutrients (corn steep liquor) & (diammonium phosphate – a source of nitrogen for the yeast), and saccharified slurry are cooled to about 106 ^{o}F and added to a train of five 1-million gallon continuous fermentors. At this point, the process actually becomes a simultaneous saccharification and co-fermentation (SSCF) process. Even though the temperature in the fermentation tanks has been reduced to account for the ethanologen's intolerance to heat, the enzymes do continue to hydrolyze cellulose, albeit at a slightly reduced rate. The main byproduct, produced during fermentation is carbon dioxide (CO_2), which is removed in a later process stage. The ethanol broth called 'beer' is collected in a storage tank, called a beer well, before it's pumped to distillation.

NREL anticipates significant capital savings for saccharification and co-fermentation between 2010 and 2015, with fewer between 2015 and 2022. We note that this area contributed 15.4% to the total installed capital cost in 2010, but only 8.8% in 2015 and 8.8% in 2022. The equipment costs for Area 300 – Saccharification and Fermentation are 2010: $20.5-million; 2015: $11.2-million; and 2022: $10.1-million.

Area 400 – In earlier studies, NREL included plans to produce enzymes in Area 400. For the current studies, Area 400 has been removed and enzymes will be purchased and grown on site under licensing agreements with enzyme suppliers.

Area 500 – Product, Solids, and Water Recovery (Distillation, Dehydration, Evaporation, and Solid-Liquid Separation). The equipment in this area includes distillation and rectification columns, pumps, condensers and coolers, pumps, pipe, filter-presses, and evaporators.

Beer, from the beer well in Area 300, is preheated and fed to a distillation column. The column overhead containing all the CO_2 and about 0.2% of the ethanol and a small quantity of water is sent to a scrubber, which recovers and recycles about 99% of the vented ethanol. In the tower bottoms, about 90% of the water has been removed and it contains approximately 0.7% of the total volume of ethanol fed to the tower. Over 99% of the total ethanol fed to the tower is removed as a 39.4% w/w mixture with water vapor through a side draw and fed directly to a rectification column for further ethanol enrichment. We discuss the distillation column bottoms in the evaporation and solid-liquid separation section of this area.

The rectification tower operating conditions are set to produce an overhead 92.5% w/w ethanol/water saturated vapor mixture. The tower bottoms are a 0.05% w/w ethanol/water mixture. In fact, only 0.1% of the total ethanol from the fermentation area is lost to the bottoms.

The rectification column overhead is superheated and fed to one of two adsorption columns in a molecular sieve adsorption unit. The two columns operate alternately; while one bed is operated to remove water from the ethanol, the other is regenerated by passing a very small slipstream of pure ethanol vapor back through the loaded bed that strips the water off the adsorbent, while the column is under a vacuum. The mixture is condensed and returned to the rectification column feed stream. The adsorption column removes 95% of the water and a small quantity of ethanol. The 99.5% pure ethanol vapor is condensed, cooled, and pumped to storage.

Evaporation, and Solid-Liquid Separation: The beer column bottoms, with about 5.8% insoluble solids, are fed to the first effect evaporator, where 24% of the water in the feed is evaporated. The evaporator bottom slurry, cooled from ~243 ^oF to ~189 ^oF, is sent to a filter-press, from which the filtrate is returned to the second evaporator effect; the filter cake is not washed. In the second effect evaporator, 44% of the feed water is evaporated. The third effect evaporates 76% of the remaining water. The final vapor is condensed and fed to a condensate drum. Of the total feed to the evaporation/separation system, 10.5% remains as syrup, 11.5% is removed as a wet cake in the pressure filter, 17% is recycled back to the process as recycle water, and 61% is evaporated. The syrup from the third evaporator bottoms is 60% water, e.g., the maximum dissolved solids level that can be achieved without rapid fouling of the evaporator; the flow of very low-pressure steam to the evaporator is set to achieve this level. This syrup is mixed with the cake from the filter-press and sent to the combustor for disposal. Air from the filter-press is used for combustion air.

The equipment costs for Area 500 – Product, Solids, and Water Recovery (Distillation, Dehydration, Evaporation, and Solid-Liquid Separation) are for 2010: $23.4-million; 2015: $26.1-million; and 2022: $23.3-million. This area's contribution to the total installed capital cost in 2010 is 17.5%; in 2015, 20.6%; and in 2022, 20.3%. We believe that some of the increase from 2010 to 2015 has to do with the increased liquid flow due to the conversion improvements; larger pipe, pumps, tanks, etc may be necessary to handle the increased flow. The changes from 2015 to 2022 are not that significant, as reflected by the percent contribution of the area to total installed equipment cost.

Area 600 – Wastewater Treatment: The equipment in Area 600 consists mainly of aerobic and anaerobic digesters, digester agitators, tanks (basins), a biogas emergency flare, coolers, and pumps. The main purpose of the wastewater treatment section is to reduce the plant makeup water requirement by recovering, treating and recycling as much process water as possible. The feed to the wastewater treatment section consists of: condensed pretreatment flash vapor, condensate from the hydrolyzate filter-press vent, boiler blowdown, cooling tower blowdown, clean-in-place waste, and the non-recycled evaporator condensate. Rain and snow run-off, equipment washing, and other non-process wastewater are assumed to flow to the municipal wastewater treatment system. The stream is screened to remove large waste particles that are sent to a landfill; any remaining organic matter is anaerobically and aerobically digested. Anaerobic digestion produces a methane rich (75%-methane, 25%-carbon dioxide) biogas that's fed to the combustor. Aerobic digestion produces relatively clean water that's recycled back to the process and sludge that's burned in the combustor.

NREL didn't expect much change over the 2010 to 2022 time period. In 2010 the installed capital cost for this area was $3.4-million; in 2015, $3.7-million; and in 2022 it was 3.1-million. As important as this area is to the entire operation its contribution to the total project installed capital cost is relatively minor. In 2010 the contribution was 2.5%; in 2015, 2.9%; and in 2022 it was 2.7%.

Area 700: Bulk Storage of Chemicals. This section of the plant stors chemicals in bulk for the process and for finished, fuel-grade ethanol. The feedstock feed surge tanks we discussed just prior to the discussion of Area 200 are not included in this area. Process chemicals stored in this area include: corn steep liquor (a nutrient), sulfuric acid, cellulase enzyme, gasoline (used as a denaturant finish the fuel grade ethanol), and water for fire suppression.

There are approximately five-days of SS316-stainless steel[238] tank sulfuric acid storage. Corn steep liquor (CSL), a nutrient for fermentation seed growth and ethanol production, also has about five-days of SS304-stainless steel[239] storage; NREL expects the plant will require about three-25,000 gallon rail cars of CSL every three-days. There are seven-days of storage for diammonium phosphate (DAP), delivered as pellets via rail car. Appropriate quantities of CSL and DAP are mixed in a day-tank and used in Area 300 for fermentation seed production and ethanol production. A producer that supplies cellulase enzymes is expected to set up an enzyme production operation either on site or on a nearby location. Liquid enzyme storage is set for four-days in SS304 stainless steel tanks. The carbon steel fire-fighting water storage tanks provide about four-hours of operating time; the firewater pump delivers 2,500 gpm. Other pumps are sized per process requirements

There are seven-days of ethanol product storage in two 600,000 gallon carbon steel tanks. Five percent gasoline (v/v), a denaturant, is added to the ethanol as it's loaded for shipment to customers. The pumps in this section are generally sized to load a 10,000 gallon truck and trailer in about 15 min. to 20 min. maximum filling time. They can also be used to fill process day tanks.

The installed capital costs for bulk storage are, for 2010, \$3.8-million; for 2015, \$2.4-million; and for 2022, \$2.4-million. The contribution to total project installed capital costs are, for 2010, 2.8%; for 2015, 1.9%; and for 2022, 2.1%.

Area 800: Combustor, Boiler, and Turbogenerator. The purpose of the combustor, boiler, and turbogenerator is to burn various by-product or waste streams to produce steam and to generate electricity. All of the feedstock lignin and some of the cellulose and hemicellulose are not hydrolyzed in Area 300.

As previously discussed, a high soluble, solids syrup is generated in Area 600 and anaerobic and aerobic digestion of the remaining wastewater produced biogas and a small quantity of biomass sludge which are burned to generate steam and produce electricity. This contributes to over-all plant energy self-sufficiency, reduces solid waste disposal costs, and generates additional revenue through sales of excess electricity. Because of heightened interest in using biomass, pulping wastes, and sewage sludge in place of fossil fuels, new methods are being developed to handle higher moisture feeds. Traditional methods include blending the wet feed with dry material or adding auxiliary fuel to maintain the combustion temperature. When the dry solids from the filter-press cake are combined with the high soluble, solids syrup, it helps

[238] SS316 is an improved version of SS304, with the addition of molybdenum and a slightly higher nickel content. The resultant composition of 316 gives it much increased corrosion resistance in many aggressive environments. The molybdenum makes the steel more resistant to pitting and crevice corrosion in chloride-contaminated media, sea water and acid vapors.

[239] SS304-stainless steel is the most versatile and the most widely used of all stainless steels. Its chemical composition, mechanical properties, weldability and corrosion/oxidation resistance provide the best all-round performance stainless steel at relatively low cost.

ensure a stable combustion bed temperature and improved boiler efficiency. In these studies NREL used a circulating fluidized bed combustor that is suitable for varying feeds and feed characteristics; however, this flexibility makes the unit more expensive than a grate or pile combustor. A Lower Heating Value (LHV) of 2,000-2,500 BTU/lb is considered the minimum for maintaining combustion.[240] The combined feed to the combustor has a LHV of 4,179 Btu/lb. Thus, the total higher-heating value energy of the combined feed streams to the combustor is 706 MMBtu/hr. The solids contribute 59% of this energy and the syrup contributes 37%. A baghouse removes particulates from the combustion flue gas after it preheats the incoming combustion air and before it's discharged through the stack.

The boiler feed water (BFW) system includes a softener for makeup and condensate water, a deaerator to remove air and other non-condensables, surge tanks and pumps. The amount of water pretreatment necessary depends on the incoming water quality, metallurgy of the boiler, and the ratio of makeup to condensate in the feed water. Pretreatment chemicals for pH control, scale removal, and oxygen removal are added. Treated well water used for makeup and condensate are softened, deaerated, preheated and mixed to provide BFW that's converted to steam that's superheated to 950 ^{o}F at 1,265 psia at the rate of 407,420 lb/hr. Support equipment includes BFW pumps, deaerator, automatic water pretreatment chemical injection, and condensate gathered from the various heat exchangers in the process. Boiler efficiency, the percentage of the feed heat converted to steam heat, is estimated to be 68%. Boiler blowdown is 3% of steam production. The turbine efficiency was estimated to be 85%.

The turbogenerator consisting of a multistage turbine with extraction ports, a generator, and condenser is used to generate electricity. After high pressure steam drives the multistage turbines, it is extracted at three different conditions for injection into the pretreatment reactor and heat exchange in distillation and evaporation. Twenty-eight percent of the steam is extracted from the turbine at 191 psia and 514°F, 60% at 65 psia and 327°F, and 3% at 25 psia and 239°F for process needs, as described. The remaining steam (9%) is condensed at 1.5 psia with cooling water and returned to the BFW system. For this design, a total of 30.4 megawatts (MW) of power is generated from the system. The process uses 11.7 MW, leaving 18.7 MW that is sold to the grid.

The installed capital cost for Area 800 are, for 2010, $45.5-million; for 2015, $46-million; and for 2022, $43.3-million. This area's contribution to the total installed capital cost is, for 2010, 34.1%; for 2015, 36.2%; and for 2022, 37.7%.

Area 900: Utilities. All utilities, except steam and electricity, necessary for the production of ethanol are accounted for in this area. The utilities provided include cooling water, chilled water, plant and instrument air, process water, and the clean-in-place (CIP) system. No chilled water is used in the plant; the required process temperatures can be achieved by cooling water year-round.

[240] Steam and Electricity Generation Options For the Biomass-To-Ethanol Process, NREL Subcontract ACO-8-18019-01, Reaction Engineering International, Salt Lake City, UT, March 16, 1998. http://www.ott.doe.gov/biofuels/process_engineering.html

The plant and instrument air systems provide compressed air for air-driven equipment, instrument operation, for clean up, and the filter-press units in the post-distillation dewatering. The process water system mixes fresh well water with treated wastewater and provides water at a constant pressure to the facility. Water is provided to seed production, boiler feed water, cooling tower make-up, the CIP system, and the scrubber. It is also mixed with recycle water for dilution before saccharification. Process water is also used throughout the facility for cleaning on an as-needed basis. The CIP system provides a solution that can be heated and includes cleaning and sterilization chemicals to saccharification and co-fermentation, seed vessels, and the distillation system.

The installed capital costs for the utilities area are, for 2010, $5.6-million; for 2015, $5.5-million; and for 2022, $6.1-million. This area's contribution to the total project installed equipment costs are, for 2010, 4.2%; for 2015, 4.3%; and for 2022, 5.3%.

Table 4.1-25 summarizes the total projected capital costs for a biochemical cellulosic ethanol plant for the years 2010, 2015 and 2022.

Table 4.1-25.
Projected Capital Costs for a Biochemical Cellulosic Ethanol Plant
($million/yr)

	2010	2015	2022
Total Capital Investment	133.5	127	114.8
Added Costs*	98.2	93.1	83.8
Total Project Investment	231.7	220.1	198.6

*Added costs include the following:

Warehouse: This is estimated to be 1.5% of total installed cost

Site Development: This includes fencing, curbing, parking, lot, roads, well drainage, rail system, soil borings, and general paving. This factor allows for minimum site development assuming a clear site, with no unusual problems such as right-of-way, difficult land clearing, or unusual environmental problems, usually calculated as 9% of the installed cost of process equipment.

Prorateable Costs: This includes fringe benefits, burdens, and insurance of the construction contractor, usually calculated as 10% of total installed cost.

Field Expenses: This includes consumables, small tool equip. rental, field services, temporary construction facilities, and field construction supervision, usually calculated as 10% of total installed cost.

Home Office and Const.: This includes engineering plus incidentals, purchasing, and construction, usually calculated as 25% of total installed cost.

Project Contingency: These costs are small because of the detail included in the process design usually calculated as 3% of total installed cost.

Other Costs: This includes start-up and commissioning costs; land, rights-of-way, permits, surveys, and fees; piling, soil compaction/dewatering, unusual foundations; sales, use, and other taxes; freight, insurance in transit and import duties on equipment, piping, steel, instrumentation, etc.; overtime pay during construction; field insurance; project team; transportation equipment, bulk shipping containers, plant vehicles, etc.; escalation or inflation of costs over time; interest on construction loan. These other costs are usually calculated as 10% of total capital investment.

The costs for cellulosic ethanol produced biochemically could be lower if not all the water would have to be removed from the ethanol. Separating the water from ethanol is costly because water forms an azeotrope with ethanol. Removing the last of the water above the azeotrope requires additional capital and operating costs. Some research conducted with hydrous ethanol as well as practical experience in Brazil suggests that by not removing the last few percent of water from ethanol, the ethanol production costs would be lower and the water contained in ethanol might not cause driveability, not cause corrosion problems and not lower the fuel economy. A lot more research needs to be conducted before hydrous ethanol would be proven as a viable and safe motor vehicle fuel in existing U.S. vehicles.

Thermochemical Conversion of Cellulose to Ethanol

Thermochemical conversion is another reaction pathway which exists for converting cellulose to ethanol. Thermochemical technology is based on the heat and pressure-based gasification or pyrolysis of nearly any biomass feedstock, including those we've highlighted as likely biochemical feedstocks. The syngas could then be converted into mixed alcohols, hydrocarbon fuels, chemicals, and power. To produce ethanol, the syngas is passed over a catalyst which converts the syngas to mixed alcohols – mainly methanol. The methanol can be reacted further to ethanol.

NREL has authored a thermochemical report which already provided a cost estimate.[1142] However, this report only hypothesized how a thermochemical ethanol plant could achieve production costs at a very low cost of $1 per gallon. However, to obtain a more detailed cost assessment that may be achievable within the timeframe of our program, EPA contracted NREL to assess the costs for a thermochemical technology which produces mixed alcohols for years 2010, 2015 and 2022.[1143] Table 4.1-26 summarizes the cost information provided by NREL.

Table 4.1-26
Summary of Mixed Cellulosic Alcohol Production Costs by NREL
(2007 dollars, 10% after tax ROI)

	2010		2015		2022	
Annual Ethanol Production	48.8		56.7		61.9	
Annual Total Alcohol Production	57.5		66.6		72.7	
Ethanol Yield	63.2		73.4		80.1	
Total Alcohol Yield	74.5		86.2		94.1	
Capital Costs						
Feed Handling and Drying	25.2		25.2		25.2	
Gasification	14.0		14.0		14.0	
Tar Reforming and Quench	53.4		38.6		41.6	
Acid Gas and Sulfur Removal	20.4		14.6		15.8	
Alcohol Synthesis Compression	35.4		18.5		17.3	
Other Synthesis Costs	6.1		4.7		5.1	
Alcohol Separation and Purification	6.8		7.5		7.8	
Steam System and Power Generation	19.2		19.7		18.2	
Cooling Water and other Utilities	4.2		4.3		3.9	
Total Installed Equipment Cost	184.7		147.1		148.9	
Added Cost Factors	72.1		57.5		58.1	
Total Project Investment	256.8		204.6		207.0	
Operating and Amortized Capital Costs	**$MM/yr**	**$/gal Ethanol**	**$MM/yr**	**$/gal Ethanol**	**$MM/yr**	**$/gal Ethanol**
Feedstock	46.4	0.95	35.4	0.63	35.6	0.58
Catalysts	7.6	0.16	0.2	0.003	0.2	0.003
Olivine	0.5	0.01	0.5	0.01	0.5	0.01
Other Raw Materials	0.4	0.02	0.4	0.02	0.3	0.02
Waste Disposal	0.3	0.01	0.3	0.01	0.3	0.01
Electricity	-1.8	-0.04	0.0	0.00	0.0	0.00
Fixed Costs	14.8	0.30	12.7	0.23	12.8	0.21
Co-Product Credits	-10.4	-0.21	-11.8	-0.21	-12.9	-0.21
Capital Depreciation, Income Tax and Return on Investment	46.3	0.95	37.1	0.66	37.5	0.61
Total	104.1	2.15	74.8	1.33	74.3	1.21

In its mixed cellulosic alcohol report, NREL did not assess the technology's costs on the same basis that EPA is using. NREL used a feedstock cost of $46.1/dry ton which is lower than our estimate of $67.4/dry ton. Also, NREL amortized the capital costs based on a 10 percent after tax return on investment (ROI) compared to our 7% before tax ROI. Thus, we adjusted the NREL cellulosic mixed alcohol costs to reflect our feedstock costs and capital cost amortization assumptions. Table 4.1-27 contains a summary of the mixed cellulosic alcohol costs based on our feedstock and capital amortization cost assumptions.

Table 4.1-27
Summary of Adjusted Mixed Cellulosic Alcohol Production Costs by NREL
(2007 dollars, 7% before tax ROI)

	2010		2015		2022	
Operating and Amortized Capital Costs	**$MM/yr**	**$/gal Ethanol**	**$MM/yr**	**$/gal Ethanol**	**$MM/yr**	**$/gal Ethanol**
Feedstock	67.8	1.39	51.8	0.92	52.1	0.85
Catalysts	7.6	0.16	0.2	0.003	0.2	0.003
Olivine	0.5	0.01	0.5	0.01	0.5	0.01
Other Raw Materials	0.4	0.02	0.4	0.02	0.3	0.02
Waste Disposal	0.3	0.01	0.3	0.01	0.3	0.01
Electricity	-1.8	-0.04	0.0	0.00	0.0	0.00
Fixed Costs	14.8	0.30	12.7	0.23	12.8	0.21
Co-Product Credits	-10.4	-0.21	-11.8	-0.21	-12.9	-0.21
Capital Depreciation, Income Tax and Return on Investment	28.3	0.58	22.8	0.40	22.8	0.37
Total	107.5	2.22	76.8	1.38	76.0	1.26

4.1.1.3 Imported Sugarcane Ethanol Costs

Our analysis of imported ethanol costs began with a literature search of recent estimates for production costs for sugar cane ethanol in Brazil. Since the liberalization of ethanol prices in Brazil, few cost estimation studies have been made and most of the cost analyses refer to the same study.[1144] This study was carried out by the Brazilian Ministry of Science and Technology (MC&T), based on 1990 data, and referred to a production cost of $0.87/gallon. Table 4.1-28 gives a breakdown of costs based on this data.

Table 4.1-28. Sugarcane Ethanol Production Costs in Brazil, circa 1990

	Average cost (US$ per gallon)
Operating costs	**$0.64**
Labor	$0.02
Maintenance	$0.02
Chemicals	$0.01
Energy	$0.01
Other	$0.02
Interest payments on working capital	$0.08
Feedstock (cane)	$0.48
Fixed costs	**$0.23**
Capital at 12% depreciation rate	$0.19
Other	$0.04
Total	**$0.87**

Since then, there have been significant variations in exchange rates, costs of sugarcane and oil products, etc. For example, earlier estimates may underestimate crude and natural gas costs which influence the cost of feedstock as well as energy costs at the plant. Another possible difference in production cost estimates is whether or not the estimates are referring to hydrous or anhydrous ethanol. Costs for anhydrous ethanol (for blending with gasoline) are typically several cents per gallon higher than hydrous ethanol (for use in dedicated ethanol vehicles in Brazil).[1145] It is not entirely clear from the majority of studies whether reported costs are for hydrous or anhydrous ethanol. Yet another difference could be the slate of products the plant is producing, for example, future plants may be dedicated ethanol facilities while others involve the production of both sugar and ethanol in the same facility. Due to economies of scale, production costs are also typically smaller per gallon for larger facilities. Table 4.1-29 summarizes the various estimates reported by others. Production costs range from as low as $0.57 per gallon of ethanol to as high as $1.48 per gallon of ethanol.

Table 4.1-29. Other Sugarcane Ethanol Production Cost Estimates

Reference	Cost (US$ per gallon)
AgraFNP. 2007. Sugar and Ethanol in Brazil: A Study of the Brazilian Sugar Cane, Sugar and Ethanol Industries.	$0.80-$1.07 per gallon (in 2006 $'s depending on region in Brazil), avg. is $0.78 per gallon for cane production cost and $0.13 per gallon for industrial costs
IEA. 2004. Biofuels for Transport: An International Perspective.	$0.87 per gallon (in 1990 $'s) references MC&T study; also reports recent production cost estimates for hydrous ethanol as low as $0.57 per gallon (at the prevailing exchange rate in Jan. 2004)
USDA. 2006. The Economic Feasibility of Ethanol Production from Sugar in the United States.	Avg. is $0.81 per gallon
Von Lampe, Martin. OECD. 2006. Working Party on Agricultural Policies and Markets: Agricultural Market Impacts of Future Growth in the Production of Biofuels.	$0.83 per gallon
Brazil Institute. April 2007. The Global Dynamics of Biofuels: Potential Supply and Demand for Ethanol. Issue No. 3.	$0.83 per gallon.
ESMAP. October 2005. Potential for Biofuels for Transport in Developing Countries.	$.87-$1.10 per gallon
OECD, March 2008. ITF Round Tables No. 138. Biofuels: Linking Support to Performance.	Avg. is $1.40 per gallon
Bain, R. December 2007. World Biofuels Assessment Worldwide Biomass Potential: Technology Characterizations. NREL/MP-510-42467.	$1.04-$1.48 per gallon depending on size of plant, i.e. 100 MGY-4.6 MGY; Sugarcane feedstock costs $0.68 per gallon, Variable operating costs $0.27 per gallon, Fixed costs $0.02-0.13 per gallon, and Capital costs $0.07-0.40 per gallon
Macedo, I.C. and L.A.H. Nogueira. 2005. "Biocombusíveis". Cadernos NAE, No. 2. Núcleo de Assuntos Estratégicos da Presidência da República, Brasilia; As sited in OECD, *op. sit*.	$0.79 per gallon in the Center-South Brazil
Kojima, M. and T. Johnson. 2006. "Potential for Biofuels for Transport in Developing Countries". ESMAP Knowledge Exchange Series, No. 4.; As sited in OECD, *op sit*.	$0.87-$1.09 per gallon
Smeets, E. 2008. The Sustainability of Brazilian Ethanol-An Assessment of the Possibilities of Certified Production. Biomass and Bioenergy	$1.18 assuming exchange rate of $1.20= 1 Euro
Van den Wall Bake, J.D., et. al. 2009. Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane	$1.29 per gallon presently; Estimates for 2020 range from $0.76-$0.98 per gallon, Sugarcane costs $0.35-$0.46 per gallon, rest from industrial costs[241]

[241] Costs were given in $/TC and $/m^3, conversions were used to translate to per gallon numbers.

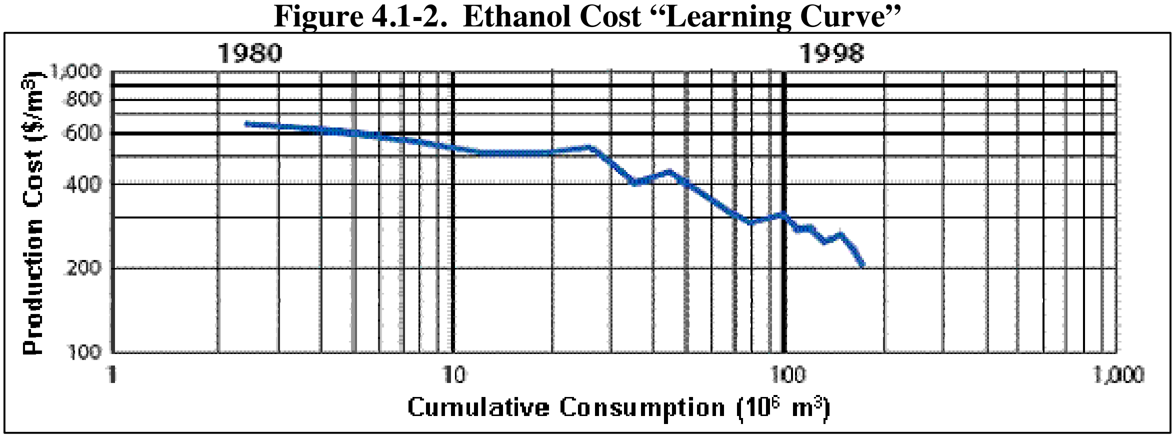
The study by OECD (2008) entitled "Biofuels: Linking Support to Performance", appears to provide the most recent and detailed set of assumptions and production costs. As such, our estimate of sugarcane production costs primarily relies on the assumptions made for the study, which are shown in Table 4.1-30. The estimate assumes an ethanol-dedicated mill and is based off an internal rate of return of 12%, a debt/equity ratio of 50% with an 8% interest rate and a selling of surplus power at $57 per MWh.

Table 4.1-30. Cost of Production in a Standard Ethanol Project in Brazil

Sugarcane Productivity	71.5 t/ha
Sugarcane Consumption	2 million tons/year
Harvesting days	167
Ethanol productivity	85 liters/ton (22.5 gal/ton)
Ethanol Production	170 million liters/year (45 MGY)
Surplus power produced	40 kWh/ton sugarcane
Investment cost in mill	USD 97 million
Investment cost for sugarcane production	USD 36 million
O & M (Operating & Maintenance) costs	$0.26/gal
Variable sugarcane production costs	$0.64/gal
Capital costs	$0.49/gal
Total production costs	**$1.40/gal**

The estimate above is based on the costs of producing ethanol in Brazil on average, today. However, we are interested in how the costs of producing ethanol will change by the year 2022. Although various cost estimates exist, analysis of the cost trends over time shows that the cost of producing ethanol in Brazil has been steadily declining due to efficiency improvements in cane production and ethanol conversion processes. Between 1980 and 1998 (total span of 19 years) ethanol cost declined by approximately 30.8%.[1146] This change in the cost of production over time in Brazil is known as the ethanol cost "Learning Curve". See Figure 4.1-2.

Figure 4.1-2. Ethanol Cost "Learning Curve"



The change in ethanol costs will depend on the likely productivity gains and technological innovations that can be made in the future. As the majority of learning has already occurred, it is likely that the decline in ethanol costs will be less drastic in the future as the production process and cane practices have matured. Industrial efficiency gains are already at about 85% and are expected to increase to 90% in 2015.[1147] Most of the productivity growth is expected to come from sugarcane production, where yields are expected to grow from the current 70 tons/ha, to 96 tons/ha in 2025.[1148] Sugarcane quality is also expected to improve, with sucrose content growing from 14.5% to 17.3% in 2025.[1149] All productivity gains together could allow the increase in the production of ethanol from 6,000 liters/ha (at 85 liters/ton sugarcane) to 10,400 liters/ha (at 109 liters/ton sugarcane) in 2025.[1150]

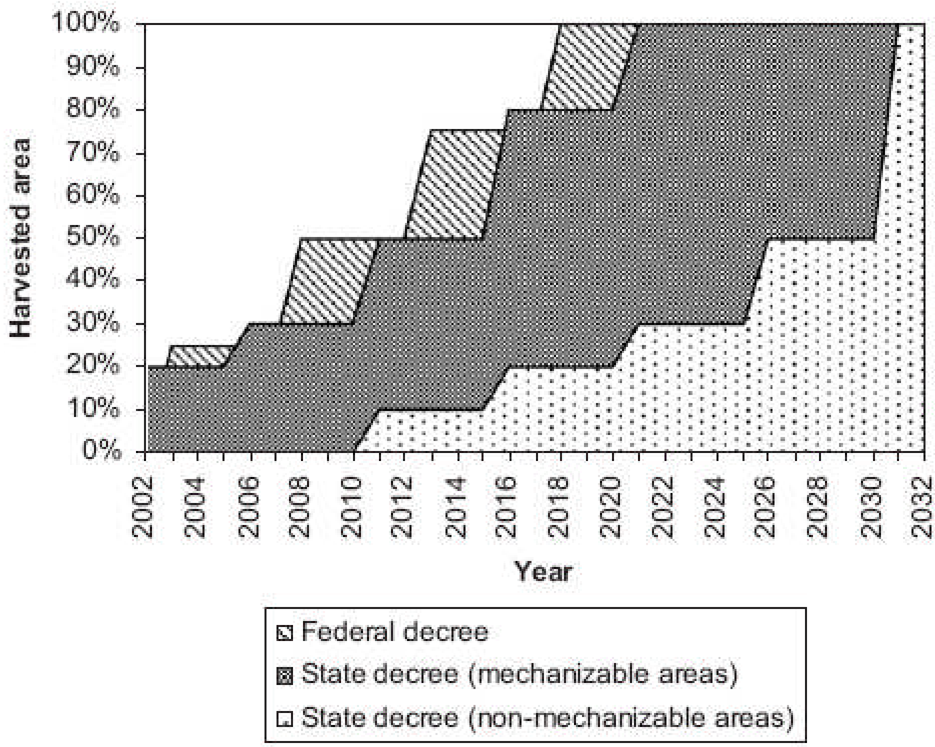
Assuming that ethanol productivity increases to 100 liters/ton by 2015 and 109 liters/ton by 2025, variable sugarcane ethanol production costs are be expected to decrease to approximately $0.51/gal from $0.64/gal since less feedstock is needed to produce the same volume of ethanol using the estimates from Table 4.1-30, above. Table 4.1-31 shows the calculated decrease for the years 2005-2025. We assumed a linear decrease between data points for 2005, 2015, and 2025. Adding operating ($0.26/gal) and capital costs ($0.49/gal) from Table 4.1-27, to a sugarcane cost of $0.51/gal, total production costs are $1.26/gal in 2022.

Table 4.1-31.
Estimated Decrease in Sugarcane Production Cost by 2022
Due to Increases in Ethanol Productivity

	Sugarcane Production Cost $/gal	liters/ton	gal/ton
2005	0.64	85	22.46
2006	0.63	86.5	22.85
2007	0.62	88	23.25
2008	0.61	89.5	23.65
2009	0.60	91	24.04
2010	0.59	92.5	24.44
2011	0.58	94	24.83
2012	0.57	95.5	25.23
2013	0.56	97	25.63
2014	0.55	98.5	26.02
2015	0.54	100	26.42
2016	0.54	100.9	26.66
2017	0.53	101.8	26.90
2018	0.53	102.7	27.13
2019	0.53	103.6	27.37
2020	0.52	104.5	27.61
2021	0.52	105.4	27.85
2022	**0.51**	**106.3**	**28.08**
2023	0.51	107.2	28.32
2024	0.50	108.1	28.56
2025	0.50	109	28.80

Brazil sugarcane producers are also expected to move from burned cane manual harvesting to mechanical harvesting. See Figure 4.1-3.[1151] As a result, large amounts of straw are expected to be available. Costs of mechanical harvesting are lower compared to manually harvesting, therefore, we would expect costs for sugarcane to decline as greater sugarcane producers move to mechanical harvesting. However, diesel use increases with mechanical harvesting and with diesel fuel prices expected to increase in the future, costs may be higher than expected. Therefore, we have not assumed any changes to harvesting costs due to the switchover from manual harvesting to mechanical harvesting.

Figure 4.1-3. Phase-out Schedule for Trash Burning Practices



As more straw is expected to be collected at future sugarcane ethanol facilities, there is greater potential for production of excess electricity. The production cost estimates in the OECD study assumes an excess of 40 kWh per ton sugarcane, however, future sugarcane plants are expected to produce 135 kWh per ton sugarcane assuming the use of higher efficiency condensing-extraction steam turbine (CEST) systems and use of 40% of available straw.[1152] Assuming excess electricity is sold for $57 per MWh, the production of an additional 95 kWh per ton would be equivalent to a credit of $0.22 per gallon ethanol produced. We have included this potential additional credit from greater use of bagasse and straw in our estimates at this time, calculated as a decrease in operating costs from $0.26 per gallon to $0.04 per gallon.

It is also important to note that ethanol production costs can increase if the costs of compliance with various sustainability criteria are taken into account. For instance, using organic or green cane production, adopting higher wages, etc. could increase production costs for sugarcane ethanol.[1153] Such sustainability criteria could also be applicable to other feedstocks, for example, those used in corn- or soy-based biofuel production. If these measures are adopted in the future, production costs will be higher than we have projected.

In addition to production costs, there are also logistical and port costs. We used the report from AgraFNP to estimate such costs since it was the only resource that included both logistical and port costs. The total average logistical and port cost for sugarcane ethanol is $0.20/gal and $0.09/gal, respectively, as shown in Table 4.1-32.

Table 4.1-32.
Imported Ethanol Cost at Port in Brazil (2007 $'s)

Region	Logistical Costs US ($/gal)	Port Cost US ($/gal)
NE Sao Paulo	0.150	0.097
W Sao Paulo	0.210	0.097
SE Sao Paulo	0.103	0.097
S Sao Paulo	0.175	0.097
N Parana	0.238	0.097
S Goias	0.337	0.097
E Mato Grosso do sul	0.331	0.097
Triangulo mineiro	0.207	0.097
NE Cost	0.027	0.060
Sao Francisco Valley	0.193	0.060
Average	0.197	0.089

Total fuel costs must also include the cost to ship ethanol from Brazil to the U.S. The average cost from 2006-2008 was estimated to be approximately $0.17 per gallon of ethanol.[1154] Costs were estimated as the difference between the unit value cost of insurance and freight (CIF) and the unit value customs price. The average cost to ship ethanol from Caribbean countries (e.g. El Salvador, Jamaica, etc.) to the U.S. from 2006-2008 was approximately $0.13 per gallon of ethanol. Although this may seem to be an advantage for Caribbean countries, it should be noted that there would be some additional cost for shipping ethanol from Brazil to the Caribbean country. Therefore, we assume all costs for shipping ethanol to be $0.17 per gallon regardless of the country importing ethanol to the U.S.

The total imported ethanol fuel costs (at U.S. ports) over the time period of 2010 to 2022 are shown in Table 4.1-33. In 2022, the total sugarcane ethanol cost estimate prior to tariffs and taxes is $1.50/gallon. Direct Brazilian imports are also subject to an additional $0.54 per gallon tariff, whereas those imports arriving in the U.S. from Caribbean Basin Initiative (CBI) countries are exempt from the tariff. In addition, all imports are given an ad valorem tax of 2.5% for undenatured ethanol and a 1.9% tax for denatured ethanol. We assumed an ad valorem tax of 2.5% for all ethanol. Thus, including tariffs and ad valorem taxes, the average cost of imported ethanol is shown in Table 4.1-34 in the "Brazil Direct w/ Tax & Tariff" and "CBI w/ Tax" columns for the years 2010-2022.

Table 4.1-33. Average Imported Ethanol Costs Prior to Tariff and Taxes

	Sugarcane Production Cost ($/gal)	Operating Cost ($/gal)	Capital Cost ($/gal)	Logistical Cost ($/gal)	Port Cost ($/gal)	Transport Cost from Port to US ($/gal)	Total Cost ($/gal)
2010	0.59	0.04	0.49	0.20	0.09	0.17	1.58
2011	0.58	0.04	0.49	0.20	0.09	0.17	1.57
2012	0.57	0.04	0.49	0.20	0.09	0.17	1.56
2013	0.56	0.04	0.49	0.20	0.09	0.17	1.55
2014	0.55	0.04	0.49	0.20	0.09	0.17	1.54
2015	0.54	0.04	0.49	0.20	0.09	0.17	1.53
2016	0.54	0.04	0.49	0.20	0.09	0.17	1.53
2017	0.53	0.04	0.49	0.20	0.09	0.17	1.52
2018	0.53	0.04	0.49	0.20	0.09	0.17	1.52
2019	0.53	0.04	0.49	0.20	0.09	0.17	1.52
2020	0.52	0.04	0.49	0.20	0.09	0.17	1.51
2021	0.52	0.04	0.49	0.20	0.09	0.17	1.51
2022	**0.51**	**0.04**	**0.49**	**0.20**	**0.09**	**0.17**	**1.50**

Table 4.1-34. Average Imported Ethanol Costs

	Brazil Direct ($/gal)	**Brazil Direct w/ Tax & Tariff ($/gal)**	**CBI ($/gal)**	**CBI w/ Tax ($/gal)**
2010	1.58	2.16	1.58	1.62
2011	1.57	2.15	1.57	1.61
2012	1.56	2.14	1.56	1.60
2013	1.55	2.13	1.55	1.59
2014	1.54	2.12	1.54	1.58
2015	1.53	2.11	1.53	1.57
2016	1.53	2.11	1.53	1.57
2017	1.52	2.10	1.52	1.56
2018	1.52	2.10	1.52	1.56
2019	1.52	2.10	1.52	1.56
2020	1.51	2.09	1.51	1.55
2021	1.51	2.09	1.51	1.55
2022	**1.50**	**2.08**	**1.50**	**1.54**

4.1.2 Biodiesel Production Costs

Virgin vegetable oils, fats, waste oils and greases costs

The feedstocks that we project to make up the largest share of biodiesel are virgin vegetable oil (primarily soy oil) and non-food-grade corn oil generated as a co-product of dry mill ethanol production. These feedstock streams were included in the agricultural commodity modeling done for this rulemaking using the FASOM model. This work is described in detail in Section 2.5 of this RIA. Table 4.1-35 summarizes the volumes and costs of these feedstocks.

Rendered fats and other waste greases are expected to make up a smaller, but still important, source of biodiesel feedstock. These were not explicitly modeled by FASOM; [242]therefore their value was estimated to be 70% that of soy oil, based on historical trends.

Table 4.1-35. Summary of biodiesel feedstock use and cost for primary control case in 2022 (2007$).

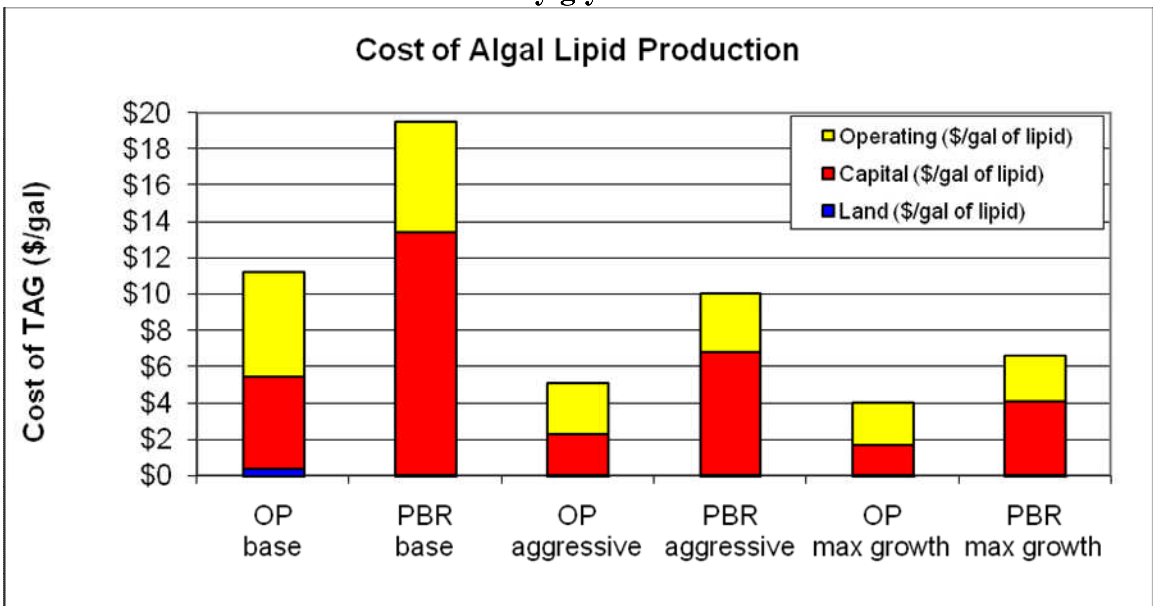
Fuel / Feedstock	Feedstock Price ($/lb)	Projected use in 2022 (MMgal)
Soy oil	0.33 [a]	660
Corn oil from dry mill ethanol production	0.17 [a]	680
Yellow grease or other rendered fats	0.23 [b]	230
Algae oil or other advanced feedstock	0.58 [c]	100

Algae-derived oils costs

Algae oil cost projections are based on Aspen modeling completed by NREL and are reported in 2007 dollars. Detailed cost information is provided in their report submitted to the docket.[1155] The results are summarized below in Figure 4.1-4. Two production pathways were assumed, open pond (OP) and photobioreactor (PBR) systems. For each production pathway a base case, aggressive case, and maximum development case were evaluated based on assumptions on key variables e.g., yield, lipid content on algae, etc. The oil production cost for the open pond case ranged from $11.25/gal in the base case to $3.99/gal for the max case. The oil production cost for the PBR case ranged from $19.49/gal in the base case to $6.62/gal in the max case.

[242] Data available from various sources suggests that tallow and yellow grease prices have been closer to half the value of crude soy oil, but we have chosen to assume 70% as this is what USDA/ARS had assumed during some initial cost modeling they had done for us. Also, given that rendered fat volumes will be more limited than vegetable feedstocks, we might expect their prices to rise against the alternative (and still more expensive) vegetable feedstocks in a climate of higher biofuel production.

Figure 4.1-4.
Cost to Produce 10 MMgal/yr oil at growth rate scenarios developed by NREL for open pond (op) and photobioreactor (PBR) production. TAG = triacylglyceride



Since algal biofuel technology is still in a relatively early stage of development, there is a higher degree of uncertainty associated with potential performance and cost relative to more established technologies. It is important to note that the "max" case merely means the maximum algae growth and oil content applied to the specific configuration and associated assumptions analyzed and does not imply that these are the absolute lowest costs that can ever be achieved as technology develops. For the algal technology systems analyzed, the report indicated that the areas with the highest economic impact include the optimum amount of nutrients required, the CO_2 delivery cost, the flocculant requirement for harvesting, and the material costs for the PBR production system. The economic modeling assumptions and results from NREL for microalgae-derived oil correspond well with other studies which report the cost of production for algae oil from $1 to >$40/gal.[1156]

NREL also investigated the uncertainty in key assumptions and the associated potential cost impact of such assumptions in a sensitivity analysis. Figure 4.1-5 shows that for open ponds, the amount of nutrients required has the highest impact on production cost of the variables evaluated. Figure 4.1-6 shows that the single largest cost item in the PBR system is the cost of the tubes themselves.

Figure 4.1-5. Open Pond Sensitivity Analysis

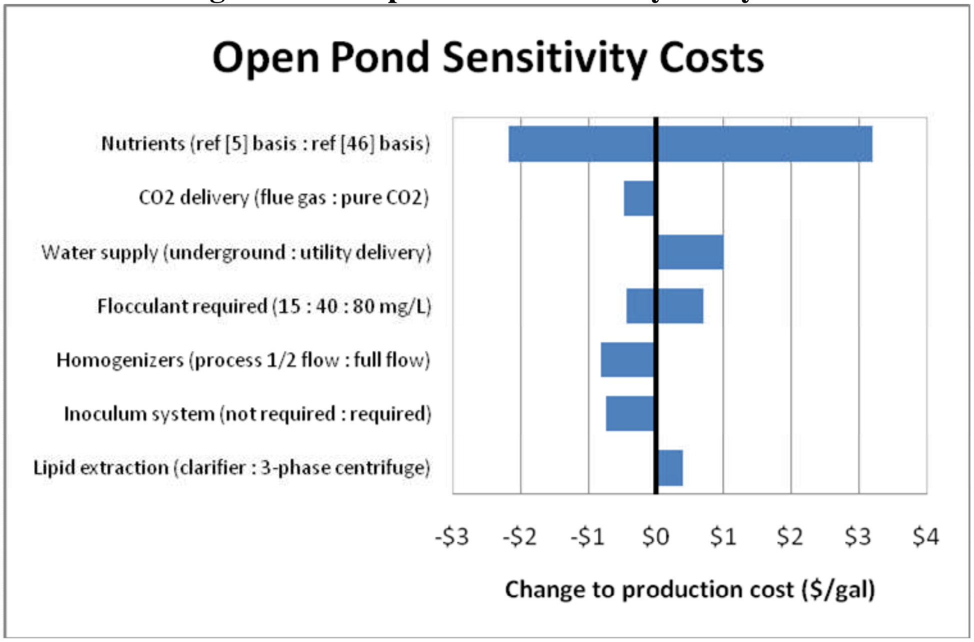
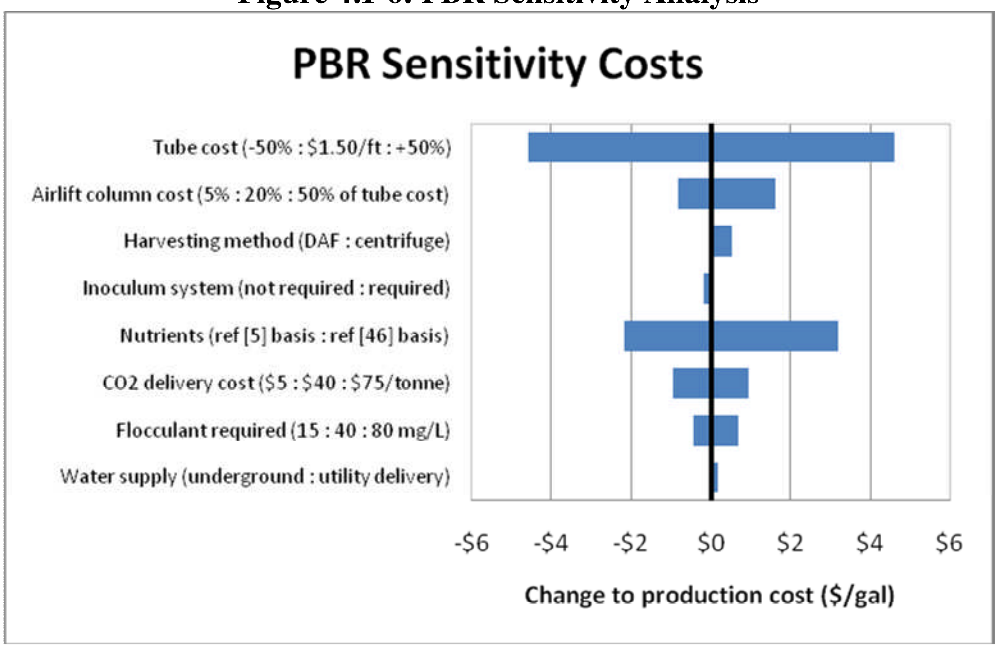


Figure 4.1-6: PBR Sensitivity Analysis



For this rulemaking, we made the simplifying assumption of using the production cost of the open pond aggressive case of $5.11/gal or $0.68/lb for this feedstock to estimate costs of algae-derived fuel. Given the uncertainties in estimating costs for algae as well as the need for a single-value estimate for algal oil for cost analyses purposes, we chose the open pond aggressive case which appears to represent a somewhat middle value as well as a more reasonably competitive feedstock with alternatives, such as soy oil.

Biodiesel production costs

Biodiesel production costs for this rule were estimated using two variations of a model generated by USDA for a 10 million gallon-per-year transesterification biodiesel plant. One version uses degummed soy oil as feedstock, and a second version includes acid pre-treatment steps required to utilize feedstocks such as rendered fat and yellow grease, which have higher free fatty acid content. USDA used the SuperPro Designer chemical process simulation software to build up a process model with estimates of heat and material flowrates and equipment sizing. Outputs from this model were then combined in a spreadsheet with capital, energy, labor, and feedstock costs to generate a final estimate of production cost. Additional details on the model are given in a 2006 technical publication in the peer-reviewed scientific journal Bioresource Technology.[1157] At 10 million gallons per year, the modeled plant size is between the mean and median plant sizes (16 million and 6 million gal/yr, respectively) as given in our industry characterization. Therefore, the model cost estimate is believed to be sufficiently accurate for our analyses and no further work was done to determine the effect of scale on production cost.

This model is periodically updated by USDA to reflect technology upgrades, changes to cost of capital, etc. Such an update was made to the model just before its outputs were used in the analyses presented here. We also made modifications to the capital cost to be consistent with typical cost amortization schemes used for regulatory programs. The capital charge estimate was derived as shown in Table 4.1-36. Installed capital cost was $11.9 million; adding 3% annual maintenance charge, we arrive at a final capital charge of 14% annually. Energy prices were taken from AEO 2009: natural gas at $7.75/MMBtu and electricity at $0.066/kWh for 2022 in 2007 dollars.

Table 4.1-36. Economic Factors Used in Deriving the Capital Cost Amortization Factor

Amortization Scheme	Depreciation Life	Economic and Project Life	Federal and State Tax Rate	Return on Investment (ROI)	Annual Maintenance Charge	Resulting Capital Amortization Factor
Societal Cost	10 Years	15 Years	0%	7%	3%	0.14

The value of the glycerin co-product has been depressed and volatile in recent years due to a large increase in production in biodiesel facilities. This has been balanced at times by new uses coming online as feedstocks for traditionally petrochemical-based products as well as increased demand in personal care and other consumer products as the standard of living increases in many parts of the world. Some facilities are even experimenting with using it as a supplemental fuel along with biomass or other materials. We can expect that new uses for glycerin will continue to be found as long as it is plentiful and cheap. For a simple and conservative projection of its value in the future, we have assumed an energy-equivalent value based on residual heating oil. Using a heating value of 7,979 Btu/lb and a heating oil value of $18.90/MMBtu in 2022, we arrive at $0.15/lb as a co-product value. Table 4.1-37 shows the overall process material balance output by the model.

Table 4.1-37. Material Balance and Values for Biodiesel Production Model in 2022

Stream	By weight	Estimated value (2007$)
Soy oil input	100	$0.33/lb
Methanol input	11	$0.16/lb
Biodiesel output (main product)	100	-
Glycerin output (co-product)	12	$0.15/lb

Table 4.1-38 shows the production cost allocation for the soy oil-to-biodiesel facility as modeled in the 2022 primary control case. Production cost for biodiesel is primarily a function of feedstock price, with other process inputs, facility, labor, and energy comprising much smaller fractions.

Table 4.1-38. Production cost allocation for soy biodiesel derived from this analysis for the primary control case in 2022

Cost Category	Share of Per-Gallon Cost
Soy Oil	85%
Other Materials [a]	6%
Capital & Facility	6%
Labor	2%
Utilities	2%

[a] Includes acids, bases, methanol, catalyst

4.1.3 Renewable Diesel Production Costs

The renewable diesel process converts rendered fats (or plant oils) into diesel fuel using thermal depolymerization, which is similar to refinery hydrotreating used to remove sulfur. The process uses hydrogen and catalyst to remove oxygen from the triglyceride molecules in the feedstocks oils via a decarboxylation and hydro-oxygenation reaction, yielding some light petroleum products and water as byproducts. The reactions also saturate the olefin bonds in the feedstock oils, converting them to paraffins, and may also isomerize some paraffins. Depending on process operating conditions, the yield to diesel-range material is typically between 90-99% volume, with the rest being naphtha and light fuel gases (primarily propane).

As described in the industry characterization discussion (see RIA Section 1.5.4), we have chosen to focus on stand-alone renewable diesel production, as we believe this will be the primary pathway given tax incentives and the definition of the biomass-based diesel fuel category. We assume a total project cost of $150MM for a standalone facility based on materials made publically available by Syntroleum Corp. related to their Geismar, LA, project.[1158]

Our operating cost and yield estimates were derived from material presented by UOP and Eni at a 2007 industry conference, which describes producing renewable diesel in a grass roots standalone production process inside a refinery.[1159] In addition to feedstock and facility costs, another significant cost input is hydrogen. For hydrogen operating costs, we used the UOP analysis and guidance from Conoco Philips to derive our estimate to make renewable diesel. [1160] The UOP paper presents a range of 1000 to 2000 standard cubic feed (scf) per barrel for converting the various feedstock to renewable diesel. Based on characteristics of rendered fats, we estimated a hydrogen demand of 1,590 SCF/bbl of feedstock processed.

Accounting for this quantity of hydrogen, along with a value taken from our refinery modeling work, we derived a figure of 6.9 cents/gallon of diesel product to cover utilities, labor, and other costs. Finally, total cost per gallon was estimated at $2.42 for the 2022 primary control case (2007 dollars). Table 4.1-39 gives more details for the process assumed in this analysis. Co-product values were also taken from refinery modeling work done for this rulemaking. Table 4.1-40 shows the cost allocation we arrived at for renewable diesel production.

Table 4.1-39.
Parameters used in renewable diesel production cost estimates.

Stream	By volume	Estimated value (2007$)
Fat input	100 gal	$0.23/lb
Hydrogen input	505 scf	$0.0044/scf
Renewable diesel output (main product)	93.5 gal	-
Naphtha output (co-product)	5 gal	$0.55/lb
Light fuel gas output (co-product)	9 gal	$0.13/lb

Table 4.1-40.
Production Cost Allocation for Renewable Diesel for Primary Control Case in 2022

Cost Category	Contribution to Cost
Feedstock	78%
Capital & Facility	11%
Hydrogen	7%
Other variable costs	3%

4.1.4. Biodiesel and Renewable Diesel Cost Summary

Table 4.1-41 summarizes the feedstock prices and fuel production cost for biodiesel. Table 4.1-42 gives the same information for renewable diesel. Combined with information from Table 4.1-35, a weighted average production cost could be estimated (our overall economic impacts take into account this information).

Table 4.1-41
Summary of Costs for Biodiesel for the Primary Control Case in 2022

Fuel / Feedstock	Feedstock Price ($/lb)	Fuel Production Cost ($/gal)
Biodiesel / soy oil	0.33 [a]	2.73
Biodiesel / corn oil extraction at ethanol plants	0.17 [a]	1.90
Biodiesel / yellow grease or other rendered fats	0.23 [b]	2.43
Biodiesel / algae or other advanced virgin oil feedstock	0.58 [c]	4.52 [d]

[a] Taken from outputs of FASOM model.
[b] Derived from outputs of FASOM model, assuming 70% value of soy oil.
[c] Derived from figures in a Technical Memo by Ryan Davis of NREL entitled "Techno-economic analysis of microalgae-derived biofuel production" (available in docket).
[d] This production cost assumes this advanced feedstock has very low free fatty acid content.

Table 4.1-42
Summary of Cost for Renewable Diesel for the Primary Control Case in 2022

Fuel / Feedstock	Feedstock Price ($/lb)	Fuel Production Cost ($/gal)
Renewable diesel / yellow grease or other rendered fats	0.23 [a]	2.42

[a] Derived from outputs of FASOM model, assuming 70% value of soy oil.

4.1.5 BTL Diesel Production Costs

Biofuels-to-Liquids (BTL) processes, which are also thermochemical processes, convert biomass to liquid fuels via a syngas route. If cellulose is converted to syngas, rather than converting the syngas to mixed alcohols, a Fischer Tropsch reactor can be added to convert the syngas to diesel fuel and naphtha. The primary product produced by this process is diesel fuel. This technology is commonly termed biomass-to-liquids (BTL) because of its similarity to gas-to-liquids and coal-to-liquids technology. Diesel fuel's higher energy density per gallon than ethanol and even biodiesel provides it an inherent advantage over these other fuels. In addition, BTL diesel fuel can be more easily distributed from production to retail outlets and used by motor vehicles. The diesel fuel produced by the Fischer Tropsch process tends to be comprised of paraffins which provide a much higher cetane number than petroleum diesel fuel, with a downside of poorer cloud point which reduces its widespread use in cold temperatures.

There are many steps involved in a BTL process which makes this a capital-intensive process. The first step, like all the cellulosic processes, requires that the feedstocks be processed to be dried and ground to a fine size. The second step is the syngas step, which thermochemically reacts the biomass to carbon monoxide and hydrogen. Since carbon monoxide production exceeds the stoichiometric ideal fraction of the mixture, a water shift reaction must be carried out to increase the relative balance of hydrogen. The syngas products must then be cleaned to facilitate the following Fischer-Tropsch (FT) reaction. The Fischer-Tropsch reaction reacts the syngas to a range of hydrocarbon compounds – a type of synthetic crude oil. This hydrocarbon mixture is then hydrocracked to maximize the production of high cetane diesel fuel, although some low octane naphtha and small amounts of wax are also produced. The many steps of the BTL process contribute to its high capital cost.

Although there were several studies available which provided costs estimates for BTL diesel fuel, they did not provide sufficient detail to understand all the cost elements of BTL diesel fuel and naphtha. EPA therefore contracted with NREL to estimate the production costs for BTL diesel fuel and naphtha. Like the other technologies, we asked for cost estimates for the same years assessed above for cellulosic ethanol which was for 2010, 2015 and 2022, however, NREL did not believe that the costs would change that much over this time span. So NREL only provided the costs for 2022, advising us that the costs would only be slightly less for earlier years, and most of that difference would because of the poorer economies of scale if the initial plants are sized smaller. Table 4.1-43 summarizes the cost information provide by NREL to EPA for a year 2022 cellulosic BTL plant.

Table 4.1-43
Year 2022 Production Costs for Thermochemcal (BTL) Cellulosic Fischer Tropsch Diesel Fuel Provided by NREL
(2007 dollars and 10% after tax rate of return)

Plant Size MMgal/yr	33.2 Diesel Fuel 49.4 All Liquid
Capital Cost $MM	346
Capital Cost 10% ROI after taxes ($MM/yr)	61.7
Fixed Costs ($MM/yr)	18.3
Feedstock Cost ($MM/yr)	39.1
Coproduct Credit ($MM/yr)[a]	-53.5
Other raw material Costs ($MM/yr)	0.9
Waste Disposal and Catalyst Costs ($MM/yr)	1.1
Total Costs ($MM/yr)	79
Total Costs (cents/gallon of diesel fuel)	206

a Based on a naphtha coproduct value of 327 cents per gallon.

NREL estimated that diesel fuel made by a 33 million gallon per year FT plant in 2022 could be produced at $2.06 per gallon estimated (in year 2007 dollars).[1161] Three adjustments however are needed to make the NREL production cost compatible with the rest of our analysis: 1) increase the feedstock costs, 2) reduce the capital charge costs and 3) adjust the co-product prices for naphtha and wax.

For capital charges, the NREL costs were based on amortizing capital assuming a 10 percent rate of return after taxes, using an annual capital charge factor of 0.178. The report's estimate for capital costs was $346 million for the plant, resulting in annual capital cost of $61.6 million or $1.85 per gallon of diesel fuel produced. We adjusted the capital cost by amortizing the capital cost assuming a 7 percent rate of return before taxes, using an annual capital charge factor of 0.11 which resulted in yearly cost of $38 million or $1.14 per gallon of diesel fuel produced.

In the NREL study, the total operating cost due to feedstock is $1.17 per gallon, using wood at $50.7 per dry ton. We adjusted the feedstock cost to $67.4 per dry ton, see subsection 4.1.1.2.1**,** which increased the feedstock costs to $1.56 per gallon of diesel fuel.

In the NREL analysis, the co-products produced have a credit value of $1.60 per gallon of diesel fuel, assuming a price for naphtha of $3.27 per gallon and wax at $0.49 per pound. The price of naphtha was set by NREL at 40 cents per gallon below the price of gasoline to account for its low octane value. The naphtha produced by the BTL process is also largely comprised of paraffins, however, as a gasoline blendstock it is poor because its octane could potentially be as low as 50. This material could be processed by refinery isomerization units raising its octane to perhaps 70 octane, but it cannot be processed by refinery reformers since it does not contain the napthenic compounds that are necessary for octane improvement by those units. Because of the large amount of octane rich ethanol which is expected to be made available from both corn and cellulose, it could be that BTL naphtha could be blended along with the ethanol into the gasoline pool. Rather than prejudge how this naphtha may be utilized in the future, for our cost analysis we simply assigned it a coproduct credit. So we set the BTL naphtha cost to be 83% as much of the cost of BTL diesel fuel based on its relative energy density. This results in a naphtha price of $1.98 per gallon. We adjusted the price of wax, by ratio-ing the NREL price by the change in price for naphtha. The price adjustment for naphtha and wax, results in a co-product value of $0.97 per gallon of FT diesel produced. The result is a diesel fuel production cost of $2.37 per gallon from the FT process.

Table 4.1-44 summarizes NREL's estimated and projected production costs for a thermochemical Fischer Tropsch biochemical cellulosic ethanol plant technology for their projected year 2022 technology in 2007 dollars reflecting a 7 percent before tax rate of return on investment. The costs are based on a cellulosic feedstock cost of $67.4 per dry ton.

Table 4.1-44
Year 2022 Production Costs for Thermochemcal (BTL) Cellulosic Fischer Tropsch Diesel Fuel Provided by NREL
(2007 dollars and 7% before tax rate of return)

Plant Size MMgal/yr	33.2 Diesel Fuel 49.4 All Liquid
Capital Cost $MM	346
Capital Cost 7% ROI before taxes ($MM/yr)	38
Fixed Costs ($MM/yr)	18
Feedstock Cost ($MM/yr)	52
Coproduct Credit ($MM/yr)[a]	-32
Other raw matl. Costs ($MM/yr)	1.5
Waste Disposal and Catalyst Costs ($MM/yr)	1.5
Total Costs ($MM/yr)	79
Total Costs (cents/gallon of diesel fuel)	237

a Based on a naphtha coproduct value of 198 cents per gallon.

Initially, the estimated cost of $2.37 per gallon seems high relative to the projected cost for a year 2022 biochemical cellulosic ethanol plant, which is 126 cents per gallon of ethanol (see subsection 4.1.1.2.4)**.** However, ethanol provides about half the energy content on a per gallon basis as Fischer Tropsch diesel fuel. So, if we double the biochemical cellulosic ethanol costs to $2.52 to be consistent with the energy per diesel fuel-equivalent gallon, the estimated costs are very consistent between the two. The cellulosic biofuel tax subsidy currently favors the biochemical ethanol plant, though, because it is a per-gallon subsidy regardless of the energy content, and it therefore offsets twice as much cost as the BTL plant producing diesel fuel. However, the cellulosic diesel fuel may still be more valuable in the marketplace than cellulosic ethanol. In 2008 and for much of 2009 diesel fuel was priced higher than gasoline, and if this trend continues in the future, it may provide a better market for selling the BTL diesel fuel than for selling biochemical ethanol into the E85 market.

It was necessary to estimate cellulosic diesel fuel costs for previous years for the year-by-year cost analysis (see Section 4.4). However, NREL did not provide costs for previous years, although NREL did say that the primary difference in costs for the previous years would be economies of scale impacts for the capital costs due to smaller sized plants. Thus, to derive a cost for 2010, we estimated that the cellulosic diesel fuel plants that would be installed in 2010 would be half the size of the plant estimated for 2022. While the total capital costs decrease, the capital costs increase relative to the volume of cellulosic diesel fuel produced. We increased the naphtha credit from 198 cents per gallon to 216 cents per gallon to maintain an 83% cost percentage relative to the cellulosic diesel fuel. For this smaller plant size, we estimate the cost for cellulosic diesel fuel to be 258 cents per gallon.

Other Cellulosic Diesel Fuel Costs

For our volumes analysis, we assumed early on for our final rule analysis that there would likely be one or more other cellulosic diesel fuel technologies, other than BTL, producing cellulosic diesel fuel. However, we were either not able to obtain cost information from them, or we were uncertain enough about their future that we felt that we should not base the cost of the program on them. For example, Cello Energy has already built a cellulosic diesel fuel facility in Alabama here in the US with projected costs of about one dollar per gallon of diesel fuel. However, the facility has had difficulty operating as designed. As a result, perhaps very conservatively, we assumed that the other cellulosic diesel fuel costs would be the same as the BTL diesel fuel costs, and used the 237 cents per gallon cost for BTL diesel fuel for the entire cost for cellulosic diesel fuel.

4.2 Renewable Fuel Distribution Costs

Our analysis of the costs associated with distributing the volumes of biofuels that we project will be used under RFS2 focuses on: 1) the capital cost of making the necessary upgrades to the fuel distribution infrastructure system directly related to handling these fuels, and 2) the ongoing additional freight costs associated with shipping renewable fuels to the point where they are blended with petroleum-based fuels. Our analysis considers distribution costs within the U.S. only. The costs associated with bringing ethanol imports to the U.S. are considered in the context of the cost of the imports themselves. We chose to evaluate the distribution costs for cellulosic distillate and renewable diesel together because the same considerations apply to their handling in the fuel distribution system and because the projected volume of renewable diesel fuel is relatively small. The following sections outline our estimates of the distribution costs for the additional volumes of ethanol, cellulosic distillate fuel/renewable diesel fuel, and biodiesel that we project will be used to meet the RFS2 standards. There will be ancillary costs associated with upgrading the basic rail, marine, and road transportation nets to handle the increase in freight volume due to the RFS2. We have not sought to quantify these ancillary costs because 1) the growth in freight traffic that is attributable to RFS2 represents a minimal fraction of the total anticipated increase in freight tonnage (approximately 0.4% by 2022, see Section 1.6.3 of this RIA), and 2) we do not believe there is an adequate way to estimate such non-direct costs.

The biofuels used in response to the RFS2 standards will displace petroleum-based fuels that would otherwise be used. Thus, it would be appropriate to subtract the distribution costs for the displaced petroleum-based fuels from the distribution costs attributed to the biofuels that replace these petroleum-based fuels. However, we chose not to do so as it is difficult to project exactly what changes would result in cost savings. As a result, our analysis should provide a conservatively high estimate of biofuel distribution costs given the uncertainties in our analysis.

A discussion of the changes that will be needed in the biofuels distribution system to accommodate the increased volumes of biofuels that we project will be used to meet the RFS2 standards is contained in Section 1.6 of this RIA. In this Section, we further detail the nature of these projected changes and estimate the associated costs. Distribution capital costs associated with the additional volume of ethanol, cellulosic distillate fuel/renewable diesel, and biodiesel that we project will be used by 2022 to meet the RFS2 standards under the primary mid-ethanol scenario relative to the AEO 2007 reference case totals $8.4 billion, of which 68% is attributed to ethanol, 17% to cellulosic distillate/renewable diesel fuel, and 14% to biodiesel.

4.2.1 Ethanol Distribution Costs

As discussed in the following sections, we estimate that the total capital costs in the U.S to support distribution of the additional volume of ethanol that will be used to meet the RFS2 standards under the primary mid-ethanol scenario will be $5.5 billion by 2022 relative to the AEO 2007 reference case. When amortized, this translates to 7 cents per gallon of additional ethanol used to meet the RFS2 standards. Amortization of capital costs was done over 15 years at a 7% annual cost of capital except in the case of the cost of tank trucks where a 10 year amortization schedule was used. These costs were calculated relative to the AEO 2007 baseline which projects that 13.2 BGY of ethanol would be used in 2022 absent the RFS2 standards. Under the mid-ethanol primary scenario, we project that 22.2 BGY of ethanol will be used by 2022. Ethanol freight costs are estimated to be 13 cents per gallon on a national average basis. Thus, we estimate that total ethanol distribution costs will be 20 cents per gallon of ethanol that we project will be used to meet the RFS2 standards.[243]

The ethanol distribution capital and freight costs for all the control scenarios relative to the 2 reference cases that we evaluated in this FRM is summarized in Table 4.2-1. The itemized ethanol capital costs are presented in Table 4.2-2 relative to the AEO 2007 reference case, and in Table 4.2-3 relative to the RFS1 reference case. These costs do not include the potential costs to supply butane to terminals for E85 blending, which are presented in Table 4.2-4. The way in which we estimated these costs is detailed in the following sections.

[243] As noted previously, we chose not to subtract the distribution costs for the petroleum-based fuels that would be displaced by the use of biofuels from our estimated biofuel distribution costs. We believe that the freight costs to ship petroleum-based fuels to the terminal are approximately 4 cents per gallon. If we were to subtract these costs from the estimated ethanol distribution costs under the mid-ethanol scenario relative to the AEO 2007 reference case, the result would be 16 cents per gallon.

Table 4.2-1.
Summary of Estimated Ethanol Distribution Capital and Freight Costs for the RFS2 Control Scenarios Relative to the Reference Cases

	Low-Ethanol Scenario		Mid-Ethanol Scenario		High-Ethanol Scenario	
	RFS1 Reference	AEO Reference	RFS1 Reference	AEO Reference	RFS1 Reference	AEO Reference
Billion $ Capital	5.5	3.0	7.9	5.5	11.9	9.9
Capital Costs (cpg)	6	8	6	7	5	6
Freight Costs (cpg)	13	13	13	13	12	12
Total Distribution Costs (cpg)	19	21	19	20	17	18

Table 4.2-2.
Summary of Estimated Ethanol Distribution Capital Costs for the RFS2 Control Scenarios Relative to the AEO 2007 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Rail Cars	365	760	1,699
Barges	22	45	102
Tank Trucks	42	87	194
Storage Tanks at Petroleum Terminals	355	739	1,568
Blending and other Miscellaneous Equipment at Petroleum Terminals	345	411	503
Unit Train Receipt Facilities	238	434	748
Manifest Rail Receipt Facilities	7	12	21
Marine Receipt Facilities for Inta-U.S. Transport	76	100	144
Import Receipt Facilities	49	53	63
E85 Retail Facilities	1,526	2,863	4,893
Total (Million $)	3,025	5,505	9,935
Total (cpg)	8	7	6

Table 4.2-3.
Summary of Estimated Ethanol Distribution Capital Costs for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Rail Cars	884	1,279	2,218
Barges	53	77	133
Tank Trucks	107	154	268
Storage Tanks at Petroleum Terminals	859	1,243	2,073
Blending and other Miscellaneous Equipment at Petroleum Terminals	1,006	1,064	1,144
Unit Train Receipt Facilities	444	586	838
Manifest Rail Receipt Facilities	15	20	28
Marine Receipt Facilities for Inta-U.S. Transport	98	130	186
Import Receipt Facilities	49	53	63
E85 Retail Facilities	1,957	3,293	4,973
Total (Million $)	5,471	7,898	11,922
Total (cpg)	6	6	5

Table 4.2-4.
Potential Costs to Provide Butane to Terminals for E85 Blending for the RFS2 Control Scenarios

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Butane Blending, Storage, Receipt and Other Miscellaneous Terminal Costs	235	536	1,249
Tank Trucks	325	830	837
Rail Cars	32	81	89
Total Capital Costs	592	942	2,175
Freight Cost (Annual cost in 2022)	16	24	40
Total Butane Distribution Costs Relative to the RFS1 Reference Case (cpg ethanol)	1	1	1
Total Butane Distribution Costs Relative to the AEO Reference Case (cpg ethanol)	2	2	2

4.2.1.1 Capital Costs to Upgrade the Ethanol Distribution System

4.2.1.1.1 Petroleum Terminal Ethanol Distribution Capital Costs

The terminal facility modifications needed to support the use of the volume of ethanol that we project will be used to meet the RFS2 standards are discussed in Section 1.6.7. A summary of the costs associated with these modifications is detailed in Tables 4.2-5 and 4.2-6.

Table 4.2-5.
Ethanol Associated Petroleum Terminal Costs for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Costs	858	1,150	1,913
Total Storage Tank Costs	355	739	1,568
New Storage Tank Construction Costs	291	606	1,287
Cost to Retrofit Existing Storage Tanks	64	133	282
Costs to Prepare Terminals to Handle Ethanol for the First Time	167	167	167
Tank Truck Unloading Facilities	277	186	123
Ethanol Blending and Miscellaneous Ethanol Handling Costs	59	57	55

Table 4.2-6.
Ethanol Associated Petroleum Terminal Costs for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Costs	2,003	2,307	3,078
Total Storage Tank Costs	859	1,243	2,073
New Storage Tank Construction Costs	705	1,020	1,701
Cost to Retrofit Existing Storage Tanks	154	223	372
Costs to Prepare Terminals to Handle Ethanol for the First Time	594	594	594
Tank Truck Unloading Facilities	366	286	231
Ethanol Blending and Ancillary Ethanol Handling Costs	184	183	180

The above cost estimates are bases on the following. Input from terminal operators indicates that the primary modifications needed to prepare a terminal to handle ethanol for the first time are associated with the modification of vapor recovery equipment to handle ethanol-containing gasoline at a cost of $1,000,000 per terminal. We added another $20,000 to account for related ancillary costs. Input from terminal operators indicates that the cost of ethanol blending equipment is $300 thousand for E10-capable equipment, $310 thousand for E85-capable equipment, and $10,000 to upgrade E10-capable equipment to handle E85. Input from companies that are familiar with the installation of ethanol truck unloading equipment at terminals indicates that the cost averages $500 thousand per facility. Input from terminal operators indicates that the cost of new ethanol storage tank construction is $40 per barrel of capacity, and that the cost of retrofitting existing gasoline storage tanks for ethanol service is $5 per barrel of capacity for the size of tanks that are likely to be used.

4.2.1.1.2 Capital Cost of Unit Train Receipt Facilities for Ethanol

Our estimation of the number of unit train receipt facilities that will be need to support the transport of the volumes of ethanol and cellulosic distillate fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. Input from industry indicates that the cost of unit train receipt facility capable of handling 229 million gallons of biofuels per year is $10 million and the cost of a facility capable of handling 613 million gallons is $25 million. We interpolated between these two estimates to derive a cost estimate for each unit train receipt facility that we projected will be constructed based on its anticipated annual throughput volume. The total cost of unit train receipt facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol + cellulosic distillate fuel/renewable diesel fuel volume under the respective control scenario.

Our projections of the total cost of unit train receipt facilities and the portion that we attributed to the volume of ethanol that we project will be used to meet the RFS2 standards is presented in Tables 4.2.7 and 4.2.8.

Table 4.2-7.
Cost of Unit Train Facilities to Facilitate the Transport of Ethanol for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Unit Train Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	748	748	748
Cost of Unit Train Facilities Attributed to Ethanol Transport	238	434	748

Table 4.2-8.
Cost of Unit Train Facilities to Facilitate the Transport of Ethanol for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Unit Train Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	838	838	838
Cost of Unit Train Facilities Attributed to Ethanol Transport	444	586	838

4.2.1.1.3 Capital Cost of Manifest Rail Receipt Facilities for Ethanol

Our estimation of the number of manifest rail receipt facilities that will be needed to support the transport of the volumes of ethanol and cellulosic distillate fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. The cost of these facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol + cellulosic distillate fuel/renewable diesel fuel volume. Based on input from companies familiar with the installation of manifest rail receipt facilities, we estimate that the total cost per facility will be $500 thousand.

Our projections of the total cost of the manifest rail receipt facilities and the portion that we attributed to the volume of ethanol that we project will be used to meet the RFS2 standards is presented in Tables 4.2.9 and 4.2.10.

Table 4.2-9.
Cost of Manifest Rail Receipt Facilities for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Manifest Rail Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	21	21	21
Cost of Manifest Rail Receipt Facilities Attributed to Ethanol Transport	14	9	21

Table 4.2-10.
Cost of Manifest Rail Receipt Facilities
for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Manifest Rail Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	28	28	28
Cost of Manifest Rail Receipt Facilities Attributed to Ethanol Transport	13	8	28

4.2.1.1.4 Ethanol Import Facility Capital Costs

Our estimation of the number of marine facilities that will be needed to support the receipt of the volume of imported ethanol that we project will be used to meet the RFS2 standards is discussed in Section 1.6.5 of this RIA. We estimate that a total of 30 port facilities will receive imported ethanol by 2022. Of these ports, 14 will need to accommodate ethanol receipts for the first time under the low-ethanol scenario, 15 under the mid-ethanol scenario, and 18 under the high ethanol scenario.

We believe that all such port facilities also serve as petroleum terminals. Thus, the cost of additional ethanol storage, ethanol blending equipment, and other miscellaneous equipment related to handling ethanol from the standpoint of terminal operations at such facilities is accounted for in the context of the costs at petroleum terminals (see Section 4.2.1.1.1 of this RIA). However, there will be additional costs at the port facilities which had not received ethanol in the past. Input from industry indicates that offloading large marine transport containers of ethanol requires significantly upgraded vapory recovery equipment. Based on this input, we estimated the cost of making the needed upgrades to vapor recovery equipment at 2.5 million dollars per facility. We further estimated miscellaneous costs associated with delivery of ethanol into storage tanks from marine vessels at 1 million dollars per facility. This is meant to include new piping, pumps, various other fittings, and a contingency cost. The actual cost could be significantly lower. Thus, we estimate that the total cost to prepare for delivery of ethanol at a port that had not received ethanol before at 3.5 million dollars per facility.

Based on the above, we estimate that the ethanol import port costs due to the importation of the additional volume of ethanol used to meet the RFS2 standards will be $49 million under the low-ethanol scenario, $52 million under the mid-ethanol scenario, and $63 million under the high-ethanol scenario. We assumed the same costs relative to both the RFS1 and AEO reference cases because we believe that the use of the incremental volume of ethanol imports attributed to meeting the RFS2 standards will take place after the RFS1 and AEO ethanol use volumes are met.

4.2.1.1.5 Capital Costs of Barge Receipt Facilities for Intra-U.S Ethanol Transport

Our estimation of the number of barge receipt facilities for intra-U.S. biofuel shipment that will be need to support the transport of the volumes of ethanol and cellulosic distillate fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.5 of this RIA. We estimate that 41 additional barge receipt facilities will receive shipments of ethanol and cellulosic distillate fuel/renewable diesel fuel relative to the AEO reference case and 53 relative to the RFS1 reference case. We used the same $3.5 million per facility cost that we estimated for the ethanol import facilities (see Section 4.2.1.1.4). The cost of these facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol + cellulosic distillate fuel/renewable diesel fuel volume.

Our projections of the total cost of the barge receipt facilities and the portion that we attributed to the volume of ethanol that we project will be used to meet the RFS2 standards is presented in Tables 4.2.11 and 4.2.12.

Table 4.2-11.
Cost of Barge Receipt Facilities
for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Barge Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	143	143	143
Cost of Barge Receipt Facilities Attributed to Ethanol Transport	76	100	143

Table 4.2-12.
Cost of Barge Receipt Facilities
for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Barge Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	185	185	185
Cost of Barge Receipt Facilities Attributed to Ethanol Transport	98	129	185

4.2.1.1.6 Ethanol Rail Car Capital Costs

Our estimation of the number of rail cars needed to transport the additional volume of ethanol that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. Based on input from rail car manufactures, we estimate that the cost of a new 30,000 gallon rail car suitable for ethanol service is $90 thousand. The cost of the additional ethanol rail cars needed under the 3 control scenarios relative to the 2 reference cases is presented in Tables 4.2-13 and 4.2-14.

Table 4.2-13.
Cost of Additional Ethanol Rail Cars
for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Rail Cars	4,050	8,450	18,870
Rail Car Cost ($Million)	$365	$760	$1,699

Table 4.2-14.
Cost of Additional Ethanol Rail Cars
for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Rail Cars	9,820	14,210	24,639
Rail Car Cost ($Million)	$884	$1,279	$2,218

4.2.1.1.7 Ethanol Barge Capital Costs

Our estimation of the number of barges needed for intra-U.S. transport of the additional volume of ethanol that we project will be used to meet the RFS2 standards is discussed in Section 1.6.5 of this RIA. Based on input from fuel barge manufactures, we estimate that the cost of a new 10,000 barrel barge suitable for ethanol service is $1.4 million. The cost of the additional ethanol barges needed under the 3 control scenarios relative to the 2 reference cases is presented in Tables 4.2-15 and 4.2-16.

Table 4.2-15.
Cost of Additional Ethanol Barges
for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Barges	16	32	73
Cost of Barges ($Million)	$22	$45	$101

Table 4.2-16.
Cost of Additional Ethanol Barges
for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Barges	38	55	95
Cost of Barges ($Million)	$53	$76	$133

4.2.1.1.8 Ethanol Tank Truck Capital Costs

Our estimation of the number of tank trucks needed to transport the additional volume of ethanol that we project will be used to meet the RFS2 standards is discussed in Section 1.6.6 of this RIA. Based on input from ethanol tank truck manufactures, we estimate that the cost of a new 8,000 gallon tank truck suitable for ethanol service is $180 thousand. The cost of the additional ethanol tank trucks needed under the 3 control scenarios relative to the 2 reference cases is presented in Tables 4.2-17 and 4.2-18.

Table 4.2-17.
Cost of Additional Ethanol Tank Trucks
for the RFS2 Control Scenarios Relative to the AEO Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Tank Trucks	230	480	1,080
Cost of Tank Trucks ($Million)	$42	$87	$194

Table 4.2-18.
Cost of Additional Ethanol Tank Trucks
for the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Tank Trucks	590	860	1,490
Cost of Tank Trucks ($Million)	$107	$154	$268

4.2.1.1.9 E85 Retail Facility Costs

Our estimates of the number of additional E85 retail facilities and the number of E85 refueling positions needed at such facilities to enable the use of the volumes of E85 that we project will be used to meet the RFS2 standards under the 3 control scenarios is contained in Section 1.6.9 of this RIA. Our estimates of the additional E85 refueling infrastructure that will be needed relative to the 2 reference cases are presented in Table 4.2-19 and 4.2-20.

Table 4.2.19.
Additional E85 Retail Facilities Needed by 2022 to Support the Projected Increase in E85 use under the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
New E85 Installation with 1 Dispenser	14,967	10,923	0
New E85 Installation with 2 Dispensers	0	12,133	0
New E85 Installation with 3 Dispensers	0	0	27,099
Addition of 2 Dispensers to Retail Facility that had 1 Dispenser	0	0	1,210

Table 4.2.20.
Additional E85 Retail Facilities Needed by 2022 to Support the Projected Increase in E85 use under the RFS2 Control Scenarios Relative to the AEO Reference Case

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
New E85 Installation with 1 Dispenser	11,677	7,633	0
New E85 Installation with 2 Dispensers	0	12,133	0
New E85 Installation with 3 Dispensers	0	0	23,809
Addition of 2 Dispensers to Retail Facility that had 1 Dispenser	0	0	4,500

The following estimates regarding the cost of E85 compatible retail equipment are based on input from gasoline retailers and other parties with experience in the requirements and costs associated with installing E85 retail equipment. The total cost of installing a two nozzle E85 dispenser is estimated at $23,000. This is composed of $17,000 for the dispenser itself, $750 for hanging hardware, $950 for refueling island hardware, $3,000 for installation, and a $1,300 contingency cost. Hanging hardware costs are composed of $310 for 2 nozzles, $135 for 2 breakaway connections, $135 for 2 swivel connections, and $170 for 2 hoses. Refueling island hardware costs are composed of $450 for the dispenser island, $250 for an island sump pump, and $250 for bumper posts. Installation costs are composed of $1,500 for concrete removal and replacement, and $1,500 for wiring and piping.

The cost of automatic tank level gauging equipment is estimated at $6,500. It is estimated that 65% of retailers will install automatic tank gauging (ATG) equipment and the remainder will rely on manual means of determining the amount of fuel remaining in their underground storage tank. Thus, the average cost per facility will be $4,225 for ATG equipment. We estimate the cost of installing a canopy addition to provide cover for an additional dispenser at $15,000. We estimated that only 10% of facilities will need to install additional canopy coverage in order to accommodate the new E85 retail dispenser. Thus, the average canopy cost per facility is estimated at $1,500. The cost of installing a new 15,000 underground E85 storage tank is estimated at $102,000. The cost of connecting the tank to the dispenser(s) is included in this cost along with other miscellaneous storage tank related costs. In the NPRM, we estimated that an 8,000 gallon storage tank would be used at E85 retail facilities. We increased the size to 15,000 based on industry comments that the added storage volume will be needed to keep pace with fuel throughput without necessitating an overly-frequent fuel delivery schedule. The use of a 15,000 gallon storage tank will also allow the delivery of a full 8,000 gallon tank truck at a single retail facility. Input from fuel retailers indicates that there typically is at least 15,000 gallons of gasoline storage at current retail facilities. Based on the above, the cost of an E85 installation with one dispenser is estimated at $131 thousand, the cost of for a new E85 installation with 2 dispensers is estimated at $154 thousand, and the cost of a new E85 installation with 3 dispensers is estimated at $177 thousand. The cost of upgrading an existing E85 facility with a single dispenser to add 2 additional dispensers is estimated at $130 thousand.

Our E85 retail facility cost estimates are presented in Table 4.2-21. These estimates are based on the above E85 equipment cost estimates and the estimated facility requirements detailed in Tables 4.2-19 and 4.2-20.

Table 4.2-21.
Cost of the Additional E85 Retail Facilities Needed by 2022
to Support the Projected Increase in E85 use under the RFS2 Control Scenarios

	E85 Capital Costs ($Billion)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Relative to the AEO 2007 Reference Case	1.526	2.863	4.893
Relative to the RFS1 Reference Case	1.956	3.293	4.973

4.2.1.1.10 Potential Costs of Supplying Special Blendstocks at Petroleum Terminals for E85

As discussed in Section 1.6.8 of this RIA, special blendstocks may need to be supplied to terminals to facilitate the manufacture of E85 which meets ASTM International minimum volatility specifications. To evaluate the potential impacts to the fuel distribution system if this is the case, we assumed that butane would be used as the special blendstock and that it would be blended into gasoline before being blended with denatured ethanol to produce E85. As such, we estimated the potential costs associated with automated inline butane blending systems, butane storage tanks, tank trucks, railcars, transloading facilities, and other facility changes needed for butane blending into E85. These costs are based upon discussions with industry representatives.

We assume that butane would be transported by tank truck and/or railcar from petroleum refineries to E85-producing petroleum terminals and stored until blended into a final product. Of the 1,063 terminals identified in our analysis, two-thirds (709) are assumed to blend E85. All of these terminals are assumed to require butane blending equipment. Our cost estimates assumed that twenty-five percent (177) of these terminals will receive butane via 31,500 gallon railcar and the remaining seventy-five percent (532) will receive butane via 8,200 gallon tank truck. Of the 177 terminals that receive butane via railcar, fifty-percent are assumed to directly off-load butane to tank storage for eventual blending into E85. The other fifty-percent of the terminals which received butane via railcar are assumed to transload the butane from railcars to tank trucks for final delivery to terminals which store butane for eventual blending into E85.

The blending of butane into E85 requires petroleum terminals to have on-site butane blending equipment. In developing our cost estimates, we assume that each terminal which blends E85 uses an automated, in-line butane blending system and two 60,000 gallon butane storage tanks. The cost of an in-line butane blending systems is assumed to be $1.5 million per unit. The cost each 60,000 gallon butane storage tank is assumed to be $150,000. Transloading equipment is assumed to cost $500,000 per unit.

Transport cost estimates were based upon the ORNL transport analysis discussed in Section 1.6.3. In that analysis, the cost of freight rail transport was assumed to average $0.12 per ton-mile. The cost of truck transport was assumed to average $0.14 per ton-mile. Average round trip distance is assumed to be 1,200 miles for railcars and 300 miles for tank trucks. Travel speed estimates are truck 35 mph and railcar 10 mph with roundtrip times being approximately 8 hours for trucks and 5 days for railcars. Each tank truck is assumed to cost $150,000 and each railcar is assumed to cost $135,000.

Estimates of the number of tank trucks and railcars required to deliver butane appears by low, medium, and high volume cases in Table 4.2-22 and a summary of cost estimates for the three volume cases appears in Table 4.2-23.

Table 4.2-22.
Estimated Number of Tank Trucks and Rail Cars Needed for Shipment of Butane under the RFS2 Control Scenarios

	Number of Tank Trucks and Rail Cars Needed to Transport Butane		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Tank Truck (8,200 gallons)	2,165	3,280	5,530
Railcar (31,500 gallons)	236	358	602

Table 4.2-23.
Summary of Potential Costs to Provide Butane for E85 Blending under the RFS2 Control Scenarios

	Freight Costs	**Capital Costs**
Low-Ethanol Scenario	$16 million	$357 million
Mid-Ethanol Scenario	$24 million	$911 million
High-Ethanol Scenario	$40 million	$927 million

4.2.1.2 Ethanol Freight Costs

Our estimates of ethanol freight costs are based on a study conducted by Oakridge National Laboratories (ORNL).[1162] The ORNL analysis contains detailed projections of which transportation modes and combination of modes (e.g. unit train to barge) are best suited for delivery of ethanol to specific markets considering ethanol source and end use locations, the current configuration and projected evolution of the distribution system, and cost considerations for the different transportation modes. The NPRM analysis assumed that all biofuel volumes other than biodiesel would be ethanol. For this FRM, we analyzed three scenarios under which varying volumes of cellulosic distillate fuel take the place of ethanol production volumes to meet the RFS2 standards. However, due to the timing of the various analyses for the FRM, the NPRM projections of the location of ethanol production facilities and end use areas contained in the NPRM had to be used as the inputs into the ORNL analysis.[244] Therefore, our use of the ORNL analysis to evaluate the freight costs for the final rule assumes that cellulosic distillate production plants will take the place of some of the ethanol production plants projected in the NPRM. It further assumes that cellulosic distillate fuel use will coincide with the ethanol end-use areas projected in the NPRM and that both fuels will be transported by the same means.

We estimated the freight costs under the FRM control scenarios by totaling the cellulosic distillate/renewable diesel fuel and ethanol volume under each scenario and interpolating between the freight costs projected by ORNL for 2 NPRM ethanol volume scenarios. This approach provides for the economy of scale in biofuel freight costs with increased volume. Based on this approach, we estimate that ethanol freight costs will be 12 cents per gallon (cpg) under the high-ethanol scenario and 13 cpg under the low-ethanol and mid-ethanol scenarios. Our use of the ORNL freight cost estimates to derive the freight FRM freight cost estimates is illustrated in Table 4.2-24.

[244] The ORNL final report contains maps of projected ethanol production locations and end use areas.

Table 4.2-24.
Interpolation of FRM Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel Freight Costs from ORNL Freight Cost Estimates for NPRM Ethanol Volume Scenarios

	Volume of Ethanol, Cellulosic Distillate Fuel, and Renewable Diesel Fuel (BGal/yr in 2022)	Freight Cost (cpg)
NPRM Control Scenario	34.14	12.2 (ORNL estimate)
FRM High-Ethanol Scenario	33.24	12 (Interpolation)
FRM Mid-Ethanol Scenario	28.68	13 (Interpolation)
FRM Low Ethanol Scenario	26.75	13 (Interpolation)
AEO 2007 Reference Case	13.18	15.3 (ORNL estimate)

4.2.2 Cellulosic Distillate Fuel Distribution Costs

As discussed in the following sections, we estimate that the total capital costs in the U.S to support distribution of the additional volume of cellulosic distillate fuel/renewable diesel fuel that will be used in to meet the RFS2 standards under the primary mid-ethanol scenario will be 1,392 billion dollars by 2022 relative to the AEO 2007 reference case. When amortized, this translates to 2 cents per gallon of additional cellulosic distillate fuel/renewable fuel attributed to the RFS2 standards. Amortization of capital costs was done over 15 years at a 7% annual cost of capital except in the case of the cost of tank trucks where a 10 year amortization schedule was used. Under the mid-ethanol primary scenario, we project that 6.7 BGY of cellulosic distillate fuel/renewable diesel fuel will be used by 2022. Cellulosic distillate fuel/renewable diesel fuel freight costs are estimated to be 13 cents per gallon on a national average basis. Thus, we estimate that total cellulosic distillate fuel/renewable diesel fuel distribution costs will be 15 cents per gallon of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards.[245]

The cellulosic distillate fuel/renewable diesel fuel distribution capital and freight costs for all the control scenarios relative to the 2 reference cases that we evaluated in this FRM is summarized in Table 4.2-25. The itemized cellulosic distillate fuel/renewable diesel fuel capital costs are presented in Table 4.2-26 relative to the AEO 2007 reference case, and in Table 4.2-27 relative to the RFS1 reference case. The way in which we estimated these costs is detailed in the following sections. As discussed in the following sections, some biofuel infrastructure assets

[245] As noted previously, we chose not to subtract the distribution costs for the petroleum-based fuels that will be displaced by the use of biofuels from our estimated biofuel distribution costs. We believe that the freight costs to ship petroleum-based fuels to the terminal are approximately 4 cents per gallon. If we were to subtract these costs from the estimated cellulosic distillate fuel/renewable diesel fuel distribution costs under the mid-ethanol scenario relative to the AEO 2007 reference case, the result would be 11 cents per gallon.

such as unit train receipt facilities are used to distribute both cellulosic distillate fuel/renewable diesel fuel and ethanol. We attributed a fraction of the capital costs for such facilities to either cellulosic distillate fuel/renewable diesel fuel or ethanol in proportion to the fraction of the total additional volume of these fuels that we project will be used to meet the RFS2 standards relative to the reference case. This approach results in a slight difference in the capital costs under the 2 reference case despite the fact that the incremental volume of cellulosic distillate/renewable diesel fuel used to meet the RFS2 standards is the same under both reference cases.

Table 4.2-25.
Summary of Estimated Cellulosic Distillate Fuel/Renewable Diesel Fuel Distribution Capital and Freight Costs under the RFS2 Control Scenarios Relative to the Reference Cases

	Low-Ethanol Scenario		Mid-Ethanol Scenario		High-Ethanol Scenario	
	RFS1 Reference	AEO Reference	RFS1 Reference	AEO Reference	RFS1 Reference	AEO Reference
Billion $ Capital	1,999	2,036	1,375	1,392	NA	NA
Capital Costs (cpg)	2	2	2	2	NA	NA
Freight Costs (cpg)	13	13	13	13	NA	NA
Total Distribution Costs (cpg)	16	16	15	15	NA	NA

Table 4.2-26.
Summary of Estimated Cellulosic Distillate Fuel/Renewable Diesel Fuel Distribution Capital Costs under the RFS2 Control Scenarios Relative to the AEO 2007 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Rail Cars	784	552	NA
Barges	47	33	NA
Tank Trucks	90	63	NA
Storage Tanks at Petroleum Terminals	218	154	NA
Blending and other Miscellaneous Equipment at Petroleum Terminals	304	223	NA
Unit Train Receipt Facilities	511	315	NA
Manifest Rail Receipt Facilities	15	9	NA
Marine Receipt Facilities for Inta-U.S. Transport	67	43	NA
Total (Million $)	2,036	1,392	NA
Total (cpg)	2	2	NA

Table 4.2-27.
Summary of Estimated Cellulosic Distillate Fuel/Renewable Diesel Fuel Distribution Capital Costs under the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Rail Cars	784	552	NA
Barges	47	33	NA
Tank Trucks	95	67	NA
Storage Tanks at Petroleum Terminals	218	154	NA
Blending and other Miscellaneous Equipment at Petroleum Terminals	361	252	NA
Unit Train Receipt Facilities	394	253	NA
Manifest Rail Receipt Facilities	13	8	NA
Marine Receipt Facilities for Inta-U.S. Transport	87	56	NA
Total (Million $)	1,999	1,375	NA
Total (cpg)	2	2	NA

4.2.2.1 Cellulosic Distillate Fuel Distribution Capital Costs

4.2.2.1.2 Petroleum Terminal Cellulosic Distillate Fuel/Renewable Diesel Fuel Distribution Capital Costs

The terminal facility modifications needed to support the use of the volume of cellulosic diesel fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards are discussed in Section 1.6.7. A summary of the costs associated with these modifications is detailed in Tables 4.2-28 and 4.2-29. The estimated costs vary depending on the reference case considered because of the way we attributed the cost of tank truck unloading facilities (which are used to handle both ethanol and cellulosic distillate fuel/renewable diesel fuel) to either ethanol or cellulosic distillate fuel/renewable diesel fuel. The cost of such facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol + cellulosic distillate fuel/renewable diesel fuel volume.

Table 4.2-28.
Cellulosic Distillate Fuel/Renewable Diesel Fuel Associated Petroleum Terminal Costs under the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Costs	522	377	NA
New Storage Tank Construction Costs	218	154	NA
Tank Truck Unloading Facilities	65	55	NA
Blending and Miscellaneous Fuel Handling Costs	239	168	NA

Table 4.2-29.
Cellulosic Distillate Fuel/Renewable Diesel Fuel Associated Petroleum Terminal Costs under the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Costs	579	406	NA
New Storage Tank Construction Costs	218	154	NA
Tank Truck Unloading Facilities	122	84	NA
Blending and Miscellaneous Fuel Handling Costs	239	168	NA

The above cost estimates are based on the following. Input from terminal operators indicates that the cost of ethanol blending equipment is $310 thousand for E85-capable equipment. Input from companies that are familiar with the installation of ethanol truck unloading equipment at terminals indicates that the cost averages $500 thousand per facility. Input from terminal operators indicates that the cost of new diesel fuel storage tank construction is $35 per barrel for the size of tanks that are likely to be used. We used the above estimates regarding the costs of installing similar equipment for cellulosic distillate fuel/renewable diesel fuels.

4.2.2.1.3 Capital Cost of Unit Train Receipt Facilities for Cellulosic Distillate Fuel/Renewable Diesel fuel

Our estimation of the number of unit train receipt facilities that will be needed to support the transport of the volumes of ethanol and cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. The cost of these facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol plus cellulosic distillate fuel/renewable diesel fuel volume. See Section 4.2.1.1.2 for additional discussion regarding the derivation of the total cost of unit train receipt facilities.

Our projections of the total cost of unit train receipt facilities and the portion that we attributed to the volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is presented in Tables 4.2-30 and 4.2-31.

Table 4.2-30.
Cost of Unit Train Facilities to Facilitate the Transport of Cellulosic Distillate Fuel/Renewable Diesel Fuel under the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Unit Train Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	748	748	748
Cost of Unit Train Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	394	253	NA

Table 4.2-31.
Cost of Unit Train Facilities to Facilitate the Transport of Cellulosic Distillate Fuel/Renewable Diesel Fuel under the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Unit Train Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	838	838	838
Cost of Unit Train Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	511	315	NA

4.2.2.1.4 Capital Cost of Manifest Rail Receipt Facilities for Cellulosic Distillate Fuel/Renewable Diesel Fuel

Our estimation of the number of manifest rail receipt facilities that will be needed to support the transport of the volumes of ethanol and cellulosic distillate fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. The cost of these facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol plus cellulosic distillate fuel/renewable diesel fuel volume. See Section 4.2.1.1.2 for additional discussion regarding the derivation of the total cost of manifest rail receipt facilities.

Our projections of the total cost of the manifest rail receipt facilities and the portion that we attributed to the volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is presented in Tables 4.2-32 and 4.2-33.

Table 4.2-32.
Cost of Manifest Rail Receipt Facilities under the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Manifest Rail Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	21	21	21
Cost of Unit Train Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	14	9	NA

Table 4.2-33.
Cost of Manifest Rail Receipt Facilities under the RFS2 Control Scenarios Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Manifest Rail Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	28	28	28
Cost of Unit Train Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	13	8	NA

4.2.2.1.5 Barge Receipt Facility Costs for Cellulosic Distillate Fuel/Renewable Diesel Fuel

Our estimation of the number of barge receipt facilities for intra-U.S. biofuel shipments that will be needed to support the transport of the volumes of ethanol and cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.5 of this RIA. The cost of these facilities was divided between ethanol and cellulosic distillate fuel/renewable diesel fuel in proportion to the fraction of the total ethanol plus cellulosic distillate fuel/renewable diesel fuel volume.

Our projections of the total cost of the barge receipt facilities and the portion that we attributed to the volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is presented in Tables 4.2-34 and 4.2-35. See Section 4.2.1.1.5 of this RIA for additional discussion of the derivation of these estimates.

Table 4.2-34.
Cost of Barge Receipt Facilities under the RFS2 Control Scenarios Relative to the AEO Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Barge Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	143	143	143
Cost of Barge Receipt Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	87	56	NA

Table 4.2-35.
Cost of Barge Receipt Facilities under the RFS2 Control Scenarios
Relative to the RFS1 Reference Case

	Capital Cost (Million $)		
	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Total Cost of Barge Receipt Facilities Needed for the Transport of Ethanol and Cellulosic Distillate Fuel/Renewable Diesel Fuel	185	185	185
Cost of Barge Receipt Facilities Attributed to Cellulosic Distillate Fuel/Renewable Diesel Fuel Transport	67	46	NA

4.2.2.1.6 Cellulosic Distillate Fuel/Renewable Diesel Fuel Rail Car Capital Costs

Our estimation of the number of rail cars needed to transport the additional volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.4 of this RIA. Based on input from rail car manufactures, we estimate that the cost of a new 30,000 gallon rail car suitable for ethanol service is $90 thousand. We used this estimate as the cost of a rail car suitable for cellulosic distillate fuel/renewable diesel fuel service. This may tend to overstate the cost of such rail cars given that ethanol rail cars need to be constructed of ethanol tolerant materials. The cost of the additional cellulosic distillate fuel/renewable diesel fuel rail cars needed under the 3 control scenarios is presented in Table 4.2-36. Our estimate of the additional number of cellulosic distillate fuel/renewable diesel fuel rail cars needed to support meeting the RFS2 standards is the same relative to both reference cases.

Table 4.2-36.
Cost of Additional Cellulosic Distillate Fuel/Renewable Diesel Fuel Rail Cars
under the RFS2 Control Scenarios

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Rail Cars	8,710	6,130	NA
Rail Car Cost ($Million)	$784	$552	NA

4.2.2.1.7 Cellulosic Distillate Fuel/Renewable Diesel Fuel Barge Capital Costs

Our estimation of the number of barges needed for intra-U.S. transport of the additional volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.5 of this RIA. Based on input from fuel barge manufactures, we estimate that the cost of a new 10,000 barrel barge suitable for ethanol service is $1.4 million. We used this estimate as the cost of a barge suitable for cellulosic distillate fuel/renewable diesel fuel service. This may tend to overstate the cost of such barges given that ethanol barges need to be constructed of ethanol tolerant materials. The cost of the additional cellulosic distillate fuel/renewable diesel fuel barges needed under the 3 control scenarios is presented in Table 4.2-37. Our estimate of the additional number of cellulosic distillate fuel/renewable diesel fuel barges needed to support meeting the RFS2 standards is the same relative to both reference cases.

Table 4.2-37.
Cost of Additional Cellulosic Distillate Fuel/Renewable Diesel Fuel Barges under the RFS2 Control Scenarios

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Barges	33	24	NA
Cost of Barges ($Million)	$47	$33	NA

4.2.2.1.8 Cellulosic Distillate Fuel/Renewable Diesel Fuel Tank Truck Capital Costs

Our estimation of the number of tank trucks needed to transport the additional volume of cellulosic distillate fuel/renewable diesel fuel that we project will be used to meet the RFS2 standards is discussed in Section 1.6.6 of this RIA. Based on input from ethanol tank truck manufactures, we estimate that the cost of a new 8,000 gallon tank truck suitable for ethanol service is $180 thousand. We used this estimate as the cost of a tank truck suitable for cellulosic distillate fuel/renewable diesel fuel service. This may tend to overstate the cost of such tank trucks given that ethanol tank trucks need to be constructed of ethanol tolerant materials. The cost of the additional cellulosic distillate fuel/renewable diesel fuel tank trucks needed under the 3 control scenarios is presented in Table 4.2-38. Our estimate of the additional number of cellulosic distillate fuel/renewable diesel fuel tank trucks needed to support meeting the RFS2 standards is the same relative to both reference cases.

Table 4.2-38.
Cost of Additional Cellulosic Distillate Fuel/Renewable Diesel Fuel Tank Trucks under the RFS2 Control Scenarios

	Low-Ethanol Scenario	Mid-Ethanol Scenario	High-Ethanol Scenario
Number of Additional Tank Trucks	500	350	NA
Cost of Tank Trucks ($Million)	$90	$63	NA

4.2.2.2 Cellulosic Distillate Fuel Freight Costs

We used a study conducted by Oakridge National Laboratories (ORNL) to estimate ethanol and cellulosic distillate fuel/renewable diesel fuel freight costs. Refer to Section 4.2.1.2 of this RIA for a discussion of how these costs were derived. We estimate that cellulosic distillate fuel/renewable diesel fuel freight costs will be 13 cents per gallon under both the low-ethanol and mid-ethanol scenarios.

4.2.3 Biodiesel Distribution Costs

As discussed in the following sections, we estimate that the total capital costs in the U.S to support distribution of the additional volume of biodiesel that we project will be used to meet the RFS2 standards will be 1,141 billion dollars relative to the AEO 2007 reference case and 1,212 billion dollars relative to the RFS1 reference case.[246] When amortized, this translates to 10 cents per gallon of additional biodiesel volume that we project will be used to meet the RFS2 standards relative to both reference cases. Amortization of capital costs was done over 15 years at a 7% annual cost of capital except in the case of the cost of tank trucks where a 10 year amortization schedule was used. We project that 1.67 BGY of biodiesel will be used by 2022 to meet the RFS2 standard volumes. Under the AEO reference case 380 BG/yr of biodiesel will be used by 2022. Under the RFS1 reference case, 300 BG/yr of biodiesel will be used by 2022. Thus, the additional amount of biodiesel that will be used by 2022 to meet the RFS2 standard volumes is 1,290 BG/yr relative to the AEO reference case and 1,370 BG/yr relative to the RFS1 reference case. Biodiesel freight costs are estimated to be 10 cents per gallon on a national average basis. Thus, we estimate that biodiesel distribution costs will be 20 cents per gallon of biodiesel that we project will be used to meet the RFS2 standards.[247]

The biodiesel distribution capital and freight costs relative to the 2 reference cases that we evaluated in this FRM are summarized in Table 4.2-39. The itemized biodiesel capital costs are presented in Table 4.2-40. The way in which we estimated these costs is detailed in the following sections.

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[246] Biodiesel distribution costs do not vary under the three control scenarios evaluated in this final rule.
[247] As noted previously, we chose not to subtract the distribution costs for the petroleum-based fuels that will be displaced by the use of biofuels from our estimated biofuel distribution costs. We believe that the freight costs to ship petroleum-based fuels to the terminal are approximately 4 cents per gallon. If we were to subtract these costs from the estimated biodiesel distribution, the result would be 16 cents per gallon.

Table 4.2-39.
Summary of Estimated Biodiesel Capital and Freight Costs for the RFS2 Control Scenario Relative to the Reference Cases

	RFS1 Reference	AEO Reference
Billion $ Capital	1,212	1,141
Capital Costs (cpg)	10	10
Freight Costs (cpg)	10	10
Total Distribution Costs (cpg)	20	20

Table 4.2-40.
Summary of Estimated Biodiesel Distribution Capital Costs for the RFS2 Control Scenario Relative to the Reference Cases

	Capital Costs (Million$)	
	RFS1 Reference	AEO Reference
Rail Cars	111	105
Barges	53	50
Tank Trucks	25	24
Storage Tanks at Petroleum Terminals	411	387
Blending and other Miscellaneous Equipment at Petroleum Terminals	612	576
Total (Million $)	1,212	1,141
Total (cpg)	10	10

4.2.3.1 Capital Costs to Upgrade the Biodiesel Distribution System

4.2.3.1.1 Petroleum Terminal Biodiesel Distribution Capital Costs

The terminal facility modifications needed to support the use of the volume of biodiesel that we project will be used to meet the RFS2 standards are discussed in Section 1.6.7. Total capital costs at terminals by 2022 are estimated at $963 million relative to the AEO reference case and $1,023 million relative to the RFS1 reference case.

We estimate that a total of 5.5 million barrels of new biodiesel storage will be needed at petroleum terminals to facilitate meeting the projected RFS2 biodiesel volume relative to the AEO reference case, and 5.9 million barrels relative to the RFS1 reference case. We assumed that all of the additional biodiesel storage will be satisfied by new construction. Based on information from industry, we estimate that the cost of constructing new biodiesel storage tanks would be 70 dollars per barrel of capacity. This is considerably higher than the 40 per barrel cost we estimated for construction of new ethanol tanks for two reasons. Biodiesel tanks need to be heated/insulated in colder climes and they tend to be of considerably smaller size compared to ethanol tanks. Both of these factors contribute significantly to the cost per barrel of constructing a new storage tank. We estimate that the total cost at petroleum terminals of new biodiesel storage tanks would be $387 million dollars relative to the AEO reference case and $411 million relative to the RFS1 reference case.

We projected that 600 additional petroleum terminals will need to install biodiesel blending equipment by 2022 to facilitate meeting the RFS2 biodiesel volume relative to the AEO reference case and 637 relative to the RFS1 reference case. Based on input from industry, we estimated that the cost of biodiesel blending equipment will be 400 thousand dollars per terminal. The cost of additional piping is estimated at 60,000 per terminal. Ancillary costs associated with receiving/blending/storing biodiesel are estimated at 500 thousand dollars per terminal.[248] Based on the above, the cost of additional biodiesel blending and other miscellaneous biodiesel handling equipment at terminals is estimated at $576 million relative to the AEO reference case, and $612 million relative to the RFS1 reference case. Estimated equipment costs for handling biodiesel are higher than those for similar equipment designed to handle ethanol due to the need for insulated/heated equipment in colder climes.

4.2.3.1.2 Biodiesel Rail Car Capital Costs

As discussed in Section 1.64 of this RIA, we estimate that an additional 1,060 rail cars will be needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2 standards relative to the AEO reference case, and 1,120 relative to the RFS1 reference case. Based on input from industry, we estimate that the cost of a new biodiesel tank car of 25,600 gallon capacity is $99,000. The estimated cost for a biodiesel rail car is 10% higher than that of an ethanol rail car to accommodate the need for insulated/heated tanks in colder climes. Thus, we estimate that the cost of the biodiesel rail tanks cars needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2

[248] This includes the installation of biodiesel truck receipt facilities, quality control testing equipment, and other ancillary equipment at terminals.

standards would be $105 million relative to the AEO reference case, and $111 million relative to the RFS1 reference case.

4.2.3.1.3 Biodiesel Barge Capital Costs

As discussed in Section 1.65 of this RIA, we estimate that an additional 32 barges will be needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2 standards relative to the AEO reference case, and 34 relative to the RFS1 reference case. Based on input from industry, we estimate that the cost of a new biodiesel barge of 10,000 bbl capacity is $1.54 million. The estimated cost for a biodiesel barge is 10% higher than that of an ethanol rail car to accommodate the need for insulated/heated storage compartments in colder climes. Thus, we estimate that the cost of the biodiesel barges needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2 standards would be $49 million relative to the AEO reference case, and $52 million relative to the RFS1 reference case.

4.2.3.1.4 Biodiesel Tank Truck Capital Costs

As discussed in Section 1.66 of this RIA, we estimate that an additional 120 tank trucks will be needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2 standards relative to the AEO reference case, and 130 relative to the RFS1 reference case. Based on input from industry, we estimate that the cost of a new biodiesel tank truck of 8,000 gallon capacity is $198,000. This is based on an 110,000 dollar cost for the tractor and an 88,000 thousand dollar cost for the tank trailer. This estimate is 25% higher than the cost of a tank trailer designed to transport ethanol due to the need for an insulated/heated tank in colder climes. Based on the above, we estimate that the cost of the biodiesel tank trucks needed by 2022 to facilitate transport of the volume of biodiesel that we project will be used to meet the RFS2 standards would be $23 million relative to the AEO reference case, and $25 million relative to the RFS1 reference case.

4.2.3.2 Biodiesel Freight Costs

Our analysis of biodiesel freight costs for this FRM draws upon the analysis conducted for the NPRM. The NPRM analysis was based on a total biodiesel production volume of 810 million gallons by 2022 and was conducted relative to the AEO reference case under which 380 million gallons of biodiesel would be used. For the FRM, we are assuming that 1,670 million gallons of biodiesel would be used by 2022. The biodiesel capital cost analysis was conducted relative both the AEO and RFS1 reference cases. Under the RFS1 reference case 300 million gallons of biodiesel would be used by 2022 compared to the 380 million gallons under the AEO reference case. We believe that the difference between to the two reference cases is sufficiently small (80 million gallons per year by 2022) so that a single analysis of biodiesel freight costs conducted relative to the AEO reference case provides a reasonable estimate relative to both reference case. Hence, we used the results of our biodiesel freight cost analysis under the AEO reference case for the RFS1 reference case as well.

Our estimation of biodiesel freight costs for the NPRM was based on our evaluation of where biodiesel would be produced and the potential biodiesel demand centers. Our projections of where biodiesel would be produced and used under the NPRM analysis is contained in Section 1.8.2 of this RIA. Our projections of where biodiesel will be produced under the final rule (FRM) analysis are contained in Section 1.5.4 of this RIA. The NPRM estimate of where biodiesel would be used was used in our final rule analysis. Due to time constraints, we used a modified NPRM biodiesel freight cost analysis (which assumes the same production and demand centers used in the NPRM) to estimate biodiesel freight costs for this final rule. This analysis is described below. Our comparison of projected biodiesel production centers under the NPRM and FRM analyses relative to the projected demand centers indicates that the biodiesel transportation modes and distances are substantially similar. As a result, the freight cost estimates should be similar.

The distribution of biodiesel from production plants to petroleum terminals where it would be blended with diesel fuel is discussed in Section 1.6.2 of this RIA. Tank truck was the assumed method of shipment for distances of less than 300 miles. Where distances are longer than 300 miles, shipment by manifest rail was assumed to be the preferred option other than in cases on the East coast where there were apparent barge routes from production to demand centers. Biodiesel that could not be consumed in the state where it was produced to meet State level biodiesel mandates, demand for biodiesel use in heating oil, or other projected biodiesel use in diesel fuel was assumed to be shipped to market by manifest rail.[249] A 1,000 mile shipping distance was selected to ensure that all biodiesel not used to satisfy a state mandate, otherwise used in state, or used for bio-heat could find a market.

Our estimates of the freight costs for shipping biodiesel by tank truck are based on the ethanol tank truck freight costs that we developed for the RFS1 final rule. These ethanol transport costs were increased by 10% to account for the increased cost associated with preventing fuel gelling during cold conditions. The cost of shipping biodiesel by truck when the trip (or multiple trips) could be completed in a day was estimated to range from 7 to 8 cents per gallon. Some long truck transports were assumed to be necessary (up to 300 miles), where a round trip could not be completed in a single day. In such cases, the need for an overnight layover was assumed to add 120 dollars to shipping costs, resulting in an estimated 9.5 cents per gallon freight cost.

Our estimate of the cost of shipping biodiesel by manifest rail cars is based on publicly available biodiesel freight tariff information from BNSF railway from February 2008.[1163] Specific tariff information was not available for source/destinations needed for our analysis. A minimum cost of 9 cents per gallon was assumed to accommodate loading, unloading, and rail car lease costs. Based on the BNSF tariff information, we estimated that every 100 miles of additional shipment by manifest rail car beyond 600 miles adds 1.4 cents per gallon to shipping cost. Thus, for the assumed 1,000 mile shipping distance for biodiesel used to meet miscellaneous demand (i.e. not used to meet state mandates or for bioheat) the cost to ship by manifest rail car was estimated at 15 cents per gallon. Barge shipping costs were assumed to be comparable to the cost of shipping by manifest rail. This will tend to overstate barge shipping

[249] Biodiesel is projected to be blended into most heating oil used in the Northeast by 2022. The blended product is commonly referred to as bioheat.

costs, since we understand that barge freight costs tend to be significantly less than rail freight costs. However, given the small fraction of biodiesel is projected to me moved by barge, this will have only a minimal effect on our overall estimation of biodiesel freight costs. Shipping distances were estimated based on a review of biodiesel production plant locations, demand centers, and the rail/barge transportation net.[250]

Considering the location of biodiesel plants and biodiesel demand centers, 86% of biodiesel was projected to be shipped by truck, 13% was estimated to be shipped by manifest rail car, and 1% was estimated to be shipped by barge. We project that approximately 44% of the biodiesel production volume in 2022 would be used in the state where it was produced to meet state mandates, satisfy the demand for bioheat, or to meet other in-state miscellaneous demand. The average cost of shipping this volume by tank truck is estimated to average 8 cents per gallon. Approximately 3% of biodiesel production volume is estimated to be shipped out-of-state by manifest rail car to meet miscellaneous biodiesel demand at an average freight cost of 16 cents per gallon. Approximately 54% of biodiesel production is projected to be shipped out of state to satisfy state mandates or bioheat demand which could not be satisfied with in-state production. We assigned portions of the production volumes from states that had already satisfied this demand to meet this demand in other states based on minimizing overall shipping distances (and costs).

A freight cost estimate was derived based on the fraction of the volumes that would be shipped by each mode and the freight cost for each mode used given the shipping distance. On average the cost of shipping biodiesel from out-of-state to satisfy state biodiesel mandates or the demand for bioheat is estimated at 10 cents per gallon. By weighting the biodiesel volumes used to satisfy the three demand categories by the respective freight cost to ship that volume we arrived at a national average biodiesel freight cost estimate of 10 cents per gallon. Biodiesel freight costs are summarized in Table 4.2-41.

Table 4.2-41.
Estimated Biodiesel Freight Costs for the RFS2 Control Case

Biodiesel Demand Category	Fraction of Biodiesel Production	Freight Cost (cpg)
Shipped In-State to Satisfy In-State Demand	43%	8
Shipped Out-of-State to Satisfy State Mandates and Demand for Bioheat	54%	11
Shipped Out-of-State to Satisfy Miscellaneous Demand	3%	16
Total (National Average)	100%	10

[250] See Section 1.8.2 of this RIA.

4.2.4 Potential Fuel Retail Costs to Facilitate the Use of Mid-Level Ethanol Blends

As discussed in Section 1.6.10 of this RIA, our preliminary projections regarding the potential costs to the fuel distribution system are based on the premise that the facility changes needed would be limited to retail facilities. There may be additional costs upstream of retail facilities if separate gasoline blendstocks are needed to blend E10 and E15.

Testing is still underway regarding what changes might be needed to retail fuel storage and dispensing equipment originally designed to handle E10 to ensure its compatibility for an E15 blend. Thus there is considerable uncertainty regarding the potential costs. Ideally, E15 could be dispensed and stored in existing retail equipment with no physical modifications. However, it seems most prudent to assume that the potential changes might range from the replacement of hanging hardware (hoses attached to the dispenser and the nozzles), to the replacement of dispensers with E85 compatible equipment, and/or to the modification to underground piping which connects the dispenser to the underground storage tanks. There may also be the need to replace the underground storage tanks themselves at some facilities. Some newer facilities might need to make fewer changes, while older facilities may require more extensive modifications.

We evaluated 3 cost scenarios regarding the potential modifications needed to ensure the compatibility of current retail fuel storage and dispensing facilities to handle E15. Under the first scenario, each retail facility would need to replace only the hanging hardware on the pumps which dispense gasoline. The National Association of Convenience Stores (NACS) estimates that there are 3.9 gasoline refueling dispensers on average at retail facilities.[1164] The National Petroleum News (NPN) estimates that there were 161,768 retail facilities in the U.S. in 2008.[1165] Thus, we estimate that there are approximately 631,000 gasoline dispensers at retail facilities. Information from fuel retailers indicates that the cost of hanging hardware that is compatible with E85 is $750 for the 2 hoses and nozzles needed for a single dispenser. We choose to use the cost for E85-compatible hardware because there is no information on whether there may be lower costs for E15-compatible equipment.[251] We assumed a $25 installation cost per dispenser. Assuming that the hanging hardware on all gasoline dispensers would need to replaced, the resulting cost would be $127 million. However, a significant fraction of this cost might be deferred to the extent that hanging hardware could be replaced on a timetable that is consistent with the normal maintenance schedule as the number of E15 facilities ramps up. Information from fuel retailers indicates that hanging hardware is typically replaced every 3 to 5 years.

Under the second scenario, the wetted components inside fuel dispensers would need to be replaced in addition to the hanging hardware.[252] Information from fuel dispenser manufactures indicates that the cost of the wetted fuel dispenser components is approximately $10,000. We assumed a $1,000 installation cost per dispenser. Fuel dispenser equipment installers indicated that the replacement of the wetted components in a fuel dispenser is not

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[251] Underwriters Laboratories has separate certification for E10, E25, and E85 retail dispensing equipment. No equipment has currently been certified for E25 or E85 use. However, there is considerable experience regarding the equipment suitable for E85 service.
[252] The wetted components refers to the components inside the fuel dispenser which come into contact with the fuel.

standard practice, and there may be logistical and administrative difficulties that would need to be overcome. The cost would be $6.940 billion, if assume that the wetted components in all fuel dispensers would need to replaced. Adding the cost of replacing the wetted dispenser components to the cost of replacing the hanging hardware, results in a total cost estimate of $7.067 billion.

Under the third scenario, a fraction of retail facilities would need to break concrete to modify underground components such as the piping between dispensers and storage tanks and the joints between piping and other underground components. This is the most speculative scenario given that the costs of modifying underground components could vary greatly depending on the extent of the modifications that might be needed. We assumed an average cost of $25,000 per facility to make the changes needed to underground facilities. We believe that this is a low-end estimate given that the cost of modifications to underground retail fuel storage facilities can escalate quickly. We assumed that 50% of all retail facilities would need to make such changes for a total cost of $2.022 billion. Adding in the cost of replacing the wetted dispenser components and cost of replacing the hanging hardware, results in a total cost estimate of $9.089 billion.

These cost estimates could be altered significantly as a result of the findings of the test programs currently underway regarding the compatibility of existing fuel retail equipment with E15. As discussed in Section 1.6.10 of this RIA, there may be difficulties in identifying what changes are needed at some retail facilities due to a lack of records on the type of equipment currently installed. This may limit the ability to make such retail facilities E15 compatible.

4.3 Reduced U.S. Refining Demand

As renewable and alternative fuel use increases, the volume of petroleum-based products, such has gasoline and diesel fuel produced by U.S. refineries, would decrease. This reduction in finished refinery petroleum products results in reduced refinery industry costs. The reduced costs would essentially be the volume of fuel displaced multiplied by the cost for producing the fuel. There is also a reduction in capital costs as investment in new refinery capacity is displaced by investments in renewable and alternative fuels capacity.

Although we conducted refinery modeling for estimating the cost of blending ethanol (see Section 4.4), we did not rely on the refinery model results for estimating the volume of displaced petroleum as other economic factors also come into play. Instead we conducted an energy balance around the increased use of renewable fuels, estimating the energy-equivalent volume of gasoline or diesel fuel displaced. This allowed us to more easily apply our best estimates for how much of the petroleum would displace imports of finished products versus crude oil for our energy security analysis which is discussed in Section 5.2 of the RIA.

As part of this petroleum displacement analysis, we accounted for the change in petroleum demanded by upstream processes related to additional production of the renewable fuels as well as reduced production of petroleum fuels. For example, growing corn used for ethanol production requires the use of diesel fuel in tractors, which reduces the volume of petroleum displaced by the ethanol. Similarly, the refining of crude oil uses by-product hydrocarbons for heating within the refinery, therefore the overall effect of reduced gasoline and diesel fuel consumption is actually greater because of the additional upstream effect. We used the lifecycle petroleum demand estimates provided for in the GREET model to account for the upstream consumption of petroleum for each of the renewable and alternative fuels, as well as for gasoline and diesel fuel. Although there may be some renewable fuel used for upstream energy, we assumed that this entire volume is petroleum because the volume of renewable and alternative fuels is fixed by the RFS2 standard.

We assumed that a portion of the gasoline displaced by ethanol would have been produced from domestic refineries causing reduced demand from US refineries, while the rest of the additional ethanol displaces imported gasoline or gasoline blendstocks which does not affect domestic refining sector costs. To estimate the portion of new ethanol which displaces US refinery production we relied on some Markal refinery modeling conducted for us by DOE. The Markal refinery model models all the refinery sectors of the world and thus can do a fair job estimating how renewable fuels would impact imports of finished gasoline and gasoline blendstocks. The Markal refinery model estimated that 2/3rds of a reduction in petroleum gasoline demand would be met by a reduction in imported gasoline or gasoline blendstocks, while the other 1/3rd would be met by reduced refining production by the US refining sector. In the case of biodiesel and renewable diesel, all of it is presumed to offset domestic diesel fuel production. For ethanol, biodiesel and renewable diesel, the amount of petroleum fuel displaced is estimated based on the relative energy contents of the renewable fuels to the fuels which they are displacing. The savings due to lower imported gasoline and diesel fuel is accounted for in the energy security analysis contained in Section 5.2.

For estimating the U.S. refinery industry cost reductions, we multiplied the estimated volume of domestic gasoline and diesel fuel displaced by the projected wholesale price for each of these fuels in 2022, which are \$3.42 per gallon for gasoline, and \$3.83 per gallon for diesel fuel (see Section 4.4). For the volume of petroleum displaced upstream, we valued it using the wholesale diesel fuel price. Table 4.3-1 shows the net volumetric impact on the petroleum portion of gasoline and diesel fuel demand, as well as the reduced refining industry costs for 2022.

Table 4.3-1
Changes in U.S. Refinery Industry Volumes and Costs for the RFS2 Program in 2022 Relative to the AEO 2007 Reference Case
(2007 dollars)

		Low Ethanol Case		Primary Case (mid-ethanol case)		High Ethanol Case	
		Bil Gals	Bil $	Bil Gals	Bil $	Bil Gals	Bil $
Upstream	Petroleum	0.34	1.3	0.34	1.3	0.33	1.3
End Use	Gasoline	-0.9	-3.1	-2.0	-6.8	-4.4	-15.0
	Diesel Fuel	-10.1	-38.7	-7.5	-28.7	-1.3	-5.0
	Total	-10.7	-40.5	-9.2	-34.2	-5.4	-18.7

For the primary control case, this analysis estimates that the RFS2 program would reduce the gasoline and diesel fuel production volume of US refineries by 9.2 billion gallons in 2022, which would reduce their production costs by $34 billion dollars. Accounting for all the petroleum displaced (domestic and foreign), the RFS2 program is estimated to reduce gasoline and diesel fuel demand by 13.6 billion gallons.

4.4 Overall Costs to Gasoline and Diesel Fuel

The previous sections of this chapter have presented estimates of the cost of producing and distributing ethanol, biodiesel and renewable and cellulosic diesel fuel. In this section, we summarize the overall cost of the RFS2 program by assessing the costs of using more renewable fuels in the transportation fuel supply. The analysis was conducted in two steps. One step involved running a refinery model for estimating the costs of using more ethanol and blending it into gasoline. We used the Haverly Linear Programming (LP) model to conduct the refinery analysis. This model is widely used by the refining industry, consultants, engineering firms and government agencies to analyze refinery economics, refinery operations, fuel quality changes, refinery capital investments, environmental changes and demand changes. This Haverly model uses Jacobs's Refining Process Technology Database to represent refining operations.

While the change in volumetric demand for petroleum-based diesel fuel was modeled with the Haverly refinery model, the modeling of the cost of blending and using cellulosic and renewable diesel fuel and biodiesel on the overall cost of diesel fuel was estimated as a second step post-refinery modelling. Assessing the costs of blending of renewable diesel fuels post-refinery modeling inherently assumes that the renewable diesel fuels will be drop in replacements for petroleum-based diesel fuel. However, if the higher cetane values for cellulosic and renewable diesel fuel and biodiesel can be taken advantage of by refiners in blending up diesel fuel, then our cost estimates are likely to be conservative. We provide a more detailed description about how we estimated the costs of using cellulosic and renewable diesel fuel and biodiesel at the end of subsection 4.4.1.

4.4.1 Description of Cases Modeled and Methodology

The fuels cost analysis was set up to analyze the volumes required by the RFS 2 as described in Section 1.2. Because of the uncertainty in how cellulosic biofuel industry will develop over time, we assessed three different renewable fuels scenarios each of which totaled 36 billion gallons based on the energy equivalency of ethanol. The three cases represent a high quantity of cellulosic ethanol and a low amount of cellulosic diesel fuel, a low amount of cellulosic ethanol and a high amount of cellulosic diesel, and a midpoint between these two cases which served as our primary control case. We also considered a small amount of biodiesel and renewable diesel as required under EISA.

The refinery modeling analysis analyzed the extent to which ethanol will be used in conventional gasoline and reformulated gasoline by region and the resulting effects on gasoline composition. The refining industry was modeled based on five aggregate complex refining regions, representing Petroleum Administration for Defense Districts (PADD) 1, 2, 3, 4 & 5 together minus California, and California separately. All of the PADDS were modeled simultaneously together in the LP model which allowed the refinery model to most efficiently rebalance the regional gasoline production volumes in response to the addition of the renewable fuels. We conducted the refinery modeling analysis assuming that crude oil would be priced at about $51 per barrel and product prices were set based on this crude oil price. We adjusted the costs to reflect a crude oil price of $116 per barrel which is the reference crude oil price estimated by the Energy Information Administration (EIA) for its 2009 Annual Energy Outlook (AEO).[1166]

The fuels cost analysis was conducted in three distinct steps which involved a base case, two reference cases and the three control cases.

4.4.1.1 Base Case

The first step involved the establishment of a 2004 base case which calibrated the refinery model against 2004 volumes, gasoline quality, and refinery capital in place. We chose 2004 because the following year, 2005, as well as the beginning of 2006, were affected by hurricanes and would not be representative of a typical year, and 2007 and 2008 were years of extreme crude oil price volatility which skews the price relationships between crude oil and gasoline and diesel fuel. Refinery unit capacities from the Oil and Gas Journal and Energy Information Administration (EIA), as well as refinery feedstock and product volumes from EIA data were entered into the refinery model. The refinery model was then run and the resulting gasoline quality compared and calibrated to actual gasoline quality data information from EPA's Reformulated Gasoline data base.

4.4.1.2 Reference Cases

The reference cases are benchmark cases that serve as references to the control cases. Thus, the only difference between the control cases and the reference cases is that the control cases model the RFS2 volumes of renewable fuels versus lesser volumes in the reference cases. We established two reference cases. One represented the volumes of renewable fuels assumed for the RFS1 program. The second reference case represented the growth of renewable fuels by

EIA's 2007 Annual Energy Outlook (AEO). The volumes for both these cases are summarized in Section 1.2 above. Because the RFS2 fuel standard becomes fully implemented in 2022, we established our reference cases using the projected volumes of finished products in 2022. These projected volumes were based on the energy demand for gasoline and diesel fuel from the EIA's AEO 2009. The projected volumes were used for establishing total finished product production which then led to refinery production levels for each PADD.

The refinery modeling was conducted using a projection of crude oil and product prices in 2022 that Jacobs made for the proposed rulemaking. The average price of crude oil was projected to be about $51 per barrel, although crude oil prices varied by PADD. Jacobs based the prices for refined products based on the historical price spreads of fuels between the PADDs, using information from EIA's 2004 price information tables, Platts, and AEO 2006. For the reference case as well as for the control cases, we assumed the same crude oil and product prices when conducting the refinery modeling work. The crude oil prices and summertime and wintertime prices for gasoline, diesel fuel and jet fuel used in the refinery modeling are summarized in Table 4.4-1.

Table 4.4-1. Crude Oil and Finished Product Prices used in Refinery Modeling

		PADD 1	PADD 2	PADD 3	PADD 4/5 CA excl.	California
Crude Oil ($/bbl)	Year-round Average	53.6	53.0	50.6	51.8	50.2
Reformulated Gasoline (c/gal)	Summer	175.2	173.5	170.8	-	186.7
	Winter	161.4	158.7	155.3	-	173.7
Conventional Gasoline (c/gal)	Summer	167.6	165.1	161.4	173.6	-
	Winter	154.0	151.8	148.5	160.4	-
Diesel Fuel (c/gal)	Summer	156.6	157.6	154.6	166.6	164.6
	Winter	162.6	163.6	160.6	172.6	170.6
Jet Fuel (c/gal)	Summer	158.6	158.6	156.6	164.6	164.6
	Winter	156.6	156.6	154.6	162.6	162.6

However, AEO 2009 projected crude oil prices to be $116 bbl in 2022, which is much higher than those that Jacobs had estimated. After completing the refinery modeling, we adjusted the costs of using the renewable fuels post-refinery modeling using a methodology described below in Subsection 4.4.1.6.

We also modeled the implementation of several environmental programs that will have required changes in fuel quality by 2022, including the 30 ppm average gasoline sulfur standard, the 15 ppm cap standards on highway and nonroad diesel fuel and the Mobile Source Air Toxics (MSAT) benzene standard. Although there may still be a small amount high sulfur diesel fuel, we assumed that all distillate fuel would be ultra low sulfur in compliance with the 15 ppm cap standard required by the highway and nonroad diesel fuel sulfur standards. We modeled the implementation of the 2005 Energy bill, which by rescinding the RFG oxygenate standard, resulted in the discontinued use of MTBE, and a large increase in the amount of ethanol blended into reformulated gasoline.[1167] By using the AEO 2009 energy demand we also included the EISA Corporate Average Fuel Economy (CAFE) standards that were mandated in EISA and modeled in AEO 2009.[1168] The assumed EISA vehicle CAFE standard as projected by EIA in AEO phases-in less aggressively than the EPA and NHTSA proposed greenhouse gas and CAFE standards. However, because both programs would be fully phased in by 2022, their net effects in 2022 would not be that different. So basing our refinery modeling analysis on the EISA CAFE standard versus the EPA/NHTSA proposed standard would not make a significant difference in our costs.

4.4.1.3 Control Cases

The third step in the refinery modeling analysis was to model the control cases. As stated above, we modeled three different control cases to capture the impacts of a range of different levels of cellulosic ethanol versus cellulosic diesel fuel. All three cases model increased volumes of corn ethanol, biodiesel and renewable diesel fuel. Tables 1.2-1 through 1.2-3 in Section 1.2 of the RIA summarize the volumes modeled for the control cases. For the additional ethanol blended into the gasoline pool, a substantial portion of the additional ethanol was blended as E85. The cost and other implications of the control cases are compared to the reference cases to assess the costs of the program. We ran these multiple cases to understand how costs change based on different levels of cellulosic ethanol versus cellulosic diesel fuel.

The gasoline and diesel fuel product energy output for each control case modeled was maintained the same as that for the reference cases which modeled the energy demand of the AEO 2009. Thus, as the volumes of lower energy dense renewable fuels increased, the total volume of combined renewable and conventional fuels was increased to maintain the same level of energy demand. Maintaining constant energy output assumes that vehicle miles traveled would remain the same between the various cases despite any change in gasoline and diesel fuel prices caused by the use of renewable fuels. In reality the increased use of renewable fuels may result in changes to fuel prices to consumers, either directly as estimated in this section, or indirectly by affecting world oil prices as discussed in Chapter 5, and changes in fuel prices would be expected to affect demand. However, our analysis was conducted in parallel without the ability to input the results of the other analysis. Furthermore, it is difficult to predict the impacts on fuel prices to consumers, especially in light of the federal tax subsidies which we attempted to account for in our analysis, and the many and diverse state tax subsidies which we did not attempt to account for. Maintaining constant fuel product energy output captures the capital cost differences between the cases. Table 4.4-3 below summarizes the volumes of gasoline and diesel fuel used for the two reference cases, the primary control case and the two other control cases. The gasoline volumes include the volumes of renewable fuels, while the diesel fuel volumes do not since diesel fuel costs were estimated post refinery modelling.

Table 4.4-2.
Volumes of Gasoline and Diesel Fuel Used in Refinery Modeling
(Billion Gallons/yr)

	RFS 1 Reference Case	AEO 2007 Reference Case	Low Ethanol Control Case	Mid-Ethanol Control Case Primary Case	High Ethanol Control Case
Gasoline Volume (Gasoline and Ethanol)	136.3	138.2	139.6	141.1	144.7
Diesel Fuel Volume (Diesel Only)	70.7	70.6	60.7	63.3	69.4

All the other fuel standards and ASTM fuel quality constraints modeled in the reference case described above are assumed to apply to the control case as well. The reference and control cases where modeled assuming that ethanol conventional gasoline blends are entitled to the current 1.0 psi RVP waiver during the summer (i.e., for all 9.0 RVP and many low RVP control programs) so as to correctly assess the use of butanes in summertime conventional gasoline. Reformulated gasoline (RFG), however, must meet the same volatility standard with or without ethanol, so the addition of ethanol into RFG forced the refinery model to remove the last of the butane and some pentanes to rebalance RVP. Wintertime conventional and reformulated gasoline are normally blended up to either the RVP or vapor/liquid ASTM limits so the addition of ethanol into the wintertime gasoline pools resulted in the removal of light hydrocarbon compounds – normally butane. The crude oil and product prices for the control cases were the same as the reference cases. The capital investments made for the reference cases are not assumed to be sunk when the refinery model is assessing the economics for capital investments for the various control cases. Thus, the refinery model is free to optimize the capital investments made for each control case incremental to the base case. The control cases are run with capital costs evaluated at a 15 percent rate of return on investment (ROI) after taxes, but are then adjusted post-modeling to a 7 percent ROI before taxes.

4.4.1.4 Ethanol Blending and Prices

A special procedure was set up in the refinery model to capture the costs of blending ethanol. Because ethanol is primarily produced in the Midwest, but distributed to the final terminals where it is blended with the gasoline (or gasoline blendstock for blending with ethanol), hypothetical terminals were set up in each PADD within the refinery model which would receive the shipped ethanol as well as the gasoline blendstock for blending with ethanol (also referred to as conventional blendstock for oxygenate blending (CBOB) for conventional gasoline and reformulated blendstock for oxygenate blending (RBOB) for RFG and for California RFG (CARBOB). The gasoline blendstock either comes from the same PADD where the terminal is located, or transferred from a different PADD. This refinery modeling technique helps to more correctly estimate the distribution costs for both the ethanol and the gasoline. The refinery model assessed ethanol's use in each PADD based on its price relative to CG and RFG, which is based on its production cost and distribution costs, and its blending economics. For the base case we assumed that ethanol would be splash blended into gasoline. But for both the reference and control cases modeled in the year 2022 we expect that most, if not all, of the ethanol will be octane match-blended for blending up E10.

The price of ethanol used in the reference case and the primary control cases were based on the 2004 yearly average price spread between regular conventional gasoline sold into the spot market in Houston and ethanol sold on the spot market on Chicago Board of Trade (CBOT). This price spread was 12.3 cents per gallon lower than gasoline in the summer, and 7.7 cents per gallon lower than gasoline in the winter. This worked out to an average ethanol price of 146.8 c/gal in the summer, and 139.4 in the summer. To derive ethanol prices for all the PADDs, the Midwest ethanol production price was then adjusted for transportation costs to deliver ethanol from the Midwest to end use terminals (see Section 4.2 for additional details about the distribution costs). This assumes that the Midwest ethanol market will continue to set the price for ethanol – a reasonable assumption considering the significant amount of corn and other biomass available in the Midwest. The sales prices assigned to ethanol are summarized in Table 4.4-4.

Table 4.4-3. Ethanol Prices used in Refinery Modeling (c/gal)

	PADD 1	PADD 2	PADD 3	PADD 4/5 CA excl.	California
Summer	166.2	158.9	164.3	170.4	170.2
Winter	158.8	151.5	156.9	163.0	162.8

After the refinery modeling was completed, the ethanol prices and the costs for each case were adjusted to reflect the ethanol production and distribution costs described above in Sections 4.1 and 4.2. The ethanol production cost is the volume-weighted average for ethanol sourced from corn, cellulose and imports. The ethanol production and distribution cost and cellulosic and renewable diesel and biodiesel costs for 2022 are shown in Table 4.4-4

Table 4.4-4.
Average 2022 Production and Distribution Costs
for Ethanol, Biodiesel and Cellulosic and Renewable Diesel Fuels

	Production Cost (c/gal)	Low Ethanol Case		Primary Case Mid Ethanol Case		High Ethanol Case	
		Distribution Cost	Total Cost	Distribution Cost	Total Cost	Distribution Cost	Total Cost
Corn Ethanol	150	23.2	173.2	21.6	171.6	18.8	168.8
Cellulosic Ethanol	127	23.2	150.2	21.6	148.6	18.8	145.8
Imported Ethanol	150	23.2	173.2	21.6	171.6	18.8	168.8
Biodiesel from virgin oils	273	20.0	293	20.0	293	20.0	293
Biodiesel from waste oil	243	20.0	263	20.0	263	20.0	263
Biodiesel from corn oil	190	20.0	210	20.0	210	20.0	210
Biodiesel from algae oil	452	20.0	472	20.0	472	20.0	472
Renewable Diesel Fuel from waste oil	242	15.7	257.7	15.4	257.4	14	256
Cellulosic diesel from BTL	237	15.7	252.7	15.4	252.4	14	251

The ethanol production and distribution costs summarized in Table 4.4-4 are different in value compared to the ethanol prices used in the refinery modeling summarized above in Table 4.4-3. To capture the costs of the RFS2 program renewable fuel volumes, we adjusted the initial costs of the refinery modeling cost analysis using the ethanol production and distribution costs. This cost adjustment was made by multiplying the difference in ethanol cost or price between Tables 4.4-4 and 4.4-3 by the difference in ethanol volume modeled between the control case and the reference case.

We also estimated the costs of the RFS2 program renewable fuel volumes taking into account the consumption subsidies for corn ethanol, cellulosic ethanol, biodiesel and renewable diesel fuel. While these subsidies conceal large portions of the costs of renewable fuels, their economic effects deserve to be understood.

4.4.1.5 E85 Blending and Prices

Today E85 is blended at 85 percent by volume in the summer and at 70 percent by volume in the winter. Ethanol must be blended at less than 85 percent in the winter because of ethanol's low blending Reid Vapor Pressure (RVP). Unlike when ethanol is blended at 10 percent and causes a large vapor pressure increase, when ethanol is blended at 85 percent it blends much closer to its very low neat blending RVP of 2.2. The denaturant provides a small

RVP increase to the neat ethanol, however, the amount of denaturant which may be blended into neat ethanol was recently limited to 2 percent. The lower denaturant volume limits the RVP increase that the denaturant will have on neat ethanol.

When ethanol is blended with gasoline at the terminal to make E85, the available gasoline blendstock must be used. Today this blendstock is either a conventional blendstock for oxygenate blending (CBOB) or reformulated blendstock for oxygenate blending (RBOB) used for blending E10 to the local gasoline specifications. For example, reformulated gasoline (RFG) must comply with the hydrocarbon standard of the RFG program and therefore RFG tends to have an RVP of 6.8, and the RBOB that is blended with ethanol has an RVP of about 5.8. When this 5.8 RVP RBOB is blended with ethanol to make E85, its final RVP is estimated to be 4.72. However, the RVP minimum specified in the E85 ASTM standard shows the summertime lower limit of E85 is 5.5, thus, blending RBOB with 85 percent ethanol would not comply with the ASTM lower RVP standard. Table 4.4-7 summarizes ethanol's blending RVP, gasoline's RVP and the final blend RVP for summertime RFG and CG gasoline, and compares the blends RVP values to that of the E85 ASTM RVP standards.[1169]

Table 4.4-5. Comparison of E85 RVP levels to the ASTM RVP Standard

	Summer E85			Winter E70	
Gasoline RVP[a]	CG 10.0	RFG & low RVP 6.8	ASTM Std	CG/RFG 14	ASTM Std
Gasoline Blendstock RVP	9.0	5.8		13	
Ethanol Blending RVP	4.37	4.37	-	6.1	
Blend RVP	5.20	4.72	5.5 minimum	5.85	9.5 minimum

[a] Summertime CG is allowed a 1 psi waiver for blending with ethanol, however, RFG and some low RVP areas and wintertime CG/RFG do not normally receive 1 psi waivers.

Table 4.4-7 shows that summertime RFG and CG and wintertime gasoline cannot meet the ASTM RVP minimum standards based on blending ethanol with the locally available gasoline blendstock for blending up E10. For this reason, we ran the refinery model assuming that E85 will be blended differently in the future than it is today if it is to be used in large volumes. We assumed in the refinery modeling that all E85 will be blended at 85 percent ethanol year-round by being blended with some butanes or pentanes (whichever is available from the nearest refineries) to bring E85 up to the maximum ASTM RVP standard for E85, in addition to the CBOB or RBOB being supplied to the local area. The maximum ASTM E85 RVP standard is 8.5 in the summertime and 12.0 in the wintertime.

E85 is expected to be priced much lower in the marketplace than E10 and even less relative to gasoline (E0) because of E85's lower energy density. E85 contains about 83,500 BTUs per gallon compared to E10 which contains about 111,300 BTUs per gallon. Thus, when consumers consider refueling their vehicle using E85, they will bypass using it unless it is priced at parity with gasoline on an energy basis. Parity pricing means that E85 would have to be priced about 25 percent lower than E10. Assuming that E85 is priced 25 percent lower than E10 at retail to account for the energy content differences, the pricing disparity between ethanol and gasoline is even greater at the terminal. Table 4.4-6 summarizes the pricing of E85 at retail and at the terminal where ethanol is usually blended with gasoline blendstock to create the E85. Retail markup averages about 10 cents per gallon.[1170] Federal and state taxes average 46 cents per gallon (although this varies significantly by state), and transportation from the terminal to retail averages 3 cents per gallon.[1171] Thus, if E10 gasoline is priced at 163 cents per gallon at the terminal,[253] it would be priced at 222 cents per gallon at retail when the costs for transporting the fuel to the retail market and taxes and retail markup are added on. Based on E85's 25 percent lower energy density, E85 would have to be priced at 167 cents per gallon at retail to reflect its lower energy density. Using the same terminal to retail costs/taxes, E85 would be priced at 108 cents per gallon at the terminal. All this is shown in Table 4.4-6. The bottom row of the table shows what ethanol (E100 plus denaturant) would have to be priced at for terminals to breakeven using ethanol in E85 (this assumes that E85's gasoline blendstock is priced the same as E10 at the terminal). Thus, unlike with E10 where the lower energy content of ethanol is largely transparent to the consumer, based on ethanol's energy content alone, ethanol used in E85 would have to be discounted significantly compared to gasoline for refiners to find it cost-effective to use.

Table 4.4-6. E85 Pricing at Retail and at Terminals (cents per gallon)

	Price at Retail	Retail Markup	Average Federal and State Taxes	Transportation terminal to retail	Terminal Price
Gasoline E10	222	10	46	3	163
E85	167	10	46	3	108
Ethanol Breakeven Price	-	-	-	-	97

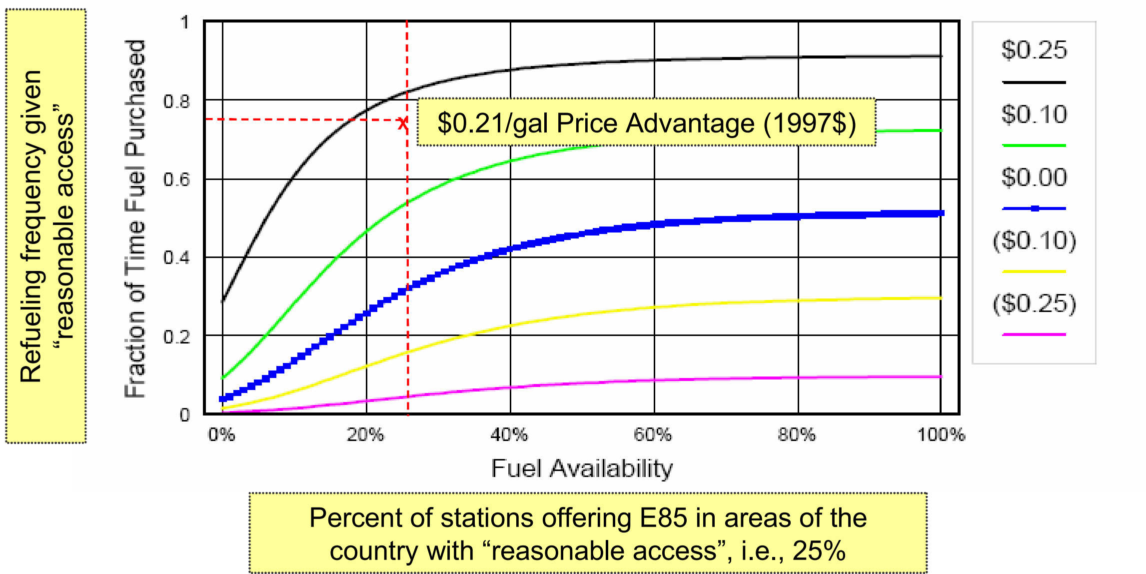
In addition to this effect of energy equivalency, Section 1.7 above outlines the difficulty of using all this E85 because of the relatively low number of fuel flexible vehicles (FFVs) that will be available to consume the fuel. The relatively low number of FFVs means that the refueling rate of these vehicles will have to be very high. In the year 2022, we estimate that FFVs will have to refuel 74 percent of the time to use the volume of ethanol required by the RFS2 standard.[254] This means that E85 may have to be priced significantly lower than gasoline for FFV owners to choose to fuel on it instead of gasoline. In addition, it is unlikely that every service station would make the capital investments to make E85 available for sale. In Section 4.2, we estimate that, at most, one out of very four service stations will carry E85. Thus, E85 may have to be priced even lower than its fuel economy-adjusted price to entice FFV owners to refuel at a station carrying E85. To estimate the marginal lower price at which FFV owners

[253] The terminal price of 163 c/gal is the wholesale gasoline priced used in the refinery modeling analysis.
[254] The FFV refueling percentage was estimated at 74% for the proposed rulemaking. Because the refinery modeling analysis was started before the FFV refueling percentage was reassessed for the final rulemaking, we continued to base our analysis on the 74% refueling figure as well as other proposed rulemaking assumptions. Section 1.7.4 contains the updated FFV refueling percentages that we estimated for the final rulemaking.

would refuel at this high rate, we referenced an analysis based on a willingness to pay survey conducted by David Greene of the Oak Ridge National Laboratory.[1172] The summary of this analysis is depicted in the Figure 4.4-1.

Figure 4.4-1

Alternative Fuel Market Share as a Function of Fuel Availability and Price Advantage (David L. Greene, 1997, Figure 6)



Based on our estimates that E85 would have to be purchased 74 percent of the time and that one out of every four service stations would carry E85, then Figure 4.4-1 estimates that E85 would have to be priced 21 cents per gallon lower than gasoline to match this availability and refueling scenario in addition to the adjustment for energy content. This cost estimate is based in 1997 dollars. Adjusting this cost estimate to 2006 dollars increases this estimate to 26 cents per gallon in addition to the adjustment for energy content.

There is one more factor which we believe could affect the price of E85. FFV owners who refuel on E85 will drive fewer miles before having to refuel compared to operating their vehicle on gasoline. The FFV drivers will therefore spend more time refueling their vehicle. As described above, FFV owners will drive 25 percent fewer miles per gallon and thus, will have to spend 25 percent more time refueling. We estimate that each refueling event requires 6 minutes of time, and that a person's time is worth an average of 30 dollars per hour.[1173,1174,1175,1176] Finally we assumed that a typical refueling volume for a refueling event is 15 gallons. Using these assumptions, the increased refueling frequency is costing the average FFV owner 5 cents per gallon more to use E85. To account for this additional cost, E85 would have to be priced 5 cents per gallon lower to make refueling FFVs a breakeven proposition. For our refinery modeling work, we reduced the refiner purchase price of E85 used in our refinery modeling analysis by this additional 5 cents per gallon.

Table 4.4-7 summarizes the E85 refinery purchase prices at terminals by PADD used in our refinery modeling work. These prices represent the total of the energy content, the price adjustment for reduced fuel availability and the cost for increased refueling events. The E85 prices should be compared to regular grade gasoline because the FFVs generally only require regular grade gasoline when operated on gasoline.

Table 4.4-7. Wholesale E85 Prices used within the Refinery Model

		E85 used in Conventional Gasoline Areas (c/gal)	E85 used in Reformulated Gasoline Areas (c/gal)
PADD 1	Summer	76	81
	Winter	67	72
PADD 2	Summer	75	80
	Winter	66	71
PADD 3	Summer	74	79
	Winter	65	70
PADDs 4/5	Summer	84	80
	Winter	75	81
CA	Summer	-	86
	Winter	-	77

While we used these E85 prices within the refinery model, they don't necessarily represent the societal costs for using E85. The pricing to reflect reduced fuel availability, in particular, contains a significant amount of transfer payments from the refining industry to consumers and other entities, and these transfer payments do not represent the true cost for using E85.[255]

For estimating the program costs for using E85 shown in Tables 4.4-12 and 4.4-13 (and subsequent tables for related cases), we adjusted E85 price back up to 5 cents per gallon less than the gasoline price for each case (the additional time spent refueling is a true cost). We then used the relative energy density of the E85 to that of gasoline as reported by the refinery model (see energy content values in Table 4.4-19 and other similar tables) to account for the energy density costs for using E85. We preferred the energy content price cost made by the refinery model to our preliminary E85 energy content price adjustments because the refinery model accounts for other changes in gasoline energy content made when accommodating the blending of ethanol . We are not assuming that the price adjustment that we made account for lower E85 availability accounts for any additional social cost. If the FFV driver would have to drive out of his way from time-to-time to find the E85, then there would be some extra cost associated with the lower availability. But most of the time FFV drivers would likely learn where to find E85 along the routes that they normally frequent, thus, no additional effort and cost would be incurred for refueling on E85. Thus, we assume that the lower E85 price to account for reduced E85 availability is purely a transfer payment from the refiner to the FFV owner. Despite assessing the costs on a different basis, estimating E85 prices for the refinery modeling is important so that the refinery model can correctly choose which gasoline type and which part of the country to

[255] The possibility for this potentially large transfer payment associated with using ethanol in E85 would encourage obligated parties to pursue the development of nonethanol renewable fuels.

blend the ethanol in the refinery model.

The assumption used here and throughout this rulemaking is that ethanol's fuel economy is directly proportional to its energy density and its concentration in the fuel. Since the volumetric energy content of ethanol is approximately 33 percent less than conventional gasoline, we assumed this loss in fuel economy proportional to its concentration in the fuel. Some studies have suggested, however, that ethanol's decrease in fuel economy may be less than its relative decrease in volumetric energy content of the fuel. In other words, there is less of a fuel consumption decrease than what the lower energy density of ethanol would suggest. However, the results may more be a function of how the testing was conducted than the true effect of ethanol on fuel economy. We therefore intend to investigate this issue more as more data becomes available.

As discussed above, we needed to adjust the estimated program costs from costs based on $51/barrel crude oil, the crude oil price at which the refinery model was run, to $116/bbl which is the crude oil costs that served as the basis for our cost analysis. To make these adjustments we estimated the wholesale gasoline and diesel fuel prices (which are the surrogate for the gasoline and diesel fuel production costs) at the adjusted crude oil price and compared these adjusted wholesale gasoline and diesel fuel adjusted prices to the baseline wholesale gasoline and diesel fuel prices. The baseline wholesale gasoline and diesel fuel prices, based on an average $51/bbl crude oil price, are summarized in Table 4.4-1. To adjust these wholesale prices, we estimated how the price of crude oil will affect them. We conducted a regression between the annual average spot price of price of Western Texas Intermediate crude oil and the annual average retail gasoline and diesel fuel prices for the years 2002 through 2008.[1177,1178] This regression is reflected in Table 4.4-8 as Gasoline Retail Price = Crude Oil Price multiplied times 2.65 plus 79.0, or Gasoline Retail Price = Crude Oil Price x "X" + "Y." The slope "X" and intercept "Y" for this equation are summarized in Table 4.4-8. The X and Y factors for diesel fuel are also summarized in Table 4.4-8 as well. However, we needed to estimate the wholesale prices instead of the retail prices, so we adjusted the equations to estimate the wholesale price using the Jacob's wholesale prices as the calibrating values. The regression, including the adjustment values to derive the wholesale prices equations are summarized in Table 4.4-8.

Table 4.4-8.
Equations Used for Estimating Wholesale Average Gasoline and Diesel Fuel Prices*

	Equation for Retail Prices		Equation for Wholesale Prices	
	X	Y	X	Adjusted Y
Gasoline	2.65	79.0	2.65	+27.0
Diesel Fuel	3.38	44.8	3.38	-11.7

* The equation is used by multiplying the crude oil price ($/bbl) times the X and then adding Y to that product resulting in a gasoline or diesel fuel cost expressed in cents per gallon.

The equations were used to estimate the average wholesale gasoline and diesel fuel prices. These average wholesale gasoline and diesel fuel prices are summarized in Table 4.4-9.

Table 4.4-9
Average Gasoline and Diesel Fuel Wholesale Prices by Crude Oil Price

Crude Oil Price	Gasoline	Diesel Fuel
$/bbl	c/gal	c/gal
51	163	160
116	342	383

Table 4.4-9 shows the nationwide average costs, but our cost analysis was conducted on a PADD basis, thus, it was necessary to estimate revised gasoline and diesel fuel wholesale prices in each PADD. This was accomplished by generating a ratio of the average wholesale gasoline and diesel fuel prices at the higher crude oil price relative to the average gasoline and diesel fuel wholesale prices at the lower crude oil price, and applying this ratio to the gasoline price in each PADD. It is important to point out one aspect of the gasoline and diesel fuel pricing changes captured by our crude oil/gasoline and diesel fuel price relationship price model. Prior to 2005, diesel fuel was priced about the same as gasoline (+/- 5 cents per gallon on a yearly average). In 2005 and 2006, when crude oil was priced higher, diesel fuel was priced 13 cents per gallon higher than gasoline. In 2007 gasoline and diesel fuel were priced about the same, but then in 2008, diesel fuel was priced much higher than gasoline. Thus, the equation picks up this relatively higher diesel fuel price at the higher crude oil prices in 2005, 2006 and 2008 and projects a greater relative higher price for diesel fuel at our high crude oil price of $116/bbl. A higher relative diesel fuel price at higher crude oil prices in the future may be appropriate for a couple reasons. The first reason is that from January to mid-October 2008, when crude oil prices were very high, diesel fuel averaged 51 cents per gallon higher than gasoline. While we cannot say for certain that this association would always hold true at higher crude oil prices, we do have a possible explanation for a possible relationship here. Higher crude oil prices are likely to affect gasoline demand more than diesel fuel as more of the trips made by gasoline powered light-duty vehicles are discretionary. For example, people may readily change their vacations plans at higher crude oil prices, while diesel fuel used to power trucks that bring food to markets would be expected to continue. Thus, as crude oil prices increase, gasoline consumption is likely more elastic resulting in greater reductions in gasoline demand compared to diesel fuel. We therefore believe that higher crude oil prices will tend towards relatively higher diesel fuel prices compared to gasoline.

For other reasons, diesel fuel prices may trend higher in the future relative to gasoline prices. Because EISA required that corporate average fuel economy (CAFE) standards be increased for light duty motor vehicles, over time light duty vehicles, which are almost exclusively gasoline powered, will become more fuel efficient. This will cause gasoline demand to decrease, while diesel demand is projected to continue to increase with GDP to transport goods and services. A second reason why refinery gasoline production will decrease is that most of the renewable fuel volume being produced to comply with the RFS will displace gasoline. This will contribute to the over supply of gasoline and the relative undersupply of diesel fuel, thus causing gasoline prices to be soft relative to diesel fuel prices.

Another adjustment we made to the costs directly estimated by the LP refinery cost model was to add additional cost for distributing gasoline from the refinery to the terminal. The refinery cost model assigned a low distribution costs to gasoline for moving the gasoline from the refinery to the terminal. We estimate that this distribution cost should be about 4 cents per gallon, but the refinery model only assigned 2.5 cents per gallon for this. Thus, we credited ethanol 1.5 cents per gallon for each gasoline-equivalent gallon of ethanol blended into each PADD's gasoline, since this roughly corresponded to the volume of gasoline displaced by the ethanol.

The diesel fuel costs are estimated based on two calculations conducted post-refinery modeling. The first calculation estimates costs based on the difference in the renewable fuels production costs compared to the production costs for petroleum-based diesel fuel multiplied times the increased volume of renewable fuels in the control case compared to the reference case. For example, producing and distributing cellulosic diesel fuel for the primary control case is estimated to cost 252 cents per gallon (see Table 4.4-4). The cost of producing diesel fuel is estimated to be 383 cents per gallon when crude oil is priced at $116 per barrel (see Table 4.4-9), which is 131 cents per gallon higher than the cellulosic diesel fuel costs. From the volume tables in Section 1.2, the incremental volume of cellulosic diesel fuel is 6.52 billion gallons for the primary reference relative to the AEO 2007 reference case. Therefore, the net production cost for cellulosic diesel fuel is -131 cents per gallon times 6.52 billion gallons for a cost of -8540 million dollars in 2022.

The second calculation for estimating the cellulosic diesel fuel costs is an estimate of the fuel economy cost. This is calculated by multiplying the percent loss in fuel economy for cellulosic diesel fuel compared to petroleum-based diesel fuel times the production cost for petroleum-based diesel fuel. Continuing with the cellulosic diesel fuel example, we assume that cellulosic diesel fuel is from the biomass-to-liquids (BTL) process and contains 123,000 BTUs per gallon versus petroleum diesel fuel which is estimated to contain 130,000 BTUs per gallon. Thus, cellulosic diesel fuel contains about 95% of the energy content of petroleum-based diesel fuel. The 5% shortfall in energy content is multiplied times the production cost of petroleum-based diesel fuel, which is 383 cents per gallon, and multiplied times 6.52 billion gallons - the volume of cellulosic diesel fuel. This results in a cost of 1250 million dollars in 2022.

The total cost for cellulosic diesel fuel is the sum of the production cost and the fuel economy cost which is -7290 million dollars in 2022. The total annual cost is converted to a per-gallon cost by dividing the total annual cost by the total volume of petroleum-based and renewable diesel fuel.

4.4.1.6 Other Adjustments to the Costs

The assumed volumes of E85 in our control cases will require increased numbers of flexible fuel vehicles (FFVs) be available to use the fuel. In Section 1.7 above, we estimate the number of FFVs that would be produced to enable the consumption of the volume of E85 that we project would have to be consumed for each control case. As the number of FFVs increases it results in higher costs due to the production of FFVs. In the following tables, we resummarize the number of FFVs that we projected would be available for the AEO 2007 reference case and each control case that we described above in Section 1.7. However, to estimate the cost impacts, we attribute a cost for every FFV produced. For the low ethanol case, we assume that each FFV would cost $100 per vehicle, which is an estimate for producing an FFV today. For the higher ethanol cases, as FFV production volumes increase, because of economies of scale, we expect that the per-vehicle costs would decrease. Furthermore, overhead costs associated with producing FFVs would be amortized over a larger number of vehicles further lowering the per-vehicle costs. For the primary case we project that FFV costs would decrease to $75 per vehicle. For the high ethanol case we assume that FFV costs would decrease to $50 per vehicle. This range in costs is consistent with estimates in literature.[1179] Tables 4.4-10 and 4.4-11 provide estimates of the FFV costs above the business-as-usual FFV costs in the AEO 2007 and RFS 1 reference cases.

Table 4.4-10
Numbers of FFVs and Total FFV Costs for the Control Cases Relative to the AEO 2007 Reference Case

	AEO 2007 Reference Case	Low Ethanol Control Case		Primary Control Case (mid ethanol case)		High Ethanol Control Case	
Year	Number of FFVs (millions)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($100/FFV)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($75/FFV)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($50/FFV)
2010	1.67	1.25	-$41.7	1.85	$13.4	3.62	$97.4
2011	1.75	1.60	-$14.8	2.66	$68.6	5.44	$184.6
2012	1.77	1.90	$13.6	3.52	$131.6	7.39	$281.2
2013	1.80	2.25	$45.6	3.74	$145.9	9.42	$381.1
2014	1.83	2.52	$69.7	3.88	$154.1	11.40	$478.8
2015	1.82	2.69	$87.6	3.96	$160.5	13.29	$573.4
2016	1.82	2.76	$94.4	3.97	$161.3	13.32	$575.3
2017	1.83	2.80	$97.8	4.00	$163.3	13.44	$580.8
2018	1.83	2.93	$109.4	4.04	$165.6	13.57	$586.9
2019	1.86	2.83	$97.0	4.08	$167.2	13.71	$592.8
2020	1.90	2.77	$87.1	4.12	$166.3	13.82	$596.2
2021	1.91	2.67	$75.6	4.10	$163.9	13.76	$592.4
2022	1.91	2.61	$69.4	4.10	$163.7	13.75	$591.9
Totals	23.7	31.6	$791	48.0	$1,826	145.9	$6,113

Table 4.4-10 summarizes our estimated costs for the increased numbers of FFVs that would be produced to use the projected increased volume of E85. For the primary control case we estimate that increased FFV production would cost $1.8 billion. For the low and high ethanol control cases we estimate that increased FFV production would cost $0.8 and $6.1 billion, respectively.

Table 4.4-11
Numbers of FFVs and Total FFV Costs for the Control Cases Relative to the RFS 1 Reference Case

Year	RFS 1 Reference Case	Low Ethanol Control Case		Primary Control Case (mid ethanol case)		High Ethanol Control Case	
	Number of FFVs (millions)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($100/FFV)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($75/FFV)	Number of FFVs (millions)	Incremental FFV Cost (millon dollars) ($50/FFV)
2010	0.98	1.25	$27.0	1.85	$64.9	3.62	$131.7
2011	1.08	1.60	$51.5	2.66	$118.3	5.44	$217.8
2012	1.16	1.90	$74.1	3.52	$177.1	7.39	$311.5
2013	1.23	2.25	$101.7	3.74	$188.0	9.42	$409.2
2014	1.28	2.52	$124.2	3.88	$195.1	11.40	$506.1
2015	1.31	2.69	$138.7	3.96	$198.9	13.29	$599.0
2016	1.31	2.76	$145.2	3.97	$199.4	13.32	$600.7
2017	1.32	2.80	$148.3	4.00	$201.2	13.44	$606.0
2018	1.33	2.93	$159.5	4.04	$203.2	13.57	$612.0
2019	1.35	2.83	$147.8	4.08	$205.2	13.71	$618.2
2020	1.36	2.77	$141.2	4.12	$206.9	13.82	$623.2
2021	1.35	2.67	$131.7	4.10	$206.0	13.76	$620.5
2022	1.35	2.61	$125.6	4.10	$205.8	13.75	$620.0
Totals	16.4	31.6	$1,516	48.0	$2,370	145.9	$6,476

Table 4.4-11 summarizes our estimated costs for the increased numbers of FFVs that would be produced to use the projected increased volume of E85. For the primary control case we estimate that increased FFV production would cost $2.4 billion. For the low and high ethanol control cases, we estimate that increased FFV production would cost $1.5 and $6.5 billion, respectively.

4.4.2 Refinery Modeling Results

In this subsection, we summarize the results of the three control cases that we modeled and compare them to the two different reference cases.

Table 4.4-12 summarizes the costs for the primary control case relative to the AEO 2007 reference case excluding federal ethanol, biodiesel and renewable diesel tax subsidies. By excluding the federal ethanol, biodiesel and renewable diesel fuel consumption subsidies, we avoid the transfer payments caused by these subsidies that would hide a portion of the program's costs. The costs are reported by different cost components and adjustments described above, as well as aggregated to show the total annual and per-gallon costs. The costs are reported separately for gasoline and diesel fuel. The estimate of gasoline costs are based on the refinery model and reflect the changes in gasoline that are estimated to occur by the refinery model accommodating the expanded use of ethanol. The refinery model variable operating costs include the labor, utility and other operating costs and are a direct output from the refinery model. These costs reflect ethanol's and E85's prices used in the refinery model and reflect crude oil priced at about $51 per barrel. The reduced refinery capital costs are shown in the table amortized annually and over the gasoline pool (the nonamortized refinery and biofuel capital costs are summarized in Table 4.4-18). The fixed costs shown in the table include the maintenance and insurance costs and are calculated to be 3 percent of the reduced capital costs. Next in the table we show the adjustment to remove the costs associated with low E85 prices, except for the 5 cent per gallon refueling cost, and then we show the costs for using lower energy density E10 gasoline and E85. The energy density costs changes rely on the fractional change in energy density shown in Table 4.4-19, multiplied by the wholesale price of gasoline. The cost adjustment is shown for basing the gasoline costs on $116 per barrel crude oil price versus the $51 per barrel price that was the basis for the refinery model runs. At $116 per barrel crude oil costs, ethanol's production and distribution costs are lower than the wholesale cost of gasoline which results in the cost savings. Finally for the gasoline costs, the table summarizes our estimated costs for producing an appropriate number of fuel flexible vehicles (FFVs) for using E85. With respect to the cellulosic and renewable diesel fuel and biodiesel costs, the production costs and for the fuel economy effects are both presented in Table 4.4-12.

Table 4.4-12.
Primary Control Case Costs without Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	10,998	-
Amortized Refinery Capital Costs $MM/yr	-997	-
Fixed Operating Costs $MM/yr	-275	-
Added Gasoline Transportation Cost $MM/yr	-88	-
Removal of E85 Pricing Effect $MM/yr	-8,338	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-15,302	-
Lower Energy Density $MM/yr	8,745	1,722
Adjustment from Ethanol Price to Cost $MM/yr	83	-
FFV Costs $MM/yr	1,826	
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-10,268
Total Costs $MM/yr	-3,349	-8,546
Refinery Model Variable Operating Cost c/gal	7.79	-
Amortized Refinery Capital Costs c/gal	-0.71	-
Fixed Operating Costs c/gal	-0.19	-
Added Gasoline Transportation Cost c/gal	-0.06	-
Removal of E85 Pricing Effect c/gal	-5.91	-
Crude Oil Cost $51 to $116/bbl c/gal	-10.84	-
Lower Energy Density c/gal	6.20	2.42
Adjustment from Ethanol Price to Cost c/gal	0.06	-
FFV Costs c/gal	1.29	
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-14.41
Total Costs c/gal	-2.37	-11.99

Our analysis shows that when considering all the costs associated with the expanded use of ethanol for the primary control case relative to the AEO 2007 reference case that the cost of gasoline will decrease by $3.3 billion in the year 2022. Expressed as per-gallon costs, these fuel changes will save the U.S. 2.4 cents per gallon of gasoline. The addition of biodiesel, renewable and cellulosic diesel fuel is estimated to reduce the cost of diesel fuel by $8.5 billion in the year 2022, or save 12.0 cents per gallon.

Table 4.4-13 expresses the total and per-gallon gasoline costs for the primary control case with the federal ethanol, biodiesel and renewable diesel subsidies included. The federal tax subsidy is 45 cents per gallon for each gallon of ethanol blended into gasoline and 101 cents per gallon for each gallon of cellulosic biofuel. Imported ethanol is also assumed to receive the 45 cents per gallon ethanol subsidy, although we assume that a greater volume of imported ethanol would be used than that which can flow through the Caribbean Basin, tariff free. Thus the 51 cents per gallon tariff would apply to that incremental volume of imported ethanol above the allowable Caribbean Basin initiative volume. We estimate that imported ethanol would earn 23 cents per gallon net subsidy. The biodiesel subsidy is 100 cents per gallon, and the renewable diesel fuel subsidy is 50 cents per gallon. The cost adjustment is estimated by multiplying the subsidy times the volume of new ethanol, biodiesel and renewable diesel estimated to be used.

Table 4.4-13.
Primary Control Case Costs Reflecting Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-3,349	-8,546
Federal Subsidies $MM/yr	-6,313	-7,944
Revised Total Cost $MM/yr	-9663	-16,490
Total Costs c/gal	-2.37	-11.99
Federal Subsidies c/gal	-4.47	-11.15
Total Costs c/gal	-6.85	-23.14

The cost including subsidies would represent gasoline and diesel fuel's apparent cost as reflected to the fuel industry as a whole because the federal tax subsidies tends to transfer a portion of the actual costs to consumers through non-fuel taxes. Our analysis estimates that relative to the AEO 2007 reference case, the primary control case would cause a 6.9 cent per gallon decrease in the apparent cost of producing gasoline, and a 23.1 cent decrease in the apparent cost of producing diesel fuel. These costs would also represent the apparent cost to consumers "at the pump" if the full tax credit were passed along to the consumers. However, it is possible that only a portion of the tax subsidy will be passed along to the consumer (historically, this has been the case). Thus, the price impact at the pump may be somewhere between the values in Tables 4.4-12 and 4.4-13. However, consumers would also pay the full tax subsidy through higher taxes in addition to the values in Tables 4.4-13.

Table 4.4-14 summarizes the volumetric inputs to refineries in each PADD for the primary control case and provides the incremental difference relative to the AEO 2007 reference case. Because of the increased use of biofuels, petroleum inputs would be expected to decrease, and this is confirmed.

Table 4.4-14.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD for the Primary Control Case Relative to the AEO 2007 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,246,981	-281,399	3,117,973	-340,516	7,056,501	-194,917	1,460,255	-73,349	1,865,224	-24,171
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	0	-43,785	0	0	0	0
VGO LS	0	0	38,063	0	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	290,427	60,773	0	0	732,497	26,283	0	0	0	0
Normal Butane	26,527	4,042	65,106	13,451	111,678	25,512	40,206	490	39,573	0
Isobutane	9,412	8,868	17,236	-6,556	25	25	19,001	12,735	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	300,677	27,590	188,968	-8,932	155,813	-19,904	69,817	-573	145,656	2,998
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	243,490	243,490	111,243	111,243	212,446	212,446	17,420	17,420	0	0
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	68,419	-12,688	135,263	-9,379	490,908	-13,379	87,228	-6,669	154,101	-1,567
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	32,124	0	52,055	0	18,580	0	0	0
Import CBOB 10%	148,371	142,085	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	65,943	-79,650	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	19,134	16,901	0	0	0	0	0	0	0	0
Import Raffinate	38,375	-15,151	0	0	0	0	0	0	45,808	0
Import Reformate	7,080	-1,749	0	0	0	0	0	0	0	0
Import FCC Naphtha	0	0	0	0	17,503	17,503	0	0	0	0
Import Lt Naphtha	0	0	0	0	0	0	0	0	584	0
Import Hvy Naph	0	0	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	23,342	19,010	0	0	0	0	0	0	23,053	4,669
Transfer Reformate	17,226	569	0	0	0	0	0	0	0	0
Transfer Alkylate	59,431	-569	9,795	9,795	0	0	0	0	60,000	0
Transfer FCC Naphtha	0	0	20,822	0	0	0	0	0	0	0
Transfer Raffinate	0	0	784	-10,853	0	0	0	0	60,000	12,556
Transfer RBOB 10%	242,605	0	37,596	37,596	0	0	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	1,355,660	219,387	81,092	27,037	0	0	9,099	2,747	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	3,278	3,178	100	0	100	0	100	0	13,287	-1,975
Isooctene	17,071	16,971	100	0	100	0	100	0	2,461	1,861

Table 4.4-14 shows that inputs of crude oil decreases substantially in most of the PADDs. In all the PADDs the input of crude oil to refineries decreases, which is expected since renewable fuels will supplant the need for petroleum feedstocks. Imports of gasoline blendstocks into PADD 1 also decreases. Butane inputs increase due to its blending into E85.

Table 4.4-15 below summarizes the refinery output volumes and changes in refinery output volumes relative to the reference case by PADD.

Table 4.4-15.
Summary of Total and Incremental Refinery Outputs by PADD for the Primary Control Case Relative to the AEO 2007 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	30,305	-1,816	50,863	-6,424	100,460	-17,092	21,022	-1,481	52,834	1,242
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	0	-4,967	1,698	733	23,031	-10,632	0	0	0	0
Isobutane	0	0	0	0	0	-411	0	0	39,318	-2,172
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	502,059	-58,642	157,500	0	0	0	0	0
CG Reg	0	0	0	0	0	0	0	0	0	0
CG Prem	0	0	0	0	0	-182,001	0	0	0	0
CG E10 Reg	1,654,618	397,669	1,277,077	-100,639	850,572	-224,891	577,355	-8,008	96,902	1,992
CG E10 Prem	214,377	144,044	267,934	5,512	209,149	4,299	113,837	2,340	18,457	379
RFG E10 Reg	885,097	-271,021	273,652	5,624	405,579	19,731	0	0	1,114,370	22,903
RFG E10 Prem	222,613	2,400	52,124	1,071	77,253	3,758	0	0	212,261	4,363
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	0	0	129,577	129,577	247,459	247,459	20,291	20,291	0	0
E85 to RFG	283,619	283,619	0	0	0	0	0	0	0	0
Transfer RBOB 10%	0	0	0	0	280,201	37,596	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,445,851	249,171	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	143,275	3,194	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	505,645	-128,972	562,879	-109,292	2,011,680	-124,623	470,858	-62,441	0	0
CARB Diesel	0	0	0	0	0	0	0	0	326,650	-37,699
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	50,000	-41,643	57,026	-7,562	262,834	0	126,642	4,352	49,880	0
Slurry	31,083	3,675	76,076	-10,192	108,692	-5,256	18,513	5,031	28,829	-178
Asphalt & Wax	91,682	0	198,329	-9,357	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	60,784	1,703	0	0	0	0
Transfer Alkylate	0	0	0	0	129,226	9,226	0	0	0	0
Transfer Reformate	0	0	0	0	17,226	569	0	0	0	0
Transfer FCC naphtha	0	0	0	0	20,822	0	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	23,342	19,010	0	0	23,053	4,669
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,008	-146	3,676	-438	11,971	-427	1,925	-162	3,504	-42
Coke (STon)	2,913	-1,037	10,524	-2,203	47,524	-2,276	7,111	-1,368	17,012	-282

What stands out in Table 4.4-15 is that E85 volumes increase while 10 percent ethanol gasoline blends decrease in response to the increased ethanol blended into the gasoline pool. Similarly, ultra low sulfur diesel fuel output decreases in response to the new volume of cellulosic and renewable diesel fuel and biodiesel.

Table 4.4-16 summarizes the change in refinery unit capacities by PADD comparing the primary control case to the AEO 2007 reference case.

Table 4.4-16.
Change in Refinery Unit Capacities by PADD
for the Primary Control Case Relative to the AEO 2007 Reference Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-414	0	0	0	-414
Vacuum Tower	0	-185	0	0	0	-185
Sats Gas Plant	-12	0	-2	0	8	-6
Unsats Gas Plant	0	0	0	0	0	0
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	4	-6	0	0	0	-2
Hydrocracker	-16	0	0	-21	0	-37
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-24	0	-24
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-1	-6	0	-1	0	-8
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-5	-5
BTX Reformer	0	0	-10	0	0	-10
C4 Isomerization	0	0	0	0	1	1
C5/C6 Isomerization	21	0	0	0	0	21
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-14	0	0	13	0	-2
Dimersol	0	0	0	0	0	0
Cat Poly	6	0	0	0	0	6
Isooctane	0	0	0	0	0	0
DHT - Total	-132	0	-75	-49	0	-256
DHT 2nd RCT - Total	-117	-116	-146	-51	-4	-435
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	0	0	0
CGH - Generic	-16	-23	-6	-2	0	-48
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	55	0	0	0	0	55
LSR Splitter	0	0	0	0	0	0
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-14	-4	1	0	0	-16
Reformate Splitter	-41	-12	4	0	0	-49
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-88	-72	-84	-71	0	-316
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-95	0	0	-204	-69	-368
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	0	0	0	0	0
BTX Reformer - Extract feed	0	0	0	0	0	0

Most of the capacity throughput changes are negative, reflecting the decreased processing of crude oil and vacuum gas oil and decreased downstream refining units as projected by the refinery model. Another important decrease in refinery unit throughput is the distillate hydrotreater and hydrocracker units which reflect the displacement of petroleum distillate by cellulosic and renewable diesel and biodiesel.

These changes in refinery unit throughputs are associated with changes in capital investments. Table 4.4-17 summarizes the projected change in capital investments between the primary control case and the AEO 2007 reference case.

Table 4.4-17.
Change in Refinery Unit Investments by PADD
for the Primary Control Case Relative to the AEO 2007 Reference Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-960	0	0	0	-960
Vacuum Tower	0	-572	0	0	0	-572
Sats Gas Plant	-67	0	-4	0	53	-18
Unsats Gas Plant	-2	0	0	0	0	-2
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	2	-7	0	0	0	-5
Hydrocracker	-584	0	0	-641	0	-1,225
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-534	0	-534
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-3	-7	0	-2	0	-12
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-30	-30
BTX Reformer	0	0	-63	0	0	-63
C4 Isomerization	0	0	0	0	6	6
C5/C6 Isomerization	187	0	0	0	0	187
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-246	0	0	246	0	1
Dimersol	0	0	0	0	0	0
Cat Poly	48	0	0	0	0	48
Isooctane	0	0	0	0	0	0
DHT - Total	-1,364	0	-496	-531	0	-2,391
DHT 2nd RCT - Total	-905	-771	-694	-308	-21	-2,699
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	0	0	0
CGH - Generic	-75	-131	-60	-7	0	-274
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	695	0	0	0	0	695
LSR Splitter	0	0	0	0	0	0
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-92	-19	5	0	0	-105
Reformate Splitter	-53	-16	2	0	0	-68
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-352	-221	-227	-237	0	-1,038
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-3	0	0	-2	-2	-6
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	0	-1	0	0	-1
BTX Reformer - Extract feed	0	0	0	0	0	0
Total	-2,814	-2,704	-1,539	-2,016	6	-9,067

Table 4.4-17 shows that incremental to the AEO 2007 reference case, refiners are expected to reduce their capital investments by $9.1 billion under the primary control case. The reduction in capital investments occurs in PADDs 1 through 4 and PADD 5 outside of California. Table 4.4-17 essentially expresses the change in refinery capacity input shown in

Table 4.4-16, but expresses the changes in terms of dollars instead of thousands of barrels per day.

The capital cost decrease in refineries is countered by the capital costs incurred to build new renewable fuels plants and to put into place the distribution system that the new renewable fuels require. The increased use of renewable and alternative fuels would require capital investments in corn and cellulosic ethanol plants, and renewable diesel fuel plants. In addition to producing the fuels, storage and distribution facilities along the whole distribution chain, including at retail, will have to be constructed for these new fuels. In Table 4.4-18, we list the total incremental capital investments that we project would be made for the primary control case incremental to the AEO 2007 reference case. All these capital costs are represented in the summary of costs in Table 4.4-12 either in the per-gallon biofuel production costs, or the per-gallon distribution costs.

Table 4.4-18.
Projected Total U.S. Capital Investments for the Primary Control Case Relative to the AEO 2007 Reference Case
(billion dollars)

Cost Type	Plant Type	Capital Investments
Production Costs	Corn Ethanol	3.9
	Cellulosic Ethanol	14.3
	Cellulosic Diesel [a]	68.0
	Renewable Diesel and Algae	1.1
Distribution Costs	All Ethanol	8.2
	Cellulosic and Renewable Diesel Fuel	1.4
	Biodiesel	1.2
	FFV Costs	1.8
	Refining	-9.4
Total Capital Investments		90.5

a The cellulosic diesel fuel capital costs are based on biomass-to-liquids (BTL) technology which is a very capital intensive technology. If other cellulosic biofuel technologies are used which are less capital intensive than BTL technologies, these capital costs would be lower.

Table 4.4-18 shows that the total U.S. incremental capital investments to achieve the RFS2 volumes under the primary control case in 2022 is $90.5 billion. One contributing reason why the capital investments made for renewable fuels technologies is so much more than the decrease in refining industry capital investments is that a part of the decrease in petroleum gasoline supply was from reduced imports. In addition, renewable fuels technologies are more capital intensive per gallon of fuel produced than incremental increases in gasoline and diesel fuel production at refineries.

Table 4.4-19 summarizes the gasoline volume and qualities by different gasoline types for the primary control case, and also, for comparison, lists the same for the AEO 2007 reference case.

Table 4.4-19.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the Primary Control Case Relative to the AEO 2007 Reference Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,376,331	1,107,710	319,080	325,776	459,343	482,832	0	0	1,299,365	1,326,631	3,454,120	3,242,949
Ethanol ('000 BPD)	139,023	111,890	32,230	32,907	46,397	48,771	0	0	131,244	134,003	348,895	327,571
RVP (psi)	10.8	10.8	10.6	10.6	9.7	9.8	0.0	0.0	9.5	9.5	10.1	10.1
Sulfur (ppm)	24.4	24.6	20.0	20.5	23.2	23.4	0.0	0.0	8.8	8.5	18.0	17.4
Density	258.9	258.9	258.2	258.3	259.5	259.4	0.0	0.0	258.5	258.7	258.8	258.8
Octane (R+M/2)	88.1	88.3	88.0	88.0	88.0	88.0	0.0	0.0	87.6	87.6	87.9	87.9
Aromatics (vol%)	19.9	19.9	19.9	19.9	19.6	19.7	0.0	0.0	22.2	22.1	20.7	20.8
Benzene (vol%)	0.57	0.57	0.57	0.57	0.56	0.56	0.00	0.00	0.53	0.54	0.55	0.56
Olefins (vol%)	13.6	14.7	9.4	9.3	11.5	11.1	0.0	0.0	5.7	5.7	10.0	9.9
Oxygen (wt%)	3.7	3.7	3.7	3.7	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.6	55.1	58.3	57.4	53.3	52.7	0.0	0.0	58.2	58.2	56.5	56.2
E300 (vol%)	93.9	95.3	93.9	93.8	93.9	93.4	0.0	0.0	86.2	86.2	91.0	91.2
Energy (MMBtu/Bbl	4.947	4.961	4.924	4.935	4.981	4.990	0.000	0.000	4.994	5.002	4.967	4.979
CG												
Total ('000 BPD)	1,830,582	1,868,996	1,640,138	1,545,011	1,280,314	1,059,721	696,861	691,193	112,988	115,359	5,560,884	5,280,279
Ethanol ('000 BPD)	134,064	188,787	165,671	156,062	129,320	107,043	70,390	69,817	11,413	11,652	510,857	533,362
RVP (psi)	11.4	11.8	11.6	11.5	10.7	10.4	11.4	11.4	10.6	10.6	11.3	11.3
Sulfur (ppm)	22.9	24.5	23.6	23.3	23.1	23.1	28.0	28.0	26.6	26.3	23.9	24.4
Density	258.9	259.5	259.1	259.1	260.5	260.1	258.1	257.9	262.7	264.1	259.3	259.4
Octane (R+M/2)	87.8	87.8	88.0	88.0	88.0	88.2	86.9	86.9	89.3	89.5	87.8	87.9
Aromatics (vol%)	23.1	22.4	22.5	22.5	22.4	21.8	15.9	15.6	26.5	28.3	21.9	21.6
Benzene (vol%)	0.53	0.53	0.53	0.52	0.51	0.51	1.05	1.01	0.59	0.61	0.59	0.59
Olefins (vol%)	13.2	14.0	11.0	11.0	13.1	12.3	8.5	7.6	17.8	18.4	12.0	12.0
Oxygen (wt%)	2.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.4	3.7
E200 (vol%)	52.5	53.1	58.8	58.0	53.0	52.5	63.0	62.7	58.0	56.4	55.9	55.8
E300 (vol%)	93.9	95.3	93.9	83.8	93.9	79.5	93.9	90.6	86.2	86.2	93.7	88.0
Energy (MMBtu/Bbl	4.995	4.980	4.925	4.937	4.988	5.005	0.000	4.912	4.942	4.964	4.961	4.963
E85												
Total ('000 BPD)	0	283,619	0	129,577	0	247,459	0	20,291	0	0	0	680,947
Ethanol ('000 BPD)	0	243,490	0	111,243	0	212,446	0	17,420	0	0	0	584,599
RVP (psi)	0.0	11.1	0.0	12.2	0.0	12.1	0.0	11.9	0.0	0.0	0.0	11.7
Sulfur (ppm)	0.0	9.5	0.0	8.8	0.0	8.8	0.0	8.8	0.0	0.0	0.0	9.1
Density	0.0	267.7	0.0	266.3	0.0	266.2	0.0	266.1	0.0	0.0	0.0	266.8
Octane (R+M/2)	0.0	107.9	0.0	108.0	0.0	108.0	0.0	107.9	0.0	0.0	0.0	107.9
Aromatics (vol%)	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Benzene (vol%)	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Olefins (vol%)	0.0	2.4	0.0	3.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	2.2
Oxygen (wt%)	0.0	30.6	0.0	30.8	0.0	30.8	0.0	30.8	0.0	0.0	0.0	30.7
E200 (vol%)	0.0	128.1	0.0	130.1	0.0	129.8	0.0	129.3	0.0	0.0	0.0	129.1
E300 (vol%)	0.0	96.1	0.0	96.6	0.0	96.6	0.0	96.6	0.0	0.0	0.0	96.4
Energy (MMBtu/Bbl	0.000	3.628	0.000	3.599	0.000	3.597	0.000	3.594	0.000	0.000	0.000	3.610
All Mogas												
Total BPD	3,206,913	3,260,324	1,959,219	2,000,364	1,739,657	1,790,012	696,861	711,484	1,412,353	1,441,990	9,015,003	9,204,175
Ethanol BPD	273086.9	544,167	197900.9	300,212	175717.0	368,259	70390.0	87,238	142657.3	145,656	859752.1	1,445,532
RVP	11.1	11.4	11.4	11.4	10.4	10.5	11.4	11.4	9.6	9.6	10.8	10.9
Sulfur ppm	24	23	23	22	23	21	28	27	10	10	22	21
Density	258.9	260	259.0	259	260.2	261	258.1	258	258.9	259	259.1	260
R+M/2	87.9	89.7	88.0	89.3	88.0	90.9	86.9	87.5	87.8	87.8	87.8	89.4
Aromatics	21.7	19.7	22.1	20.6	21.7	18.2	15.9	15.2	22.5	22.6	21.5	19.7
Benzene	0.55	0.50	0.53	0.50	0.53	0.45	1.05	0.98	0.54	0.55	0.58	0.53
Olefins	13.4	13.2	10.7	10.2	12.7	10.6	8.5	7.4	6.7	6.7	11.2	10.6
Oxygen (wt%)	3.1	6.1	3.7	5.5	3.7	7.5	3.7	4.5	3.7	3.7	3.5	5.8
E200	53.8	60.3	58.7	62.6	53.1	63.2	63.0	64.6	58.2	58.1	56.1	61.4
E300	93.9	95.4	93.9	86.3	93.9	85.6	93.9	90.8	86.2	86.2	92.7	89.7
Energy (MMBtu/Bbl	4.974	4.856	4.925	4.850	4.986	4.806	4.913	4.874	4.990	4.999	4.963	4.869

Several very important differences are evident when comparing the U.S. gasoline (mogas) qualities of the primary control case to the AEO 2007 reference case in Table 4.4-19. First, the energy content of the control case gasoline is lower than that of the reference case.

Other obvious changes include decreases in aromatics, benzene, olefins and sulfur. Another important change is the increase in the gasoline pool octane. Since the reference case gasoline pool was compliant in octane, the increased octane of the control case represents octane giveaway. After further review, it is evident that virtually all these changes are caused by the blending of E85 which significantly dilutes these properties in the gasoline blendstock in E85.

Year-by-Year Costs

To understand entire costs of the increase in renewable fuel use mandated by EISA, their impacts on the U.S. economy, and to compare those costs to the benefits, we estimated the year-by-year costs from 2010, the first year of the RFS2 program, to 2030. We first estimated renewable fuels volumes for each renewable fuels type based on the RFS2 volume standards and based on our projections of which renewable fuels would be used to comply with the standard (see Section 1.2). These volumes represent the increment between the AEO 2007 reference case and the primary control case. Based on AEO 2009, we also estimated the overall gasoline and diesel fuel volumes. Table 4.4-20 below summarizes the projected year-by-year incremental renewable fuel, and total gasoline and diesel fuel volumes.

Table 4.4-20.
Summary of Year-by-Year Volumes
for the Primary Control Case Relative to the AEO 2007 Reference Case
(Billion Gallons/year)

Year	Diesel Fuel Volume	Cellulosic Diesel Fuel	Renewable Diesel Fuel	Biodiesel (all types)	Gasoline Volume	Corn Ethanol	Imported Ethanol	Cellulosic Ethanol
2010	62.93	0.04	0.04	0.51	158.65	0.75	0.00	-0.09
2011	63.98	0.10	0.08	0.56	162.54	1.38	0.00	-0.11
2012	65.47	0.20	0.08	0.71	162.15	2.01	0.00	-0.10
2013	66.42	0.41	0.08	0.87	161.03	2.49	0.00	0.06
2014	66.50	0.71	0.15	1.01	159.48	3.08	0.00	0.29
2015	66.65	1.22	0.15	1.13	157.14	3.69	0.00	0.67
2016	67.21	1.73	0.15	1.06	154.50	3.84	0.12	1.06
2017	67.85	2.24	0.15	1.09	152.44	3.70	0.54	1.44
2018	68.57	2.85	0.15	1.13	149.84	3.51	0.97	1.90
2019	69.23	3.46	0.15	1.16	148.08	3.31	1.38	2.36
2020	69.98	4.28	0.15	1.20	145.78	3.17	1.29	2.98
2021	70.59	5.50	0.15	1.24	144.14	2.93	1.19	3.90
2022	71.25	6.52	0.15	1.28	141.10	2.71	1.60	4.67
2023	72.16	6.52	0.15	1.28	141.18	2.71	1.60	4.67
2024	73.17	6.52	0.15	1.28	141.80	2.71	1.60	4.67
2025	74.21	6.52	0.15	1.28	141.66	2.71	1.60	4.67
2026	75.16	6.52	0.15	1.28	141.70	2.71	1.60	4.67
2027	76.07	6.52	0.15	1.28	139.74	2.71	1.60	4.67
2028	76.99	6.52	0.15	1.28	139.65	2.71	1.60	4.67
2029	77.87	6.52	0.15	1.28	138.14	2.71	1.60	4.67
2030	78.97	6.52	0.15	1.28	138.59	2.71	1.60	4.67

Also for our year-by-year cost analysis, we needed year-by-year estimates of the production and distribution cost for each renewable fuel type. The feedstock costs were available for the years 2012, 2017 and 2022 from FASOM for corn ethanol and soy oil, used for producing biodiesel, with crude oil priced at $116 per barrel. We entered those feedstock costs into the respective cost models and interpolated and extrapolated the production costs for the years provided to develop production costs for the in-between years. For cellulosic ethanol, we assumed the same feedstock costs for all years, but we adjusted the production costs based on our adjusted NREL production costs, interpolating between the years for which we have specific cost data. Imported ethanol costs by year are from Section 4.1 above. Tables 4.4-21 summarize the renewable fuels production costs by year along with the projected crude oil, gasoline and diesel fuel wholesale costs.

Table 4.4-21.
Renewable Fuel Production Costs Used in the Year-by-Year Analysis for the Primary Control Case Relative to the AEO 2007 Reference Case

Year	Crude Oil Price ($/bbl)	Wholesale Diesel Fuel Cost (c/gal)	Cellulosic Diesel Fuel Cost (c/gal)	Renewable Diesel Fuel Cost (c/gal)	Biodiesel Fuel Cost (c/gal)	Wholesale Gasoline Cost (c/gal)	Corn Ethanol Cost (c/gal)	Imported Ethanol Cost (c/gal)	Cellulosic Ethanol Cost (c/gal)
2010	49.0	154	258	236	261	157	160	158	220
2011	62.0	198	256	236	264	191	160	157	203
2012	72.1	232	255	236	227	218	160	156	186
2013	81.0	262	253	238	227	241	159	155	168
2014	88.6	288	251	240	225	262	158	154	151
2015	96.8	315	249	243	226	283	158	153	134
2016	101.9	333	248	245	228	297	157	153	133
2017	106.2	347	246	247	232	308	156	152	132
2018	110.5	362	244	246	234	320	155	152	131
2019	112.8	369	242	245	235	326	154	152	130
2020	114.5	375	241	244	238	330	152	151	129
2021	115.8	380	239	243	241	334	151	151	128
2022	116.5	383	237	242	244	335	150	150	127
2023	117.7	386	237	242	244	339	150	150	127
2024	118.3	388	237	242	244	340	150	149	127
2025	116.1	380	237	242	244	334	150	149	127
2026	117.5	385	237	242	244	338	150	149	127
2027	119.2	391	237	242	244	343	150	149	127
2028	121.2	398	237	242	244	348	150	149	127
2029	121.9	400	237	242	244	350	150	149	127
2030	124.4	409	237	242	244	356	150	149	127

Based on the volumes and renewable fuels production and distribution costs, we estimated the net cost for the increased volumes of renewable fuels in years other than 2022 and summarized them in Table 4.4-22. We started with the year 2022 costs as our basis. We then adjusted those costs using the volume and price relationship between ethanol and gasoline to estimate the costs in other years. We also calculated the total dollar amount of the subsidies based on the volumes of renewable fuels and the subsidy that applies to each renewable fuel, and what the subsidized cost would be when the subsidies are applied.

Table 4.4-22.
Year-by-Year Annual Average and Per-Gallon Costs for Gasoline for the Primary Control Case Relative to the AEO 20007 Reference Case

Year	Gasoline Costs				Diesel Fuel Costs			
	Total Annual Cost ($MM/yr)	Per-Gallon Cost (c/gal)	Subsidy ($MM/yr)	Subsidized Per-Gallon Cost (c/gal)	Total Annual Cost ($MM/yr)	Per-Gallon Cost (c/gal)	Subsidy ($MM/yr)	Subsidized Per-Gallon Cost (c/gal)
2010	456	0.3	242	0.1	815	1.3	602	0.3
2011	703	0.4	511	0.1	719	1.1	693	0.0
2012	835	0.5	808	0.0	377	0.6	940	-0.9
2013	831	0.5	1181	-0.2	152	0.2	1312	-1.7
2014	758	0.5	1678	-0.6	-251	-0.4	1771	-3.0
2015	198	0.1	2339	-1.4	-963	-1.4	2405	-5.1
2016	-229	-0.1	2839	-2.0	-1601	-2.4	2797	-6.5
2017	-1110	-0.7	3275	-2.9	-2351	-3.5	3343	-8.4
2018	-2076	-1.4	3726	-3.9	-3400	-5.0	3992	-10.8
2019	-2825	-1.9	4150	-4.7	-4333	-6.3	4640	-13.0
2020	-2922	-2.0	4721	-5.2	-5479	-7.8	5504	-15.7
2021	-2936	-2.0	5554	-5.9	-7099	-10.1	6779	-19.7
2022	-3349	-2.4	6308	-6.8	-8546	-12.0	7849	-23.0
2023	-3545	-2.5	6308	-7.0	-8787	-12.2	7849	-23.1
2024	-3640	-2.6	6308	-7.0	-8933	-12.2	7849	-22.9
2025	-3285	-2.3	6308	-6.8	-8369	-11.3	7849	-21.9
2026	-3512	-2.5	6308	-6.9	-8728	-11.6	7849	-22.1
2027	-3769	-2.7	6308	-7.2	-9157	-12.0	7849	-22.4
2028	-4097	-2.9	6308	-7.5	-9679	-12.6	7849	-22.8
2029	-4199	-3.0	6308	-7.6	-9857	-12.7	7849	-22.7
2030	-4589	-3.3	6308	-7.9	-10473	-13.3	7849	-23.2

The projected costs in Table 4.4-22 show that in the initial years of 2010 to 2013 for diesel fuel and 2010 to 2015 for gasoline, the per-gallon costs are positive reflecting the generally higher projected production costs for renewable fuels and the lower crude oil prices. After those initial years, the program would accrue a cost savings assuming that the crude oil prices projected by EIA hold true.

4.4.2.1.2 Primary (Mid-Ethanol) Control Case Incremental to the RFS 1 Reference Case

We also assessed the gasoline and diesel fuel costs and other impacts of the primary control case relative to the RFS1 reference case. The costs contained in Table 4.4-23 are reported by different cost components as well as aggregated total and per-gallon costs.

Table 4.4-23.
Primary Control Case Costs without Tax Subsidies
Relative to the RFS 1 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	11,252	-
Amortized Refinery Capital Costs $MM/yr	-1,031	-
Fixed Operating Costs $MM/yr	-284	-
Added Gasoline Transportation Cost $MM/yr	-148	-
Removal of E85 Pricing Effect $MM/yr	-8,338	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-25,884	-
Lower Energy Density $MM/yr	15,928	1,750
Adjustment from Ethanol Price to Cost $MM/yr	507	-
FFV Costs $MM/yr	2,370	
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-10,382
Total Costs $MM/yr	-5,628	-8,632
Refinery Model Variable Operating Cost c/gal	7.97	-
Amortized Refinery Capital Costs c/gal	-0.73	-
Fixed Operating Costs c/gal	-0.20	-
Added Gasoline Transportation Cost c/gal	-0.10	-
Removal of E85 Pricing Effect c/gal	-5.91	-
Crude Oil Cost $51 to $116/bbl c/gal	-18.34	-
Lower Energy Density c/gal	11.29	2.45
Adjustment from Ethanol Price to Cost c/gal	0.36	-
FFV Costs c/gal	1.68	
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-14.56
Total Costs c/gal	-3.99	-12.10

Our analysis shows that when considering all the costs associated with the expanded use of ethanol for the primary control case relative to the RFS 1 reference case that the cost of gasoline will decrease by $5.6 billion in the year 2022. Expressed as per-gallon costs, these fuel changes will reduce the cost of producing gasoline in the U.S. by 4.0 cents per gallon. The addition of biodiesel, renewable and cellulosic diesel fuel is estimated to reduce the cost of diesel fuel by $8.6 billion in the year 2022, or save 12.1 cents per gallon.

Table 4.4-24.
Primary Control Case Costs Reflecting Tax Subsidies
Relative to the RFS 1 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-5,628	-8,632
Federal Subsidies $MM/yr	-9,075	-8,026
Revised Total Cost $MM/yr	-14,703	-16,659
Total Costs c/gal	-3.99	-12.10
Federal Subsidies c/gal	-6.43	-11.25
Total Costs c/gal	-10.42	-23.35

Our analysis of the primary control case costs relative to the RFS 1 reference case reflecting the federal tax subsidies would cause a 10.4 cent per gallon decrease in the apparent cost of producing gasoline, and a 23.4 cent decrease in the apparent cost of producing diesel fuel. While this could represent the cost of the renewable fuel use to consumers at retail, it is possible that only a portion of the tax subsidy will be passed along to the consumer. Thus, the price impact at the pump may be somewhere between the values in Tables 4.4-23 and 4.4-24. However, consumers would also pay the full tax subsidy through higher taxes which would offset the cost savings caused by the subsidies.

Table 4.4-25 summarizes the volumetric inputs to refineries in each PADD for this control case and shows the relative changes of the primary control case compared to the RFS 1 reference case. Because of the increased use of biofuels, petroleum inputs would be expected to decrease, and this is confirmed.

Table 4.4-25.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD for the Primary Control Case Relative to the RFS 1 Reference Case
(barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,347,342	-151,714	3,058,241	-475,740	7,117,305	-241,263	1,534,859	-4,119	1,886,357	-1,136
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	0	-33,772	0	0	0	0
VGO LS	0	0	7,920	-23,914	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	279,819	39,889	0	0	738,057	21,829	0	0	0	0
Normal Butane	30,814	8,329	78,293	19,185	69,363	-14,040	25,526	-13,917	39,573	0
Isobutane	12,582	12,582	16,476	-8,390	8,234	8,234	1,178	-22,245	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	270,313	130,437	168,062	63,684	142,590	88,811	66,626	40,273	143,845	8,610
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	575,048	575,048	332,715	332,715	361,999	361,999	60,129	60,129	46,969	46,969
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	74,115	-6,201	136,509	-5,559	493,553	6,876	86,015	-3,625	154,032	-2,444
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	58	-32,066	52,055	0	0	-17,467	0	0
Import CBOB 10%	0	0	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	0	-200,000	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	45,167	45,167	0	0	0	0	0	0	0	0
Import Raffinate	3,442	-61,147	0	0	0	0	0	0	45,808	0
Import Reformate	0	0	0	0	0	0	0	0	0	0
Import FCC Naphtha	15,980	15,980	0	0	11,943	11,943	18,580	18,580	0	0
Import Lt Naphtha	0	0	17,575	17,575	0	0	0	0	584	0
Import Hvy Naph	0	0	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	0	-23,342	0	-20,822	0	0	0	0	11,387	-9,842
Transfer Reformate	16,658	0	0	-14,074	0	0	0	0	0	0
Transfer Alkylate	60,000	17,381	0	0	0	0	0	0	60,000	16,933
Transfer FCC Naphtha	0	0	20,822	20,822	0	0	0	0	0	0
Transfer Raffinate	0	0	11,353	-5,888	0	0	0	0	60,000	11,077
Transfer RBOB 10%	242,605	0	0	0	0	0	0	0	0	0
Transfer RBOB 20%	0	0	8,720	8,720	0	0	0	0	0	0
Transfer CBOB 10%	1,398,409	1,381,833	80,262	77,306	0	0	6,493	-19,539	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	100	0	100	0	100	0	100	0	16,462	2,029
Isooctene	100	0	100	0	100	0	100	0	600	0

The changes in 4.4-25 are similar to those in 4.4-14 except because the new volume of ethanol is larger, some of the differences are larger.

Table 4.4-26 below summarizes the refinery output volumes and changes in refinery output volumes for the primary control case relative to the RFS 1 reference case by PADD.

Table 4.4-26.
Summary of Total and Incremental Refinery Outputs by PADD for the Primary Control Case Relative to the RFS 1 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	34,143	1,539	50,843	-12,263	103,144	-32,064	23,369	-1,541	52,782	1,461
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	0	-7,832	0	-2,370	0	-45,506	0	0	0	0
Isobutane	0	0	0	0	0	-345	0	0	40,012	5,009
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	455,618	-108,658	157,500	0	0	0	0	0
CG Reg	0	-118,066	0	-852,131	0	-2,020,447	0	-374,129	0	-53,481
CG Prem	0	0	0	0	0	-416,926	0	-51,984	0	0
CG E10 Reg	1,535,198	1,516,962	1,172,450	704,964	872,274	872,274	542,856	325,693	99,374	59,284
CG E10 Prem	306,669	306,669	274,765	23,409	214,485	134,887	116,742	72,990	18,928	1,105
RFG E10 Reg	605,554	-542,443	163,150	-101,096	246,042	-134,362	0	0	1,088,091	12,026
RFG E10 Prem	228,678	10,012	53,454	3,122	78,844	6,386	0	0	217,676	12,712
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	74,814	74,814	270,064	270,064	253,773	253,773	70,039	70,039	0	0
E85 to RFG	595,006	595,006	117,484	117,484	167,888	167,888	0	0	54,710	54,710
Transfer RBOB 10%	0	0	0	0	251,325	8,720	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,485,164	1,439,600	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	138,523	-3,108	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown t	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	587,042	-39,165	643,331	-30,227	2,150,901	2,423	523,035	-11,120	0	0
CARB Diesel	0	0	0	0	0	0	0	0	358,152	-6,714
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	68,283	-21,481	67,826	8	262,834	0	138,312	22,862	45,680	-4,199
Slurry	30,026	3,876	67,363	-19,645	112,554	-4,041	12,295	-4,210	29,893	1,191
Asphalt & Wax	86,013	-5,669	198,329	-11,671	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	71,353	5,190	0	0	0	0
Transfer Alkylate	0	0	0	0	120,000	34,314	0	0	0	0
Transfer Reformate	0	0	0	0	16,658	16,658	0	0	0	0
Transfer FCC naphtha	0	0	0	0	20,822	20,822	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	0	-23,342	0	0	11,387	-9,842
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,076	-74	3,571	-630	12,042	-533	2,038	-59	3,559	-10
Coke (STon)	3,495	-227	10,154	-3,068	48,646	-2,278	7,899	-790	17,358	86

Table 4.4-27 summarizes the change in refinery unit capacities by PADD comparing the primary control case to the RFS 1 reference case.

Table 4.4-27.
Change in Refinery Unit Capacities by PADD
for the Primary Control Case Relative to the RFS 1 Reference Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-439	0	0	0	-439
Vacuum Tower	0	-196	0	-2	0	-198
Sats Gas Plant	3	0	-30	0	9	-18
Unsats Gas Plant	-2	0	0	0	0	-2
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-8	0	-8
FCC Splitter	2	-6	0	0	0	-5
Hydrocracker	-18	0	0	-14	0	-33
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-28	0	-28
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-1	-6	0	-1	0	-8
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-1	-1
BTX Reformer	0	-10	-18	0	0	-27
C4 Isomerization	0	0	0	0	1	1
C5/C6 Isomerization	26	0	0	0	0	26
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	1	0	0	-5	0	-4
Dimersol	0	0	0	0	0	0
Cat Poly	0	0	0	0	0	0
Isooctane	0	0	0	0	0	0
DHT - Total	-132	0	-103	-50	-4	-290
DHT 2nd RCT - Total	-117	-153	-174	-52	-4	-501
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-4	0	-4
CGH - Generic	-12	-19	-19	-6	0	-57
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	37	0	0	0	0	37
LSR Splitter	0	41	38	0	0	80
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-4	-4	1	0	0	-7
Reformate Splitter	-12	-12	3	0	0	-21
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-72	11	109	-47	0	1
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-128	0	0	-204	-71	-402
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-1	-1	0	0	-2
BTX Reformer - Extract feed	-1	0	0	0	0	-1

These changes in refinery unit throughputs are associated with changes in capital investments. Table 4.4-28 summarizes the projected change in capital investments between the primary control case and the RFS 1 reference case.

Table 4.4-28.
Change in Refinery Unit Investments by PADD
for the Primary Control Case Relative to the RFS 1 Reference Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-997	0	0	0	-997
Vacuum Tower	0	-591	0	0	0	-591
Sats Gas Plant	12	0	-101	0	55	-34
Unsats Gas Plant	-10	0	0	0	0	-10
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-193	0	-193
FCC Splitter	1	-7	0	0	0	-6
Hydrocracker	-631	0	0	-505	0	-1,137
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-592	0	-592
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-3	-7	0	-3	0	-13
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-4	-4
BTX Reformer	0	-93	-231	0	0	-324
C4 Isomerization	0	0	0	0	8	8
C5/C6 Isomerization	227	0	0	0	0	227
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	16	0	0	-70	0	-54
Dimersol	0	0	0	0	0	0
Cat Poly	-1	0	0	0	0	-1
Isooctane	0	0	0	0	0	0
DHT - Total	-1,367	0	-702	-539	-96	-2,703
DHT 2nd RCT - Total	-904	-998	-840	-312	-21	-3,076
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-46	0	-46
CGH - Generic	-58	-63	-92	-25	0	-238
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	555	0	0	0	0	555
LSR Splitter	0	29	18	0	0	47
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-46	-19	4	0	0	-60
Reformate Splitter	-20	-16	2	0	0	-34
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-255	69	274	-171	0	-84
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-3	0	0	-2	-2	-7
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-2	-1	0	0	-3
BTX Reformer - Extract feed	-3	0	0	0	0	-3
Total	-2,491	-2,694	-1,669	-2,459	-59	-9,373

Table 4.4-28 shows that incremental to the RFS 1 reference case, refiners under the primary control case are expected to reduce their capital investments by \$9.4 billion compared to

business as usual. The reduction in capital investments occurs in PADDs 1 through 4 and PADD 5 outside of California. Table 4.4-17 essentially expresses the change in refinery capacity input shown in Table 4.4-16, but expresses the changes in terms of dollars instead of thousands of barrels per day.

Table 4.4-29 summarizes the gasoline volume and qualities by different gasoline types for the primary control case, and also, for comparison, lists the same for the RFS 1 reference case.

Table 4.4-29.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the Primary Control Case Relative to the RFS 1 Reference Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,366,663	1,107,710	314,578	325,776	452,862	482,832	0	0	1,281,031	1,326,631	3,415,134	3,242,949
Ethanol ('000 BPD)	138,034	111,890	31,773	32,907	45,739	48,771	0	0	129,386	134,003	344,932	327,571
RVP (psi)	10.7	10.8	10.3	10.6	9.6	9.8	0.0	0.0	9.5	9.5	10.1	10.1
Sulfur (ppm)	23.8	24.6	20.1	20.5	23.5	23.4	0.0	0.0	8.7	8.5	17.8	17.4
Density	258.5	258.9	256.2	258.3	259.1	259.4	0.0	0.0	258.5	258.7	258.4	258.8
Octane (R+M/2)	88.1	88.3	88.0	88.0	88.0	88.0	0.0	0.0	87.6	87.6	87.9	87.9
Aromatics (vol%)	19.9	19.9	18.2	19.9	19.5	19.7	0.0	0.0	22.2	22.1	20.5	20.8
Benzene (vol%)	0.57	0.57	0.57	0.57	0.57	0.56	0.00	0.00	0.54	0.54	0.56	0.56
Olefins (vol%)	13.1	14.7	8.0	9.3	9.3	11.1	0.0	0.0	5.7	5.7	9.3	9.9
Oxygen (wt%)	3.7	3.7	3.8	3.7	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.7	55.1	62.5	57.4	54.5	52.7	0.0	0.0	58.5	58.2	57.2	56.2
E300 (vol%)	93.9	95.3	91.5	93.8	93.9	93.4	0.0	0.0	86.2	86.2	90.8	91.2
Energy (MMBtu/Bbl)	4.963	4.961	4.864	4.935	5.027	4.990	0.000	0.000	4.988	5.002	4.971	4.979
CG												
Total ('000 BPD)	1,841,024	1,868,996	1,570,973	1,545,011	1,262,249	1,059,721	687,028	691,193	111,394	115,359	5,472,668	5,280,279
Ethanol ('000 BPD)	1,842	188,787	72,606	156,062	8,040	107,043	26,352	69,817	5,849	11,652	114,689	533,362
RVP (psi)	10.5	11.8	11.8	11.5	10.7	10.4	11.3	11.4	10.8	10.6	11.0	11.3
Sulfur (ppm)	27.8	24.5	25.3	23.3	27.3	23.1	24.6	28.0	26.4	26.3	26.6	24.4
Density	259.3	259.5	258.8	259.1	259.4	260.1	256.8	257.9	260.8	264.1	258.9	259.4
Octane (R+M/2)	88.0	87.8	88.0	88.0	88.0	88.2	86.8	86.9	88.0	89.5	87.8	87.9
Aromatics (vol%)	28.7	22.4	26.3	22.5	28.4	21.8	19.3	15.6	26.8	28.3	26.7	21.6
Benzene (vol%)	0.65	0.53	0.64	0.52	0.65	0.51	0.80	1.01	0.62	0.61	0.67	0.59
Olefins (vol%)	15.2	14.0	11.2	11.0	16.0	12.3	8.0	7.6	18.6	18.4	13.4	12.0
Oxygen (wt%)	0.0	3.7	1.7	3.7	0.2	3.7	1.4	3.7	1.9	3.7	0.8	3.7
E200 (vol%)	45.2	53.1	52.9	58.0	45.9	52.5	58.9	62.7	54.5	56.4	49.5	55.8
E300 (vol%)	93.9	95.3	91.5	83.8	93.9	79.5	93.9	90.6	86.2	86.2	93.0	88.0
Energy (MMBtu/Bbl)	5.133	4.980	5.007	4.937	5.127	5.005	5.004	4.912	4.998	4.964	5.077	4.963
E85												
Total ('000 BPD)	0	283,619	0	129,577	0	247,459	0	20,291	0	0	0	680,947
Ethanol ('000 BPD)	0	243,490	0	111,243	0	212,446	0	17,420	0	0	0	584,599
RVP (psi)	0.0	11.1	0.0	12.2	0.0	12.1	0.0	11.9	0.0	0.0	0.0	11.7
Sulfur (ppm)	0.0	9.5	0.0	8.8	0.0	8.8	0.0	8.8	0.0	0.0	0.0	9.1
Density	0.0	267.7	0.0	266.3	0.0	266.2	0.0	266.1	0.0	0.0	0.0	266.8
Octane (R+M/2)	0.0	107.9	0.0	108.0	0.0	108.0	0.0	107.9	0.0	0.0	0.0	107.9
Aromatics (vol%)	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Benzene (vol%)	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Olefins (vol%)	0.0	2.4	0.0	3.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	2.2
Oxygen (wt%)	0.0	30.6	0.0	30.8	0.0	30.8	0.0	30.8	0.0	0.0	0.0	30.7
E200 (vol%)	0.0	128.1	0.0	130.1	0.0	129.8	0.0	129.3	0.0	0.0	0.0	129.1
E300 (vol%)	0.0	96.1	0.0	96.6	0.0	96.6	0.0	96.6	0.0	0.0	0.0	96.4
Energy (MMBtu/Bbl)	0.000	3.628	0.000	3.599	0.000	3.597	0.000	3.594	0.000	0.000	0.000	3.610
All Mogas												
Total BPD	3,207,687	3,260,324	1,885,551	2,000,364	1,715,111	1,790,012	687,028	711,484	1,392,425	1,441,990	8,887,802	9,204,175
Ethanol BPD	139875.7	544,167	104378.5	300,212	53779.6	368,259	26352.4	87,238	135235.5	145,656	459621.7	1,445,532
RVP	10.6	11.4	11.5	11.4	10.4	10.5	11.3	11.4	9.6	9.6	10.6	10.9
Sulfur ppm	26.1	23.2	24.5	21.9	26.3	21.2	24.6	27.4	10.1	9.9	23.2	20.8
Density	258.9	260.0	258.4	259.5	259.3	260.8	256.8	258.1	258.7	259.2	258.7	259.8
R+M/2	88.0	89.7	88.0	89.3	88.0	90.9	86.8	87.5	87.7	87.8	87.8	89.4
Aromatics	24.9	19.7	24.9	20.6	26.0	18.2	19.3	15.2	22.6	22.6	24.3	19.7
Benzene	0.62	0.50	0.63	0.50	0.63	0.45	0.80	0.98	0.55	0.55	0.63	0.53
Olefins	14.3	13.2	10.7	10.2	14.2	10.6	8.0	7.4	6.7	6.7	11.8	10.6
Oxygen (wt%)	1.6	6.1	2.0	5.5	1.2	7.5	1.4	4.5	3.6	3.7	1.9	5.8
E200	49.7	60.3	54.5	62.6	48.1	63.2	58.9	64.6	58.1	58.1	52.5	61.4
E300	93.9	95.4	91.5	86.3	93.9	85.6	93.9	90.8	86.2	86.2	92.2	89.7
Energy (MMBtu/Bbl)	5.061	4.856	4.983	4.850	5.101	4.806	5.004	4.874	4.988	4.999	5.036	4.869

4.4.2.2 Low Ethanol Control Case

This section contains the tables which summarize the costs and other impacts of the low ethanol control case relative to the AEO 2007 and RFS 1 reference cases.

4.4.2.2.1 Low Ethanol Control Case Incremental to the AEO 2007 Reference Case

This subsection summarizes the costs and other impacts of the low ethanol control case relative to the AEO 2007 reference case.

Table 4.4-30
Low Ethanol Control Case Costs without Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	6,066	-
Amortized Refinery Capital Costs $MM/yr	-1,138	-
Fixed Operating Costs $MM/yr	-314	-
Added Gasoline Transportation Cost $MM/yr	-42	-
Removal of E85 Pricing Effect $MM/yr	-3,549	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-7,232	-
Lower Energy Density $MM/yr	4,098	2,254
Adjustment from Ethanol Price to Cost $MM/yr	648	-
FFV Costs $MM/yr	791	
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-13,962
Total Costs $MM/yr	-672	-11,707
Refinery Model Variable Operating Cost c/gal	4.35	-
Amortized Refinery Capital Costs c/gal	-0.82	-
Fixed Operating Costs c/gal	-0.22	-
Added Gasoline Transportation Cost c/gal	-0.03	-
Removal of E85 Pricing Effect c/gal	-2.54	-
Crude Oil Cost $51 to $116/bbl c/gal	-5.18	-
Lower Energy Density c/gal	2.94	3.16
Adjustment from Ethanol Price to Cost c/gal	0.46	-
FFV Costs c/gal	0.57	
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-19.56
Total Costs c/gal	-0.48	-16.40

Table 4.4-31.
Low Ethanol Control Case Costs Reflecting Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-672	-11,707
Federal Subsidies $MM/yr	-1,597	-10,712
Revised Total Cost $MM/yr	-2,269	-22,419
Total Costs c/gal	-0.48	-16.40
Federal Subsidies c/gal	-1.14	-15.00
Total Costs c/gal	-1.63	-31.40

Table 4.4-32.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD for the Low Ethanol Control Case Relative to the AEO 2007 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,279,888	-248,492	3,227,551	-230,937	6,947,777	-303,641	1,418,700	-114,904	1,842,788	-46,607
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	11,581	-32,204	0	0	0	0
VGO LS	0	0	38,063	0	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	296,982	67,329	0	0	738,419	32,205	0	0	0	0
Normal Butane	22,485	0	55,234	3,579	111,678	25,512	39,858	142	39,573	0
Isobutane	9,412	8,868	15,826	-7,966	617	617	20,399	14,133	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	319,378	46,291	200,104	2,203	157,892	-17,825	68,870	-1,520	144,107	1,450
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	25,821	25,821	27,311	27,311	178,439	178,439	18,976	18,976	0	0
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	71,943	-9,163	135,126	-9,516	486,804	-17,483	84,312	-9,585	150,902	-4,765
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	32,124	0	52,055	0	18,580	0	0	0
Import CBOB 10%	241,570	235,283	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	107,364	-38,229	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	19,290	17,057	0	0	0	0	0	0	0	0
Import Raffinate	45,299	-8,228	0	0	0	0	0	0	45,808	0
Import Reformate	0	-8,829	0	0	0	0	0	0	0	0
Import FCC Naphtha	0	0	0	0	0	0	0	0	0	0
Import Lt Naphtha	0	0	0	0	0	0	0	0	584	0
Import Hvy Naph	7,291	7,291	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	39,298	34,965	0	0	0	0	0	0	22,233	3,849
Transfer Reformate	9,504	-7,154	0	0	0	0	0	0	0	0
Transfer Alkylate	48,790	-11,210	1,609	1,609	0	0	0	0	60,000	0
Transfer FCC Naphtha	2,408	2,408	20,822	0	0	0	0	0	0	0
Transfer Raffinate	0	0	1,066	-10,571	0	0	0	0	59,963	12,519
Transfer RBOB 10%	242,605	0	37,596	37,596	0	0	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	1,289,975	153,702	114,969	60,914	0	0	9,099	2,747	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	6,030	5,930	100	0	100	0	100	0	13,445	-1,817
Isooctene	24,113	24,013	100	0	100	0	100	0	804	204

Table 4.4-33.
Summary of Total and Incremental Refinery Outputs by PADD for the Low Ethanol Control Case Relative to the AEO 2007 Control Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	30,661	-1,460	54,531	-2,756	101,580	-15,973	20,156	-2,347	52,426	834
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	6,350	1,383	2,614	1,650	22,377	-11,285	0	0	0	0
Isobutane	0	0	0	0	0	-411	0	0	41,656	167
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	535,896	-24,805	157,500	0	0	0	0	0
CG Reg	0	0	0	0	0	0	0	0	0	0
CG Prem	0	0	0	0	0	-182,001	0	0	0	0
CG E10 Reg	1,684,887	427,937	1,388,234	10,518	878,511	-196,953	569,190	-16,174	95,872	961
CG E10 Prem	168,009	97,675	270,485	8,063	206,925	2,075	112,627	1,129	18,261	183
RFG E10 Reg	1,094,702	-61,416	270,743	2,715	401,267	15,419	0	0	1,102,523	11,057
RFG E10 Prem	214,244	-5,969	51,570	517	76,432	2,937	0	0	210,004	2,106
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	0	0	31,813	31,813	207,848	207,848	22,103	22,103	0	0
E85 to RFG	30,077	30,077	0	0	0	0	0	0	0	0
Transfer RBOB 10%	0	0	0	0	280,201	37,596	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,414,043	217,363	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	143,275	3,194	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown to Storage	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	487,798	-146,819	552,466	-119,705	1,937,875	-198,428	448,555	-84,744	0	0
CARB Diesel	0	0	0	0	0	0	0	0	313,223	-51,127
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	50,000	-41,643	56,903	-7,686	262,834	0	115,134	-7,157	49,880	0
Slurry	32,981	5,572	76,116	-10,151	106,272	-7,675	20,000	6,518	28,956	-51
Asphalt & Wax	91,682	0	210,000	2,314	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	61,029	1,948	0	0	0	0
Transfer Alkylate	0	0	0	0	110,399	-9,601	0	0	0	0
Transfer Reformate	0	0	0	0	9,504	-7,154	0	0	0	0
Transfer FCC naphtha	0	0	0	0	34,440	13,618	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	28,088	23,755	0	0	22,233	3,849
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,034	-120	3,768	-345	11,741	-657	1,880	-207	3,459	-86
Coke (STon)	3,201	-749	10,908	-1,818	46,210	-3,591	7,111	-1,368	16,750	-544

Table 4.4-34.
Change in Refinery Unit Capacities by PADD
for the Low Ethanol Control Case Relative to the AEO 2007 Control Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-175	0	0	0	-175
Vacuum Tower	0	-78	0	0	0	-78
Sats Gas Plant	-12	0	-13	0	6	-18
Unsats Gas Plant	1	0	0	0	0	1
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	4	-6	0	0	0	-2
Hydrocracker	-16	0	0	-33	0	-49
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-24	0	-24
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-1	-4	0	-1	0	-6
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-9	-9
BTX Reformer	0	7	-6	0	0	1
C4 Isomerization	0	0	0	0	1	1
C5/C6 Isomerization	21	0	0	0	0	21
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-14	0	0	15	0	0
Dimersol	0	0	0	0	0	0
Cat Poly	6	0	0	0	0	6
Isooctane	0	0	0	0	0	0
DHT - Total	-136	0	-213	-61	0	-410
DHT 2nd RCT - Total	-127	-150	-220	-63	-10	-571
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	0	0	0
CGH - Generic	24	-10	-17	-3	0	-6
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	57	0	0	0	0	57
LSR Splitter	0	0	0	0	0	0
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-14	-9	1	0	0	-22
Reformate Splitter	-43	-27	3	0	0	-66
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-79	-52	-149	-101	0	-381
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-95	0	0	-264	-73	-432
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	0	0	0	0	0
BTX Reformer - Extract feed	0	0	0	0	0	0

Table 4.4-35.
Change in Refinery Unit Investments by PADD
for the Low Ethanol Control Case Relative to the AEO 2007 Control Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-372	0	0	0	-372
Vacuum Tower	0	-297	0	0	0	-297
Sats Gas Plant	-65	0	-24	0	48	-41
Unsats Gas Plant	6	0	0	0	0	6
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	2	-7	0	0	0	-5
Hydrocracker	-584	0	0	-891	0	-1,475
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-534	0	-534
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-3	-3	0	-2	0	-9
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-66	-66
BTX Reformer	0	70	-38	0	0	32
C4 Isomerization	0	0	0	0	5	5
C5/C6 Isomerization	184	0	0	0	0	184
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-245	0	0	274	0	29
Dimersol	0	0	0	0	0	0
Cat Poly	48	0	0	0	0	48
Isooctane	0	0	0	0	0	0
DHT - Total	-1,394	0	-1,511	-606	0	-3,510
DHT 2nd RCT - Total	-949	-985	-1,103	-443	-57	-3,536
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	0	0	0
CGH - Generic	157	-88	-87	-12	0	-29
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	709	0	0	0	0	709
LSR Splitter	0	0	0	0	0	0
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-94	-60	5	0	0	-149
Reformate Splitter	-55	-36	2	0	0	-88
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-324	-172	-385	-363	0	-1,244
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-3	0	0	-2	-2	-7
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	1	0	0	0	1
BTX Reformer - Extract feed	0	0	0	0	0	0
Total	-2,609	-1,948	-3,141	-2,578	-72	-10,349

Table 4.4-36.
Projected Total U.S. Capital Investments
for the Low Ethanol Control Case Relative to the AEO 2007 Reference Case
(billion dollars)

Cost Type	Plant Type	Capital Investments
Production Costs	Corn Ethanol	3.9
	Cellulosic Ethanol	0
	Cellulosic Diesel [a]	96.5
	Renewable Diesel and Algae	1.1
Distribution Costs	All Ethanol	5.6
	Cellulosic and Renewable Diesel Fuel	2.0
	Biodiesel	1.2
	FFV Costs	0.8
	Refining	-10.3
Total Capital Investments		110.0

Table 4.4-37.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the Low Ethanol Control Case Relative to the AEO 2007 Control Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,376,331	1,308,946	319,080	322,313	459,343	477,699	0	0	1,299,365	1,312,528	3,454,120	3,421,486
Ethanol ('000 BPD)	139,023	132,217	32,230	32,557	46,397	48,252	0	0	131,244	132,579	348,895	345,605
RVP (psi)	10.8	10.7	10.6	10.6	9.7	9.7	0.0	0.0	9.5	9.5	10.1	10.1
Sulfur (ppm)	24.4	24.5	20.0	20.7	23.2	24.1	0.0	0.0	8.8	8.8	18.0	18.0
Density	258.9	258.6	258.2	258.2	259.5	258.5	0.0	0.0	258.5	258.7	258.8	258.6
Octane (R+M/2)	88.1	88.1	88.0	88.0	88.0	88.0	0.0	0.0	87.6	87.6	87.9	87.9
Aromatics (vol%)	19.9	19.8	19.9	19.9	19.6	18.5	0.0	0.0	22.2	22.1	20.7	20.5
Benzene (vol%)	0.57	0.56	0.57	0.57	0.56	0.56	0.00	0.00	0.53	0.54	0.55	0.55
Olefins (vol%)	13.6	14.8	9.4	9.1	11.5	11.2	0.0	0.0	5.7	5.7	10.0	10.2
Oxygen (wt%)	3.7	3.7	3.7	3.7	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.6	54.8	58.3	57.6	53.3	53.7	0.0	0.0	58.2	58.3	56.5	56.3
E300 (vol%)	93.9	82.3	93.9	91.1	93.9	93.9	0.0	0.0	86.2	86.2	91.0	86.2
Energy (MMBtu/Bbl)	4.947	4.953	4.924	4.939	4.981	4.973	0.000	0.000	4.994	5.000	4.967	4.972
CG												
Total ('000 BPD)	1,830,582	1,852,896	1,640,138	1,658,720	1,280,314	1,085,436	696,861	681,817	112,988	114,133	5,560,884	5,393,001
Ethanol ('000 BPD)	134,064	187,161	165,671	167,547	129,320	109,640	70,390	68,870	11,413	11,529	510,857	544,748
RVP (psi)	11.4	11.8	11.6	11.5	10.7	10.5	11.4	11.4	10.6	10.6	11.3	11.4
Sulfur (ppm)	22.9	24.2	23.6	23.6	23.1	23.0	28.0	28.0	26.6	26.0	23.9	24.3
Density	258.9	258.9	259.1	258.9	260.5	259.6	258.1	257.6	262.7	263.4	259.3	259.0
Octane (R+M/2)	87.8	87.7	88.0	88.0	88.0	88.1	86.9	86.9	89.3	89.4	87.8	87.8
Aromatics (vol%)	23.1	22.4	22.5	22.5	22.4	21.8	15.9	15.2	26.5	27.6	21.9	21.5
Benzene (vol%)	0.53	0.52	0.53	0.53	0.51	0.51	1.05	1.03	0.59	0.63	0.59	0.59
Olefins (vol%)	13.2	13.9	11.0	10.8	13.1	11.9	8.5	7.6	17.8	17.5	12.0	11.8
Oxygen (wt%)	2.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.4	3.7
E200 (vol%)	52.5	52.9	58.8	58.5	53.0	52.5	63.0	63.1	58.0	57.2	55.9	55.9
E300 (vol%)	93.9	79.3	93.9	84.0	93.9	79.3	93.9	91.0	86.2	86.2	93.7	82.4
Energy (MMBtu/Bbl)	4.995	4.966	4.925	4.939	4.988	4.990		4.907	4.942	4.946	4.961	4.955
E85												
Total ('000 BPD)	0	30,077	0	31,813	0	207,848	0	22,103	0	0	0	291,840
Ethanol ('000 BPD)	0	25,821	0	27,311	0	178,439	0	18,976	0	0	0	250,548
RVP (psi)	0.0	12.9	0.0	12.2	0.0	12.1	0.0	11.9	0.0	0.0	0.0	12.1
Sulfur (ppm)	0.0	8.9	0.0	8.8	0.0	8.8	0.0	8.8	0.0	0.0	0.0	8.8
Density	0.0	266.0	0.0	266.3	0.0	266.2	0.0	266.1	0.0	0.0	0.0	266.2
Octane (R+M/2)	0.0	108.1	0.0	108.0	0.0	107.9	0.0	107.9	0.0	0.0	0.0	108.0
Aromatics (vol%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benzene (vol%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Olefins (vol%)	0.0	3.0	0.0	3.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	1.5
Oxygen (wt%)	0.0	30.8	0.0	30.8	0.0	30.8	0.0	30.8	0.0	0.0	0.0	30.8
E200 (vol%)	0.0	130.1	0.0	130.1	0.0	129.7	0.0	129.3	0.0	0.0	0.0	129.7
E300 (vol%)	0.0	96.6	0.0	96.6	0.0	96.6	0.0	96.6	0.0	0.0	0.0	96.6
Energy (MMBtu/Bbl)	0.000	3.591	0.000	3.599	0.000	3.596	0.000	3.594	0.000	0.000	0.000	3.596
All Mogas												
Total BPD	3,206,913	3,191,919	1,959,219	2,012,845	1,739,657	1,770,983	696,861	703,921	1,412,353	1,426,660	9,015,003	9,106,327
Ethanol BPD	273,087	345,199	197,901	227,416	175,717	336,332	70,390	87,846	142,657	144,107	859,752	1,140,900
RVP	11.1	11.4	11.4	11.4	10.4	10.5	11.4	11.4	9.6	9.6	10.8	10.9
Sulfur ppm	24	24	23	23	23	22	28	27	10	10	22	21
Density	259	259	259	259	260	260	258	258	259	259	259	259
R+M/2	87.9	88.0	88.0	88.3	88.0	90.4	86.9	87.6	87.8	87.8	87.8	88.5
Aromatics	21.7	21.1	22.1	21.7	21.7	18.3	15.9	14.8	22.5	22.6	21.5	20.4
Benzene	0.55	0.53	0.53	0.52	0.53	0.46	1.05	1.00	0.54	0.55	0.58	0.56
Olefins	13.4	14.1	10.7	10.4	12.7	10.5	8.5	7.4	6.7	6.6	11.2	10.9
Oxygen (wt%)	3.1	4.0	3.7	4.2	3.7	7.0	3.7	4.6	3.7	3.7	3.5	4.6
E200	53.8	54.4	58.7	59.5	53.1	61.9	63.0	65.2	58.2	58.2	56.1	58.4
E300	93.9	80.7	93.9	85.3	93.9	85.3	93.9	91.2	86.2	86.2	92.7	84.3
Energy (MMBtu/Bbl)	4.974	4.948	4.925	4.918	4.986	4.822	4.913	4.866	4.990	4.995	4.963	4.918

4.4.2.2.2 Low Ethanol Control Case Incremental to the RFS 1 Reference Case

This subsection summarizes the gasoline and diesel fuel costs and other impacts of the low ethanol control case relative to the RFS1 reference case.

Table 4.4-38.
Low Ethanol Control Case Costs without Tax Subsidies
Relative to the RFS 1 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	6,289	-
Amortized Refinery Capital Costs $MM/yr	-1,172	-
Fixed Operating Costs $MM/yr	-323	-
Added Gasoline Transportation Cost $MM/yr	-102	-
Removal of E85 Pricing Effect $MM/yr	-3,549	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-17,805	-
Lower Energy Density $MM/yr	10,917	2,283
Adjustment from Ethanol Price to Cost $MM/yr	1,108	-
FFV Costs $MM/yr	1,516	
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-14,071
Total Costs $MM/yr	-3,121	-11,788
Refinery Model Variable Operating Cost c/gal	4.50	-
Amortized Refinery Capital Costs c/gal	-0.84	-
Fixed Operating Costs c/gal	-0.23	-
Added Gasoline Transportation Cost c/gal	-0.07	-
Removal of E85 Pricing Effect c/gal	-2.54	-
Crude Oil Cost $51 to $116/bbl c/gal	-12.75	-
Lower Energy Density c/gal	7.82	3.19
Adjustment from Ethanol Price to Cost c/gal	0.79	-
FFV Costs c/gal	1.09	
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-19.69
Total Costs c/gal	-2.24	-16.49

Table 4.4-39.
Low Ethanol Control Case Costs Reflecting Tax Subsidies
Relative to the RFS 1 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-3,121	-11,788
Federal Subsidies $MM/yr	-4,358	-10,794
Revised Total Cost $MM/yr	-7479	-22,582
Total Costs c/gal	-2.24	-16.49
Federal Subsidies c/gal	-3.12	-15.10
Total Costs c/gal	-5.36	-31.60

Table 4.4-40.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,279,888	-219,169	3,227,551	-306,429	6,947,777	-410,791	1,418,700	-120,278	1,842,788	-44,705
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	11,581	-22,191	0	0	0	0
VGO LS	0	0	38,063	6,229	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	296,982	57,053	0	0	738,419	22,191	0	0	0	0
Normal Butane	22,485	0	55,234	-3,874	111,678	28,274	39,858	415	39,573	0
Isobutane	9,412	9,412	15,826	-9,041	617	617	20,399	-3,024	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	319,378	179,502	200,104	95,726	157,892	104,113	68,870	42,518	144,107	8,872
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	25,821	25,821	27,311	27,311	178,439	178,439	18,976	18,976	0	0
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	71,943	-8,373	135,126	-6,941	486,804	126	84,312	-5,329	150,902	-5,574
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	32,124	0	52,055	0	18,580	1,113	0	0
Import CBOB 10%	241,570	241,570	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	107,364	-92,636	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	19,290	19,290	0	0	0	0	0	0	0	0
Import Raffinate	45,299	-19,291	0	0	0	0	0	0	45,808	0
Import Reformate	0	0	0	0	0	0	0	0	0	0
Import FCC Naphtha	0	0	0	0	0	0	0	0	0	0
Import Lt Naphtha	0	0	0	0	0	0	0	0	584	0
Import Hvy Naph	7,291	7,291	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	39,298	15,956	0	-20,822	0	0	0	0	22,233	1,004
Transfer Reformate	9,504	-7,154	0	-14,074	0	0	0	0	0	0
Transfer Alkylate	48,790	6,171	1,609	1,609	0	0	0	0	60,000	16,933
Transfer FCC Naphtha	2,408	2,408	20,822	20,822	0	0	0	0	0	0
Transfer Raffinate	0	0	1,066	-16,175	0	0	0	0	59,963	11,040
Transfer RBOB 10%	242,605	0	37,596	37,596	0	0	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	1,289,975	1,273,399	114,969	112,012	0	0	9,099	-16,933	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	6,030	5,930	100	0	100	0	100	0	13,445	-988
Isooctene	24,113	24,013	100	0	100	0	100	0	804	204

Table 4.4-41.
Summary of Total and Incremental Refinery Outputs by PADD for the Low Ethanol Control Case Relative to the RFS 1 Control Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	30,661	-1,943	54,531	-8,575	101,580	-33,628	20,156	-4,754	52,426	1,106
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	6,350	-1,482	2,614	244	22,377	-23,129	0	0	0	0
Isobutane	0	0	0	0	0	-345	0	0	41,656	6,653
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	535,896	-28,380	157,500	0	0	0	0	0
CG Reg	0	-118,066	0	-852,131	0	-2,020,447	0	-374,129	0	-53,481
CG Prem	0	0	0	0	0	-416,926	0	-51,984	0	0
CG E10 Reg	1,684,887	1,666,651	1,388,234	920,748	878,511	878,511	569,190	352,027	95,872	55,782
CG E10 Prem	168,009	168,009	270,485	19,129	206,925	127,328	112,627	68,875	18,261	438
RFG E10 Reg	1,094,702	-53,295	270,743	6,497	401,267	20,863	0	0	1,102,523	26,457
RFG E10 Prem	214,244	-4,422	51,570	1,238	76,432	3,974	0	0	210,004	5,040
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	0	0	31,813	31,813	207,848	207,848	22,103	22,103	0	0
E85 to RFG	30,077	30,077	0	0	0	0	0	0	0	0
Transfer RBOB 10%	0	0	0	0	280,201	37,596	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,414,043	1,368,478	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	143,275	1,643	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	487,798	-138,408	552,466	-121,092	1,937,875	-210,603	448,555	-85,599	0	0
CARB Diesel	0	0	0	0	0	0	0	0	313,223	-51,643
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	50,000	-39,764	56,903	-10,915	262,834	0	115,134	-316	49,880	0
Slurry	32,981	6,831	76,116	-10,892	106,272	-10,322	20,000	3,494	28,956	254
Asphalt & Wax	91,682	0	210,000	0	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	61,029	-5,135	0	0	0	0
Transfer Alkylate	0	0	0	0	110,399	24,713	0	0	0	0
Transfer Reformate	0	0	0	0	9,504	9,504	0	0	0	0
Transfer FCC naphtha	0	0	0	0	34,440	34,440	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	28,088	4,746	0	0	22,233	1,004
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,034	-115	3,768	-433	11,741	-834	1,880	-216	3,459	-110
Coke (STon)	3,201	-520	10,908	-2,313	46,210	-4,714	7,111	-1,577	16,750	-523

Table 4.4-42.
Change in Refinery Unit Capacities by PADD
for the Low Ethanol Control Case Relative to the RFS 1 Control Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-200	0	0	0	-200
Vacuum Tower	0	-89	0	-2	0	-92
Sats Gas Plant	4	0	-40	0	7	-29
Unsats Gas Plant	0	0	0	0	0	0
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-8	0	-8
FCC Splitter	2	-6	0	0	0	-5
Hydrocracker	-18	0	0	-26	0	-45
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-28	0	-28
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-1	-4	0	-1	0	-6
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-5	-5
BTX Reformer	0	-3	-14	0	0	-16
C4 Isomerization	0	0	0	0	1	1
C5/C6 Isomerization	25	0	0	0	0	25
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	1	0	0	-3	0	-2
Dimersol	0	0	0	0	0	0
Cat Poly	0	0	0	0	0	0
Isooctane	0	0	0	0	0	0
DHT - Total	-137	0	-241	-62	-4	-444
DHT 2nd RCT - Total	-126	-187	-248	-64	-10	-637
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-4	0	-4
CGH - Generic	28	-6	-30	-7	0	-15
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	39	0	0	0	0	39
LSR Splitter	0	41	38	0	0	80
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-4	-9	1	0	0	-13
Reformate Splitter	-13	-27	3	0	0	-38
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-62	31	44	-77	0	-64
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-128	0	0	-264	-75	-467
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-1	0	0	0	-1
BTX Reformer - Extract feed	-1	0	0	0	0	-1

Table 4.4-43.
Change in Refinery Unit Investments by PADD
for the Low Ethanol Control Case Relative to the RFS 1 Control Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-408	0	0	0	-408
Vacuum Tower	0	-317	0	0	0	-317
Sats Gas Plant	14	0	-120	0	50	-57
Unsats Gas Plant	-1	0	0	0	0	-1
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-193	0	-193
FCC Splitter	1	-7	0	0	0	-6
Hydrocracker	-631	0	0	-755	0	-1,386
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-592	0	-592
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-3	-3	0	-3	0	-10
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-40	-40
BTX Reformer	0	-22	-206	0	0	-229
C4 Isomerization	0	0	0	0	7	7
C5/C6 Isomerization	224	0	0	0	0	224
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	17	0	0	-42	0	-25
Dimersol	0	0	0	0	0	0
Cat Poly	-1	0	0	0	0	-1
Isooctane	0	0	0	0	0	0
DHT - Total	-1,397	0	-1,716	-614	-96	-3,822
DHT 2nd RCT - Total	-948	-1,212	-1,249	-447	-57	-3,913
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-46	0	-46
CGH - Generic	175	-20	-119	-29	0	7
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	569	0	0	0	0	569
LSR Splitter	0	29	18	0	0	47
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-48	-60	4	0	0	-104
Reformate Splitter	-21	-36	2	0	0	-55
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-227	118	117	-298	0	-290
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-3	0	0	-2	-2	-7
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-1	-1	0	0	-2
BTX Reformer - Extract feed	-3	0	0	0	0	-3
Total	-2,285	-1,938	-3,272	-3,021	-138	-10,654

Table 4.4-44.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the Low Ethanol Control Case Relative to the RFS 1 Control Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,366,663	1,308,946	314,578	322,313	452,862	477,699	0	0	1,281,031	1,312,528	3,415,134	3,421,486
Ethanol ('000 BPD)	138,034	132,217	31,773	32,557	45,739	48,252	0	0	129,386	132,579	344,932	345,605
RVP (psi)	10.7	10.7	10.3	10.6	9.6	9.7	0.0	0.0	9.5	9.5	10.1	10.1
Sulfur (ppm)	23.8	24.5	20.1	20.7	23.5	24.1	0.0	0.0	8.7	8.8	17.8	18.0
Density	258.5	258.6	256.2	258.2	259.1	258.5	0.0	0.0	258.5	258.7	258.4	258.6
Octane (R+M/2)	88.1	88.1	88.0	88.0	88.0	88.0	0.0	0.0	87.6	87.6	87.9	87.9
Aromatics (vol%)	19.9	19.8	18.2	19.9	19.5	18.5	0.0	0.0	22.2	22.1	20.5	20.5
Benzene (vol%)	0.57	0.56	0.57	0.57	0.57	0.56	0.00	0.00	0.54	0.54	0.56	0.55
Olefins (vol%)	13.1	14.8	8.0	9.1	9.3	11.2	0.0	0.0	5.7	5.7	9.3	10.2
Oxygen (wt%)	3.7	3.7	3.8	3.7	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.7	54.8	62.5	57.6	54.5	53.7	0.0	0.0	58.5	58.3	57.2	56.3
E300 (vol%)	93.9	82.3	91.5	91.1	93.9	93.9	0.0	0.0	86.2	86.2	90.8	86.2
Energy (MMBtu/Bbl)	4.963	4.953	4.864	4.939	5.027	4.973	0.000	0.000	4.988	5.000	4.971	4.972
CG												
Total ('000 BPD)	1,841,024	1,852,896	1,570,973	1,658,720	1,262,249	1,085,436	687,028	681,817	111,394	114,133	5,472,668	5,393,001
Ethanol ('000 BPD)	1,842	187,161	72,606	167,547	8,040	109,640	26,352	68,870	5,849	11,529	114,689	544,748
RVP (psi)	10.5	11.8	11.8	11.5	10.7	10.5	11.3	11.4	10.8	10.6	11.0	11.4
Sulfur (ppm)	27.8	24.2	25.3	23.6	27.3	23.0	24.6	28.0	26.4	26.0	26.6	24.3
Density	259.3	258.9	258.8	258.9	259.4	259.6	256.8	257.6	260.8	263.4	258.9	259.0
Octane (R+M/2)	88.0	87.7	88.0	88.0	88.0	88.1	86.8	86.9	88.0	89.4	87.8	87.8
Aromatics (vol%)	28.7	22.4	26.3	22.5	28.4	21.8	19.3	15.2	26.8	27.6	26.7	21.5
Benzene (vol%)	0.65	0.52	0.64	0.53	0.65	0.51	0.80	1.03	0.62	0.63	0.67	0.59
Olefins (vol%)	15.2	13.9	11.2	10.8	16.0	11.9	8.0	7.6	18.6	17.5	13.4	11.8
Oxygen (wt%)	0.0	3.7	1.7	3.7	0.2	3.7	1.4	3.7	1.9	3.7	0.8	3.7
E200 (vol%)	45.2	52.9	52.9	58.5	45.9	52.5	58.9	63.1	54.5	57.2	49.5	55.9
E300 (vol%)	93.9	79.3	91.5	84.0	93.9	79.3	93.9	91.0	86.2	86.2	93.0	82.4
Energy (MMBtu/Bbl)	5.133	4.966	5.007	4.939	5.127	4.990	5.004	4.907	4.998	4.946	5.077	4.955
E85												
Total ('000 BPD)	0	30,077	0	31,813	0	207,848	0	22,103	0	0	0	291,840
Ethanol ('000 BPD)	0	25,821	0	27,311	0	178,439	0	18,976	0	0	0	250,548
RVP (psi)	0.0	12.9	0.0	12.2	0.0	12.1	0.0	11.9	0.0	0.0	0.0	12.1
Sulfur (ppm)	0.0	8.9	0.0	8.8	0.0	8.8	0.0	8.8	0.0	0.0	0.0	8.8
Density	0.0	266.0	0.0	266.3	0.0	266.2	0.0	266.1	0.0	0.0	0.0	266.2
Octane (R+M/2)	0.0	108.1	0.0	108.0	0.0	107.9	0.0	107.9	0.0	0.0	0.0	108.0
Aromatics (vol%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benzene (vol%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Olefins (vol%)	0.0	3.0	0.0	3.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	1.5
Oxygen (wt%)	0.0	30.8	0.0	30.8	0.0	30.8	0.0	30.8	0.0	0.0	0.0	30.8
E200 (vol%)	0.0	130.1	0.0	130.1	0.0	129.7	0.0	129.3	0.0	0.0	0.0	129.7
E300 (vol%)	0.0	96.6	0.0	96.6	0.0	96.6	0.0	96.6	0.0	0.0	0.0	96.6
Energy (MMBtu/Bbl)	0.000	3.591	0.000	3.599	0.000	3.596	0.000	3.594	0.000	0.000	0.000	3.596
All Mogas												
Total BPD	3,207,687	3,191,919	1,885,551	2,012,845	1,715,111	1,770,983	687,028	703,921	1,392,425	1,426,660	8,887,802	9,106,327
Ethanol BPD	139,876	345,199	104,378	227,416	53,780	336,332	26,352	87,846	135,236	144,107	459,622	1,140,900
RVP	10.6	11.4	11.5	11.4	10.4	10.5	11.3	11.4	9.6	9.6	10.6	10.9
Sulfur ppm	26.1	24.2	24.5	22.9	26.3	21.6	24.6	27.4	10.1	10.2	23.2	21.4
Density	258.9	258.9	258.4	258.9	259.3	260.1	256.8	257.9	258.7	259.1	258.7	259.1
R+M/2	88.0	88.0	88.0	88.3	88.0	90.4	86.8	87.6	87.7	87.8	87.8	88.5
Aromatics	24.9	21.1	24.9	21.7	26.0	18.3	19.3	14.8	22.6	22.6	24.3	20.4
Benzene	0.62	0.53	0.63	0.52	0.63	0.46	0.80	1.00	0.55	0.55	0.63	0.56
Olefins	14.3	14.1	10.7	10.4	14.2	10.5	8.0	7.4	6.7	6.6	11.8	10.9
Oxygen (wt%)	1.6	4.0	2.0	4.2	1.2	7.0	1.4	4.6	3.6	3.7	1.9	4.6
E200	49.7	54.4	54.5	59.5	48.1	61.9	58.9	65.2	58.1	58.2	52.5	58.4
E300	93.9	80.7	91.5	85.3	93.9	85.3	93.9	91.2	86.2	86.2	92.2	84.3
Energy (MMBtu/Bbl)	5.061	4.948	4.983	4.918	5.101	4.822	5.004	4.866	4.988	4.995	5.036	4.918

4.4.2.3 High Ethanol Control Case

This section summarizes the costs and other impacts of the high ethanol control case relative to the AEO 2007 and RFS 1 reference cases. This case assumes that the cellulosic biofuel standard would be met solely through the production and use of cellulosic ethanol.

4.4.2.3.1 High Ethanol Control Case Relative to the AEO 2007 Reference Case

This subsection summarizes the gasoline and diesel fuel costs and other impacts of the high ethanol control case relative to the AEO 2007 reference case.

Table 4.4-45.
High Ethanol Control Case Costs without Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	23,616	-
Amortized Refinery Capital Costs $MM/yr	-426	-
Fixed Operating Costs $MM/yr	-117	-
Added Gasoline Transportation Cost $MM/yr	-197	-
Removal of E85 Pricing Effect $MM/yr	-19,854	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-34,958	-
Lower Energy Density $MM/yr	21,728	473
Adjustment from Ethanol Price to Cost $MM/yr	-1,866	-
FFV Costs $MM/yr	6,113	-
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-1,744
Total Costs $MM/yr	-5,961	-1,271
Refinery Model Variable Operating Cost c/gal	16.32	-
Amortized Refinery Capital Costs c/gal	-0.29	-
Fixed Operating Costs c/gal	-0.08	-
Added Gasoline Transportation Cost c/gal	-0.14	-
Removal of E85 Pricing Effect c/gal	-13.72	-
Crude Oil Cost $51 to $116/bbl c/gal	-24.16	-
Lower Energy Density c/gal	15.02	0.67
Adjustment from Ethanol Price to Cost c/gal	-1.29	-
FFV Costs c/gal	4.22	-
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-2.46
Total Costs c/gal	-4.12	-1.79

Table 4.4-46.
High Ethanol Control Case Costs Reflecting Tax Subsidies
Relative to the AEO 2007 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-5,961	-1,271
Federal Subsidies $MM/yr	-17,504	-1,359
Revised Total Cost $MM/yr	-23,465	-2,630
Total Costs c/gal	-4.12	-1.79
Federal Subsidies c/gal	-12.10	-1.92
Total Costs c/gal	-16.22	-3.71

Table 4.4-47.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD for the High Ethanol Control Case Relative to the AEO 2007 Reference Case
(barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,347,342	-181,037	3,058,241	-400,248	7,117,305	-134,113	1,534,859	1,256	1,886,357	-3,037
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	0	-43,785	0	0	0	0
VGO LS	0	0	7,920	-30,143	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	279,819	50,165	0	0	738,057	31,843	0	0	0	0
Normal Butane	30,814	8,329	78,293	26,638	69,363	-16,802	25,526	-14,190	39,573	0
Isobutane	12,582	12,038	16,476	-7,315	8,234	8,234	1,178	-5,088	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	270,313	-2,774	168,062	-29,838	142,590	-33,127	66,626	-3,764	143,845	1,188
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	575,048	575,048	332,715	332,715	361,999	361,999	60,129	60,129	46,969	46,969
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	74,115	-6,992	136,509	-8,134	493,553	-10,734	86,015	-7,881	154,032	-1,636
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	58	-32,066	52,055	0	0	-18,580	0	0
Import CBOB 10%	0	-6,286	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	0	-145,593	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	45,167	42,933	0	0	0	0	0	0	0	0
Import Raffinate	3,442	-50,084	0	0	0	0	0	0	45,808	0
Import Reformate	0	-8,829	0	0	0	0	0	0	0	0
Import FCC Naphtha	15,980	15,980	0	0	11,943	11,943	18,580	18,580	0	0
Import Lt Naphtha	0	0	17,575	17,575	0	0	0	0	584	0
Import Hvy Naph	0	0	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	0	-4,333	0	0	0	0	0	0	11,387	-6,997
Transfer Reformate	16,658	0	0	0	0	0	0	0	0	0
Transfer Alkylate	60,000	0	0	0	0	0	0	0	60,000	0
Transfer FCC Naphtha	0	0	20,822	0	0	0	0	0	0	0
Transfer Raffinate	0	0	11,353	-284	0	0	0	0	60,000	12,556
Transfer RBOB 10%	242,605	0	0	0	0	0	0	0	0	0
Transfer RBOB 20%	0	0	8,720	8,720	0	0	0	0	0	0
Transfer CBOB 10%	1,398,409	262,136	80,262	26,208	0	0	6,493	142	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	100	0	100	0	100	0	100	0	16,462	1,200
Isooctene	100	0	100	0	100	0	100	0	600	0

Table 4.4-48.
Summary of Total and Incremental Refinery Outputs by PADD for the High Ethanol Control Case Relative to the AEO 2007 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	34,143	2,023	50,843	-6,445	103,144	-14,409	23,369	866	52,782	1,190
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	0	-4,967	0	-965	0	-33,663	0	0	0	0
Isobutane	0	0	0	0	0	-411	0	0	40,012	-1,478
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	455,618	-105,083	157,500	0	0	0	0	0
CG Reg	0	0	0	0	0	0	0	0	0	0
CG Prem	0	0	0	0	0	-182,001	0	0	0	0
CG E10 Reg	1,535,198	278,248	1,172,450	-205,266	872,274	-203,190	542,856	-42,507	99,374	4,464
CG E10 Prem	306,669	236,335	274,765	12,343	214,485	9,635	116,742	5,244	18,928	850
RFG E10 Reg	605,554	-550,564	163,150	-104,878	246,042	-139,806	0	0	1,088,091	-3,375
RFG E10 Prem	228,678	8,465	53,454	2,401	78,844	5,349	0	0	217,676	9,778
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	74,814	74,814	270,064	270,064	253,773	253,773	70,039	70,039	0	0
E85 to RFG	595,006	595,006	117,484	117,484	167,888	167,888	0	0	54,710	54,710
Transfer RBOB 10%	0	0	0	0	251,325	8,720	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,485,164	288,485	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	138,523	-1,557	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	587,042	-47,575	643,331	-28,840	2,150,901	14,598	523,035	-10,264	0	0
CARB Diesel	0	0	0	0	0	0	0	0	358,152	-6,197
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	68,283	-23,360	67,826	3,237	262,834	0	138,312	16,021	45,680	-4,199
Slurry	30,026	2,617	67,363	-18,904	112,554	-1,394	12,295	-1,187	29,893	886
Asphalt & Wax	86,013	-5,669	198,329	-9,357	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	71,353	12,273	0	0	0	0
Transfer Alkylate	0	0	0	0	120,000	0	0	0	0	0
Transfer Reformate	0	0	0	0	16,658	0	0	0	0	0
Transfer FCC naphtha	0	0	0	0	20,822	0	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	0	-4,333	0	0	11,387	-6,997
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,076	-78	3,571	-542	12,042	-356	2,038	-49	3,559	14
Coke (STon)	3,495	-455	10,154	-2,572	48,646	-1,154	7,899	-580	17,358	64

Table 4.4-49.
Change in Refinery Unit Capacities by PADD
for the High Ethanol Control Case Relative to the AEO 2007 Reference Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-459	0	0	0	-459
Vacuum Tower	0	-205	0	8	0	-197
Sats Gas Plant	-21	0	-45	0	10	-56
Unsats Gas Plant	1	0	0	0	0	1
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	1	-6	0	0	0	-4
Hydrocracker	14	0	0	-6	0	7
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-1	0	-1
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	0	-6	0	0	0	-6
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	9	9
BTX Reformer	0	7	-9	0	0	-1
C4 Isomerization	0	0	0	0	3	3
C5/C6 Isomerization	16	0	0	0	0	16
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-27	0	0	0	0	-27
Dimersol	0	0	0	0	0	0
Cat Poly	1	0	0	0	0	1
Isooctane	0	0	0	0	0	0
DHT - Total	-40	0	-19	-10	0	-69
DHT 2nd RCT - Total	-38	-52	-20	-10	0	-120
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	2	0	2
CGH - Generic	13	-30	-6	1	0	-23
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	24	0	0	0	0	24
LSR Splitter	0	-25	0	0	0	-25
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-18	0	-2	0	0	-20
Reformate Splitter	-54	0	-6	0	0	-59
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-2	-43	-80	-31	0	-156
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-24	0	0	-30	-22	-76
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	0	0	0	0	0
BTX Reformer - Extract feed	0	0	0	0	0	0

Table 4.4-50.
Change in Refinery Unit Investments by PADD
for the High Ethanol Control Case Relative to the AEO 2007 Reference Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-1,121	0	0	0	-1,121
Vacuum Tower	0	-676	0	70	0	-606
Sats Gas Plant	-107	0	-129	0	60	-176
Unsats Gas Plant	8	0	0	0	0	8
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	0	0	0
FCC Splitter	1	-7	0	0	0	-6
Hydrocracker	305	0	0	-129	0	176
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-22	0	-22
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	0	-7	0	0	0	-7
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	45	45
BTX Reformer	0	70	-55	0	0	16
C4 Isomerization	0	0	0	0	20	20
C5/C6 Isomerization	156	0	0	0	0	156
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	-470	0	0	0	0	-470
Dimersol	0	0	0	0	0	0
Cat Poly	8	0	0	0	0	8
Isooctane	0	0	0	0	0	0
DHT - Total	-390	0	-82	-174	0	-646
DHT 2nd RCT - Total	-355	-361	-64	-43	0	-822
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	31	0	31
CGH - Generic	109	-157	-59	4	0	-102
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	319	0	0	0	0	319
LSR Splitter	0	-17	0	0	0	-17
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-110	0	-9	0	0	-119
Reformate Splitter	-64	0	-4	0	0	-68
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSCF	-7	-148	-186	-129	0	-469
Lube Unit	0	0	0	0	0	0
Sulfur Plant	0	0	0	0	0	-1
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	1	0	0	0	1
BTX Reformer - Extract feed	0	0	0	0	0	0
Total	-597	-2,422	-587	-391	124	-3,874

Table 4.4-51.
Projected Total U.S. Capital Investments
for the High Ethanol Control Case Relative to the AEO 2007 Reference Case
(billion dollars)

Cost Type	Plant Type	Capital Investments
Production Costs	Corn Ethanol	3.9
	Cellulosic Ethanol	48.3
	Cellulosic Diesel [a]	0
	Renewable Diesel and Algae	1.1
Distribution Costs	All Ethanol	11.9
	Cellulosic and Renewable Diesel Fuel	-
	Biodiesel	1.2
	FFV Costs	6.1
	Refining	-4.1
Total Capital Investments		68.4

Table 4.4-52.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the High Ethanol Control Case Relative to the AEO 2007 Reference Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,376,331	834,232	319,080	216,604	459,343	324,886	0	0	1,299,365	1,305,768	3,454,120	2,681,490
Ethanol ('000 BPD)	139,023	84,266	32,230	21,879	46,397	32,817	0	0	131,244	131,896	348,895	270,858
RVP (psi)	10.8	10.3	10.6	12.5	9.7	11.3	0.0	0.0	9.5	9.4	10.1	10.1
Sulfur (ppm)	24.4	23.4	20.0	24.5	23.2	22.4	0.0	0.0	8.8	8.9	18.0	16.3
Density	258.9	259.4	258.2	257.1	259.5	258.7	0.0	0.0	258.5	258.9	258.8	258.9
Octane (R+M/2)	88.1	88.6	88.0	88.5	88.0	88.5	0.0	0.0	87.6	87.7	87.9	88.1
Aromatics (vol%)	19.9	20.0	19.9	20.0	19.6	19.8	0.0	0.0	22.2	22.2	20.7	21.1
Benzene (vol%)	0.57	0.58	0.57	0.57	0.56	0.54	0.00	0.00	0.53	0.55	0.55	0.56
Olefins (vol%)	13.6	14.0	9.4	11.4	11.5	13.7	0.0	0.0	5.7	5.7	10.0	9.7
Oxygen (wt%)	3.7	3.7	3.7	3.8	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.6	56.7	58.3	60.7	53.3	54.2	0.0	0.0	58.2	58.2	56.5	57.4
E300 (vol%)	93.9	95.1	93.9	95.1	93.9	95.1	0.0	0.0	86.2	86.2	91.0	90.7
Energy (MMBtu/Bbl)	4.947	4.956	4.924	4.895	4.981	4.951	0.000	0.000	4.994	4.997	4.967	4.970
CG												
Total ('000 BPD)	1,830,582	1,841,867	1,640,138	1,447,215	1,280,314	1,086,759	696,861	659,598	112,988	118,302	5,560,884	5,153,740
Ethanol ('000 BPD)	134,064	186,047	165,671	146,183	129,320	109,774	70,390	66,626	11,413	11,950	510,857	520,580
RVP (psi)	11.4	11.7	11.6	11.4	10.7	10.4	11.4	11.2	10.6	10.6	11.3	11.3
Sulfur (ppm)	22.9	24.1	23.6	24.7	23.1	22.6	28.0	28.0	26.6	25.6	23.9	24.5
Density	258.9	260.0	259.1	259.3	260.5	260.8	258.1	259.1	262.7	262.5	259.3	259.9
Octane (R+M/2)	87.8	88.0	88.0	88.1	88.0	88.2	86.9	87.0	89.3	89.2	87.8	88.0
Aromatics (vol%)	23.1	22.5	22.5	22.5	22.4	22.4	15.9	17.7	26.5	26.7	21.9	22.0
Benzene (vol%)	0.53	0.53	0.53	0.53	0.51	0.51	1.05	1.03	0.59	0.57	0.59	0.59
Olefins (vol%)	13.2	13.9	11.0	10.9	13.1	12.6	8.5	9.5	17.8	16.1	12.0	12.3
Oxygen (wt%)	2.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.4	3.7
E200 (vol%)	52.5	53.5	58.8	58.9	53.0	51.4	63.0	63.5	58.0	58.5	55.9	56.0
E300 (vol%)	93.9	80.4	93.9	95.0	93.9	79.2	93.9	95.8	86.2	86.2	93.7	86.3
Energy (MMBtu/Bbl)	4.995	4.974	4.925	4.938	4.988	4.998	0.000	4.930	4.942	4.929	4.961	4.962
E85												
Total ('000 BPD)	0	669,821	0	387,549	0	421,660	0	70,039	0	54,710	0	1,603,779
Ethanol ('000 BPD)	0	575,048	0	332,715	0	361,999	0	60,129	0	46,969	0	1,376,860
RVP (psi)	0.0	9.9	0.0	10.3	0.0	10.7	0.0	11.9	0.0	12.0	0.0	10.4
Sulfur (ppm)	0.0	10.1	0.0	9.7	0.0	9.6	0.0	9.0	0.0	8.8	0.0	9.8
Density	0.0	268.9	0.0	268.1	0.0	267.8	0.0	266.6	0.0	266.2	0.0	268.2
Octane (R+M/2)	0.0	107.7	0.0	107.7	0.0	107.8	0.0	107.9	0.0	107.9	0.0	107.7
Aromatics (vol%)	0.0	1.2	0.0	0.8	0.0	0.7	0.0	0.1	0.0	0.0	0.0	0.9
Benzene (vol%)	0.00	0.03	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03
Olefins (vol%)	0.0	2.4	0.0	2.0	0.0	2.1	0.0	2.8	0.0	1.2	0.0	2.2
Oxygen (wt%)	0.0	30.5	0.0	25.7	0.0	30.6	0.0	28.6	0.0	30.8	0.0	29.3
E200 (vol%)	0.0	126.8	0.0	127.7	0.0	128.0	0.0	129.8	0.0	129.6	0.0	127.6
E300 (vol%)	0.0	95.6	0.0	95.9	0.0	96.0	0.0	96.6	0.0	96.6	0.0	95.8
Energy (MMBtu/Bbl)	0.000	3.656	0.000	3.642	0.000	3.633	0.000	3.605	0.000	3.596	0.000	3.642
All Mogas												
Total BPD	3,206,913	3,345,919	1,959,219	2,051,367	1,739,657	1,833,305	696,861	729,637	1,412,353	1,478,780	9,015,003	9,439,008
Ethanol BPD	273,087	845,361	197,901	500,777	175,717	504,590	70,390	126,755	142,657	190,815	859,752	2,168,297
RVP	11.1	11.0	11.4	11.3	10.4	10.6	11.4	11.3	9.6	9.6	10.8	10.8
Sulfur ppm	24	21	23	22	23	19	28	26	10	10	22	20
Density	259	262	259	261	260	262	258	260	259	259	259	261
R+M/2	87.9	92.1	88.0	91.9	88.0	92.7	86.9	89.0	87.8	88.5	87.8	91.4
Aromatics	21.7	17.6	22.1	18.1	21.7	16.9	15.9	16.0	22.5	21.8	21.5	18.1
Benzene	0.55	0.44	0.53	0.44	0.53	0.40	1.05	0.93	0.54	0.53	0.58	0.49
Olefins	13.4	11.6	10.7	9.3	12.7	10.3	8.5	8.9	6.7	6.4	11.2	9.8
Oxygen (wt%)	3.1	9.2	3.7	8.0	3.7	10.0	3.7	6.2	3.7	4.7	3.5	8.2
E200	53.8	69.0	58.7	72.1	53.1	69.5	63.0	69.9	58.2	60.9	56.1	68.6
E300	93.9	87.1	93.9	95.1	93.9	85.9	93.9	95.9	86.2	86.6	92.7	89.2
Energy (MMBtu/Bbl)	4.974	4.706	4.925	4.689	4.986	4.676	4.913	4.803	4.990	4.939	4.963	4.740

4.4.2.3.2 High Ethanol Control Case Relative to the RFS 1 Reference Case

This subsection summarizes the gasoline and diesel fuel costs and other impacts of the high ethanol control case relative to the RFS1 reference case.

Table 4.4-53.
High Ethanol Control Case Costs without Tax Subsidies
Relative to the RFS 1 Reference Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Refinery Model Variable Operating Cost $MM/yr	23,894	-
Amortized Refinery Capital Costs $MM/yr	-460	-
Fixed Operating Costs $MM/yr	-127	-
Added Gasoline Transportation Cost $MM/yr	-257	-
Removal of E85 Pricing Effect $MM/yr	-19,854	-
Crude Oil Cost $51 to $116/bbl $MM/yr	-45,548	-
Lower Energy Density $MM/yr	29,609	502
Adjustment from Ethanol Price to Cost $MM/yr	-1,524	-
FFV Costs $MM/yr	6,476	
Renewable Diesel Cost vs Petroleum Diesel $MM/yr	-	-1,851
Total Costs $MM/yr	-7,790	-1,350
Refinery Model Variable Operating Cost c/gal	16.51	-
Amortized Refinery Capital Costs c/gal	-0.32	-
Fixed Operating Costs c/gal	-0.09	-
Added Gasoline Transportation Cost c/gal	-0.18	-
Removal of E85 Pricing Effect c/gal	-13.72	-
Crude Oil Cost $51 to $116/bbl c/gal	-31.48	-
Lower Energy Density c/gal	20.46	0.71
Adjustment from Ethanol Price to Cost c/gal	-1.05	-
FFV Costs c/gal	4.48	
Renewable Diesel Cost vs Petroleum Diesel c/gal	-	-2.61
Total Costs c/gal	-5.38	-1.90

Table 4.4-54.
High Ethanol Control Case Costs Reflecting Tax Subsidies
Relative to the RFS 1 Control Case
(2007 dollars, 7% ROI before taxes)

	Gasoline	Diesel Fuel
Total Costs $MM/yr	-7,790	-1,350
Federal Subsidies $MM/yr	-20,266	-1,441
Revised Total Cost $MM/yr	-28,055	-2,791
Total Costs c/gal	-5.38	-1.90
Federal Subsidies c/gal	-14.01	-2.03
Total Costs c/gal	-19.39	-3.94

Table 4.4-55.
Summary of the Total and Incremental Volumetric Refinery Inputs by PADD for the High Ethanol Control Case Relative to the RFS 1 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
PADD Crude	1,347,342	-151,714	3,058,241	-475,740	7,117,305	-241,263	1,534,859	-4,119	1,886,357	-1,136
GTL Naphtha	0	0	0	0	0	0	0	0	0	0
GTL Diesel	0	0	0	0	0	0	0	0	0	0
VGO HS	0	0	0	0	0	-33,772	0	0	0	0
VGO LS	0	0	7,920	-23,914	0	0	0	0	0	0
HS AR (A960)	0	0	0	0	0	0	0	0	0	0
LS AR (Alg)	279,819	39,889	0	0	738,057	21,829	0	0	0	0
Normal Butane	30,814	8,329	78,293	19,185	69,363	-14,040	25,526	-13,917	39,573	0
Isobutane	12,582	12,582	16,476	-8,390	8,234	8,234	1,178	-22,245	0	0
Other	0	0	0	0	0	0	0	0	0	0
MTBE	0	0	0	0	0	0	0	0	0	0
Ethanol - E10	270,313	130,437	168,062	63,684	142,590	88,811	66,626	40,273	143,845	8,610
Ethanol - E20	0	0	0	0	0	0	0	0	0	0
Ethanol - E85	575,048	575,048	332,715	332,715	361,999	361,999	60,129	60,129	46,969	46,969
Reformer Feed	0	0	0	0	0	0	0	0	0	0
Methanol	0	0	0	0	0	0	0	0	0	0
Natural Gas (FOE)	74,115	-6,201	136,509	-5,559	493,553	6,876	86,015	-3,625	154,032	-2,444
Hydrogen (MSCF)	0	0	0	0	0	0	0	0	0	0
Pentanes Plus	0	0	58	-32,066	52,055	0	0	-17,467	0	0
Import CBOB 10%	0	0	0	0	0	0	0	0	0	0
Import CBOB 20%	0	0	0	0	0	0	0	0	0	0
Import RBOB 10%	0	-200,000	0	0	0	0	0	0	0	0
Import RBOB 20%	0	0	0	0	0	0	0	0	0	0
Import Alkylate	45,167	45,167	0	0	0	0	0	0	0	0
Import Raffinate	3,442	-61,147	0	0	0	0	0	0	45,808	0
Import Reformate	0	0	0	0	0	0	0	0	0	0
Import FCC Naphtha	15,980	15,980	0	0	11,943	11,943	18,580	18,580	0	0
Import Lt Naphtha	0	0	17,575	17,575	0	0	0	0	584	0
Import Hvy Naph	0	0	0	0	41,644	0	0	0	0	0
Transfer Lt Naphtha	0	-23,342	0	-20,822	0	0	0	0	11,387	-9,842
Transfer Reformate	16,658	0	0	-14,074	0	0	0	0	0	0
Transfer Alkylate	60,000	17,381	0	0	0	0	0	0	60,000	16,933
Transfer FCC Naphtha	0	0	20,822	20,822	0	0	0	0	0	0
Transfer Raffinate	0	0	11,353	-5,888	0	0	0	0	60,000	11,077
Transfer RBOB 10%	242,605	0	0	0	0	0	0	0	0	0
Transfer RBOB 20%	0	0	8,720	8,720	0	0	0	0	0	0
Transfer CBOB 10%	1,398,409	1,381,833	80,262	77,306	0	0	6,493	-19,539	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Isooctane	100	0	100	0	100	0	100	0	16,462	2,029
Isooctene	100	0	100	0	100	0	100	0	600	0

Table 4.4-56.
Summary of Total and Incremental Refinery Outputs by PADD for the High Ethanol Control Case Relative to the RFS 1 Reference Case (barrels/day)

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA	
	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case	Control Case	Difference from Ref Case
Propane	34,143	1,539	50,843	-12,263	103,144	-32,064	23,369	-1,541	52,782	1,461
Propylene	18,685	0	42,525	0	245,407	0	2,041	0	11,774	0
Normal Butane	0	-7,832	0	-2,370	0	-45,506	0	0	0	0
Isobutane	0	0	0	0	0	-345	0	0	40,012	5,009
PC Naphtha	15,830	0	40,290	0	432,937	0	0	0	0	0
PC Gasoil	0	0	455,618	-108,658	157,500	0	0	0	0	0
CG Reg	0	-118,066	0	-852,131	0	-2,020,447	0	-374,129	0	-53,481
CG Prem	0	0	0	0	0	-416,926	0	-51,984	0	0
CG E10 Reg	1,535,198	1,516,962	1,172,450	704,964	872,274	872,274	542,856	325,693	99,374	59,284
CG E10 Prem	306,669	306,669	274,765	23,409	214,485	134,887	116,742	72,990	18,928	1,105
RFG E10 Reg	605,554	-542,443	163,150	-101,096	246,042	-134,362	0	0	1,088,091	12,026
RFG E10 Prem	228,678	10,012	53,454	3,122	78,844	6,386	0	0	217,676	12,712
CG E20 Reg	0	0	0	0	0	0	0	0	0	0
RFG E20 Reg	0	0	0	0	0	0	0	0	0	0
E85 to CG	74,814	74,814	270,064	270,064	253,773	253,773	70,039	70,039	0	0
E85 to RFG	595,006	595,006	117,484	117,484	167,888	167,888	0	0	54,710	54,710
Transfer RBOB 10%	0	0	0	0	251,325	8,720	0	0	0	0
Transfer RBOB 20%	0	0	0	0	0	0	0	0	0	0
Transfer CBOB 10%	0	0	0	0	1,485,164	1,439,600	0	0	0	0
Transfer CBOB 20%	0	0	0	0	0	0	0	0	0	0
Jet/Kero A (450ppm)	70,000	0	138,523	-3,108	936,227	0	274,537	0	229,653	0
X-Fer Diesel Rundown t	0	0	0	0	0	0	0	0	0	0
HSD Gr 76 (0.2%)	0	0	0	0	0	0	0	0	0	0
LSD Gr 74 (.05%)	0	0	0	0	0	0	0	0	0	0
ULSD (15 ppm)	587,042	-39,165	643,331	-30,227	2,150,901	2,423	523,035	-11,120	0	0
CARB Diesel	0	0	0	0	0	0	0	0	358,152	-6,714
X-Fer C5's to Storage	0	0	0	0	0	0	0	0	0	0
1% Residual Fuel	0	0	0	0	0	0	0	0	0	0
Residual Fuel	68,283	-21,481	67,826	8	262,834	0	138,312	22,862	45,680	-4,199
Slurry	30,026	3,876	67,363	-19,645	112,554	-4,041	12,295	-4,210	29,893	1,191
Asphalt & Wax	86,013	-5,669	198,329	-11,671	157,500	0	5,250	0	41,774	0
Gasoil	0	0	4,895	0	0	0	0	0	9,814	0
Lubes	18,706	0	17,313	0	157,500	0	0	0	20,149	0
Benzene	11,003	0	11,003	0	51,347	0	0	0	0	0
Toluene	0	0	0	0	34,910	0	0	0	0	0
Xylenes	0	0	0	0	7,777	0	0	0	0	0
Cumene	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0
Cyclohexane	0	0	0	0	0	0	0	0	0	0
Transfer Raffinate	0	0	0	0	71,353	5,190	0	0	0	0
Transfer Alkylate	0	0	0	0	120,000	34,314	0	0	0	0
Transfer Reformate	0	0	0	0	16,658	16,658	0	0	0	0
Transfer FCC naphtha	0	0	0	0	20,822	20,822	0	0	0	0
Transfer Lt Naphtha	0	0	0	0	0	-23,342	0	0	11,387	-9,842
Transfer Blendstock	0	0	0	0	0	0	0	0	0	0
Sulfur (STons)	1,076	-74	3,571	-630	12,042	-533	2,038	-59	3,559	-10
Coke (STon)	3,495	-227	10,154	-3,068	48,646	-2,278	7,899	-790	17,358	86

Table 4.4-57.
Change in Refinery Unit Capacities by PADD
for the High Ethanol Control Case Relative to the RFS 1 Reference Case
(thousand barrels/day)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-439	0	0	0	-439
Vacuum Tower	0	-196	0	-2	0	-198
Sats Gas Plant	3	0	-30	0	9	-18
Unsats Gas Plant	-2	0	0	0	0	-2
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-8	0	-8
FCC Splitter	2	-6	0	0	0	-5
Hydrocracker	-18	0	0	-14	0	-33
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-28	0	-28
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-1	-6	0	-1	0	-8
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-1	-1
BTX Reformer	0	-10	-18	0	0	-27
C4 Isomerization	0	0	0	0	1	1
C5/C6 Isomerization	26	0	0	0	0	26
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	1	0	0	-5	0	-4
Dimersol	0	0	0	0	0	0
Cat Poly	0	0	0	0	0	0
Isooctane	0	0	0	0	0	0
DHT - Total	-132	0	-103	-50	-4	-290
DHT 2nd RCT - Total	-117	-153	-174	-52	-4	-501
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-4	0	-4
CGH - Generic	-12	-19	-19	-6	0	-57
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	37	0	0	0	0	37
LSR Splitter	0	41	38	0	0	80
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-4	-4	1	0	0	-7
Reformate Splitter	-12	-12	3	0	0	-21
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-72	11	109	-47	0	1
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-128	0	0	-204	-71	-402
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-1	-1	0	0	-2
BTX Reformer - Extract feed	-1	0	0	0	0	-1

Table 4.4-58.
Change in Refinery Unit Investments by PADD
for the High Ethanol Control Case Relative to the RFS 1 Reference Case
(million dollars/year)

	PADD 1	PADD 2	PADD 3	PADD 4/5 ex CA	California	US Total
Crude Tower	0	-997	0	0	0	-997
Vacuum Tower	0	-591	0	0	0	-591
Sats Gas Plant	12	0	-101	0	55	-34
Unsats Gas Plant	-10	0	0	0	0	-10
FCC DeC5 Tower	0	0	0	0	0	0
FCC	0	0	0	-193	0	-193
FCC Splitter	1	-7	0	0	0	-6
Hydrocracker	-631	0	0	-505	0	-1,137
H-Oil Unit	0	0	0	0	0	0
Delayed Coker	0	0	0	-592	0	-592
Visbreaker	0	0	0	0	0	0
Thermal Naphtha Splitter	-3	-7	0	-3	0	-13
CRU Reformer	0	0	0	0	0	0
SRU Reformer	0	0	0	0	-4	-4
BTX Reformer	0	-93	-231	0	0	-324
C4 Isomerization	0	0	0	0	8	8
C5/C6 Isomerization	227	0	0	0	0	227
HF Alkylation	0	0	0	0	0	0
H2SO4 Alkylation	16	0	0	-70	0	-54
Dimersol	0	0	0	0	0	0
Cat Poly	-1	0	0	0	0	-1
Isooctane	0	0	0	0	0	0
DHT - Total	-1,367	0	-702	-539	-96	-2,703
DHT 2nd RCT - Total	-904	-998	-840	-312	-21	-3,076
DHT Arom Saturation	0	0	0	0	0	0
NHT - Total Fd	0	0	0	-46	0	-46
CGH - Generic	-58	-63	-92	-25	0	-238
CGH - Olefin Sat'n	0	0	0	0	0	0
FCCU Fd HDT	555	0	0	0	0	555
LSR Splitter	0	29	18	0	0	47
LSR Bz Saturator	0	0	0	0	0	0
Reformate Saturator	-46	-19	4	0	0	-60
Reformate Splitter	-20	-16	2	0	0	-34
SDA	0	0	0	0	0	0
MTBE	0	0	0	0	0	0
TAME	0	0	0	0	0	0
Hydrogen Plant - Total MSC	-255	69	274	-171	0	-84
Lube Unit	0	0	0	0	0	0
Sulfur Plant	-3	0	0	-2	-2	-7
Merox Jet	0	0	0	0	0	0
Merox Diesel	0	0	0	0	0	0
BTX Reformer - Tower feed	0	-2	-1	0	0	-3
BTX Reformer - Extract feed	-3	0	0	0	0	-3
Total	-2,491	-2,694	-1,669	-2,459	-59	-9,373

Table 4.4-59.
Ethanol and Gasoline Volume, Quality and Energy Density by Gasoline Type at the PADD Terminal for the High Ethanol Control Case Relative to the RFS 1 Reference Case

	PADD 1		PADD 2		PADD 3		PADD 4/5 ex CA		CA		US	
	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control	Ref Case	Control
RFG												
Total ('000 BPD)	1,366,663	834,232	314,578	216,604	452,862	324,886	0	0	1,281,031	1,305,768	3,415,134	2,681,490
Ethanol ('000 BPD)	138,034	84,266	31,773	21,879	45,739	32,817	0	0	129,386	131,896	344,932	270,858
RVP (psi)	10.7	10.3	10.3	12.5	9.6	11.3	0.0	0.0	9.5	9.4	10.1	10.1
Sulfur (ppm)	23.8	23.4	20.1	24.5	23.5	22.4	0.0	0.0	8.7	8.9	17.8	16.3
Density	258.5	259.4	256.2	257.1	259.1	258.7	0.0	0.0	258.5	258.9	258.4	258.9
Octane (R+M/2)	88.1	88.6	88.0	88.5	88.0	88.5	0.0	0.0	87.6	87.7	87.9	88.1
Aromatics (vol%)	19.9	20.0	18.2	20.0	19.5	19.8	0.0	0.0	22.2	22.2	20.5	21.1
Benzene (vol%)	0.57	0.58	0.57	0.57	0.57	0.54	0.00	0.00	0.54	0.55	0.56	0.56
Olefins (vol%)	13.1	14.0	8.0	11.4	9.3	13.7	0.0	0.0	5.7	5.7	9.3	9.7
Oxygen (wt%)	3.7	3.7	3.8	3.8	3.7	3.7	0.0	0.0	3.7	3.7	3.7	3.7
E200 (vol%)	55.7	56.7	62.5	60.7	54.5	54.2	0.0	0.0	58.5	58.2	57.2	57.4
E300 (vol%)	93.9	95.1	91.5	95.1	93.9	95.1	0.0	0.0	86.2	86.2	90.8	90.7
Energy (MMBtu/Bbl	4.963	4.956	4.864	4.895	5.027	4.951	0.000	0.000	4.988	4.997	4.971	4.970
CG												
Total ('000 BPD)	1,841,024	1,841,867	1,570,973	1,447,215	1,262,249	1,086,759	687,028	659,598	111,394	118,302	5,472,668	5,153,740
Ethanol ('000 BPD)	1,842	186,047	72,606	146,183	8,040	109,774	26,352	66,626	5,849	11,950	114,689	520,580
RVP (psi)	10.5	11.7	11.8	11.4	10.7	10.4	11.3	11.2	10.8	10.6	11.0	11.3
Sulfur (ppm)	27.8	24.1	25.3	24.7	27.3	22.6	24.6	28.0	26.4	25.6	26.6	24.5
Density	259.3	260.0	258.8	259.3	259.4	260.8	256.8	259.1	260.8	262.5	258.9	259.9
Octane (R+M/2)	88.0	88.0	88.0	88.1	88.0	88.2	86.8	87.0	88.0	89.2	87.8	88.0
Aromatics (vol%)	28.7	22.5	26.3	22.5	28.4	22.4	19.3	17.7	26.8	26.7	26.7	22.0
Benzene (vol%)	0.65	0.53	0.64	0.53	0.65	0.51	0.80	1.03	0.62	0.57	0.67	0.59
Olefins (vol%)	15.2	13.9	11.2	10.9	16.0	12.6	8.0	9.5	18.6	16.1	13.4	12.3
Oxygen (wt%)	0.0	3.7	1.7	3.7	0.2	3.7	1.4	3.7	1.9	3.7	0.8	3.7
E200 (vol%)	45.2	53.5	52.9	58.9	45.9	51.4	58.9	63.5	54.5	58.5	49.5	56.0
E300 (vol%)	93.9	80.4	91.5	95.0	93.9	79.2	93.9	95.8	86.2	86.2	93.0	86.3
Energy (MMBtu/Bbl	5.133	4.974	5.007	4.938	5.127	4.998	5.004	4.930	4.998	4.929	5.077	4.962
E85												
Total ('000 BPD)	0	669,821	0	387,549	0	421,660	0	70,039	0	54,710	0	1,603,779
Ethanol ('000 BPD)	0	575,048	0	332,715	0	361,999	0	60,129	0	46,969	0	1,376,860
RVP (psi)	0.0	9.9	0.0	10.3	0.0	10.7	0.0	11.9	0.0	12.0	0.0	10.4
Sulfur (ppm)	0.0	10.1	0.0	9.7	0.0	9.6	0.0	9.0	0.0	8.8	0.0	9.8
Density	0.0	268.9	0.0	268.1	0.0	267.8	0.0	266.6	0.0	266.2	0.0	268.2
Octane (R+M/2)	0.0	107.7	0.0	107.7	0.0	107.8	0.0	107.9	0.0	107.9	0.0	107.7
Aromatics (vol%)	0.0	1.2	0.0	0.8	0.0	0.7	0.0	0.1	0.0	0.0	0.0	0.9
Benzene (vol%)	0.00	0.03	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03
Olefins (vol%)	0.0	2.4	0.0	2.0	0.0	2.1	0.0	2.8	0.0	1.2	0.0	2.2
Oxygen (wt%)	0.0	30.5	0.0	25.7	0.0	30.6	0.0	28.6	0.0	30.8	0.0	29.3
E200 (vol%)	0.0	126.8	0.0	127.7	0.0	128.0	0.0	129.8	0.0	129.6	0.0	127.6
E300 (vol%)	0.0	95.6	0.0	95.9	0.0	96.0	0.0	96.6	0.0	96.6	0.0	95.8
Energy (MMBtu/Bbl	0.000	3.656	0.000	3.642	0.000	3.633	0.000	3.605	0.000	3.596	0.000	3.642
All Mogas												
Total BPD	3,207,687	3,345,919	1,885,551	2,051,367	1,715,111	1,833,305	687,028	729,637	1,392,425	1,478,780	8,887,802	9,439,008
Ethanol BPD	139,876	845,361	104,378	500,777	53,780	504,590	26,352	126,755	135,236	190,815	459,622	2,168,297
RVP	10.6	11.0	11.5	11.3	10.4	10.6	11.3	11.3	9.6	9.6	10.6	10.8
Sulfur ppm	26.1	21.0	24.5	21.8	26.3	19.5	24.6	26.1	10.1	10.3	23.2	19.6
Density	258.9	261.7	258.4	260.8	259.3	262.1	256.8	259.8	258.7	259.4	258.7	261.1
R+M/2	88.0	92.1	88.0	91.9	88.0	92.7	86.8	89.0	87.7	88.5	87.8	91.4
Aromatics	24.9	17.6	24.9	18.1	26.0	16.9	19.3	16.0	22.6	21.8	24.3	18.1
Benzene	0.62	0.44	0.63	0.44	0.63	0.40	0.80	0.93	0.55	0.53	0.63	0.49
Olefins	14.3	11.6	10.7	9.3	14.2	10.3	8.0	8.9	6.7	6.4	11.8	9.8
Oxygen (wt%)	1.6	9.2	2.0	8.0	1.2	10.0	1.4	6.2	3.6	4.7	1.9	8.2
E200	49.7	69.0	54.5	72.1	48.1	69.5	58.9	69.9	58.1	60.9	52.5	68.6
E300	93.9	87.1	91.5	95.1	93.9	85.9	93.9	95.9	86.2	86.6	92.2	89.2
Energy (MMBtu/Bbl	5.061	4.706	4.983	4.689	5.101	4.676	5.004	4.803	4.988	4.939	5.036	4.740

Chapter 5: Economic Impacts and Benefits

5.1 Agricultural Impacts

5.1.1 Models Utilized

EPA used a suite of tools to model the potential domestic and international impacts of the RFS2 renewable fuel volumes on the agricultural sector. The Forest and Agricultural Sector Optimization Model (FASOM), developed by Professor Bruce McCarl of Texas A&M University and others, provides detailed information on domestic agricultural and greenhouse gas impacts of renewable fuels. The Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University and the University of Missouri-Columbia maintains a number of econometric models that are capable of providing detailed information on impacts on international agricultural markets from the wider use of renewable fuels in the U.S. EPA worked directly with the Center for Agriculture and Rural Development (CARD) at Iowa State University to implement the FAPRI model to analyze the impacts of the RFS2 on the global agriculture sector. Thus, this model will henceforth be referred to as the FAPRI-CARD model.

FASOM is a long-term economic model of the U.S. forest and agricultural sectors that maximizes the net present value of the sum of producer and consumer surplus across the two sectors over time subject to market, technology, and other constraints. Using a number of inputs, the agricultural component of FASOM determines the equilibrium combination of crops, livestock, and processed agricultural products that would be produced in the U.S. for each model solution period. In each model simulation, crops and livestock compete for price sensitive inputs such as land and labor at the regional level. The cost of these and other inputs are used to determine the price and level of production of primary commodities (e.g., field crops, livestock, and biofuel products). FASOM also estimates prices using costs associated with the processing of primary commodities into secondary products (e.g., converting livestock to meat and dairy products, crushing soybeans to soybean meal and oil). FASOM does not capture short-term fluctuations (i.e., month-to-month, annual) in prices and production, however, as it is designed to identify long-term trends.

The FASOM model also contains a forestry component, which details forest acres across the U.S., as well as production of forestry products. Running the forestry and agriculture components of the model simultaneously shows the interaction between these two sectors as they compete for land, as well as the effect on products and prices in each respective sector. In total, FASOM includes a representation of seven major land use categories, including cropland, cropland pasture, forestland, forest pasture, rangeland, developed land, and acres enrolled in the Conservation Reserve Program (CRP). More information on these land categories can be found below in Chapter 5.1.2.

FASOM uses supply and demand curves for the 11 major U.S. domestic regions,[256] which are calibrated to historic price and production data. FASOM also includes detailed supply

[256] U.S. regions consist of the Pacific Northwest (West and East), Pacific Southwest, Rocky Mountains, Great Plains, Southwest, South Central, Corn Belt, Lake States, Southeast, and the Northeast.

and demand data for corn, wheat, soybeans, rice and sorghum across 37 foreign regions.[257] FASOM contains transportation costs to all regions and then uses all of this information to solve for the level of U.S. exports where prices are then equated in all markets.

We chose to use FASOM to model the full potential impacts on the domestic agricultural and forestry sectors given higher renewable fuel volumes, in part because FASOM also provides detailed greenhouse gas information resulting from these changes (see Chapter 2 of this RIA for more information). FASOM does not model agricultural sector changes internationally, however. Therefore, we are working with the FAPRI-CARD modeling system to better understand international agricultural impacts. Additional details on the FASOM model are included in the docket.[258]

The FAPRI-CARD models are a system of econometric models covering many agricultural commodities. These models capture the biological, technical, and economic relationships among key variables within a particular commodity and across commodities. They are based on historical data analysis, current academic research, and a reliance on accepted economic, agronomic, and biological relationships in agricultural production and markets. The international modeling system includes international grains, oilseeds complex, biofuel (ethanol and biodiesel), sugar, cotton, dairy, and livestock models. In general, for each commodity sector, the equilibrium economic relationship that supply equals demand is solved by determining a market-clearing price for the commodity. In countries where domestic prices are not solved endogenously, these prices are modeled as a function of the world price using a price transmission equation. Since econometric models for each sector are linked, changes in one commodity sector will impact other sectors. Elasticity values for supply and demand responses are based on econometric analysis and on consensus estimates. Additional details on the FAPRI-CARD models are included in the docket.[259]

Agricultural and trade policies for each commodity in a country are included in the models to the extent that they affect the supply and demand decisions of the economic agents. These policies include taxes on exports and imports, tariffs, tariff rate quotas, export subsidies, intervention prices, and set-aside rates. The FAPRI-CARD models assume that existing agricultural and trade policy variables will remain unchanged in the outlook period.

We recognize that there are inherent challenges in reconciling the results from two different models, however using two models provides a more complete and robust analysis than either model would be able to provide alone. As described in Chapter 5.1.3, we have attempted to align as many of the key assumptions as possible to get a consistent set of modeling results. However, there are structural differences in the models that account for some of the differences

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[257] FASOM Foreign Regions include: the European Economic Community, North Central Europe, Southwest Europe, Eastern Europe, Adriatic, Eastern Mediterranean, Former Soviet Union, North Africa, East Africa, West Africa, South Africa, Red Sea, Iran, India, Taiwan, Japan, South Korea, North Korea, China, Bangladesh, Indonesia, Myanmar, Pakistan, Philippines, Thailand, Vietnam, West Asia, Southeast Asia, Australia, Caribbean, Eastern Mexico, Eastern South America, Western South America, Argentina, Brazil, Canada, Other.
[258] Beach, Robert; McCarl, Bruce, *U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description*, RTI International, January, 2010.
[259] *Technical Report: An Analysis of EPA Renewable Fuel Scenarios with the FAPRI-CARD International Models*, CARD Staff, December, 2009.

in the model results. For example, since FASOM is a long-term dynamic optimization model, short-term spikes are smoothed out over the five year reporting period. In comparison, the FAPRI-CARD model captures annual fluctuations that may include short-term supply and demand responses. In addition, some of the discrepancies may be attributed to different underlying assumptions pertaining to elasticities of supply and demand for different commodities. These differences, in turn, affect projections of imports and exports, acreage shifting, and total consumption and production of various commodities. Some of the differences in results are described in more detail in the following sections.

5.1.2 Model Modifications Since the RFS2 Proposal

Since the analysis for the RFS2 proposal was completed, a number of updates have been made to the FASOM and FAPRI-CARD models to reflect comments received and the availability of new data. The major changes to the agricultural modeling framework include adding price-induced yields, updating cellulosic yields, updating distillers grains replacement rates of corn and soybean meal in animal feed, adding corn oil from extraction as a biodiesel fuel pathway, adding additional land categories in the FASOM model, and adding a detailed Brazil module to the FAPRI-CARD modeling system.

5.1.2.1 Price-Induced Yields

The FAPRI-CARD model includes elasticity factors for yields to respond to changes in prices over time both in the U.S. and internationally. As the price of corn increase, farmers, seed producers, and others involved in crop production have an additional incentive to improve yields. The price induced yield phenomenon is partially offset by the reduced yields that result from expanding on to new crop acres, which is often referred to as extensification. However, the price-induced yield impact is projected to be larger than the extensification effect. For example, in 2022 the price of corn increases by $0.10 (3.3 percent) in the U.S. In response, the average corn yield in 2022 increases by 0.4 bushels per acre (0.4 percent). In another example, in 2022, world corn prices increase by $0.12 per bushel (3.1 percent). As a result, corn yields in China increased from 101.9 bushels per acre in the Reference Case to 102.3 bushels per acre in the Control Case in 2022, a 0.3 percent improvement. Additional details on the methodology behind the estimation of price-induced yields can be found in the FAPRI-CARD Technical Report in the docket.[260] Additional international results can be found below in this chapter.

5.1.2.2 Cellulosic Yields

Based on new research conducted by the National Renewable Energy Laboratory (NREL), we have updated the rates of conversion for cellulosic feedstocks into ethanol in the FASOM model.[261] As a result of these changes, the gallons per ton yields for switchgrass and several other feedstocks increased from the values used in the RFS2 proposal, while the yields for corn residue and several other feedstocks decreased slightly from the values used in the proposal. For additional detail, please see chapters 1 and 2. In addition, we also updated our

[260] *Technical Report: An Analysis of EPA Renewable Fuel Scenarios with the FAPRI-CARD International Models*, CARD Staff, December, 2009.
[261] Tao, Aden, *Technoeconomic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR)*, Nov. 2008.

switchgrass production yields based on new work conducted by the Pacific Northwest National Laboratory (PNNL).[262] In the analysis for the RFS2 proposal, national average switchgrass yields were 6.3 wet tons per acre in the Control Case in 2022. For the final rulemaking analysis, national average switchgrass yields are 7.8 wet tons per acre in the Control Case in 2022. For more information on switchgrass yields, please refer to the FASOM technical documentation.[263]

5.1.2.3 Distillers Grains Replacement Rates

One of the byproducts of the dry mill ethanol processes is the creation of distillers grains with solubles (DGS). This byproduct is a common source of animal feed, and can be used to feed beef cattle, dairy cows, swine, and poultry. When DGS are used in feed, they can replace other sources of feed that would otherwise be used, such as corn and soybean meal. Based on research conducted by Argonne National Laboratory,[264] one pound of DGS can be used to replace 1.196 pounds of total corn and soybean meal for various beef cattle and dairy cows due to the ability of this livestock to take advantage of the higher nutritional content of DGS per pound compared to corn and soybean meal. Current livestock production practices use 1 pound of DGS to replace 1 pound of a combination of corn and soybean meal. For our analysis, the replacement rates for corn and soybean meal increase steadily over time from a 1:1 replacement rate, to the maximum technological replacement rate of 1:1.196 in 2015 for beef cattle and dairy cows. A replacement rate of 1:1 is used for swine and poultry throughout the time period analyzed. Based on work by Shurson,[265] DGS produced in combination with the corn oil fractionation/extraction processes has different nutritional characteristics than traditional DGS containing higher levels of oil. According to this research, fractionated/extracted DGS replaces a slightly higher proportion of soybean meal rather than corn compared to traditional DGS when used for swine and poultry feed (although the total displacement rate for both types of DGS is 1:1). We have therefore used these modified replacement rates of corn and soybean meal for fractionated/extracted DGS fed to swine and poultry. The Shurson paper does not include changes in replacement rates of corn and soybean meal for beef cattle and dairy cows, so replacement rates are assumed to be the same for traditional DGS and fractionated/extracted DGS. Maximum inclusion rates for DGS in feed are 40 to 50 percent for beef, 27 to 30 percent for dairy, and 21 to 25 percent for swine and poultry.

5.1.2.4 Corn Oil Extraction as Biodiesel Pathway

For the RFS2 analysis, both FASOM and FAPRI-CARD explicitly model corn oil withdrawn from the extraction as a source for biodiesel. Based on engineering research (see Chapter 1.4) regarding expected technological adoption, it is estimated that 70 percent of dry mill ethanol plants will withdraw corn oil via extraction from distillers grains, resulting in corn

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[262] Thomson, A.M., R.C. Izarrualde, T.O. West, D.J. Parrish, D.D. Tyler, and J.R. Williams. 2009. *Simulating Potential Switchgrass Production in the United States*. PNNL-19072. College Park, MD: Pacific Northwest National Laboratory.
[263] Beach, Robert; McCarl, Bruce, *U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description*, RTI International, January, 2010.
[264] Salil Arora, May Wu, and Michael Wang, "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis," September 2008. See http://www.transportation.anl.gov/pdfs/AF/527.pdf
[265] Shurson, *The Value of High-Protein Distillers Coproducts in Swine Feeds*, Distillers Grains Quarterly, First Quarter 2006.

oil that is non-food grade and can only be used as a biodiesel source; 20 percent will withdraw corn oil via fractionation (prior to the creation of distillers grains), resulting in corn oil that is food-grade; and 10 percent will do neither extraction or fractionation.

5.1.2.5 Detailed Land Use Categories

Since the proposal, the FASOM model has been updated to include several additional land use categories covering the majority of the U.S. land base. These categories are based on the USDA National Agriculture Statistics Service (NASS) data. These land classifications enable the FASOM model to explicitly link the interaction between livestock, pasture land, cropland, and forest land. For each of these categories, FASOM accounts for how much is actively used in production, and how much idled, in a particular time period. A brief description of these categories is described below. Additional detail on the land categories are included in the technical report on the FASOM model included in the docket.[266]

- **Cropland** is actively managed cropland, used for both traditional crops (e.g., corn and soybeans) and dedicated energy crops (e.g., switchgrass).
- **Cropland pasture** is managed pasture land used for livestock production, but which can also be converted to cropland production.
- **Forestland** contains a number of sub-categories, tracking the number of acres of private forestland existing at the starting point of the model that remain in standing forests (i.e., have not yet been harvested), the number of acres harvested, the number of harvested acres that are reforested, and the area converted from other land uses (afforested). Public forestland area is not explicitly tracked because it is assumed to remain constant over time, although exogenous estimates of forest products production from these lands are included in the model.
- **Forest pasture** is unmanaged pasture land with varying amounts of tree cover that can be used for livestock production. A portion of this land may be used for timber harvest.
- **Rangeland** is unmanaged land that can be used for livestock grazing production. While the amount of rangeland idled or used for production may vary, it is assumed that rangeland may not be used for any other purpose than for animal grazing due to its low productivity. In addition, much of the rangeland in the U.S. is publicly owned.
- **Developed** (urban) land is assumed to have an inherently higher value than land used for any other use. Thus, the rate of urbanization is assumed to be exogenous based on projections of population and income growth and does not change between the cases analyzed.
- **Conservation Reserve Program (CRP)** refers to land that is voluntarily taken out of crop production and placed in the USDA CRP. Land in the CRP is generally marginal cropland retired from production and converted to vegetative cover, such as grass, trees, or woody vegetation to conserve soil, improve water quality, enhance wildlife habitat, or produce other environmental benefits.

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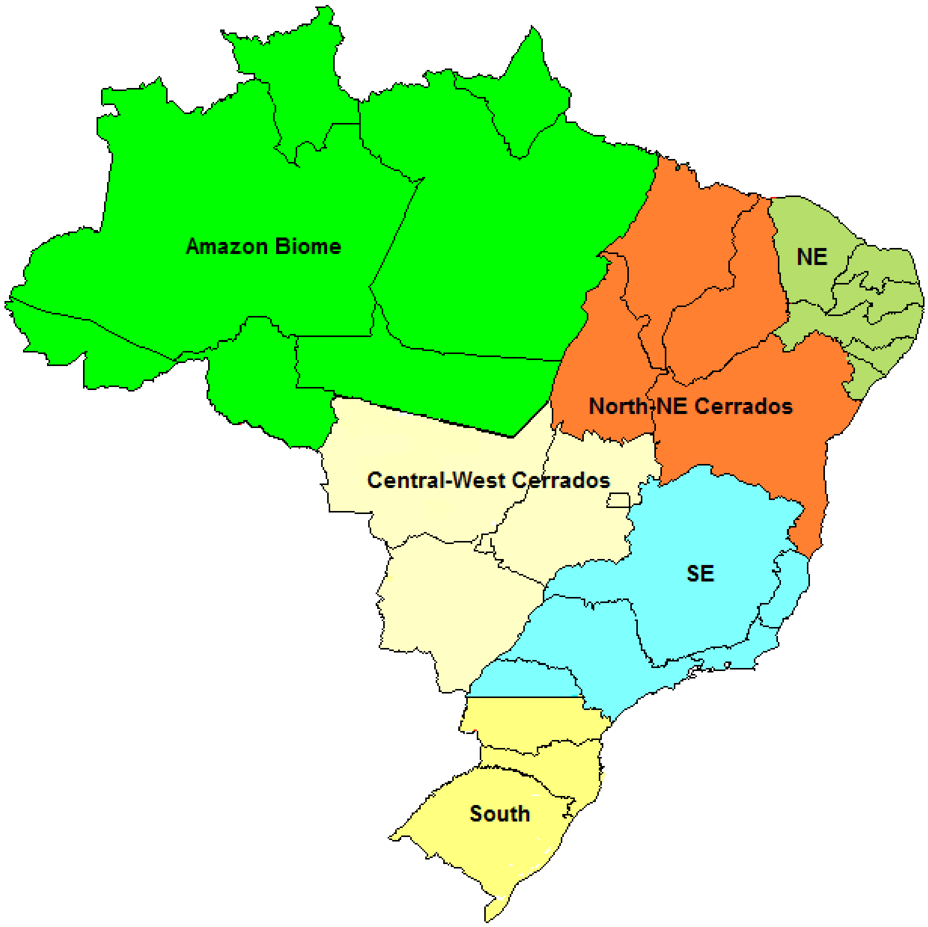
[266] Beach, Robert; McCarl, Bruce, *U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description*, RTI International, January, 2010.

5.1.2.6 Brazil Module

In the FAPRI-CARD modeling system, all non-U.S. countries are analyzed at the national level, with the exception of Brazil. Due to the importance of Brazil in determining the international impacts of increased biofuel demand, including the increase in U.S. demand for imported ethanol, the FAPRI-CARD model was updated to include additional agricultural detail in Brazil. The FAPRI-CARD model now includes an integrated Brazil module that provides additional detail on agricultural land use in Brazil for six geographic regions: the Amazon Biome, Northeast (NE), North-Northeast Cerrados (North-NE Cerrados), Central-West Cerrados, Southeast (SE), and the South. The Brazil module explicitly models the competition between cropland and pastureland used for livestock production in each region. In addition, the Brazil module allows for region-specific agriculture practices such as double cropping and livestock intensification in response to higher commodity prices. This level of detail allows for a more refined analysis of land use change and economic impacts in Brazil than a national-level analysis. For more detail on the Brazil module and its development, please refer to the FAPRI-CARD model technical report in the docket.[267]

[267] *Technical Report: An Analysis of EPA Renewable Fuel Scenarios with the FAPRI-CARD International Models*, CARD Staff, December, 2009

Figure 5.1-1.
Map of Brazil by Geographic Region in FAPRI-CARD



5.1.3 Key Modeling Assumptions

To analyze the U.S. and international agriculture sectors impact of the RFS2 renewable fuel volumes, a number of key assumptions and input parameters were standardized in the FASOM and FAPRI-CARD models. These assumptions were developed with the input of other government agencies, such as USDA and DOE. As shown in Table 5.1-1, key assumptions include corn and soybean yields,[268] corn ethanol dry and wet mill plant processing energy use, corn ethanol yields, corn ethanol by-product use, estimated corn stover yields, domestic energy prices,[269] and others. For other estimates of input parameters, we relied on external expertise, such as the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET)

[268] USDA Agricultural Projections to 2018 (OCE-2009-1), February, 2008.
[269] Energy prices in all cases are based on the April Release of the 2009 Annual Energy Outlook, published by the Energy Information Administration (EIA) within DOE. Prices used include Gasoline, Diesel, E85, Coal, and Electricity. See: http://www.eia.doe.gov/oiaf/servicerpt/stimulus/index.html

model;[270] the Assessment System for Population Exposure Nationwide (ASPEN) model;[271] and the Agriculture Resource Management Survey (ARMS).[272] Additional details on the assumptions included in FASOM[273] and FAPRI-CARD[274] are included in the docket.

[270] The GREET model is run by Argonne National Laboratory at the Department of Energy. GREET can simulate more than 100 fuel production pathways and more than 80 vehicle/fuel systems.

[271] ASPEN is a computer simulation model used to estimate toxic air pollutant concentrations is called the Assessment System for Population Exposure Nationwide. This model is based on the EPA's Industrial Source Complex Long Term model (ISCLT) which simulates the behavior of the pollutants after they are emitted into the atmosphere. ASPEN uses estimates of toxic air pollutant emissions and meteorological data from National Weather Service Stations to estimate air toxics concentrations nationwide.

[272] ARMS is sponsored by the Economic Research Service (ERS) and National Agricultural Statistics Service (NASS) at USDA, and provides observations of field-level farm practices, the economics of the farm business, and the characteristics of the American farm household.

[273] Beach, Robert; McCarl, Bruce, *U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description*, RTI International, January, 2010.

[274] *Technical Report: An Analysis of EPA Renewable Fuel Scenarios with the FAPRI-CARD International Models*, CARD Staff, December, 2009.

Table 5.1-1.
Agriculture Model Assumptions

Assumption	Notes
Feedstock Production	
Prices for Gasoline, Diesel, E85, Coal, and Electricity used in all volume cases	AEO 2009, April Release
U.S. national average corn yields are approximately 170 bu/acre in 2017 and 180 bu/acre in 2022 (a 1.6% annual increase over the baseline year)	Consistent with USDA projections (http://www.ers.usda.gov/publications/oce081/)
U.S. national average soybean yields are approximately 50 bu/acre in 2022 (a 0.4% annual increase)	
International corn yields increasing over time, for example: Argentina ~134 bu/acre in 2022 (a 1.2% annual increase) Brazil ~72 bu/acre in 2022 (a 1.7% annual increase)	FAPRI-CARD Models
International soybean yields increasing over time, for example: Argentina ~46 bu/acre in 2022 (a 0.9% annual increase) Brazil ~46 bu/acre in 2022 (a 0.9% annual increase)	
Price-Induced Yields, for example: World Price of Corn increases by 3.1% from the Reference Case to the Control Case in 2022; Corn Yields in China increases by 0.3% from the Reference Case to the Control Case in 2022	
High Yield sensitivity runs for corn and soybeans: For example, U.S. High Yields in 2022: Corn: approximately 232 bu/acre (28% higher than Base Yield) Soybeans: approximately 61 bu/acre (31% higher than Base Yield) Similar yield increases for top producers of corn (China, Mexico, EU, Argentina, Brazil) and soybeans (China, Argentina, Brazil)	FASOM and FAPRI-CARD Models Represented as increases in technological rates of progress, no additional inputs required
Corn residue removal rates of 50% are allowed for no till practices; 35% removal rate allowed for reduced till practices (no removal from conventional till)	Derived from Graham et. al., Agronomy Journal, 99:1–11 (2007). “Current and Potential U.S. Corn Stover Supplies.” and Perlack, R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-ton Annual Supply. Report prepared for the U.S. Department of Energy and the U.S. Department of Agriculture.

Updated Conversion Rates (gallons per dry ton) for all cellulosic ethanol feedstock sources. For example: Proposal Analysis: Corn Resiude: 94.2 gallons/dry ton Switchgrass: 78.9 gallons/dry ton Final Rule Analysis: Corn Resiude: 92.3 gallons/dry ton Switchgrass: 92.3 gallons/dry ton	Based on NREL Research Tao, Aden, *Technoeconomic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR)*, Nov. 2008.
Switchgrass Yields by Region in the U.S.	Based on preliminary PNNL Research
Non-Food Grade (NFG) Corn Oil modeled in FASOM and FAPRI-CARD as a biodiesel feedstock. NFG Corn Oil is a byproduct of the extraction and fractionation processes of dry mill ethanol plants.	Based on engineering cost projections and expected rates of technology adoption. See Chapter 1 of the RIA. By 2022: 70% of dry mill ethanol plants will conduct extraction, 20% will conduct fractionation, and 10% will do neither
The Conservation Reserve Program (CRP) has a maximum limit of 32 million acres enrolled in the program at any given time	2008 Farm Bill USDA baseline assumptions
Fertilizer Use	
U.S. nitrogen application rate for corn is approximately 136 lbs/acre in the corn belt in 2022 U.S. phosphorous application rate for corn is approximately 28 lbs/acre in the corn belt in 2022	Based on ARMS data, adjusted for differences in regions and irrigation practices
For U.S. assume higher yields require no increase in fertilizer use	Based on USDA baseline assumptions This holds for all farming rotations (e.g., corn / soybean and corn / corn) and land types (e.g., prime and marginal land); see below for stover removal impacts
Nitrogen nutrient replacement application = 7 lbs/ton corn residue removed Phosphorous nutrient replacement application = 3.6 lbs/ton corn residue removed	These numbers come from the Argonne National Lab Report, Fuel Cycle Assessment of Selected Bioethanol Production Pathways in the United States. (November 7, 2006). (Used and cited by GREET)
Processing	
1 bushel of corn produces 17 lbs of dried distillers grains (dry tons). 1 pound of DGS substitutes 1.196 pounds of corn and soybean meal feed for beef cattle, dairy cows by 2015 1 pound of DGS substitutes 1 pound of corn and soybean meal feed for swine and poultry, with adjustments for fractionated/extracted DGS	www.ethanol.org Argonne National Laboratory: Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis," September 2008 Shurson: The Value of High-Protein Distillers Coproducts in Swine Feeds, Distillers Grains Quarterly, First Quarter 2006.

Projected crop yields, both domestically and internationally, are an important factor in the analysis of increased renewable fuel volumes. The U.S. yields presented in Table 5.1-1 are based on the USDA projections through 2018 (the last year of the USDA baseline projections report) and then extrapolated out to 2022. The U.S. yields in this table represent the national weighted average yields, with yields varying across regions. Regional yields are based on historical averages for the region. Although the initial crop yields vary by region, the regional yield for each crop is increased at the same crop-specific annual percentage rate. For instance, FASOM assumes the rate of increase for corn yields are 1.6 percent per year. The rates of increase are assumed to be the same in both the AEO 2007 Reference Case and the EISA Control Case.

The international crop yields included in FAPRI-CARD are different for each country and for each crop. The FAPRI-CARD model bases each country's crop yield on historical trends and projects this technical rate of progress into the future. As described in the previous section, the FAPRI-CARD model also incorporates yield responses to changes in price and for expansion onto marginal lands. Examples of how yields vary by region and crop are included in Table 5.1-1.

For the lifecycle analysis, sensitivity runs were conducted in both FASOM and FAPRI-CARD to observe the effects of higher yields for both corn and for soybeans. The assumption behind these high-yield runs is that the technological rate of progress over time is higher for corn and soybeans than compared to our "base yield" modeling efforts used for the rulemaking impacts. This increase in the technological rate of progress begins in 2012 in the FASOM model, and in 2010 in the FAPRI-CARD model (the next future time period in each respective model). By 2012, Corn yields in the U.S. are 7.1 percent higher in the High Yield Control Case than in the Base Yield Control Case. By 2017, it is 18 percent higher, and by 2022 it is 30 percent higher. Similarly, soybean yields in the U.S. are 7.8 percent higher in 2012, 20 percent higher in 2017, and 31 percent higher in the High Yield Control Case than in the Base Yield Control Case. In the FAPRI-CARD model, similar increases in technological rates of progress for corn were applied to other top corn producers (China, Mexico, the EU, Argentina, and Brazil), and likewise for other top soybean producers (China, Argentina, and Brazil). Results from these high yield sensitivity runs can be found in Chapter 2 of the RIA. Table 5.1-2 lists the yields for the top producers of corn and soybeans in the Control Case in 2022, both for the "base" results and for the "high-yield" results. For overall impacts of the "high-yield" sensitivity model runs, please refer to Chapter 2.

Table 5.1-2.
Corn and Soybean Yields of Top Producers in the Control Case in 2022 with "Base Yield" and "High-Yield" Sensitivity Runs (bushels per acre)

Corn			
Country	**Base Yield**	**High Yield**	**% Difference**
U.S.	181.2	231.6	27.9%
China	102.3	129.9	27.0%
Mexico	55.8	70.9	27.0%
EU	110.5	140.4	27.0%
Argentina	133.9	170.1	27.0%
Brazil *	72.2	81.8	13.3%
Soybeans			
Country	**Base Yield**	**High Yield**	**% Difference**
U.S.	46.0	60.5	31.4%
China	29.8	38.9	30.4%
Argentina	46.1	60.1	30.4%
Brazil *	46.3	57.8	25.0%

* Note: Yields in individual regions in Brazil are 27% higher than in the Base yield, similar to other countries. However, since some regions are more productive than others, the regional distribution of soybean production is different between the "Base" and "High-Yield" model runs. This results in the overall yields of corn and soybeans in Brazil in the "High Yield" sensitivity run to not be the same percentage higher than the "Base" model run compared to other countries.

For cellulosic biofuels from corn residues, the current assumptions in FASOM for residue removal rates are based on the Graham et. al. paper[275] and the Perlack et. al. study.[276] This approach uses a maximum percent removal of residues on acres based on tillage practices.[277] Although we requested comment on whether a better metric is the minimum amount of mass that must remain on an acre of land to prevent runoff and maintain soil carbon levels, we did not receive sufficient data to incorporate this approach into our modeling framework.[278]

FASOM assumes fertilizer application rates do not increase over time in proportion to the increase in yields (i.e., delinks fertilizer application rates and crop yield changes through time). The principal reason for this is USDA data that shows fertilizer application rates per acre remaining relatively steady for the past 30 years, during which time corn yields have increased approximately 70 percent.[279] However, when residues are removed from the field, some of the nutrients that are contained in the residue must be replaced through additional fertilizer use. For the analysis, we assumed that 7 additional pounds of nitrogen and 3.6 pounds of phosphorous must be applied per ton of corn stover residue removed.[280]

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[275] See also http://www.cpnrd.org/Harvesting%20Stover.pdf
[276] Available at http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf.
[277] Many site specific factors associated with the sustainable removal of residue (e.g., crop type, soil type, soil fertility, slope, and climate) affect which geographic regions are suitable for crop residue removal. Detailed modeling of these factors was beyond the scope of this analysis.
[278] Wilhelm et. al Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply, Ag Journal (2007)
[279] Data from the National Agriculture Statistics Service (NASS) at USDA: http://www.nass.usda.gov/
[280] Wu, M., M. Wang, and H. Huo. Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States. ANL/ESD/06-7. November 2006.

Lastly, there is a limit to how many acres of cropland can be placed in the Conservation Reserve Program (CRP).[281] CRP is run by the Natural Resources Conservation Service at USDA. This program is designed to maintain Federal, State, and tribal environmental laws by making payments to farmers equivalent to the income otherwise earned from developing the land enrolled in the program. In the 2008 Farm Bill, the number of acres enrolled in the CRP was given a maximum limit of 32 million acres. Based on input from USDA, we assumed that USDA will increase payments to maintain 32 million acres in CRP through 2022.

5.1.4 Volumes

For the agricultural sector analysis, we modeled the AEO2007 Reference Case and the Control Case (i.e., EISA mandated) volumes described in Chapter 1.2. Where possible, we modeled the same volumes in both FASOM and FAPRI-CARD. However, some of the projected future sources of renewable fuels are not explicitly included in both models. For example, since FASOM is a domestic agriculture and forestry model, it cannot explicitly model U.S. biofuel imports and their impacts on worldwide trade and land use as the FAPRI-CARD model does. In addition, the FAPRI-CARD model does not currently model cellulosic renewable fuel feedstock production. Therefore, the cellulosic renewable fuel analysis relies on results from the FASOM model.[282] Neither of the two models used for this analysis — FASOM or FAPRI-CARD — include biofuel produced from domestic municipal solid waste (MSW). Thus, for the RFS2 analysis, this biofuel was modeled outside of the agriculture sector. For more information on how MSW was modeled elsewhere in the RFS2 analysis, please see Chapters 1 and 2. We estimate that approximately 2.3 Bgal of cellulosic renewable fuels will be produced from municipal solid waste in 2022.

All the results presented in the following section are relative to the AEO 2007 Reference Case renewable fuel volumes, which include 12.3 Bgal of grain-based ethanol, 0.1 Bgal of biodiesel from soybean oil, 0.3 Bgal of biodiesel from waste oils and greases, 0.3 Bgal of cellulosic ethanol, and 0.6 Bgal of imported ethanol in 2022. The domestic figures are provided by FASOM and FAPRI-CARD, and all of the international numbers are provided by FAPRI-CARD. For a more detailed set of results of the agricultural sector impacts of the RFS2 volumes, see the analytical reports submitted by the FASOM and FAPRI-CARD modeling groups in the docket of this rule.

For ethanol, we assumed 15 billion gallons (Bgal) of corn ethanol would be produced for use as transportation fuel in the U.S. by 2022 in the Control Case in both FASOM and FAPRI-CARD. FASOM modeled an increase of 13.5 Bgal of cellulosic renewable fuel from the Reference Case in 2022.[283] To satisfy the cellulosic renewable fuel requirements, the FASOM model was allowed to choose how much cellulosic renewable fuel was produced from different feedstocks, taking account the various harvesting and processing costs and the income the

[281] See: http://www.nrcs.usda.gov/programs/CRP/
[282] The FAPRI-CARD model was used to estimate the indirect land use effects of additional switchgrass acres on other crops in the U.S., as shown by the FASOM model, and the resultant impacts on trade and land use worldwide. Please refer to Chapter 2 of the RIA for more information.
[283] FASOM does not include renewable diesel or biomass to liquids as potential cellulosic pathways, therefore all cellulosic volumes were assumed to be ethanol.

agriculture and forestry sectors derive from each feedstock. FASOM projects that 7.9 Bgal of cellulosic renewable fuel will be produced from switchgrass in 2022, 4.9 Bgal from corn residue, 0.4 Bgal from sugarcane bagasse, and 0.1 billion gallons from forestry logging and milling residues. FAPRI-CARD modeled an increase of 1.6 Bgal from ethanol imported to the U.S. over the AEO2007 Reference Case level in 2022.

For biodiesel, both FASOM and FAPRI-CARD modeled an increase of 0.5 Bgal of biodiesel produced from soybean oil above the AEO2007 Reference Case in 2022. FASOM and FAPRI-CARD also modeled an increase of 0.1 Bgal of biodiesel produced from various animal fats, waste oils, and greases to 0.4 Bgal in the Control Case in 2022. Similarly, FASOM and FAPRI-CARD modeled an increase of 0.6 Bgal of biodiesel from non-food grade corn oil. This non-food grade corn oil used for biodiesel production is a byproduct of dry mill ethanol plants that undertake the extraction processes.

Table 5.1-3.
Biofuel Volumes Modeled in 2022
(Billions of Gallons)

Biofuel	AEO2007 Reference Case	Control Case	Change
Corn Ethanol	12.3	15.0	2.7
Switchgrass Cellulosic Ethanol	0	7.9	7.9
Corn Residue Cellulosic Ethanol	0	4.9	4.9
Sugarcane Bagasse Cellulosic Ethanol	0.2	0.6	0.4
Forest Residue Cellulosic Ethanol	0	0.1	0.1
Imported Ethanol	0.6	2.2	1.6
Total Ethanol (FASOM)	12.5	28.7	16.2
Total Ethanol (FAPRI-CARD)	13.2	17.5	4.3
Soybean Oil Biodiesel	0.1	0.6	0.5
Corn Oil NFG Biodiesel	0.0	0.6	0.6
Biodiesel from Other Fats, Oils, Greases	0.3	0.4	0.1
Total Biodiesel	0.4	1.7	1.3

5.1.5 Domestic Agricultural Impacts

For this economic analysis, the FASOM model is utilized for all domestic agriculture impacts. Although the FAPRI-CARD models do not provide the same amount of detail on GHG emissions for the domestic agriculture impacts as the FASOM model, FAPRI-CARD does estimate some of the same outputs, such as national crop acres, prices, and exports. In this section, we present both the FASOM and FAPRI-CARD results to demonstrate the range of potential agricultural impacts. Presenting both sets of results allows for a useful comparison between the two models, reinforces the accuracy of our domestic analysis, and ensures consistency when analyzing the impacts of the RFS2 fuel volume requirements on the domestic and international agriculture markets.

5.1.5.1 Commodity Prices

To meet the RFS2 renewable fuel volumes, there are a number of price effects on the agricultural commodities. For instance, FASOM estimates that the Control Case renewable fuel volumes result in an increase in the U.S. corn price of $0.27 per bushel (8.2 percent) above the Reference Case price in 2022. By 2022, FASOM projects that U.S. soybean prices increase by $1.02 per bushel (10.3 percent) above the Reference Case price. FASOM also projects the price of soybean oil increases by $183 per ton (37.9 percent) over the 2022 Reference Case price. In 2022, FAPRI-CARD projects that the price of corn increases by $0.10 per bushel (3.3 percent), the price of soybeans increases by $0.07 per bushel (0.9 percent), and the price of soybean oil increases by $12.35 (1.6 percent) relative to the AEO2007 Reference Case.

FASOM projects that the price of switchgrass increases by $20.12 per wet ton as a result of the Control Case renewable fuel volumes in 2022. Similarly, the price of corn residue increases by $29.48 per wet ton in 2022, relative to the AEO2007 reference case. FASOM also projects that the Control Case price of sugarcane bagasse increases by $23.27 per wet ton in 2022. By 2022, FASOM projects that hardwood and softwood logging residues are used to produce cellulosic ethanol, and their prices are $23.22 per wet ton and $18.37 per wet ton, respectively, in 2022 in the Control Case. These prices do not include the storage, handling, or delivery costs. Since the FAPRI-CARD models do not explicitly model cellulosic ethanol production from agriculture residues or dedicated energy crops, comparable price impacts are not available. Additional details on the changes in commodity prices are included in Table 5.1.4.

The prices for byproducts of renewable fuel production are also affected by the increased demand for renewable fuels required by the RFS2 rule. Soybean meal, while not exclusively used for animal feed, is an important element of the feed market. In 2022, FASOM projects that the price of soybean meal decreases by $0.48 per ton (-0.1 percent) relative to the AEO2007 Reference Case. In 2022, FASOM projects the price of fractionated/extracted DGS increases by $7.69 per ton (6.5 percent) relative to the AEO2007 Reference Case. FASOM projects that the price of traditional DGS, produced by corn ethanol plants that do not conduct fractionation or extraction of corn oil, increases by $7.94 per ton (6.8 percent) relative to the AEO2007 Reference Case in 2022. In FAPRI-CARD, the price of soybean meal increases by $1.05 (0.5 percent), and the price of DGS increases by $3.52 per ton (3.9 percent) in 2022 relative to the AEO2007 Reference Case.

Table 5.1-4.
U.S. Commodity Prices in 2022
(2007$ per Unit)

Biofuel Feedstocks								
Commodity (Unit)	**FASOM**				**FAPRI-CARD**			
	AEO 2007 Reference Case	**Control Case**	**Change**	**% Change**	**AEO 2007 Reference Case**	**Control Case**	**Change**	**% Change**
Corn (bushel)	$3.32	$3.60	$0.27	8.2%	$2.96	$3.06	$0.10	3.3%
Soybeans (bushel)	$9.85	$10.87	$1.02	10.3%	$8.12	$8.19	$0.07	0.9%
Soybean Oil (ton)	$483.10	$666.42	$183.32	38%	$782.13	$794.48	$12.35	1.6%
Switchgrass (wet ton)	$20.73	$40.85	$20.12	97%	N/A	N/A	N/A	N/A
Corn Residue (wet ton)	$5.01	$34.49	$29.48	588%	N/A	N/A	N/A	N/A
Bagasse (wet ton)	$6.43	$29.70	$23.27	362%	N/A	N/A	N/A	N/A
Hardwood Logging Residue (wet ton)	$5.37	$23.22	$17.85	332%	N/A	N/A	N/A	N/A
Softwood Logging Residue (wet ton)	$9.37	$18.37	$8.99	96%	N/A	N/A	N/A	N/A
Byproducts								
Commodity (Unit)	**FASOM**				**FAPRI-CARD**			
	AEO 2007 Reference Case	**Control Case**	**Change**	**% Change**	**AEO 2007 Reference Case**	**Control Case**	**Change**	**% Change**
Soybean Meal (ton)	$402.11	$401.63	-$0.48	-0.1%	$206.81	$207.87	$1.05	0.5%
DGS Traditional (ton)	$116.75	$124.69	$7.94	6.8%	N/A	N/A	N/A	N/A
DGS Fractionated/Extracted (ton)	$118.88	$126.57	$7.69	6.5%	N/A	N/A	N/A	N/A
DGS (Overall, FAPRI-CARD)	N/A	N/A	N/A	N/A	$90.60	$94.12	$3.52	3.9%

5.1.5.2 Commodity Use Changes

The increased demand for renewable fuels also affects the use of these feedstocks in other markets. This section will review the use of these commodities for biofuels, their levels of exports, and their use in the animal feed market. In 2022, FASOM projects an additional 1 billion bushels of corn will be used for corn ethanol production (22 percent) relative to the Reference Case. FASOM also projects that in 2022, an additional 98 million wet tons of switchgrass, 60 million wet tons of corn residue, 6.1 million tons of sugarcane bagasse, and 1.7 million tons of forestry residues will be used to produce cellulosic ethanol, relative to the AEO2007 Reference Case.

FASOM estimates that an additional 2 million tons of soybean oil is used to produce soybean biodiesel in 2022, relative to the AEO2007 Reference Case. In addition, FASOM projects that an additional 17.5 million tons of non-food grade corn oil from the extraction process will be used for biodiesel production in 2022.

The increase in renewable fuel volumes required by the RFS2 also impacts U.S. exports. For instance, FASOM estimates that the amount of corn exported from the U.S. decreases by 188 million bushels (-8.2 percent) in 2022, relative to the AEO2007 Reference Case. This change represents a decrease of $57 million (-0.8 percent) in the total value of corn exports in the FASOM model in 2022. In FAPRI-CARD, U.S. corn exports decrease by 407 million bushels (-15.7 percent) in 2022. This change translates into a decrease in the total value of corn exports of $991 million (-12.9 percent) in 2022.

Similarly, as more soybean oil is used for biodiesel production, the amount of soybeans and soybean oil exported from the U.S. can be expected to be affected. In FASOM, soybean exports decrease by 135 million bushels (-13.6 percent) in 2022 relative to the AEO2007 Reference Case. This change represents a decrease of $453 million (-4.6 percent) in the total value of U.S. soybean exports in 2022. In FAPRI-CARD, soybean exports decrease by 32 million bushels (-3 percent), relative to the AEO2007 Reference Case. This change represents a decrease in the total value of U.S. soybean exports of $185 million (-2.1 percent) in 2022. The FASOM model projects that U.S. soybean oil exports decrease by 1.2 million tons (-51 percent) in 2022 relative to the AEO2007 Reference Case. In the FAPRI-CARD model, soybean oil exports decrease by 0.3 million tons (-6.2 percent) in 2022 relative to the AEO2007 Reference Case.

Table 5.1-5.
U.S. Exports in 2022

Exports (millions of units)								
Commodity (Unit)	**FASOM**				**FAPRI-CARD**			
	AEO 2007 Reference Case	**Control Case**	**Change**	**% Change**	**AEO 2007 Reference Case**	**Control Case**	**Change**	**% Change**
Corn (bushel)	2,281	2,093	-188	-8.2%	2,589	2,182	-407	-15.7%
Soybeans (bushel)	993	858	-135	-13.6%	1,073	1,041	-32	-3.0%
Soybean Oil (ton)	2.3	1.1	-1.2	-51.2%	4.8	4.5	-0.3	-6.2%
Total Value of Exports (millions of 2007$)								
Commodity	**FASOM**				**FAPRI-CARD**			
	AEO 2007 Reference Case	**Control Case**	**Change**	**% Change**	**AEO 2007 Reference Case**	**Control Case**	**Change**	**% Change**
Corn	$7,585	$7,527	-$57	-0.8%	$7,669	$6,679	-$991	-12.9%
Soybeans	$9,780	$9,327	-$453	-4.6%	$8,709	$8,524	-$185	-2.1%

Higher U.S. demand for renewable fuels leads to an increase in the price of corn and causes a decrease in the use of corn for U.S. livestock feed. Substitutes are available for feed corn and this market is price sensitive. The total amount of corn used for feed in FASOM decreases by 3.3 million tons (-2.5 percent) in 2022 relative to the AEO2007 Reference Case. Several ethanol processing byproducts can be used to replace a portion of the corn used as feed, depending on the type of animal. DGS are a byproduct of the dry milling process, whereas gluten meal and gluten feed are byproducts of wet milling corn ethanol production. FASOM estimates that total DGS used in feed increases by 5.2 million tons (15.2 percent), gluten meal used in animal feed decreases by 0.1 million tons (-4.5 percent), and gluten feed use increases by 0.3 million tons (6.4 percent) in 2022 relative to the AEO2007 Reference Case. As DGS are used more in the feed market in the Control Case than in the Reference Case, corn and soybean meal used in the feed market is replaced. Thus, soybean meal used in feed decreases by 0.04 million tons (-0.4 percent) in 2022 to 10.5 million tons in the Control Case. Overall, the total ethanol byproducts used in feed (DGS, gluten meal, and gluten feed) increase by 5.4 million tons (13.2 percent) in 2022 relative to the AEO2007 Reference Case.

Table 5.1-6.
Animal Feed Sources in 2022
(millions of tons)

Feed Source	FASOM				FAPRI-CARD			
	AEO 2007 Reference Case	Control Case	Change	% Change	AEO 2007 Reference Case	Control Case	Change	% Change
Corn	134.4	131.1	-3.3	-2.5%	158.8	152.3	-6.5	-4.1%
Soybean Meal	10.53	10.49	-0.04	-0.4%	39.4	38.7	-0.7	-1.7%
DGS Total	34.1	39.3	5.2	15.2%	33.9	39.1	5.2	15.2%
Gluten Meal	2.2	2.1	-0.1	-4.5%	1.0	1.1	0.1	7.5%
Gluten Feed	4.5	4.8	0.3	6.4%	7.6	7.9	0.3	4.1%
Total Ethanol Byproducts	40.7	46.1	5.4	13.2%	42.5	48.1	5.5	13.0%

5.1.5.3 Changes in Crop Acres

In order to meet the Control Case volumes of renewable fuels, FASOM estimates an increase of 3.6 million acres (4.6 percent) for harvested corn acres in 2022.[284] Most of the new corn acres come from a reduction in existing crop acres, such as rice, wheat, barley, rye and hay. FASOM projects that rice acres decrease by 788 thousand acres (-20.6 percent), wheat acres decrease by 2.9 million acres (-4.9 percent), and hay acres decrease by 752 thousand acres (-1.5 percent) in 2022 relative to the AEO2007 Reference Case. See Table 5.1-7 for additional changes in crop acres in the FASOM and FAPRI-CARD models.

Although the RFS2 Control Case includes more soybean biodiesel than the AEO2007 Reference Case, competing demands for land results in a decrease in U.S. harvested soybean acres. According to the FASOM model, harvested soybean acres decrease by approximately 1.4 million acres (-2.1 percent) in 2022 relative to the Control Case. As described in the previous section, most of the additional soybeans needed for increased biodiesel production are diverted from exports. FAPRI-CARD also projects that the increased demand for biodiesel from soybean oil results chiefly in a reduction in soybean oil exports, rather than an increase in acres harvested. FAPRI-CARD projects that harvested soybean acres decrease by 0.9 million acres (-1.1 percent) in 2022 relative to the AEO2007 Reference Case.

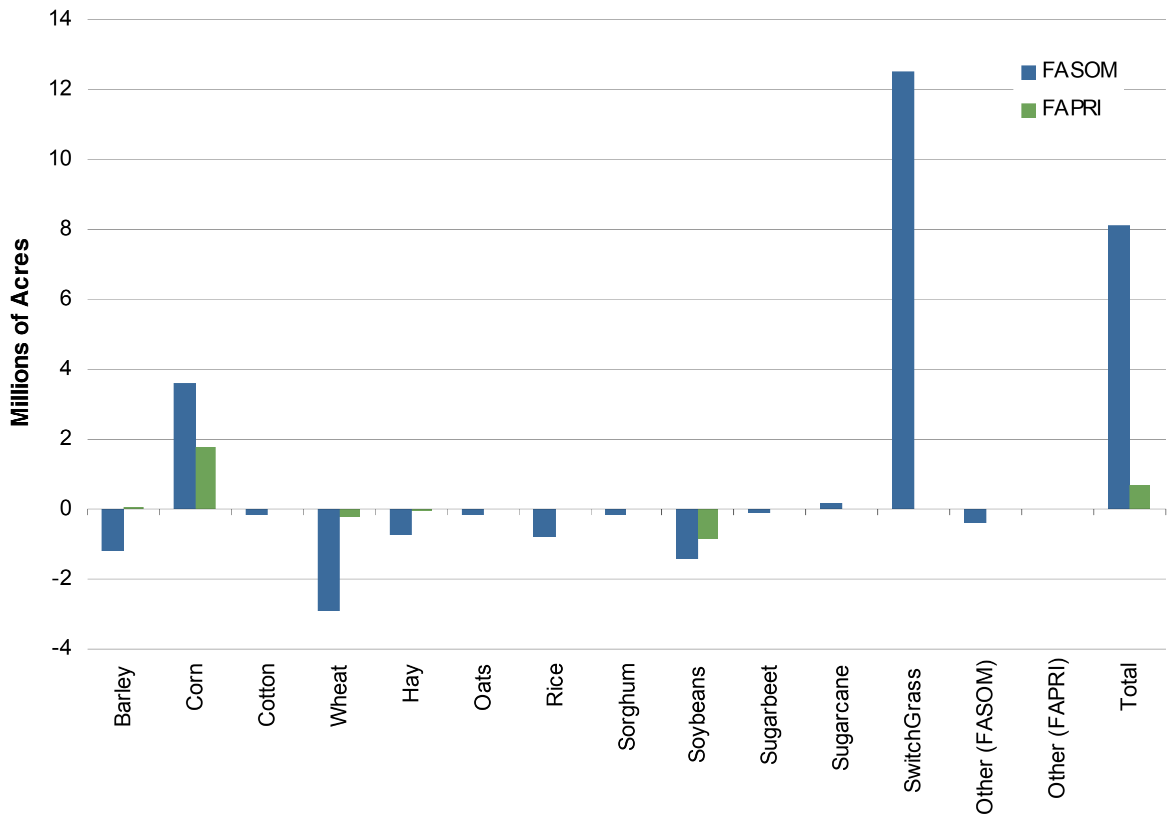
[284] FASOM estimates that total planted corn acres increase to 89.4 million acres in the Control Case from the Reference Case level of 84.6 million acres in 2017. Total planted acres increases to 87.1 million acres in the Control Case from the Reference Case level of 83.5 million acres in 2022.

As the demand for cellulosic renewable fuels increases, FASOM projects that most of the cellulosic biofuels will be derived from switchgrass. In 2022, switchgrass acres increase by 12.5 million acres, relative to the AEO2007 Reference Case. The remainder of the cellulosic biofuel is produced from corn residue, forestry residues, and sugarcane bagasse. The FAPRI-CARD models do not explicitly model the production of cellulosic renewable fuel, nor does it explicitly model the feedstocks for cellulosic renewable fuel. Table 5.1-7 and Figure 5.1-2 shows the change in acres for all crops in the U.S. in 2022.

Table 5.1-7.
U.S. Crop Acres in 2022
(millions of acres)

Crop	FASOM				FAPRI-CARD			
	AEO 2007 Reference Case	Control Case	Change	% Change	AEO 2007 Reference Case	Control Case	Change	% Change
Barley	9.7	8.5	-1.2	-12.4	2.96	3.0	0.04	1.2%
Corn	77.9	81.5	3.6	4.6%	79.1	80.9	1.8	2.2%
Cotton	11.3	11.1	-0.2	-1.7%	7.7	7.7	0.0	0.1%
Wheat	59.0	56.0	-2.9	-4.9%	48.3	48.1	-0.2	-0.5%
Hay	50.7	50.0	-0.8	-1.5%	60.8	60.8	0.0	-0.1%
Oats	5.5	5.4	-0.2	-3.2%	1.1	1.1	0.0	-1.0%
Rice	3.8	3.0	-0.8	-20.6%	2.6	2.6	0.0	0.0%
Sorghum	8.7	8.5	-0.2	-1.8%	5.8	5.8	0.0	0.3%
Soybeans	68.1	66.6	-1.4	-2.1%	78.3	77.4	-0.9	-1.1%
Sugarbeet	1.3	1.2	-0.1	-7.8%	1.2	1.2	0.0	-0.3%
Sugarcane	0.7	0.9	0.1	19.8%	0.8	0.8	0.0	0.2%
Switchgrass	0.1	12.6	12.5	20,261%	0.0	0.0	0.0	N/A
Other (FASOM)*	9.5	9.1	-0.4	-4.4%	N/A	N/A	N/A	N/A
Other (FAPRI-CARD)**	N/A	N/A	N/A	N/A	4.7	4.7	0.0	0.1%
Total	306.3	314.4	8.1	2.6%	288.7	289.4	0.7	0.2%

Figure 5.1-2.
Estimated Change in U.S. Crop Acres
Relative to the AEO 2007 Reference Case in 2022



As switchgrass and corn residue are the largest feedstocks of cellulosic renewable fuel, it is important to know which regions in the U.S. these feedstocks are the most competitive. Corn residue removal takes place chiefly in the Corn Belt region of the U.S. Based on the residue removal rates outlined in Table 5.1-1, corn acres with residue removal in the Control Case takes place mostly in Iowa (9 million acres) and Illinois (7.4 million acres). Switchgrass production, on the other hand, takes place mostly in the Southwest region of the U.S. This includes 2.7 million acres in Kansas, 1.7 million acres each in Missouri and Texas, as well as 1.3 million acres in Oklahoma. To see the top ten producing states for corn residue and switchgrass, please refer to Figures 5.1-3 and 5.1-4 below.

Figure 5.1-3.
Top Ten Producing States of Corn Acres with Residue Removal in 2022
FASOM Control Case

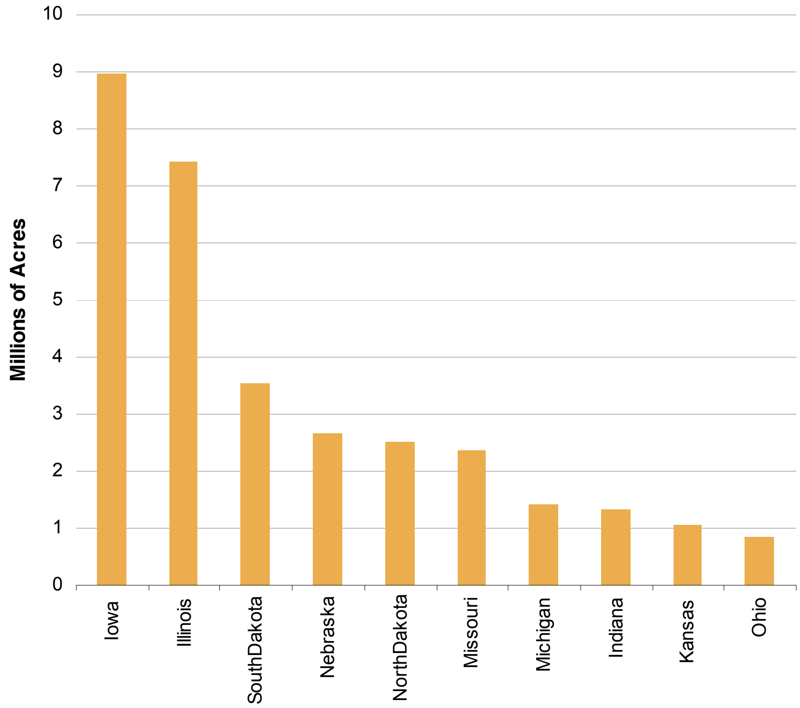
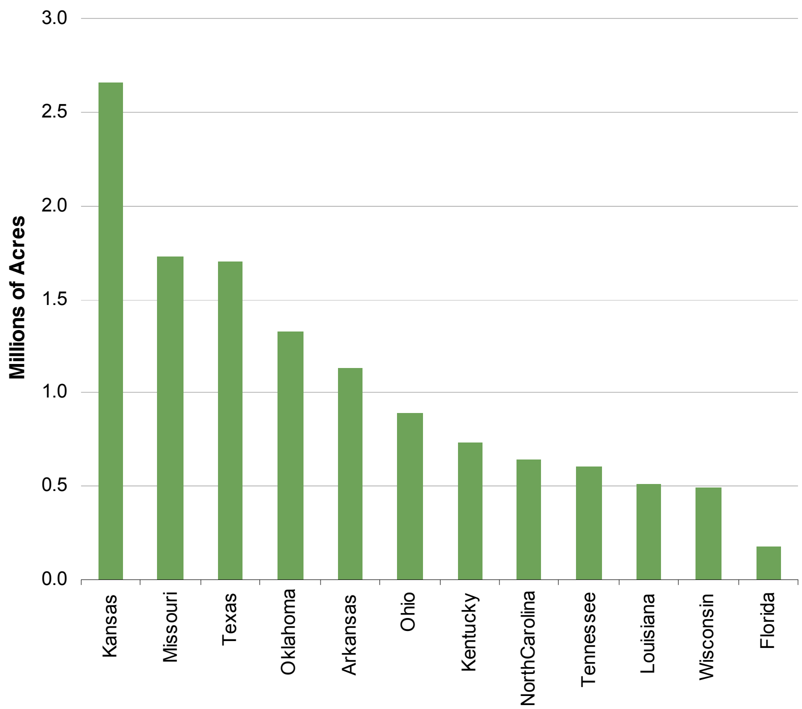


Figure 5.1-4.
Top Ten Producing States of Switchgrass in 2022
FASOM Control Case



5.1.5.4 Land Use Change

Changes in these land categories are summarized in Table 5.1-8 below. In 2022, FASOM projects that total cropland increases by 3.1 million acres (1.0 percent) relative to the Reference Case. The increase in cropland is derived primarily from a combination of decreased cropland pasture acres, and a decrease in forest acres. FAPRI-CARD does not explicitly model U.S. forest or pasture acres.

Table 5.1-8.
Change in U.S. Major Land Use Categories in 2022
Relative to the Reference Case
(millions of acres)

Land Category	AEO 2007 Reference Case	Control Case	Change	% Change
Cropland	311.7	314.8	3.1	1.0%
Used for Production	306.3	314.4	8.1	2.6%
Idled	5.4	0.4	-5.0	-93.0%
Cropland Pasture	32.0	30.1	-1.9	-5.8%
Used for Production	23.1	25.0	1.8	8.0%
Idled	8.9	5.2	-3.7	-41.7%
Forest Pasture	148.4	149.5	1.1	0.7%
Used for Production	113.1	114.4	1.3	1.1%
Idled	35.3	35.1	-0.2	-0.5%
Forestland	344.5	343.3	-1.2	-0.3%
Rangeland	578.8	578.8	0	0%
Used for Production	522.6	516.8	-5.8	-1.1%
Idled	56.3	62.0	5.7	10.2%
CRP	32.0	32.0	0.0	0%
Developed Land	35.0	35.0	0.0	0%

5.1.5.5 Fertilizer Use

As crop acres increase to meet the additional demand for corn and other crops for biofuel production, fertilizer use increases as a result. In addition, the harvesting of corn stover and other crop residues used to make cellulosic renewable fuel removes nutrients from the soil and requires greater fertilizer application. In 2022, FASOM estimates that nitrogen fertilizer use in the U.S. agricultural sector will increase by 1.5 billion pounds (5.7%) relative to the AEO2007 Reference Case levels. FASOM also projects that phosphorous fertilizer use will increase by 714 million pounds (12.7%) relative to the Reference Case level in 2022. The FAPRI-CARD model does not provide estimates for fertilizer use.

Table 5.1-9.
Change in U.S. Fertilizer Use
Relative to the Reference Case
(millions of pounds)

Fertilizer	AEO 2007 Reference Case	Control Case	Change	%Change
Nitrogen	26,209	27,710	1,501	5.7%
Phosphorous	5,614	6,328	714	12.7%

5.1.5.6 Impact on U.S. Farm Income

The increase in renewable fuel production provides a significant increase in net farm income to the U.S. agricultural sector. FASOM predicts that net U.S. farm income will increase by $13 billion dollars in 2022 (36 percent).

5.1.5.7 Impact on U.S. Food Prices

Higher corn and soybean prices also result in higher meat prices, although the increased production of coproducts that can be used as animal feed (e.g., DGS) that accompanies expanded biofuels production tends to limit price effects. For example, in 2022, the average price for all meat production in the FASOM model increases by 0.1 percent. In FAPRI-CARD, the price of beef increases by $0.37 per hundredweight (0.4 percent) in 2022 to $95.84 per hundredweight in the Control Case, and the price of pork increases by $0.77 per hundredweight (1.6 percent) in 2022 to $49.19 per hundredweight in the Control Case.

Due to higher commodity prices, FASOM estimates that U.S. food costs[285] would increase by roughly $10 per person per year by 2022, relative to the Reference Case.[286] Total effective farm gate food costs would increase by $3.6 billion (0.2 percent) in 2022.[287] To put these changes in perspective, average U.S. per capita food expenditures in 2007 were $3,778 or approximately 10 percent of personal disposable income. The total amount spent on food in the U.S. in 2007 was $1.14 trillion dollars.[288]

5.1.6 International Impacts

The FAPRI-CARD models are utilized to assess the international impacts on trade, land use, and food consumption as a result of the RFS2 renewable fuel volume requirement in the U.S. In the FAPRI-CARD models, links between the U.S. and international models are made through commodity prices and net trade equations. In general, for each commodity sector, the economic relationship that quantity supplied equals quantity demanded is achieved through a market-clearing price for the commodity. In non-U.S. countries, domestic prices are modeled as a function of the world price using a price transmission equation. Since econometric models for each sector can be linked, changes in one commodity sector will impact the other sectors.

The model for each commodity considers a number of specific countries/regions, and then includes a rest-of-the-world aggregate to close the model. The models specify behavioral equations for production, use, stocks, and trade between countries/regions. The models solve for representative world prices by equating excess supply and demand across countries. Using price

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[285] FASOM does not calculate changes in price to the consumer directly. The proxy for aggregate food price change is an indexed value of all food prices at the farm gate. It should be noted, however, that according to USDA, approximately 80% of consumer food expenditures are a result of handling after it leaves the farm (e.g., processing, packaging, storage, marketing, and distribution). These costs consist of a complex set of variables, and do not necessarily change in proportion to an increase in farm gate costs. In fact, these intermediate steps can absorb price increases to some extent, suggesting that only a portion of farm gate price changes are typically reflected at the retail level. See http://www.ers.usda.gov/publications/foodreview/septdec00/FRsept00e.pdf.

[286] These estimates are based on U.S. Census population projections of 331 million people in 2017 and 348 million people in 2022. See http://www.census.gov/population/www/projections/summarytables.html

[287] Farm Gate food prices refer to the prices that farmers are paid for their commodities.

[288] See www.ers.usda.gov/Briefing/CPIFoodAndExpenditures/Data/table15.htm.

transmission equations, the domestic price for each country is linked with the representative world price through exchange rates. It is through changes in world prices that change in worldwide commodity production and trade is determined.

5.1.6.1 Global Commodity Price Changes

As demand for renewable fuels in the U.S. increases, the FAPRI-CARD model projects that U.S. and world commodity prices will generally increase. FAPRI-CARD projects that the world price of corn increases by $0.12/bu (3.1 percent) relative to the AEO2007 Reference Case in 2022. Similarly, FAPRI-CARD projects that world soybean prices increase by $0.08/bu (0.8 percent) and the world soybean oil price increases by $13.22 per ton (1.5 percent) in 2022 relative to the AEO2007 Reference Case.

Since increased biofuel demand in the U.S. also impacts the livestock market, in terms of land use (i.e., pasture) and the feed market, we expect prices to change as well. The world price for beef, which is based on U.S. prices, increases $7.34 per ton (0.4 percent) in 2022 to $1,917 per ton in the Control Case.

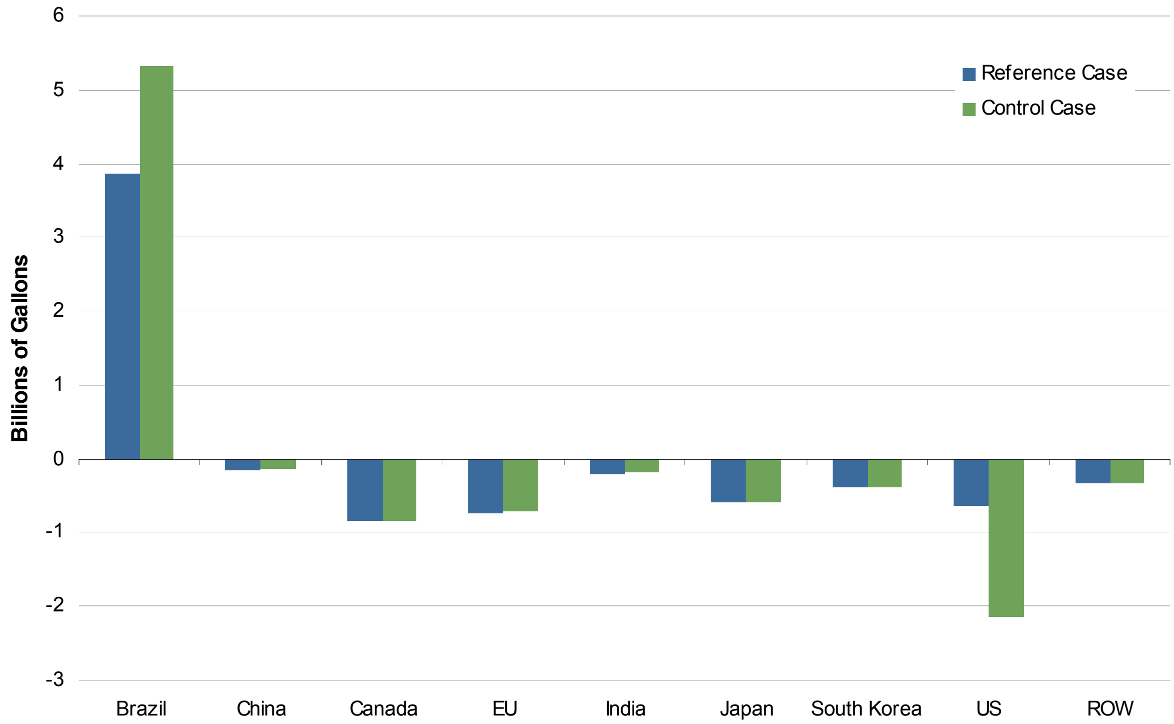
Table 5.1-10.
Global Commodity Price
Changes from RFS2 in 2022
(2007$ per unit)

Commodity (Unit)	AEO 2007 Reference Case	Control Case	Change	% Change
Corn (bushel)	$3.76	$3.88	$0.12	3.1%
Soybeans (bushel)	$9.55	$9.63	$0.08	0.8%
Soybean Oil (ton)	$854.45	$867.67	$13.22	1.5%
Beef (ton)	$1,909.42	$1,916.76	$7.34	0.4%

5.1.6.2 World Renewable Fuels Trade

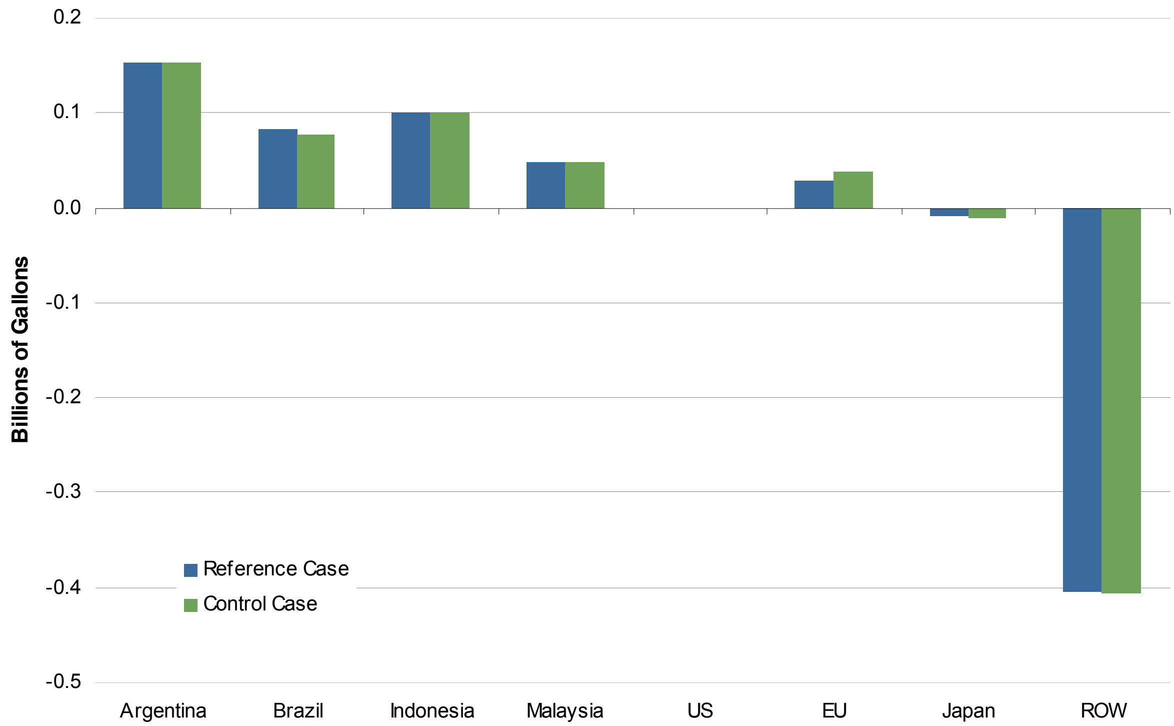
As the U.S. increases its demand for renewable fuels, world trade markets for renewable fuels are also likely to be impacted. As described in Section 1.2, we estimate that in 2022, the U.S. will increase net imports of ethanol by 1.6 billion gallons (248%) relative to the AEO2007 Reference Case. In response, FAPRI-CARD projects that Brazil will increase net exports by 1.5 billion gallons (37.8 percent) in 2022 relative to the Reference Case. However, since the U.S. demand for ethanol imports exceeds the increase in Brazilian net exports, FAPRI-CARD projects that other countries will reduce their net imports of ethanol. In 2022, FAPRI-CARD projects that China decreases net imports of ethanol by 7.9 million gallons (-5.3 percent), the European Union decreases net imports by 16.8 million gallons (-2.3 percent), India decreases net imports by 15.2 million gallons (-7.4 percent), Japan decreases net imports by 3.1 million gallons (-0.5 percent), and South Korea decreases net imports by 1.6 million gallons (-0.4 percent) relative to the AEO2007 Reference Case. The rest of the world decreases net imports of ethanol by 0.7 million gallons (-0.2 percent) in 2022 relative to the Reference Case.

Figure 5.1-5.
Ethanol Net Exports by Country in 2022



Since the world price of soybean oil increases (1.5 percent), whereas the world price of biodiesel decreases (-1.3 percent) due to the RFS2 renewable fuel volume requirements, it becomes relatively more profitable to increase net exports of soybean oil for major producers. This results in less soybean oil being used in the production of biodiesel and therefore a decrease in biodiesel net exports in some countries. Argentina decreases their biodiesel net exports by 1.3 million gallons (-0.8 percent) to 152.4 million gallons, Brazil decreases their biodiesel net exports by 6.2 million gallons (-7.4 percent) to 77.4 million gallons in 2022. In response the EU increases their net exports of biodiesel by 8.6 million gallons (29.6 percent) to 37.8 million gallons in the Control Case. Additionally, Japan reduces its net imports of biodiesel by 0.5 million gallons (-5.9 percent).

Figure 5.1-6.
Biodiesel Net Exports by Country in 2022

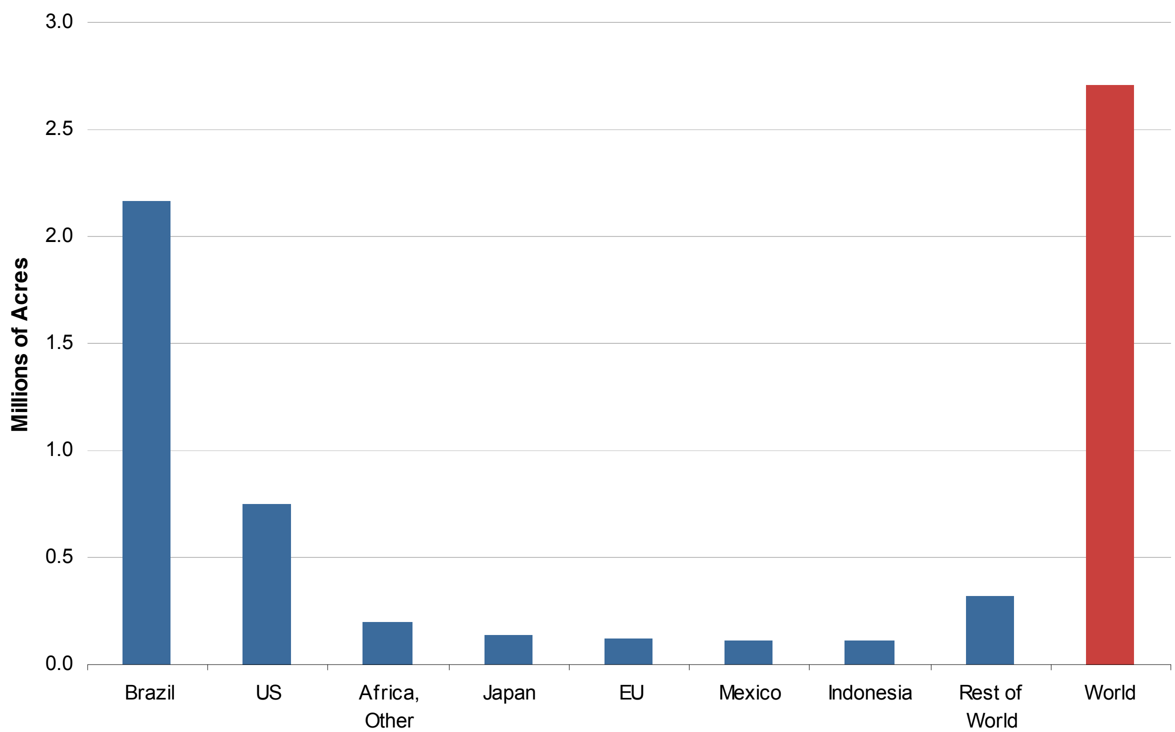


5.1.6.3 International Crop Acre Changes

Changes to the global commodity trade markets and world commodity prices result in changes in international land use. The FAPRI-CARD model provides international change in crop acres as a result of the RFS2 renewable fuel volumes. Internationally, Brazil has the largest increase in crop acres in 2022, followed by a subset of nations in Africa, Japan, the EU, Mexico, and Indonesia. As the U.S. increases its net imports of ethanol by 1.5 billion gallons in 2022, the major supplier of this increase in ethanol is Brazil which produces ethanol from sugarcane. The FAPRI-CARD model estimates that Brazil crop acres increase by 2.2 million acres (1.6 percent) relative to the AEO2007 Reference Case. The major crop contributing to this increase is sugarcane, which increases by 1.2 million acres (4.4 percent) in 2022. "Africa, Other" increases total crop acres by 0.20 million acres (0.25 percent), the large majority of which is corn, which increases by 0.19 million acres (0.32 percent). Japan increases its total crop acres by 0.14 million acres (3.3 percent), solely due to a 0.14 million acre increase in rice acres. The EU increases its crop acres as well, by 0.12 million acres (0.1 percent). This is a result of a 0.06 million acre increase in wheat (0.1 percent), a 0.04 million acre increase in barley (0.1 percent), and a 0.02 million acre increase in corn (0.1 percent). Mexico increases its crop acres by 0.11 million acres in 2022 (0.4 percent), which is primarily due to a 0.14 million acre increase in corn (0.6 percent) and small decreases in other crops. Indonesia increases its total crop acres by 0.11

million acres in 2022 (0.2 percent), including a 0.09 million acre increase in corn (0.9 percent) and a 0.02 million acre increase in rice (0.1 percent).

Figure 5.1-7.
Change in World Crop Acres from the RFS2 Rule by Country in 2022



In response to the increased U.S. demand for imported ethanol, which FAPRI-CARD estimates will be satisfied by increases in Brazil exports of sugarcane ethanol, sugarcane acres increase in various regions in Brazil. For instance, FAPRI-CARD projects 2022 sugarcane acres will increase by 0.01 million acres (2.7 percent) in the Amazon Biome region, 0.13 million acres (3.8 percent) in the Central-West Cerrados region, 0.15 million acres (3.6 percent) in the Northeast Coast region, 0.02 million acres (2.7 percent) in the North-Northeast Cerrados region, 0.05 million acres (2.5 percent) in the South region, and 0.87 million acres (5.0 percent) in the Southeast region, relative to the AEO2007 Reference Case.

Area for other crops in Brazil, including corn and soybeans, are affected not only by the increase in sugarcane crop acres, but also by the changes in world price for each commodity. Overall, total crop area in Brazil increases by 2.2 million acres (1.6 percent) in 2022 relative to the AEO2007 Reference Case. This change is includes an increase of 0.2 million acres (1.8 percent) in the Amazon Biome, an increase of 0.6 million acres (1.9 percent) in the Central-West Cerrados, an increase of 0.2 million acres (2.1 percent) in the Northeast Coast, an increase of 0.2 million acres (1.6 percent) in the North-Northeast Cerrados, an increase of 0.2 million acres (0.4

percent) in the South, and an increase of 0.7 million acres (2.6 percent) in the Southeast, relative to the AEO2007 Reference Case in 2022.

Table 5.1-11.
Change in Brazil Sugarcane Acres and Total Crop Area from the RFS2 Rule by Region in 2022 (millions of acres)

Region	Sugarcane				Total Crops			
	AEO 2007 Reference Case	Control Case	Change	% Change	AEO 2007 Reference Case	Control Case	Change	% Change
Amazon Biome	0.45	0.46	0.01	2.7%	12.0	12.2	0.2	1.8%
Central-West Cerrados	3.38	3.51	0.13	3.8%	31.8	32.4	0.6	1.9%
Northeast Coast	4.07	4.21	0.15	3.6%	11.1	11.3	0.2	2.1%
North-Northeast Cerrados	0.64	0.66	0.02	2.7%	14.6	14.8	0.2	1.6%
South	2.02	2.07	0.05	2.5%	39.9	40.1	0.2	0.4%
Southeast	17.47	18.34	0.87	5.0%	26.3	27.0	0.7	2.6%
Brazil, Total	28.04	29.27	1.23	4.4%	135.7	137.9	2.2	1.6%

5.1.6.4 World Food Markets

The increase in renewable fuel volumes associated with the RFS2 will also impact world food consumption patterns.[289] Since major agricultural commodity prices increase globally, FAPRI-CARD projects that world consumption of food decreases by 2.5 million metric tons (-0.1 percent) in 2022, relative to the AEO2007 Reference Case. This change is includes a decrease of consumption of dairy food products of 0.1 million metric tons (-0.03 percent), a decrease of 0.1 million metric tons (-0.05 percent) of livestock, a decrease of 0.3 million metric tons (-0.15 percent) of sugar, a decrease of 0.4 million metric tons (-0.12 percent) of grains, a decrease of 1.7 million metric tons (-4.5 percent) of vegetable oils, and an increase of 0.1 million metric tons (0.03 percent) of rice, relative to the AEO2007 Reference Case in 2022. Wheat consumption levels do not change between the Reference Case and the Control Case. While FAPRI-CARD provides estimates of changes in world food consumption, estimating effects on global nutrition is beyond the scope of this analysis.

[289] The food commodities included in the FAPRI model include corn, wheat, sorghum, barley, soybeans, sugar, peanuts, oils, beef, pork, poultry, and dairy products.

Table 5.1-12.
Change in World Food Consumption Relative to the Reference Case
(millions of metric tons)

Category	AEO 2007 Reference Case	Control Case	Change	% Change
Dairy	288.2	288.1	-0.1	-0.03%
Livestock	301.4	301.3	-0.1	-0.05%
Sugar	206.3	206.0	-0.3	-0.15%
Wheat	605.9	605.9	0.0	0.00%
Grains	314.5	314.1	-0.4	-0.12%
Vegetable Oils	37.1	35.4	-1.7	-4.5%
Rice	500.6	500.7	0.1	0.03%
Total Food	2,258.4	2,256.0	-2.5	-0.1%

5.2 Petroleum, Renewable Fuels and Energy Security Impacts

Increasing usage of renewable fuels helps to reduce U.S. petroleum imports. A reduction of U.S. petroleum consumption and imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risks is a measure of improved U.S. energy security. In this section, we detail an updated methodology for estimating the energy security benefits of reduced U.S. oil imports which explicitly includes renewable fuels. Based upon this updated approach, we estimate the monetary value of the energy security benefits associated with the increased usage of renewable fuels in the U.S. required by the RFS2 rule.

5.2.1 Implications of Reduced Petroleum Use on U.S. Imports

In 2008, U.S. petroleum import expenditures represented 21 percent of total U.S. imports of all goods and services.[290] In 2008, the U.S. imported 66 percent of the petroleum it consumed, and the transportation sector accounted for 70 percent of total U.S. petroleum consumption. This compares to approximately 37 percent of petroleum from imports and 55 percent consumption of petroleum in the transportation sector in 1975.[291] It is clear that petroleum imports have a significant impact on the U.S. economy. Requiring the wider use of renewable fuels in the U.S. is expected to lower U.S. petroleum imports.

For this rule, EPA estimated the reductions in U.S. petroleum imports using a modified version of the National Energy Modeling System (EPA-NEMS). EPA-NEMS is an energy-economy modeling system of U.S. energy markets through the 2030 time period. EPA-NEMS projects U.S. production, imports, conversion, consumption, and prices of energy subject to

[290] Source: U.S. Bureau of Economic Analysis, U.S. International Transactions Accounts Data, as shown on June 24, 2009.
[291] Source: U.S. Department of Energy, Annual Energy Review 2008, Report No. DOE/EIA-0384(2008), Tables 5.1 and 5.13c, June 26, 2009.

assumptions on world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics. For this analysis, the 2009 NEMS model was modified to use the 2007 (pre-EISA) Annual Energy Outlook (AEO) levels of renewable fuels in the Reference Case. These results were compared to our Control Case, which assumes the renewable fuel volumes required by EISA will be met by 2022. Details on how the EPA-NEMS model was adjusted to incorporate these volumes are included in the docket.[292] The reduction in U.S. oil imports projected by EPA-NEMS is roughly 0.9 million barrels per day (a 9.5 per cent reduction in 2022). It is estimated that U.S. oil production in 2022 declines by much less, just 0.01 million barrels per day.

Using the EPA-NEMS model, we also calculated the change in expenditures in both U.S. petroleum and renewable fuel imports with the RFS2 rule and compared these with the U.S. trade position measured as U.S. net exports of all goods and services economy-wide. Changes in fuel expenditures were estimated by multiplying the changes in petroleum and renewable fuel net imports by the respective imported petroleum prices and wholesale ethanol price forecasts. In Table 5.2.1-1, the net expenditures in reduced petroleum imports and increased renewable fuel imports are compared to the total value of U.S. net exports of goods and services of the whole economy for 2022 as estimated by the EPA-NEMS model. We project that avoided expenditures on imported crude oil and petroleum products from the 2022 RFS2 volumes of renewable fuels would be roughly $41.5 billion. Taking into consideration imports of renewable fuels, the total avoided expenditures on imported transportation fuels are projected to be $37.2 billion in the RFS2 control case.

[292] See OnLocation, Inc. RFS2 Modeling Analysis Documentation, dated January 12, 2010.

Table 5.2.1-1.
Selected U.S. Exports and Imports in 2022
(billions of 2007$)

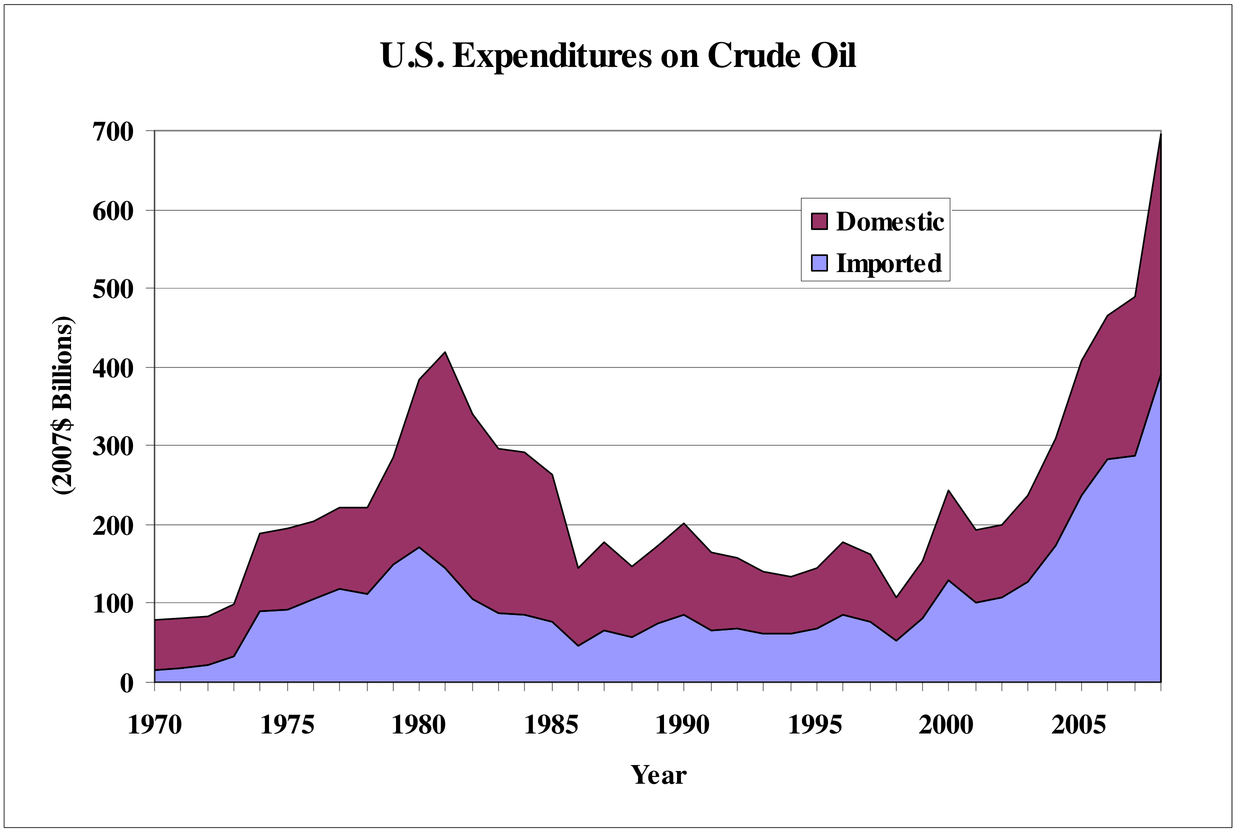
Category	AEO 2007 Reference Case	RFS2 Control Case	Change	Percent Change
Total U.S. Exports of Goods and Services	3,838	3831	7	+0.22%
Total U.S. Imports of Goods and Services	3,840	3833	7	+0.23%
Total U.S. Net Imports of Goods and Services	2	2	0	0%
Expenditures on Net Petroleum Imports	456	414	-41.5	-9.1%[293]
Expenditures on Imported Ethanol	1	5.3	+4.3	+419%
Total Expenditures on Transportation Fuel Imports	457	420	-37.2	-8.1%

5.2.2 Background on U.S. Energy Security

U.S. energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs. Most discussion of U.S. energy security revolves around the topic of the economic costs of U.S. dependence on oil imports, although energy security is also a function of the stability of overall fuel supply and the flexibility of demand. An important part of the problem stems from U.S. reliance on imported oil, and the global oil market is strongly influenced by potentially unfriendly and unstable sources. In addition, oil exporters have the ability to raise the price of oil by exerting monopoly power through the formation of a cartel, the Organization of Petroleum Exporting Countries (OPEC). Finally, these factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes. In 2008, U.S. imports of crude oil were roughly $391 billion (2007$, see Figure 5.2.2-1).

[293] Note: the 9.1 per cent reduction included in this table is a change in the monetary value of the oil reductions, whereas the 9.5 per cent reduction in oil imports cited in the previous paragraph refers to the volumetric change in imports.

Figure 5.2.2-1. U.S. Expenditures on Crude Oil



Source: Annual Energy Reviews and AEO 2009.

By requiring the wider use of renewable fuels, the RFS2 rule promotes diversification of transportation fuels in the U.S. and helps to improve the U.S.'s energy security. For the RFS2 proposal, an "oil import premium" approach was utilized to identify those energy security-related impacts which are not reflected in the market price of oil, and which are expected to change in response to an incremental change in the level of U.S. oil imports. For this analysis, the "oil import premium" approach was extended to explicitly consider the energy security implications of the expansion of renewable fuels required by the RFS2 rule.

5.2.3 Methodology Used to Estimate U.S. Energy Security Benefits

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. In a recent study entitled "*The Energy Security Benefits of Reduced Oil Use, 2006-2015*," completed in 2007 for the final RFS1 rulemaking, ORNL updated and applied the method used in the 1997 report "*Oil Imports: An Assessment of Benefits and Costs*", by Leiby, Jones, Curlee and Lee.[294,295] The updated 2007

[294] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs*, ORNL-6851, Oak Ridge National Laboratory, November, 1997.

report was included as part of the record in the final RFS1 rulemaking, and revisions were made based on external comment and peer review. [296,297]

Significant factors that drive energy security costs have been changing over the last decade, including: projected world oil prices, current and anticipated levels of OPEC production, U.S. oil import levels, the estimated responsiveness of regional oil supplies and demands to price, and the likelihood of oil supply disruptions. For this analysis, oil prices and supply and demand energy balances from the EIA's AEO 2009 Reference Case were used. In many instances, the recent market trends and projections suggest reasons for greater concern about oil security costs, compared to the prior decade: higher oil prices; growing U.S. import levels; and a larger value-share of oil in GDP. To the extent that the U.S. economy has become more resilient, and less sensitive to oil shocks, or that improved macroeconomic policies have reduced the impact of oil shocks, there may be influences countervailing to the oil market trends. This possibility is considered in the security estimates, but recent macroeconomic disturbances indicate that greater future macroeconomic stability cannot be assured. The degree to which sharply higher oil prices contributed to, or exacerbated, the recent global recession has not yet been resolved.[298]

In order to understand the energy security implications of this rule, EPA used the Oil Security Metrics Model[299,300,301] (OSMM), developed and maintained by Oak Ridge National Laboratory. The OSMM estimates the U.S. energy security benefits from increased availability and use of renewable transportation fuels. The OSMM took as inputs the renewable fuel volumes

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[295] The 1997 ORNL paper was cited and its results used in DOT/NHTSA's rules establishing CAFE standards for 2008 through 2011 model year light trucks. See DOT/NHTSA, Final Regulatory Impacts Analysis: Corporate Average Fuel Economy and CAFE Reform MY 2008-2011, March 2006.

[296]Leiby, Paul N. *"Estimating the Energy Security Benefits of Reduced U.S. Oil Imports: Final Report",* ORNL/TM-2007/028, Oak Ridge National Laboratory, March, 2008.

[297] Updating the ORNL methodology to incorporate the comments from the Peer Reviewers, based on AEO2007, ORNL estimated that the total energy security benefits associated with a reduction of imported oil is $12.38/barrel, with a range of $6.88 - $18.52/barrel of imported oil reduced ($2006). When the same methods and assumptions are applied to the AOE2009 Reference outlook, comparable estimates for 2025 are $19.21/barrel, with a range of $10.8 to $29.6/barrel.

[298] See Hamilton, J. D. 2009, "*Causes and Consequences of the Oil Shock of 2007-08*", Brookings Papers on Economic Activity, 2009, or the congressional testimony of Yergin, D. "*The Long Aftershock: Oil: Oil and Energy Security After the Price Collapse*" Testimony to U.S. Congress, Hearings, Joint Economic Committee, Oil and the Economy: The Impact of Rising Global Demand on the U.S. Recovery. May 20, 2009.

[299] The OSMM methods are consistent with the recommended methodologies of the National Resource Council's (NRC's) (2005) Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs. The OSMM defines and implements a method that makes use of the NRC's typology of prospective benefits and methodological framework, satisfies the NRC's criteria for prospective benefits evaluation, and permits measurement of prospective energy security benefits for policies and technologies related to oil. It has been used to estimate the prospective oil security benefits of Department of Energy's Energy Efficiency and Renewable Energy R&D programs, and is also applicable to other strategies and policies aimed at changing the level and composition of U.S. petroleum demand. To evaluate the RFS2, the OSMM was modified to include supplies and demand of biofuels as well as petroleum.

[300] Greene D.L. and P.N. Leiby, 2006. *The Oil Security Metrics Model: A Tool for Evaluating the Prospective Oil Security Benefits of DOE's Energy Efficiency and Renewable Energy R&D Programs*, ORNL/TM-2006/505, Oak Ridge National Laboratory (ORNL), 2006.

[301] Leiby, P.N., *Energy Security Impacts of Renewable Fuel Use Under the RFS2 Rule – Methodology*, Oak Ridge National Laboratory, January 19, 2010.

that are required under EISA as well at the renewable fuel costs estimated in Chapter 4.4 of this RIA. In addition, it assumed EPA's projections of flexible fueled vehicles and use of E85. In conducting this analysis, ORNL considered the full economic cost of importing petroleum into the U.S. The full economic cost of importing petroleum into the U.S. is defined for this analysis to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs for oil imports resulting from the effect of U.S. import demand on the world oil price and OPEC market power (i.e., the "import demand" or "monopsony" costs); and (2) the risk of reductions in U.S. economic output and disruption of the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (i.e., "macroeconomic disruption/adjustment costs"). Analogously, this analysis for the RFS2 rule also considers the economic costs of importing renewable fuels to meet the RFS2 rule requirements, and the estimated disruption/adjustment costs to the economy of renewable fuel price volatility due to renewable fuel supply disruptions (e.g., droughts and floods, etc.).

This energy security analysis extends the prior "oil import premium" analysis by considering risk-shifting that might occur as the U.S. reduces its dependency on petroleum by increasing its use of renewable fuels. The analysis accounts for the energy security implications associated with renewable fuels, such as possible supply disruptions of ethanol made from corn or ethanol derived from cellulosic feedstocks such as switchgrass. The use of OSMM broadens our energy security analysis to incorporate estimates of overall motor fuel supply and demand flexibility and reliability, and the impacts of possible agricultural sector market disruptions. For example, the use of renewable fuels can modestly alter short and long run demand elasticities (i.e., flexibility) in the motor fuel market, with implications for robustness of the fuel system in the face of diverse supply shocks.

As in the "oil import premium" analysis for the RFS2 proposal, U.S. military costs are excluded from the analysis performed by ORNL because their attribution to particular missions or activities is difficult. Most military forces serve a broad range of security and foreign policy objectives. Attempts to attribute some share of U.S. military costs to oil imports are further challenged by the need to estimate how those costs might vary with incremental variations in U.S. oil consumption and imports. Similarly, the Strategic Petroleum Reserve (SPR) size and policy is assumed unchanged by the RFS2 rule.

5.2.4 Effect of Oil Use on Long-Run Oil Price and U.S. Import Costs

The first component of the full economic costs of oil use in the U.S. follows from the effect of U.S. import demand on the world oil price over the long-run. Because the U.S. is a sufficiently large purchaser of foreign oil supplies, its purchases can affect the world oil price. This monopsony power means that increases in U.S. petroleum demand can cause the world price of crude oil to rise, and conversely, that reductions in U.S. petroleum demand can reduce the world price of crude oil. Thus, one benefit of decreasing U.S. oil purchases, due to the increased availability and use of other transportation fuels, is the potential decrease in the crude oil price paid for all crude oil purchased.

The demand or monopsony effect can be readily illustrated with an example. If the U.S. imports 10 million barrels per day at a world oil price of $50 per barrel, its total daily bill for oil imports is $500 million. If a decrease in U.S. imports to 9 million barrels per day causes the world oil price to drop to $49 per barrel, the daily U.S. oil import bill drops to $441 million (9 million barrels times $49 per barrel). While the world oil price only declines $1, the resulting decrease in oil purchase payments of $59 million per day ($500 million minus $441 million) is equivalent to an incremental benefit of $59 per barrel of oil imports reduced, or $10 more than the newly-decreased world price of $49 per barrel. This additional $10 per barrel "import cost premium" or "monopsony" benefit represents the incremental external benefit to U.S. society as a whole for avoided import costs beyond the price paid for oil purchases. This additional benefit arises only to the extent that the reduction in U.S. oil imports affects the world oil price.

A similar rationale can be applied to estimate the monopsony disbenefits of the increased use of renewable fuels from the RFS2 rule. In the same way, but working in the opposite direction of the oil market, increased use of renewable fuels in the U.S. is expected to increase demand for domestic and imported renewable fuels, and to increase the world price of renewable fuels. This results in higher total costs of U.S. renewable fuel imports. While the total cost of renewable fuel imports under a policy like RFS2 rule will include the cost of the additional imports, the monopsony cost portion is the added amount paid for the imports that would have occurred without the RFS2 rule renewable fuel volumes. Thus, to look at the total monopsony impacts of the RFS2 rule renewable fuel volumes, two separate impacts need to be assessed. First, U.S. oil import reductions result in paying lower prices for all barrels of U.S. imported oil, providing monopsony benefits. Second, increased use of renewable fuels results in higher prices of U.S. imported renewable fuels, yielding monopsony disbenefits for renewable fuels. The total monopsony benefit is the combined sum of these separate market impacts.

Table 5.2.4.1 shows the RFS2 Reference Case levels of U.S. oil and renewable fuel imports as well as the average change in oil prices and renewable fuel prices projected due to the RFS2 volumes in 2022. The Reference Case renewable fuel imports are relatively modest compared to oil (roughly 0.015 billions of barrels of renewable fuel are imported versus 3.283 billion barrels of oil). Projected U.S. renewable fuel imports in 2022 are ethanol, principally made from sugar cane harvested in Brazil. In 2022, the estimated change in ethanol price due to the RFS2 renewable fuel volumes is $0.61/barrel, and the estimated reduction in the world oil price is $1.05/barrel. The monopsony effect is the change in costs of the quantities of fuel imported without the RFS2 renewable fuel volumes (i.e., the Reference Case fuel volumes). Since the change in the renewable fuel price applies to a much smaller quantity of renewable fuel imports than U.S. oil imports, the monopsony disbenefit per barrel of increased renewable fuel use is much smaller, only $0.02/barrel, compared to the oil monopsony benefit, $7.88/barrel. Thus, including the impact of expanded renewable fuel use on renewable fuel imports and price yields a slightly lower estimate of the total monopsony benefits.

Table 5.2.4-1.
Determinates of Monopsony Benefits
of the RFS2 Renewable Fuel Volumes
vs. AEO2007 Reference Case

Fuel	Reference Case Import Quantity (billions of barrels in 2022)	Change in Price ($ per barrel in 2022)	Monopsony Benefit ($ billion in 2022)	Monopsony Benefit ($/barrel of renewable fuel) in 2022)
Renewable Fuels	0.015	0.61	-0.009	-0.02
Oil	3.282	-1.06	3.476	7.88
Total				7.86

This analysis of the import cost and monopsony effect is based on the net import levels of petroleum as projected by the EPA-NEMS, and is not sensitive to the mix of crude and product imports. It is possible that in the future, while the U.S. will import most of its crude oil and some petroleum products, it may be a net exporter of others, e.g. diesel fuel.[302] However, oil security concerns stem from the total consumption and net import of all petroleum fuels, whose prices are all directly dependent on the volatile (and non-competitive) world crude oil market. For this analysis, the key issue is not the trade balance for particular petroleum products, but the net level of U.S. consumption and import of all petroleum, both crude and products. Reducing domestic gasoline or diesel fuel with renewable fuels use can reduce net imports of all petroleum, and net import costs, even if the U.S. remains a net exporter of some petroleum products. Consider the case of U.S. diesel fuel. Replacing U.S. diesel fuel consumption with renewable biodiesel, whose root supply volatility is largely independent of that of petroleum, can reduce the volatility of productive inputs to the macroeconomy, regardless of the trade balance in diesel fuel.

5.2.5 Macroeconomic Dislocation Costs Associated with Oil and Renewable Fuel Price Variability

Fluctuations in oil and renewable fuel prices are estimated to cause macroeconomic losses due to dislocations and adjustment costs. Macroeconomic losses during price shocks reflect both aggregate output losses and so called "allocative" losses. The former are a reduction in the level of output that the U.S. economy can produce fully using its available resources; and the latter stem from temporary dislocation and underutilization of available resources due to the shock, such as labor unemployment and idle plant capacity. The aggregate output effect, a reduction in "potential" economic output, will last so long as the price is elevated. It depends on the extent and duration of any disruption in the world supply of oil, since these factors determine

[302] While at the time of the implementation of this rule, the U.S. exports some diesel fuel, it is not clear that this situation will long persist. Under EIA AEO2009, the U.S. is a net importer of refined products (as well as crude) throughout the forecast horizon. In particular, over the RFS2 horizon (2010-2022) diesel fuel consumption is expected to grow at 1.4 per cent per year (Table 11) while gasoline demand will decline at 1.0 per cent per year. Thus, under this outlook, crude refinery runs needed to meet gasoline supply will decline, while U.S. demand for the distillate/diesel cuts will grow.

the magnitude of the resulting increase in prices for petroleum products, as well as whether and how rapidly these prices return to their pre-disruption levels.

In addition to the aggregate contraction, there are "allocative" or "adjustment" costs associated with dislocated energy markets. Because supply disruptions and resulting price increases occur suddenly, empirical evidence shows they impose additional costs on businesses and households which must seek to adjust their use of petroleum and other productive factors more rapidly than if the same price increase had occurred gradually. Opportunities for short run adjustments of energy use and other productive factors of the economy are limited and costly. Dislocational effects include the unemployment of workers and other resources during the time needed for their intersectoral or interregional reallocation, and pauses in capital investment due to uncertainty. These adjustments temporarily reduce the level of economic output that can be achieved even below the "potential" output level that would ultimately be reached once the economy's adaptation to higher petroleum prices was complete. The additional costs imposed on businesses and households for making these adjustments reflect their limited ability to adjust prices, output levels, and their use of energy, labor and other inputs quickly and smoothly in response to rapid changes in prices for petroleum products.

In the prior "oil import premium" analysis undertaken for the RFS2 proposal, oil price shocks were estimated to have macroeconomic losses based on a single fixed elasticity of Gross Domestic Product (GDP) with respect to oil price. For this final RFS2 rule analysis in the OSMM, it is recognized that the dislocation portion of disruption costs depends not only on the magnitude of the price change, but on the changing importance of both oil and renewable fuels in the economy, as well as the degree to which the price movement is novel and disturbing.[303] Thus, when a shock causes fuel prices to jump up and stay up, initially the dislocation is larger, and over time the economy adjusts to higher prices and the macroeconomic dislocation dissipates. To account for this, OSMM tracks the evolution of an "adjusted" oil price and renewable fuel price, which is based on a lagged partial adjustment process, essentially yielding a weighted average of past prices with geometrically declining weights. This weighted-lag adjusted price is constructed to represent the average price level to which the economy has already had time to adjust.[304] It is deviations from this level that are dislocational and costly. For both oil price and renewable fuel price fluctuations, the macroeconomic dislocation cost is calculated by applying a GDP loss elasticity to the ratio of the current price to the adjusted price. Furthermore, the applied GDP elasticity varies with the value share of expenditure on the fuel, both for oil and renewable fuels, in the economy. The estimated GDP losses from renewable

[303] This attention to the degree to which the observed price is unusual or "novel" follows the work of Lee et al. (Lee, K.; Ni, S. & Ratti, R. "*Oil shocks and the Macroeconomy: The Role of Price Variability*" *Energy Journal*, 1995, 16, 39-56, and Hamilton's NOPI formulation (e.g. Hamilton, J. "*What is an Oil Shock*?", *Journal of Econometrics*, Elsevier, 2003, 113, 363-398). Several works of Brown, Huntington, and Gately, for example, also consider the role of an "adjusted price" in the determination of supply and demand responses.

[304] The adjusted price is the geometric distributed (i.e., Koyck) lag average of all prior prices, to represent that the economy only partially adjusts to changing prices each year. The annual adjustment rate of this price, which corresponds to the assumed annual accommodation of new prices by the macroeconomy, is taken as 33 per cent. This is consistent with empirical evidence that the dislocational impact of energy price shocks extends more than one year, but is mostly complete after three years.

fuel price fluctuations are based on a GDP Adjustment Cost[305] elasticity with respect to oil prices, but rescaled in accordance with the ratio of renewable fuel expenditures to total oil expenditures.

One feature of the OSMM is its explicit treatment of renewable fuel volatility. Renewable fuel supply and hence, the price of renewable fuels, is also subject to disturbances, and the resulting production cost volatility is anticipated to impose some costs on the economy. While E85 and gasoline prices are often strongly correlated at the level of individual retail stations, this correlation reflects primarily the process of market substitution, and the expected phenomenon that ordinarily end-use prices for close substitutes will equilibrate and track one another. Further upstream (i.e., closer to the terminal and production plant gate), this price correlation diminishes. The historical prices of agricultural products that are likely to be used as feedstocks for renewable fuels are somewhat volatile, but almost completely uncorrelated with oil prices. For example, consider monthly price changes between crude oil and key agricultural crops that would be used as feedstocks for renewable fuels—sugar, corn, switchgrass, and softwood lumber—during the time period from January, 1990 to December, 2008 (Table 5.2.5-1 below). In the case considered here, wheat prices are used as a surrogate for switchgrass prices, since both crops are likely to be grown in similar agricultural areas in the U.S. (i.e., the Southwest region of the U.S.) and subject to similar weather patterns. These agricultural commodities have relatively low correlations with crude oil; 3 percent, 5 percent, -1 percent and 1 percent, for sugar, wheat, corn and softwood lumber, respectively.

Table 5.2.5-1. Cross Correlations of Monthly Price Changes of Crude Oil and Selected Key Renewable Fuel Feedstocks, January, 1990 to December, 2008

	Crude Oil	Sugar	Wheat	Corn	Softwood
Crude Oil	100%	3%	5%	-1%	1%
Sugar		100%	20%	10%	2%
Wheat			100%	46%	23%
Corn				100%	-10%
Softwood					100%

Source: Leiby 2009, based on IMF/IFS database, Commodity Prices & Indices, Monthly, 1970 to December 2008.

From the standpoint of quantifying the macroeconomic/disruption of the increased use of renewable fuels, two factors are important. The first factor is an estimate of the variability in the supply of renewable fuels. The second factor is the change in renewable fuel production costs that stems from fundamental supply volatility at the feedstock level. This analysis represents renewable fuel supply volatility and risk based on historical variations in annual crop yields. Crop yields vary substantially from year to year based on growing conditions, including droughts

[305] GDP Adjustment Costs from biofuel price fluctuations are based on applying the adjustment cost elasticity to the ratio of the current year price to the adjusted price. See Huntington (2005, "*The Economic Consequences of Higher Crude Oil Prices*," Final Report EMF SR 9, Energy Modeling Forum, Stanford University, October, p. 43) notes "Economic theory suggests strongly that, in the absence of major threshold effects, the direct response of the GDP and price levels to oil price changes should be proportional to oil's value share in total output." In the OSMM, for both oil and biofuels, the adjustment cost elasticity varies from year to year according to the expenditure share in GDP. For biofuels it is given by the 1983 reference value for oil times the ratio of current biofuel expenditure share to 1983 oil expenditure share.

and floods, and a variety of other factors.[306] The supply risk of lower volumes of feedstock production due to a host of factors is assumed to be independent of oil prices.

Data on renewable fuel feedstock yield volatilities are presented in Table 5.2.5-2 below. Resulting estimates of renewable fuel cost volatility, based upon standard deviations from historical trends in renewable fuel feedstock yields, vary from 2.4 percent to 8.7 percent, with ethanol derived from sugar cane estimated to have the lowest volatility, and ethanol derived from corn estimated to have the highest volatility. These estimates of feedstock yield volatility are then used to estimate variations in feedstock cost[307] and implied variations in renewable fuel production costs at the plant gate.[308] As one would expect, renewable fuel cost volatility increases with the volatility of feedstock supply, but decreases in cases where feedstocks comprise a lower percentage of total production cost (as is the case with cellulosic renewable fuel). By way of comparison, the historical volatility of world oil prices over the last twenty-five years is 28 percent, considerably higher than the estimated volatility of renewable fuels.[309]

Table 5.2.5-2.
Selected Key Renewable Fuel Feedstocks Annual Yield Volatility

Renewable Fuel Feedstock	Corn	Soybeans	Wheat	Sugar Cane
Historical Yield Volatility	8.69%	6.81%	13.07%	2.37%
Based on Years	1960-2008	1960-2008	1960-2008	1997-2008

Source: OSSM Supporting Data, Leiby/ORNL 2009. Volatility is measured as the standard deviation of annual percentage deviation from historical trend yields. Yield data and volatility are from Bruce Babcock, CARD, Iowa State, November, 2009.

The introduction of renewable fuels affects macroeconomic disruption costs from oil by reducing the oil-intensity of the economy, and by changing oil price movements slightly (since the addition of renewable fuels slightly alters the elasticity of demand for motor fuels). In addition, the introduction of renewable fuels affects the macroeconomic disruption costs by adding separate disruption costs associated with the independent volatility of renewable fuels supply. The magnitude of GDP dislocation losses for a given oil price change is calculated based on a summary parameter, "GDP elasticity." That elasticity is adjusted from historical (i.e.,

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306 In applying historical yield and feedstock price variations to projected outcomes, it was recognized that two offsetting factors may cause future biofuel feedstock supply risk to differ from the past. These factors may offset each other: future drought risk may increase with climate change; yet some crops are also becoming increasingly drought resistant.

307 Data on yield volatility were obtained from Bruce Babcock of CARD, Iowa State. Variations in yield were converted to estimated variations in feedstock cost based on elasticities from Thompson, W., Meyer, S. & Westhoff, P. "*How Does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets With and Without an Ethanol Use Mandate?*" Energy Policy, Elsevier, 2009, 37, Pages 745-749.

308 Biofuel production cost economics used in this analysis are based upon estimates from Tao L. and A. Aden 2009, "*The Economics of Current and Future Biofuels*," In Vitro Cell. Dev.Biol. - Plant, 45:199-217.

309 Volatility is calculated as the standard deviation of annual percentage price changes in the real price of imported crude oil, 1984-2009, U.S. EIA data. This result is robust over the choice of the starting year for the volatility calculation: 2000-2009: 30.0 percent; 29.2 percent; 1990-2009: 26.4 percent; 1980-2009: 27.2 percent; and 1970-2009: 29.5 percent.

early 1980's) levels based on the oil expenditure share in GDP. In the Reference Case, from 2010 to 2022, oil expenditures as a cost share of the U.S. economy vary from 2.5 percent in 2010 to peak at 4.7 percent in 2017, while declining thereafter to 3.8 percent by 2020. By way of comparison, in 1983, the oil cost share was 4.6 percent (for which the assumed 1983 macroeconomic adjustment elasticity is -0.041). Under the RFS2 control case, renewable fuel cost shares in the economy are quite small, growing from under 0.1 percent to about 0.2 percent, an order of magnitude lower than the oil cost shares.

The reduction in GDP adjustment losses due to oil shocks is a result of both the reduction in oil price and the slight decrease in oil share (about 0.2%). As mentioned above, the estimated volatility of crude oil price is greater than renewable fuel production costs under the RFS2 control case. This is understandable for two reasons: historical crude prices are more volatile than agricultural commodity prices that are projected to be the renewable fuel feedstocks; and renewable fuel production costs are less volatile than feedstock costs. The combination of these effects—lower costs shares of oil because of the introduction of higher levels of renewable fuels and less volatility in renewable fuel costs compared to oil—leads to the offsetting gains and losses in terms of macroeconomic dislocation costs, with the avoided losses from crude shocks being greater than the added losses from renewable fuel shocks. Estimates of the avoided macroeconomic dislocation benefits, in dollars per barrel of renewable fuel, are displayed in Table 5.2.5-3 below.

Table 5.2.5-3.
Avoided Macroeconomic Dislocations Benefits for the RFS2 Control Case vs. the AEO2007 Reference Case ($ per barrel of renewable fuel)

Reduction in Dislocation Cost from Oil Shocks	$7.08
Reduction in Dislocation Cost from Renewable Fuel Shocks	-$0.52
Avoided Macroeconomic Dislocation Benefits	$6.56

This approach has implications for estimated GDP losses due to shock and price fluctuations. If the use of renewable fuels reduces the expenditure share of oil in the U.S. economy, then the sensitivity of the economy to oil shocks is also reduced, and estimated GDP adjustment losses from oil shocks are lower. These effects are all relatively modest, since the changes in the renewable fuel cost share are fairly modest. However, the overall importance of oil in the economy and the greater estimated volatility of oil prices lead to a significant gain per barrel of oil use avoided. The applicable GDP elasticity for renewable fuel price shocks is much smaller than that for oil, in proportion to the expenditure share of renewable fuels. It does, of course, grow over time with increased use renewable fuels.

Although retail renewable fuel prices will move closely with petroleum prices, and to a lesser extent the renewable fuel plant-gate market prices and feedstock prices, there is still a macroeconomic benefit from replacing oil with renewable fuels. This is true for three reasons. First, the nature of the oil price increase and renewable fuel price increases are quite distinct. When the price of oil increases from an oil supply shock, the resulting increase in renewable fuels has a very different origin–it is due to substitution toward renewable fuels, and thus reflects a demand response rather than a supply shock. While price change is commonly used as the summary measure of the shock, the underlying quantity changes cannot be forgotten as the root cause of the economic loss. Unlike oil, the quantity of renewable fuel supplied during an oil shock will increase, or at least remain little changed. Second, the short-run increase in the price of renewable fuel is no different from the induced price increase in all other substitutes for oil: energy or non-energy. Adding a new, independent supply source like renewable fuel is equivalent to adding any other alternative fuel, or even to adding a conservation alternative. The price of all of these alternatives will rise to some extent with oil prices, but this substitution effect is part of the solution to the disruption rather than part of the problem. Through substitution, renewable fuels can also dampen the oil price shock, a beneficial effect that is only partially represented in this analysis. Third, to the extent that renewable fuel prices rise with little change in production, the payments will be largely to domestic producers, as windfall gains rather than losses.

5.2.6 Estimates of per Barrel Energy Security Benefits

Table 5.2.6-1 below summarizes ORNL's estimate of the energy security benefits associated with the RFS2 renewable fuel volumes, including the components of the energy security benefit.

Table 5.2.6-1.
Energy Security Benefits from the RFS2
Control Case vs. the AEO 2007 Reference Case
(2007$/barrel of renewable fuel)

Effect	Updated ORNL Study
Monopsony (best estimate) (range)	$7.86 ($5.37-$10.71)
Macroeconomic Disruption (best estimate) (range)	$6.56 ($0.94-$12.23)
Total (best estimate) (range)	$14.42 ($6.31-$22.95)

The literature on the energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global value for the Social Cost of Carbon (SCC) the question arises: how should the energy security premium be used when some benefits from the rule, such as the benefits of reducing greenhouse gas emissions, are calculated using a global value? Monopsony benefits represent avoided payments by the U.S. to oil producers in foreign countries that result from a decrease in the world oil price as the U.S. decreases its consumption of imported oil (net of increased imported renewable fuel payments by the U.S.) Although there is clearly a benefit to the U.S. when considered from the domestic perspective, the decrease in price due to decreased demand in the U.S. also represents a loss to other countries. Given the redistributive nature of this effect, do the negative effects on other countries "net out" the positive impacts to the U.S.? If this is the case, then, the monopsony portion of the energy security premium should be excluded from the net benefits calculation for the rule. Based on this reasoning, EPA's estimates of net benefits for this rule exclude the portion of energy security benefits stemming from the U.S. exercising its monopsony power in oil markets. Thus, EPA only includes the macroeconomic disruption/adjustment cost portion of the energy security premium.

However, even when the global value for greenhouse gas reduction benefits is used, an argument can be made that the monopsony benefits should be included in net benefits calculation for this rule. Maintaining the earth's climate is a global public good and as such requires that a global cooperative perspective be taken on the benefits of GHG mitigation by all nations, including the U.S. Given that a cooperative global approach is required to address the climate change issue, each country (and market participant) should face the global SCC. In other words, using the global SCC does not transform the calculation from a domestic (i.e., U.S.) to a global one. Instead, the global SCC represents the domestic value that the U.S. should utilize to contribute cooperatively to a global solution of the climate change problem.

Energy security, on the other hand, is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs. Energy security is inherently a domestic benefit. However, the use of the domestic monopsony benefit is not necessarily in conflict with the use of the global SCC, because the global SCC represents the benefits against which the costs associated with our (i.e., the U.S.'s) domestic mitigation efforts should be judged. In addition, the U.S. values both maintaining the earth's climate and providing for its own energy security. If this reasoning holds, the two benefits—the global benefits of reducing greenhouse gas emissions and the full energy security premium, including the monopsony benefits—should be counted in the net benefits estimates of the rule. In the final analysis, the Agency determined that the first argument is more compelling and therefore has determined that using only the macroeconomic disruption component of the energy security benefit is the appropriate metric for this rule.

5.2.7 Total Energy Security Benefits from RFS2 Rule

The energy security benefits of increasing the total renewable fuel volumes from the AEO 2007 Reference Case volumes of 13.56 billion gallons to the Primary Control Case volumes of 30.5 billion gallons are shown in Table 5.2.7-1. Total annual energy security benefits are estimated by multiplying the change in renewable fuel volumes (16.94 billion gallons or 403 million barrels) and the macroeconomic disruption/adjustment portion of the energy security premium ($6.56/barrel of renewable fuels).

Table 5.2.7-1.
Total Energy Security Benefits from
the RFS2 Control Case vs. the AEO 2007 Reference Case
(billions of 2007$)

Year	**2022**
Benefits	$2.6

5.3. Benefits of Reducing GHG Emissions

5.3.1 Introduction

As discussed in Chapter 2, the increased volumes of renewable fuels mandated by the RFS2 standards are projected to reduce greenhouse gas emissions (GHG). This section presents estimates of the economic benefits that could be monetized for the reductions in GHG emissions projected due to the RFS2 renewable fuel volumes. The total benefit estimates were calculated by multiplying a marginal dollar value (i.e., cost per ton) of carbon emissions, also referred to as "social cost of carbon" (SCC), by the anticipated level of emissions reductions in tons.

The SCC values underlying the benefits estimates for this rule represent U.S. government-wide interim values for SCC. As discussed below, federal agencies will use these interim values to assess some of the economic benefits of GHG reductions while an interagency workgroup develops SCC values for use in the long-term. The interim values should not be viewed as an expectation about the results of the longer-term process. Although these values were not used in the NPRM, some commenters raised issues with these values and the methodology used to develop them in response to their publication elsewhere. Many of these issues are being examined by the interagency workgroup.

The rest of this section provides the basis for the interim SCC values, and the estimates of the total climate-related benefits of the RFS2 renewable fuel volumes that follow from these interim values. As discussed below, the interim dollar estimates of the SCC represent a partial accounting of climate change impacts.

In addition to the partial quantitative account presented in this section, a qualitative appraisal of climate-related impacts that are not fully captured in these values is published in other recent climate change analyses. For example, EPA's final Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act and the accompanying Technical Support Document (TSD) presents a summary of impacts and risks of climate change projected in the absence of actions to mitigate GHG emissions.[310] The TSD synthesizes major findings from the best available scientific assessments of the scientific literature that have gone through rigorous and transparent peer review, including the major assessment reports of both the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program (CCSP).

5.3.2 Derivation of Interim Social Cost of Carbon Values

The "social cost of carbon" (SCC) is intended to be a monetary measure of the incremental damage resulting from carbon dioxide (CO_2) emissions, including (but not limited to) net agricultural productivity loss, human health effects, property damages from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the consequences associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization of impacts, the SCC can be used to provide an estimate of the social benefits of reductions in GHG emissions.

[310] See Federal Register /Vol.74, No.2398/Wednesday, December 16, 2009/Rules and Regulations at http://frwebgate4.access.gpo.gov/cgi-bin/PDFgate.cgi?WAISdocID=969788398047+0+2+0&WAISaction=retrieve

For at least three reasons, any particular figure will be contestable. First, scientific and economic knowledge about the impacts of climate change continues to grow. With new and better information about relevant questions, including the cost, burdens, and possibility of adaptation, current estimates will inevitably change over time. Second, some of the likely and potential damages from climate change—for example, the loss of endangered species—are generally not included in current SCC estimates. These omissions may turn out to be significant in the sense that they may mean that the best current estimates are too low. As noted by the IPCC Fourth Assessment Report, "It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts." Third, when economic efficiency criteria, under specific assumptions, are juxtaposed with ethical considerations, the outcome may be controversial. These ethical considerations, including those involving the treatment of future generations, should and will also play a role in judgments about the SCC (see in particular the discussion of the discount rate, below).

To date, SCC estimates presented in recent regulatory documents have varied within and among agencies, including DOT, DOE, and EPA. For example, a regulation proposed by DOT in 2008 assumed a value of $7 per metric ton CO_2[311] (2006$) for 2011 emission reductions (with a range of $0-14 for sensitivity analysis). One of the regulations proposed by DOE in 2009 used a range of $0-$20 (2007$). Both of these ranges were designed to reflect the value of damages to the United States resulting from carbon emissions, or the "domestic" SCC. In the final MY2011 CAFE EIS, DOT used both a domestic SCC value of $2/t-$CO_2$ and a global SCC value of $33/t-$CO_2$ (with sensitivity analysis at $80/t-$CO_2$) (in 2006 dollars for 2007 emissions), increasing at 2.4% per year thereafter. The final MY2011 CAFE rule also presented a range from $2 to $80/t-$CO_2$.

In the May 2009 RFS2 Proposal leading to today's final rule, EPA identified preliminary SCC estimates that spanned three orders of magnitude. EPA's May 2009 proposal also presented preliminary global SCC estimates developed from a survey analysis of the peer reviewed literature (i.e., meta analysis). The global mean values from the meta analysis were $68 and $40/t-$CO_2$ for discount rates of 2% and 3% respectively (in 2006 real dollars for 2007 emissions).[312]

Since publication of the May 2009 RFS2 proposal, a federal interagency working group has established a methodology for selecting a range of interim SCC estimates for use in regulatory analyses. Today's final rule presents the methodology and the resulting interim set of SCC estimates, which reflect the Administration's current understanding of the relevant literature. Recent federal regulatory documents have also presented the interim SCC estimates, including a proposal to limit vehicle greenhouse gas emissions that requests public comment on the estimates and underlying methodology.[313]

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[311] For the purposes of this discussion, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Some discussions of the SCC in the literature use an alternative presentation of a dollar per metric ton of carbon. The standard adjustment factor is 3.67, which means, for example, that a SCC of $10 per ton of CO_2 would be equivalent to a cost of $36.70 for a ton of carbon emitted. Unless otherwise indicated, a "ton" refers to a metric ton.
[312] 74 FR 25094 (May 26, 2009).
[313] Federal Register 40 CFR Parts 86 and 600, September 28, 2009 "Proposed Rulemaking To Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Proposed Rule"

It should be emphasized that the analysis here is preliminary. These interim estimates are being used for the short-term while an interagency group develops a more comprehensive characterization of the distribution of SCC values for future economic and regulatory analyses. The interim values should not be viewed as an expectation about the results of the longer-term process.

This process will allow the workgroup to explore questions raised in the May 2009 RFS2 Proposal as they are relevant to the development of SCC values for use in the long-term. The workgroup may evaluate factors not currently captured in today's estimates due to time constraints, such as the quantification of additional impact categories where possible and an uncertainty analysis. The Administration will seek comment on all of the scientific, economic, and ethical issues before establishing improved estimates for use in future rulemakings.

The outcomes of the Administration's process to develop interim values are judgments in favor of a) global rather than domestic values, b) an annual growth rate of 3%, and c) interim global SCC estimates for 2007 (in 2007 dollars) of $56, $34, $20, $10, and $5 per metric ton of CO_2. The interim set of values is based on the following judgments.

5.3.2.1 Global and Domestic Measures

Because of the distinctive nature of the climate change problem, we present both a global SCC and a fraction of that value that represents impacts that may occur within the borders of the U.S. alone, or a "domestic" SCC, but fix our attention on the global measure. This approach represents a departure from past practices, which relied, for the most part, on domestic measures. As a matter of law, both global and domestic values are permissible; the relevant statutory provisions are ambiguous and allow selection of either measure.[314]

Under OMB guidance, analysis from the domestic perspective is required, while analysis from the international perspective is optional. The domestic decisions of one nation are not typically based on a judgment about the effects of those decisions on other nations. But the climate change problem is highly unusual in the sense that it involves (a) a global public good in which (b) the emissions of one nation may inflict significant damages on other nations and (c) the United States is actively engaged in promoting an international agreement to reduce worldwide emissions.

In these circumstances, we believe the global measure is preferred. Use of a global measure reflects the reality of the problem and is consistent with the continuing efforts of the United States to ensure that emissions reductions occur in many nations.

Domestic SCC values are also presented. The development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from EPA's ANPR Benefits TSD, using the

[314] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

FUND model. The resulting estimates suggest that the ratio of domestic to global benefits varies with key parameter assumptions. With a 3% discount rate, for example, the U.S. benefit is about 6 percent of the global benefit of GHG reductions for the "central" (mean) FUND results, while, for the corresponding "high" estimates associated with higher climate sensitivity and lower global economic growth, the U.S. benefit is less than 4 percent of the global benefit. With a 2 percent discount rate, the U.S. share is about 2-5 percent of the global estimate.

Based on this available evidence, an interim domestic SCC value equal to 6 percent of the global damages is proposed. It is recognized that the 6 percent figure is approximate and highly speculative and alternative approaches will be explored before establishing improved values for future rulemakings. However, it should be noted that it is difficult to properly apportion global benefits to different regions, because not all the damages citizens of one country would be willing to pay to avoid will occur only within their own borders. For example, impacts outside U.S. border can have significant welfare implications for U.S. populations (e.g. tourism, disaster relief) and if not included, these omissions will lead to an underestimation of the "domestic" SCC.

5.3.2.2 Filtering existing analyses

There are numerous SCC estimates in the existing literature, and it is reasonable to make use of those estimates in order to produce a figure for current use. A starting point is provided by the meta-analysis in Richard Tol, 2008.[315] With that starting point, the Administration proposes to "filter" existing SCC estimates by using those that (1) are derived from peer-reviewed studies; (2) do not weight the monetized damages to one country more than those in other countries; (3) use a "business as usual" climate scenario; and (4) are based on the most recent published version of each of the three major integrated assessment models (IAMs): FUND, PAGE, and DICE.

Proposal (1) is based on the view that those studies that have been subject to peer review are more likely to be reliable than those that have not. Proposal (2) avoids treating the citizens of one nation (or different citizens within the US) differently on the basis of income considerations, which some may find controversial and in any event would complicate that analysis. Further it is consistent with the potential compensation tests of Kaldor (1939) and Hicks (1940), which form the conceptual foundations of benefit-cost analysis and use unweighted sums of willingness to pay. Finally, this is the approach used in rulemakings across a variety of settings and consequently keeps USG policy consistent across contexts.

Proposal (3) stems from the judgment that as a general rule, the proper way to assess a policy decision is by comparing the implementation of the policy against a counterfactual state where the policy is not implemented. In addition, our expectation is that most policies to be evaluated using these interim SCC estimates will constitute small enough changes to the larger economy to safely assume that the marginal benefits of emissions reductions will not change between the baseline and policy scenarios.

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[315] Richard Tol, The Social Cost of Carbon: Trends, Outliers, and Catastrophes, Economics: The Open-Access, Open-Assessment E-Journal, Vol. 2, 2008-25. http://www.economics-ejournal.org/economics/journalarticles/2008-25 (2008).

Proposal (4) is based on four complementary judgments. First, the FUND, PAGE, and DICE models now stand as the most comprehensive and reliable efforts to measure the economic damages from climate change. Second, the latest versions of the three IAMs are likely to reflect the most recent evidence and learning, and hence they are presumed to be superior to those that preceded them. However, it is acknowledged that the most recently published results do not necessarily repeat prior modeling exercises with an updated model, so valuable information may be lost, for instance, estimates of the SCC using specific climate sensitivities or economic scenarios. In addition, although some older model versions were used to produce estimates between 1996 and 2001, there have been no significant modeling paradigm changes since 1996.

Third, any effort to choose among them, or to reject one in favor of the others, would be difficult to defend at the present time. In the absence of a clear reason to choose among them, it is reasonable to base the SCC on all of them. Fourth, in light of the uncertainties associated with the SCC, a range of values is more representative and the additional information offered by different models is important.

5.3.2.3 Use a Model-weighted Average of the Estimates at Each Discount Rate

At this time, a strong reason to prefer any of the three major IAMs (FUND, PAGE, and DICE) over the others has not been identified. Accordingly, to address the concern that certain models not be given unequal weight relative to the other models, the estimates are based on an equal weighting of the means of the estimates from each of the models. Among estimates that remain after applying the filter, we begin by taking the average of all estimates within a model. The estimated SCC is then calculated as the average of the three model-specific averages. This approach is used to ensure that models with a greater number of published results do not exert unequal weight on the interim SCC estimates. However, note that the resulting set of SCC estimates does not provide information about variability among or within models except in so far as they have different discounting assumptions. In the future interagency process to generate a more comprehensive distribution of SCC, we expect to exercise the available SCC models in a systematic manner such that the resulting distributions of SCC values may incorporate a wider range of uncertainties including discount rates, growth rates, climate sensitivities, and other important parameters. This may lead to changes in the span of SCC estimates that are relevant for policy analyses.

5.3.2.4 Apply a 3 Percent Annual Growth Rate to the Chosen SCC Values

SCC is expected to increase over time, because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed as the magnitude of climate change increases. Indeed, an implied growth rate in the SCC can be produced by most of the models that estimate economic damages caused by increased GHG emissions in future years. But neither the rate itself nor the information necessary to derive its implied value is commonly reported. In light of the limited amount of debate thus far about the appropriate growth rate of the SCC, applying a rate of 3 percent per year seems appropriate at this stage. This value is consistent with the range recommended by IPCC (2007) and close to the latest published estimate (Hope 2008).

5.3.2.5 Discount Rates

For estimation of the benefits associated with the mitigation of climate change, one of the most complex issues involves the appropriate discount rate. OMB's current guidance offers a detailed discussion of the relevant issues and calls for discount rates of 3 percent and 7 percent. It also permits a sensitivity analysis with low rates (1 – 3 percent) for intergenerational problems: "If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent."[316]

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. See, e.g., William Nordhaus, The Challenge of Global Warming (2008); Nicholas Stern, The Economics of Climate Change (2008); Discounting and Intergenerational Equity (Paul Portney and John Weyant eds. 1999). It is not clear that future generations would be willing to trade environmental quality for consumption at the same rate as the current generations. Under imaginable assumptions, decisions based on cost-benefit analysis with high discount rates might harm future generations – at least if investments are not made for the benefit of those generations. See Robert Lind, Analysis for Intergenerational Discounting, id. at 173, 176-177. It is also possible that the use of low discount rates for particular projects might itself harm future generations, by diverting resources from private or public sector investments with higher rates of return for future generations. In the context of climate change, questions of intergenerational equity are especially important.

Because of the substantial length of time in which CO_2 and other GHG emissions reside in the atmosphere, choosing a discount rate which is higher than the actual discount rate could result in irreversible changes in CO_2 concentrations, and possibly irreversible climate changes (unless substantial reductions in short-lived climate forcing emissions are achieved). Even if these changes are reversible, delaying mitigation efforts could result in substantially higher costs of stabilizing CO_2 concentrations. On the other hand, using too low a discount rate in benefit-cost analysis may recommend some potentially economically unwarranted investments in mitigation. In many cases these investments could be discontinued with little long term economic disruptions. However, it is also possible that the use of low discount rates for particular projects might itself harm future generations, by ensuring that resources are not used in a way that would greatly benefit them.

Reasonable arguments support the use of a 3 percent discount rate. First, that rate is among the two figures suggested by OMB guidance, and hence it fits with existing national policy. Second, it is standard to base the discount rate on the compensation that people receive for delaying consumption, and the 3 percent is close to the risk-free rate of return, proxied by the return on long term inflation-adjusted U.S. Treasury Bonds, as of this writing. Although these rates are currently closer to 2.5 percent, the use of 3 percent provides an adjustment for the liquidity premium that is reflected in these bonds' returns. However, this approach does not adjust for the significantly longer time horizon associated with climate change impacts. It also

[316] See OMB Circular A-4, pp. 35-36, citing Portney and Weyant, eds. (1999), Discounting and Intergenerational Equity, Resources for the Future, Washington, DC.

could be argued that the appropriate interest rate should be lower than 3 percent if the benefits of climate mitigation policies tend to be higher than expected in time periods when the returns to investments in rest of the economy are lower than normal.

At the same time, others would argue that a 5 percent discount rate can be supported. The argument relies on several assumptions. First, this rate can be justified by reference to the level of compensation for delaying consumption, because it fits with market behavior with respect to *individuals'* willingness to trade-off consumption across periods as measured by the estimated post-tax average real returns to risky private investments (e.g., the S&P 500). In the climate setting, the 5 percent discount rate may be preferable to the riskless rate because the benefits to mitigation are not known with certainty. In principal, the correct discount rate would reflect the variance in payoff from climate mitigation policy and the correlation between the payoffs of the policy and the broader economy.[317]

Second, 5 percent, and not 3 percent, is roughly consistent with estimates implied by inputs to the theoretically derived Ramsey equation presented below, which specifies the optimal time path for consumption. That equation specifies the optimal discount rate as the sum of two components. The first term (the product of the elasticity of the marginal utility of consumption and the growth rate of consumption) reflects the fact that consumption in the future is likely to be higher than consumption today, so diminishing marginal utility implies that the same monetary damage will cause a smaller reduction of utility in the future. Standard estimates of this term from the economics literature are in the range of 3 percent-5 percent.[318] The second component reflects the possibility that a lower weight should be placed on utility in the future, to account for social impatience or extinction risk, which is specified by a pure rate of time preference (PRTP). A common estimate of the PRTP is 2 percent, though some observers believe that a principle of intergenerational equity suggests that the PRTP should be close to zero. It follows that discount rate of 5 percent is near the middle of the range of values that are able to be derived from the Ramsey equation.[319]

It is recognized that the arguments above – for use of market behavior and the Ramsey equation – face objections in the context of climate change, and of course there are alternative

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[317] Specifically, if the benefits of the policy are highly correlated with the returns from the broader economy, then the market rate should be used to discount the benefits. If the benefits are uncorrelated with the broader economy the long term government bond rate should be applied. Furthermore, if the benefits are negatively correlated with the broader economy, a rate less than that on long term government bonds should be used (Lind, 1982 pp. 89-90).

[318] For example, *see:* Arrow KJ, Cline WR, Maler K–G, Munasinghe M, Squitieri R, Stiglitz JE. 1996. Intertemporal equity, discounting, and economic efficiency. Chapter 4 in Economic and Social Dimensions of Climate Change: Contribution of Working Group III to the Second Assessment Report, Summary for Policy Makers. Cambridge: Cambridge University Press; Dasgupta P. 2008. Discounting climate change. Journal of Risk and Uncertainty 37:141–169; Hoel M, Sterner T. 2007. Discounting and relative prices. Climatic Change 84:265–280; Nordhaus WD. 2008. A Question of Balance: Weighing the Options on Global Warming Policies. New Haven, CT: Yale University Press; Stern N. 2008. The economics of climate change. The American Economic Review 98(2):1–37..

[319] Sterner and Persson (2008) note that a consistent treatment of the marginal utility of consumption would require that if higher discount rates are justified by the diminishing marginal utility of consumption, e.g., a dollar of damages is worth less to future generations because they have greater income, then so-called equity weights should be used to account for the higher value that countries with lower income would place on a dollar of damages relative to the U.S. This is a consistent and logical outcome of application of the Ramsey framework. Because the distribution of climate change related damages is expected to be skewed towards developing nations with lower incomes, this can have significant implications for estimates of total global SCC if the Ramsey framework is used to derive discount rates.

approaches. In light of climate change, it is possible that consumption in the future will not be higher than consumption today, and if so, the Ramsey equation will suggest a lower figure. The historical evidence is consistent with rising consumption over time.[320]

Some critics note that using observed interest rates for inter-generational decisions imposes current preferences on future generations, which some economists say may not be appropriate. For generational equity, they argue that the discount rate should be below market rates to correct for market distortions and inefficiencies in intergenerational transfers of wealth (which are presumed to compensate future generations for damage), and to treat generations equitably based on ethical principles (see Broome 2008).[321]

Additionally, some analyses attempt to deal with uncertainty with respect to interest rates over time. We explore below how this might be done.[322]

5.3.2.6 Interim Social Cost of Carbon Estimates

The application of the methodology outlined above yields interim estimates of the SCC that are reported in Table 5.3.2.6-1. These estimates are reported separately using 3 percent and 5 percent discount rates. The cells are empty in rows 10 and 11, because these studies did not report estimates of the SCC at a 3 percent discount rate. The model-weighted means are reported in the final or summary row; they are \$34 per t-CO_2 at a 3% discount rate and \$5 per t-CO_2 with a 5 percent discount rate.

[320]However, because climate change impacts may be outside the bounds of historical evidence, predictions about future growth in consumption based on past experience may be inaccurate.

[321] See Arrow, K.J., W.R. Cline, K-G Maler, M. Munasinghe, R. Squiteri, J.E.Stiglitz, 1996. "Intertemporal equity, discounting and economic efficiency," in Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. See also Weitzman, M.L., 1999, in Portney P.R. and Weyant J.P. (eds.), Discounting and Intergenerational Equity, Resources for the Future, Washington, D.C.

[322] Richard Newell and William Pizer, Discounting the distant future: how much do uncertain rates increase valuations? J. Environ. Econ. Manage. 46 (***2003***) 52-71.

Table 5.3.2.6-1.
Global Social Cost of Carbon (SCC) Estimates ($/t-$CO_2$ in 2007 (2007$)), Based on 3 Percent and 5 Percent Discount Rates *

	Model	Study	Climate Scenario	3%	5%
1	FUND	Anthoff et al. 2009	FUND default	6	-1
2	FUND	Anthoff et al. 2009	SRES A1b	1	-1
3	FUND	Anthoff et al. 2009	SRES A2	9	-1
4	FUND	Link and Tol 2004	No THC	12	3
5	FUND	Link and Tol 2004	THC continues	12	2
6	FUND	Guo et al. 2006	Constant PRTP	5	-1
7	FUND	Guo et al. 2006	Gollier discount 1	14	0
8	FUND	Guo et al. 2006	Gollier discount 2	7	-1
			FUND Mean	**8.47**	**0**
9	PAGE	Wahba & Hope 2006	A2-scen	59	7
10	PAGE	Hope 2006			7
11	DICE	Nordhaus 2008			8
Summary			**Model-weighted Mean**	**34**	**5**

*The sample includes all peer reviewed, non-equity-weighted estimates included in Tol (2008), Nordhaus (2008), Hope (2008), and Anthoff et al. (2009), that are based on the most recent published version of FUND, PAGE, or DICE and use business-as-usual climate scenarios.[323][324] All values are based on the best available information from the underlying studies about the base year and year dollars, rather than the Tol (2008) assumption that all estimates included in his review are 1995 values in 1995$. All values were updated to 2007 using a 3% annual growth rate in the SCC, and adjusted for inflation using GDP deflator.

In today's rule, benefits of reducing GHG emissions have been estimated using global SCC values of $34 and $5 as these represent the estimates associated with the 3 percent and 5 percent discount rates, respectively.[325] The 3 percent and 5 percent estimates have independent

[323] Most of the estimates in Table 1 rely on climate scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC published a new set of scenarios in 2000 for use in the Third Assessment Report (Special Report on Emissions Scenarios - SRES). The SRES scenarios define four narrative storylines: A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. The storylines are summarized in Nakicenovic et al., 2000 (see also http://sedac.ciesin.columbia.edu/ddc/sres/). Although they were intended to represent BAU scenarios, at this point in time the B1 and B2 storylines are widely viewed as representing policy cases rather than business-as-usual projections, estimates derived from these scenarios to be less appropriate for use in benefit-cost analysis. They are therefore excluded.

[324] Guo et al. (2006) report estimates based on two Gollier discounting schemes. The Gollier discounting assumes complex specifications about individual utility functions and risk preferences. After various conditions are satisfied, declining social discount rates emerge. Gollier Discounting Scheme 1 employs a certainty-equivalent social rate of time preference (SRTP) derived by assuming the regional growth rate is equally likely to be 1% above or below the original forecast growth rate. Gollier Discounting Scheme 2 calculates a certainty-equivalent social rate of time preference (SRTP) using five possible growth rates, and applies the new SRTP instead of the original. Hope (2008) conducts Monte Carlo analysis on the PRTP component of the discount rate. The PRTP is modeled as a triangular distribution with a min value of 1%/yr, a most likely value of 2 %/yr, and a max value of 3 %/yr.

[325] It should be noted that reported discount rates may not be consistently derived across models or specific applications of models: while the discount rate may be identical, it may reflect different assumptions about the individual components of the Ramsey equation identified earlier.

appeal and at this time a clear preference for one over the other is not warranted. Thus, we have also included – and centered our current attention on – the average of the estimates associated with these discount rates, which is \$20. (Based on the \$20 global value, the approximate domestic fraction of these benefits would be \$1.20 per metric ton of CO_2 assuming that domestic benefits are 6% of the global benefits.

The distinctions between sets of estimates generated using different discount rates are due only in part to discount rate differences, because the models and parameters used to generate the estimates in the sets associated with different discount rates also vary.

It is true that there is uncertainty about interest rates over long time horizons. Recognizing that point, Newell and Pizer (2003) have made a careful effort to adjust for that uncertainty. The Newell-Pizer approach models discount rate uncertainty as something that evolves over time.[326] This is a different way to model discount rate uncertainty than the approach outlined above, which assumes there is a single discount rate with equal probability of 3 percent and 5 percent.

Table 5.3.2.6-2 reports on the application of the Newell-Pizer adjustments. The precise numbers depend on the assumptions about the data generating process that governs interest rates. Columns (1a) and (1b) assume that "random walk" model best describes the data and uses 3 percent and 5 percent discount rates, respectively. Columns (2a) and (2b) repeat this, except that it assumes a "mean-reverting" process. While the empirical evidence does not rule out a mean-reverting model, Newell and Pizer find stronger empirical support for the random walk model.

[326] In contrast, an alternative approach based on Weitzman (2001) would assume that there is a constant discount rate that is uncertain and represented by a probability distribution. The Newell and Pizer, and Weitzman approaches are relatively recent contributions to the literature. .

Table 5.3.2.6-2.
Global Social Cost of Carbon (SCC) Estimates ($ per metric ton CO_2 in 2007 (2007$))*, Using Newell & Pizer (2003) Adjustment for Future Discount Rate Uncertainty**

	Model	**Study**	**Climate Scenario**	Random-walk model		Mean-reverting model	
				3% (1a)	5% (1b)	3% (2a)	5% (2b)
1	FUND	Anthoff et al. 2009	FUND default	10	0	7	-1
2	FUND	Anthoff et al. 2009	SRES A1b	2	0	1	-1
3	FUND	Anthoff et al. 2009	SRES A2	15	0	10	-1
4	FUND	Link and Tol 2004	No THC	21	6	13	4
5	FUND	Link and Tol 2004	THC continues	21	4	13	2
6	FUND	Guo et al. 2006	Constant PRTP	9	0	6	-1
7	FUND	Guo et al. 2006	Gollier discount 1	14	0	14	0
8	FUND	Guo et al. 2006	Gollier discount 2	7	-1	7	-1
			FUND Mean	**12**	**1**	**9**	**0**
9	PAGE	Wahba & Hope 2006	A2-scen	100	13	65	8
10	PAGE	Hope 2006			13		8
11	DICE	Nordhaus 2008			15		9
Summary			**Model-weighted Mean**	**56**	**10**	**37**	**6**

*The sample includes all peer reviewed, non-equity-weighted estimates included in Tol (2008), Nordhaus (2008), Hope (2008), and Anthoff et al. (2009), that are based on the most recent published version of FUND, PAGE, or DICE and use business-as-usual climate scenarios. All values are based on the best available information from the underlying studies about the base year and year dollars, rather than the Tol (2008) assumption that all estimates included in his review are 1995 values in 1995$. All values were updated to 2007 using a 3% annual growth rate in the SCC, and adjusted for inflation using GDP deflator. See the Notes to Table 1 for further details.
**Assumes a starting discount rate of 3% or 5%. Newell and Pizer (2003) based adjustment factors are not applied to estimates from Guo et al. (2006) that use a different approach to account for discount rate uncertainty (rows 7-8). Note that the correction factor from Newell and Pizer is based on the DICE model. The proper adjustment may differ for other integrated assessment models that produce different time schedules of marginal damages. We would expect this difference to be minor.

The resulting estimates of the social cost of carbon are necessarily greater. When the adjustments from the random walk model are applied, the estimates of the social cost of carbon are $10 and $56 per ton of CO_2, with the 5 percent and 3 percent discount rates, respectively. The application of the mean-reverting adjustment yields estimates of $6 and $37. Relying on the random walk model, analyses are also conducted with the value of the SCC set at $10 and $56.

5.3.2.7 Caveats

There are at least four caveats to the approach outlined above.

First, the impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain, because of the inherent randomness in the Earth's atmospheric processes, the U.S. and global economies, and the behaviors of current and future populations. The existing IAMs do not currently individually account for and assign value to all of the important physical and other impacts of climate change that are recognized in the climate change literature.[327] Therefore, as noted by the IPCC, SCC estimates are "very likely" underestimated.[328] In addition, the SCC approach also likely underestimates the value of GHG reductions because the marginal values apply only to CO_2 emissions, which have different impacts than non-CO_2 emissions because of variances in atmospheric lifetimes and radiative forcing.[329] Although it is likely that our capability to quantify and monetize impacts will improve with time, it is also likely that even in future applications, a number of potentially significant benefits categories will remain unmonetized. In order to more fully characterize of benefits of mitigation these non-monetized benefits should be discussed along with monetized benefits based on the SCC.

Second, in the opposite direction, it is unlikely that the damage estimates adequately account for the directed technological change that climate change will cause. In particular, climate change will increase the return on investment to develop technologies that allow individuals to better cope with climate change. For example, it is likely that scientists will develop crops that are better able to withstand high temperatures. In this respect, the current estimates may overstate the likely quantified damages, though the costs associated with the investments in adaptive technologies must also be considered (technologies must also be included in the calculations, as the benefits should reflect net welfare changes to society).

Third, there has been considerable recent discussion of the risk of catastrophic impacts and of how best to account for worst-case scenarios. Recent research by Weitzman (2009) specifies some conditions under which the possibility of catastrophe would undermine the use of IAMs and conventional cost-benefit analysis. This research requires further exploration before its generality is known and the proper way to incorporate it into regulatory reviews is understood.

Fourth, it is also worth noting that the SCC estimates are only relevant for incremental policies relative to the projected baselines, which capture business-as-usual scenarios. To evaluate non-marginal changes, such as might occur if the U.S. acts in tandem with other nations, then it might be necessary to go beyond the simple expedient of using the SCC along the BAU path. This would require explicitly calculating the total benefits in a move from the BAU scenario to the policy scenario, without imposing the restriction that the marginal benefit remains constant over this range.

5.3.2.8 Other Options

[327]Examples of impacts that are difficult to monetize, and have generally not been included in SCC estimates, include risks from extreme weather (death, disease, agricultural damage, and other economic damage from droughts, floods and wildfires) and possible long-term catastrophic events, such as collapse of the West Antarctic ice sheet or the release of large amounts of methane from melting permafrost.

[328] IPCC WGII. 2007. *Climate Change 2007 - Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the IPCC*.

[329]Radiative forcing is the change in the balance between solar radiation entering the atmosphere and the Earth's radiation going out. On average, a positive radiative forcing tends to warm the surface of the Earth while negative forcing tends to cool the surface. Greenhouse gases have a positive radiative forcing because they absorb and emit heat. See http://www.epa.gov/climatechange/science/recentac.html for more general information about GHGs and climate science.

The Administration considered other interim SCC options in addition to the approach described above. Similar to May 2009 RFS2 Proposal, one alternative option was to bring in SCC estimates in studies published after 1995, rather than limiting the estimates to those in studies relying on the most recent published version of each of the three major integrated assessment models: PAGE, FUND, and DICE. Although some older model versions (and old versions of other models) were used to produce estimates between 1996 and 2001, there have been no significant modeling paradigm changes since 1996. Rather, improvements to PAGE, FUND, and DICE since 1996 have reflected incremental technical enhancements.

Another option was to select a range of SCC values for separate discount rates. For example, sensitivity analysis could be conducted at the lowest and highest SCC values reported in the filtered set of estimates for each discount rate considered. If considering SCC estimates from studies published after 1995 and a discount rate of 2 percent, this option would result in a range of SCC values of \$5/t-CO_2 to \$260/t-CO_2 (2007 emissions in 2007 dollars); at a 3 percent discount rate, the range would be \$0 to \$58/ t-CO_2.

Finally, we considered that the use of certain key assumptions under the Ramsey framework, such as placing approximately equal weight on the welfare of current and future generations, would imply use of a 2% discount rate. The Newell and Pizer (2003) method applied to recent long-term risk free rates would likewise be approximately consistent with a rate of 2 percent.[330]

5.3.2.9 Ongoing SCC Development

As noted, this is an emphatically interim SCC value. The judgments herein will be subject to further scrutiny and exploration.

5.3.3 Application of Interim SCC Estimates to GHG Emissions Reductions from this Final Rule

While no single rule or action can independently achieve the deep worldwide emissions reductions necessary to halt and reverse the growth of GHGs, the combined effects of multiple strategies to reduce GHG emissions domestically and abroad could make a major difference in the climate change impacts experienced by future generations.[331] The projected net GHG emissions reductions associated with this final rule reflect an incremental change to projected total global emissions. Given that the climate response is projected to be a marginal change relative to the baseline climate, we estimate the marginal value of changes in climate change impacts over time and use this value to measure the monetized marginal benefits of the GHG emissions reductions projected for this rule.

[330] Specifically, Newell and Pizer (2003) found that modeling of uncertainty in economic growth causes the effective discount rate to decline over time. When starting at a 4% discount rate, the effective discount rate is 2% at 100 years and 1% at 200 years.

[331] The Supreme Court recognized in *Massachusetts v. EPA* that a single action will not on its own achieve all needed GHG reductions, noting that "[a]gencies, like legislatures, do not generally resolve massive problems in one fell regulatory swoop.'' See *Massachusetts v*. EPA, 549 U.S. at 524 (2007).

Accordingly, EPA has used the set of interim, global SCC values described above to estimate the benefits resulting from the renewable fuel volumes mandated by EISA. The interim SCC values, which reflect the Administration's interim interpretation of the current literature, are $5, $10, $20, $34, and $56, in 2007 dollars, and are based on a CO_2 emissions change of 1 metric ton in 2007. Table 5.3.3-1 presents the interim SCC values for the years 2007 and 2022 in 2007 dollars.

Table 5.3.3-1. Interim SCC Schedule (2007$ per metric tonne of CO_2)

Year	5%	5% (Newell-Pizer)*	Average SCC from 3% and 5%	3%	3% (Newell-Pizer)*
2007	$5	$10	$20	$34	$56
2022	$8	$16	$30	$53	$88

Note: The SCC values are dollar-year and emissions-year specific. These values are presented in 2007$, for individual year of emissions. To determine values for years not presented in the table, use a 3% growth rate. SCC values represent only a partial accounting for climate impacts.
*SCC values are adjusted based on Newell and Pizer (2003) to account to future uncertainty in discount rates.

Tables 5.3.3-2 through 5.3.3-4 provide, for the high, base, and low cases, the average annual GHG emissions reductions in 2022. The annualized emissions reductions are multiplied by the SCC estimates for 2022 from Table 5.3.3-1 to produce the average annual monetized benefit from the emissions reductions from the rule for CO_2-equivalent GHGs. This is equivalent to taking the time stream of emissions from the increase in renewable fuel volumes, multiplying them by the SCC (which is increasing at a rate of 3 percent per year), and then discounting the stream of benefits by 3 percent.

Table 5.3.3-2.
Average Annual Emissions Reduction (Million Metric Tonnes CO_2-e) and Monetized Benefits (Million 2007$) of RFS-2 Volumes in 2022, High Case

	CO_2	Non-CO_2 GHG	Total GHG
Emissions Reductions	148.525	-8.234	140.291
5%	$1,188	-$66	$1,122
5% (Newell-Pizer)	$2,376	-$132	$2,245
Average SCC from 3% and 5%	$4,515	-$250	$4,265
3%	$7,842	-$435	$7,407
3% (Newell-Pizer)	$13,069	-$725	$12,344

Table 5.3.3-3.
Average Annual Emissions Reduction (Million Metric Tonnes CO_2-e) and Monetized Benefits (Million 2007$) of RFS-2 Volumes in 2022, Base Case

	CO_2	Non-CO_2 GHG	Total GHG
Emissions Reductions	146.645	-8.234	138.411
5%	$1,173	-$66	$1,107
5% (Newell-Pizer)	$2,346	-$132	$2,215
Average SCC from 3% and 5%	$4,458	-$250	$4,208
3%	$7,743	-$435	$7,308
3% (Newell-Pizer)	$12,903	-$725	$12,179

Table 5.3.3-4.
Average Annual Emissions Reduction (Million Metric Tonnes CO_2-e) and Monetized Benefits (Million 2007$) of RFS-2 Volumes in 2022, Low Case

	CO_2	Non-CO_2 GHG	Total GHG
Emissions Reductions	144.338	-8.234	136.104
5%	$1,155	-$66	$1,089
5% (Newell-Pizer)	$2,309	-$132	$2,178
Average SCC from 3% and 5%	$4,388	-$250	$4,138
3%	$7,621	-$435	$7,186
3% (Newell-Pizer)	$12,700	-$725	$11,976

Table 5.3.3-5 provides, for the high, base, and low cases, the monetized benefits from the emissions reductions from the increase in renewable fuel volumes for CO_2-equivalent GHGs in 2022. The SCC estimates for 2022 increase at a rate of 3 percent per year, and are then multiplied by the stream of emissions for each respective year for 30 years. The monetized benefits in table 5.3.3-5 represent the net present value of these emissions for 30 years using a discount rate of 7 percent.

Table 5.3.3-5.
Monetized Benefits (Million 2007$) of RFS-2 Volumes in 2022
Using a 7% Discount Rate

	High	Base	Low
5%	$606	$620	$631
5% (Newell-Pizer)	$1,212	$1,239	$1,262
Average SCC from 3% and 5%	$2,302	$2,355	$2,397
3%	$3,999	$4,089	$4,163
3% (Newell-Pizer)	$6,665	$6,816	$6,939

5.4 Quantified and Monetized Co-pollutant Health and Environmental Impacts

5.4.1 Overview

This section describes EPA's analysis of the co-pollutant health and environmental impacts that can be expected to occur as a result of the increase in renewable fuel use throughout the period from initial implementation through 2022. Although the purpose of this final rule is to implement the renewable fuel requirements established by the Energy Independence and Security Act (EISA) of 2007, the increased use of renewable fuels will also impact emissions of criteria and air toxic pollutants and their resultant ambient concentrations. The fuels changes detailed in Section 3.1 of the RIA will influence emissions of VOCs, PM, NO_X, and SO_X and air toxics and affect exhaust and evaporative emissions of these pollutants from vehicles and equipment. They will also affect emissions from upstream sources such as fuel production, storage, distribution and agricultural emissions. Any decrease or increase in ambient ozone, $PM_{2.5}$, and air toxics associated with the increased use of renewable fuels will impact human health in the form of a decrease or increase in the risk of incurring premature death and other serious human health effects, as well as other important public health and welfare effects.

This analysis reflects the impact of the 2022 mandated renewable fuel volumes (the "RFS2 control case") compared with two different reference scenarios that include the use of renewable fuels: a 2022 baseline projection based on the RFS1-mandated volume of 7.1 billion gallons of renewable fuels, and a 2022 baseline projection based on the AEO 2007 volume of roughly 13.6 billion gallons of renewable fuels.[332] Thus, the results represent the impact of an incremental increase in ethanol and other renewable fuels. We note that the air quality modeling results presented in this final rule do not constitute the "anti-backsliding" analysis required by Clean Air Act section 211(v). EPA will be analyzing air quality and health impacts of increased renewable fuel use through that study and will promulgate appropriate mitigation measures under section 211(v), separate from this final action.

As can be seen in Section 3.4 of this RIA, there are both increased and decreased concentrations of ambient criteria pollutants and air toxics. Overall, we estimate that the final rule will lead to a net increase in criteria pollutant-related health impacts. By 2022, the final RFS2 rule volumes relative to both reference case scenarios (RFS1 and AEO2007), are projected to adversely impact $PM_{2.5}$ air quality over parts of the U.S., while some areas will experience decreases in ambient $PM_{2.5}$. As described in Section 3.4, ambient $PM_{2.5}$ is likely to increase as a result of emissions at renewable fuel production plants and from renewable fuel transport, both of which are more prevalent in the Midwest. PM concentrations are also likely to decrease in some areas. While the PM-related air quality impacts are relatively small, the increase in population-weighted national average $PM_{2.5}$ exposure results in a net increase in adverse PM-related human health impacts. (the increase in national population weighted annual average

[332] The 2022 modeled scenarios assume the following: RFS1 reference case assumes 6.7 Bgal/yr ethanol and 0.38 Bgal/yr biodiesel; AEO2007 reference case assumes 13.18 Bgal/yr ethanol and 0.38 Bgal/yr biodiesel; RFS2 control case assumes 34.14 Bgal/yr ethanol, 0.81 Bgal/yr biodiesel, and 0.38 Bgal/yr renewable diesel. Please refer to Chapter 3.3 and Table 3.3-1 for more information about the renewable fuel volumes assumed in the modeled analyses and the corresponding emissions inventories.

$PM_{2.5}$ is 0.006 μg/m3 and 0.002 μg/m3 relative to the RFS1 and AEO2007 reference cases, respectively).

The required renewable fuel volumes, relative to both reference scenarios, are also projected to adversely impact ozone air quality over much of the U.S., especially in the Midwest, Northeast and Southeast. These adverse impacts are likely due to increased upstream emissions of NOx in many areas that are NOx-limited (acting as a precursor to ozone formation). There are, however, ozone air quality improvements in some highly-populated areas that currently have poor air quality. This is likely due to VOC emission reductions at the tailpipe in urban areas that are VOC-limited (reducing VOC's role as a precursor to ozone formation). Relative to the RFS1 mandate reference case, the RFS2 volumes result in a small increase in ozone-related health impacts (population weighted maximum 8-hour average ozone increases by 0.177 ppb). Relative to the AEO2007 reference case, the RFS2 volumes result in a small increase in ozone-related health impacts (population weighted maximum 8-hour average ozone increases by 0.116 ppb).

The analysis of national-level $PM_{2.5}$- and ozone-related health and environmental impacts associated with the final rule is based on peer-reviewed studies of air quality and human health effects (see US EPA, 2006 and US EPA, 2008).[1180,1181] We are also consistent with the benefits analysis methods that supported the recently proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA (U.S. EPA, 2009a),[1182] the proposed NO_2 primary NAAQS RIA (U.S. EPA, 2009b),[1183] and the proposed Category 3 Marine Diesel Engines RIA (U.S. EPA, 2009c).[1184] To model the ozone and PM air quality impacts of the 2022 renewable fuel volumes, we used the Community Multiscale Air Quality (CMAQ) model (see Chapter 3.4). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[333] BenMAP is a computer program developed by the U.S. EPA that integrates a number of the modeling elements used in previous analyses (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

Emissions and air quality modeling decisions were made early in the analytical process and as a result, there are a number of important limitations and uncertainties associated with the air quality modeling analysis that must be kept in mind when considering the results. A key limitation of the analysis is that it employed interim emission inventories, which were enhanced compared to what was described in the proposal, but did not include some of the later enhancements and corrections of the final emission inventories presented in this FRM (see Section 3.3 of this RIA). Most significantly, our modeling of the air quality impacts of RFS2 relied upon interim inventories that assumed that ethanol will make up 34 of the 36 billion gallon renewable fuel mandate, that approximately 20 billion gallons of this ethanol will be in the form of E85, and that the use of E85 results in fewer emissions of direct $PM_{2.5}$ from vehicles. The emission impacts, air quality results and benefits analysis would be different if, instead of E85, more non-ethanol biofuels are used or mid-level ethanol blends are approved and utilized. In fact, as explained in Chapter 1, our more recent analyses indicate that ethanol and E85 volumes are likely to be significantly lower than what we assumed in the interim inventories.

[333] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/ benmodels.html.

Furthermore, the final emission inventories do not include vehicle-related PM reductions associated with E85 use, as discussed in Chapters 3.1-3.3 of this RIA. There are additional, important limitations and uncertainties associated with the interim inventories that must be kept in mind when considering the results, which are described in more detail in Chapter 3.4. While it is difficult to describe the overall impact of these limitations and uncertainties on the quantified and monetized health impacts of the increased renewable fuel volumes without updating the air quality modeling analysis, we believe the results are still useful for describing potential national-level health impacts.

Additionally, after the air quality modeling was completed, we discovered an error in the way that $PM_{2.5}$ emissions from locomotive engines were allocated to counties in the inventory. The mismatched allocations between the reference and control scenarios resulted in $PM_{2.5}$ emission changes that were too high in some counties and too low in others, by varying degrees. As a result, we did not present the modeling results for specific localized $PM_{2.5}$ impacts in Section 3.4. However, because the error was random and offsetting, there was very little impact on national-level $PM_{2.5}$ emissions. An analysis of the error's impact on the national emission inventories found that direct $PM_{2.5}$ emissions were inflated by 8% relative to the AEO reference case and by 0.6% relative to the RFS1 reference case, leading to a small overestimation of national PM-related adverse health impacts. Note that this error did not impact other PM precursor inventories such as NOx and SO2. As a result, we have concluded that $PM_{2.5}$ modeling results are still informative for national-level benefits assessment, particularly given that other uncertainties in the $PM_{2.5}$ inventory (such as E85 usage**,** discussed below) have a more important (and offsetting) effect.

Table 5.4-1.
Estimated 2022 Monetized PM-and Ozone-Related Health Impacts from the Mandated Renewable Fuel Volumes[a]

2022 Total Ozone and PM Benefits, RFS2 Control Case Compared to RFS1 Reference Case[a]			
Premature Ozone Mortality Function	Reference	Total Benefits (Billions, 2007$, 3% Discount Rate)[b,c]	Total Benefits (Billions, 2007$, 7% Discount Rate)[b,c]
Multi-city analyses	Bell et al., 2004	Total: -$1.4 to -$2.8 PM: -$0.92 to -$2.3 Ozone: -$0.52	Total: -$1.4 to -$2.6 PM: -$0.84 to -$2.0 Ozone: -$0.52
	Huang et al., 2005	Total: -$1.8 to -$3.1 PM: -$0.92 to -$2.3 Ozone: -$0.83	Total: -$1.7 to -$2.9 PM: -$0.84 to -$2.0 Ozone: -$0.83
	Schwartz, 2005	Total: -$1.7 to -$3.0 PM: -$0.92 to -$2.3 Ozone: -$0.77	Total: -$1.6 to -$2.8 PM: -$0.84 to -$2.0 Ozone: -$0.77
Meta-analyses	Bell et al., 2005	Total: -$2.5 to -$3.8 PM: -$0.92 to -$2.3 Ozone: -$1.6	Total: -$2.4 to -$3.6 PM: -$0.84 to -$2.0 Ozone: -$1.6
	Ito et al., 2005	Total: -$3.1 to -$4.5 PM: -$0.92 to -$2.3 Ozone: -$2.2	Total: -$3.0 to -$4.2 PM: -$0.84 to -$2.0 Ozone: -$2.2
	Levy et al., 2005	Total: -$3.1 to -$4.5 PM: -$0.92 to -$2.3 Ozone: -$2.2	Total: -$3.1 to -$4.3 PM: -$0.84 to -$2.0 Ozone: -$2.2
2022 Total Ozone and PM Benefits, RFS2 Control Case Compared to AEO Reference Case[a]			
Premature Ozone Mortality Function	Reference	Total Benefits (Millions, 2007$, 3% Discount Rate)[b,c]	Total Benefits (Millions, 2007$, 7% Discount Rate)[b,c]
Multi-city analyses	Bell et al., 2004	Total: -$0.63 to -$1.0 PM: -$0.29 to -$0.70 Ozone: -$0.34	Total: -$0.60 to -$0.98 PM: -$0.26 to -$0.63 Ozone: -$0.34
	Huang et al., 2005	Total: -$0.84 to -$1.3 PM: -$0.29 to -$0.70 Ozone: -$0.55	Total: -$0.81 to -$1.2 PM: -$0.26 to -$0.63 Ozone: -$0.55
	Schwartz, 2005	Total: -$0.80 to -$1.2 PM: -$0.29 to -$0.70 Ozone: -$0.51	Total: -$0.77 to -$1.1 PM: -$0.26 to -$0.63 Ozone: -$0.51
Meta-analyses	Bell et al., 2005	Total: -$1.3 to -$1.8 PM: -$0.29 to -$0.70 Ozone: -$1.0	Total: -$1.3 to -$1.7 PM: -$0.26 to -$0.63 Ozone: -$1.0
	Ito et al., 2005	Total: -$1.7 to -$2.2 PM: -$0.29 to -$0.70 Ozone: -$1.5	Total: -$1.7 to -$2.1 PM: -$0.26 to -$0.63 Ozone: -$1.5
	Levy et al., 2005	Total: -$1.8 to -$2.2 PM: -$0.29 to -$0.70 Ozone: -$1.5	Total: -$1.7 to -$2.1 PM: -$0.26 to -$0.63 Ozone: -$1.5

[a] Total includes premature mortality-related and morbidity-related ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).
[b] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 5.4-2.

[c] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

The monetized estimates in Table 5.4-1 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including acid and particulate deposition damage to cultural monuments and other materials, and environmental impacts of eutrophication in coastal areas. These are listed in Table 5.4-2.

Table 5.4-2.
Unquantified and Non-Monetized Potential Effects from the Mandated Renewable Fuel Volumes

POLLUTANT/EFFECTS	EFFECTS NOT INCLUDED IN ANALYSIS - CHANGES IN:
Ozone Health[a]	Chronic respiratory damage[b] Premature aging of the lungs[b] Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
Ozone Welfare	Yields for -commercial forests -some fruits and vegetables -non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Ecosystem functions Exposure to UVb (+/-)[e]
PM Health[c]	Premature mortality - short term exposures[d] Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
PM Welfare	Residential and recreational visibility in non-Class I areas Soiling and materials damage Damage to ecosystem functions Exposure to UVb (+/-)[e]
Nitrogen and Sulfate Deposition Welfare	Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Existence values for currently healthy ecosystems Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
CO Health	Behavioral effects
HC/Toxics Health[f]	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein)
HC/Toxics Welfare	Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] The public health impact of biological responses such as increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection are likely partially represented by our quantified endpoints.
[b] The public health impact of effects such as chronic respiratory damage and premature aging of the lungs may be partially represented by quantified endpoints such as hospital admissions or premature mortality, but a number of other related health impacts, such as doctor visits and decreased athletic performance, remain unquantified.
[c] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[d] While some of the effects of short-term exposures are likely to be captured in the estimates, there may be premature mortality due to short-term exposure to PM not captured in the cohort studies used in this analysis. However, the PM mortality results derived from the expert elicitation do take into account premature mortality effects of short term exposures.
[e] May result in benefits or adverse impacts.
[f] Many of the key hydrocarbons related to this rule are also hazardous air pollutants listed in the Clean Air Act.

While there will be impacts associated with air toxic pollutant emission changes that result from the increased use of renewable fuels, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[334] While EPA has since improved the tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics. EPA continues to work to address these limitations; however, we did not have the methods and tools available for national-scale application in time for the analysis of the final rule.[335]

5.4.2 Quantified Human Health Impacts

Tables 5.4-3 and 5.4-4 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the RFS2 volumes relative to both the RFS1 and AEO reference cases for 2022. For each endpoint presented in Tables 5.4-3 and 5.4-4, we provide both the mean estimate and the 90% confidence interval.

Using EPA's preferred estimates, based on the ACS and Six-Cities studies and no threshold assumption in the model of mortality, we estimate that the RFS2 volumes will result in

[334] Science Advisory Board. 2001. NATA – Evaluating the National-Scale Air Toxics Assessment for 1996 – an SAB Advisory. http://www.epa.gov/ttn/atw/sab/sabrev.html.
[335] In April, 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit http://epa.gov/air/toxicair/2009workshop.html for more information about the workshop and its associated materials.

between 110 and 270 cases of $PM_{2.5}$-related premature deaths annually in 2022 when compared to the RFS1 reference case. When compared to the AEO reference scenario, we estimate that the RFS2 volumes will result in between 33 and 85 cases of avoided $PM_{2.5}$-related premature deaths annually in 2022. As a sensitivity analysis, when the range of expert opinion is used we estimate that in 2022 the RFS2 volumes will result in between 34 and 360 PM-related premature mortalities when compared to the RFS1 reference case and between 11 and 110 PM-related premature mortalities when compared to the AEO reference case.

The range of ozone impacts associated with the RFS2 volumes is based on changes in risk estimated using several sources of ozone-related mortality effect estimates. This analysis presents six alternative estimates for the association based upon different functions reported in the scientific literature, derived from both multi-city studies, such as the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Bell et al., 2004, Huang et al., 2005, and Schwartz et al., 2005) and from a series of recent meta-analyses (Bell et al., 2005, Ito et al., 2005, and Levy et al., 2005). This approach is not inconsistent with recommendations provided by the NRC in their recent report (NRC, 2008) on the estimation of ozone-related mortality risk, "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously published studies." For ozone-related premature mortality, we estimate that national changes in ambient ozone will contribute to between 54 to 250 additional premature mortalities in 2022 as a result of the RFS2 volumes relative to the RFS1 scenario. When compared to the AEO reference scenario, we estimate that the RFS2 volumes will contribute to between 36 to 160 additional ozone-related premature mortalities in 2022.

Following these tables, we also provide a more comprehensive presentation of the distributions of mortality-related incidence generated using the available information from empirical studies and expert elicitation associated with the RFS2 volumes compared to each reference scenario. Tables 5.4-5 and 5.4-6 present the distributions of $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-cities study (Laden et al., 2006). The 90% confidence interval for each separate estimate of PM-related mortality is also provided.

When comparing the RFS2 fuel volume scenario to the RFS1 reference case, the effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. Only one expert falls below this range, while two of the experts are above this range. This same relationship occurs when comparing the RFS2 fuel volume scenario to the AEO reference case. Although the overall range across experts is summarized in these tables, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

Table 5.4-3.
Estimated $PM_{2.5}$-Related Health Impacts Associated with the Mandated Renewable Fuel Volumes[a]

Health Effect	2022 RFS2 Control Case Compared to RFS1 Reference Case (5^{th}% - 95^{th}%ile)	2022 RFS2 Control Case Compared to AEO Reference Case (5^{th}% - 95^{th}%ile)
Premature Mortality – Derived from Epidemiology Literature[b]		
Adult, age 30+, ACS Cohort Study (Pope et al., 2002)	-110 (-42 - -170)	-33 (-13 - -53)
Adult, age 25+, Six-Cities Study (Laden et al., 2006)	-270 (-150 - -400)	-85 (-46 - -120)
Infant, age <1 year (Woodruff et al., 1997)	0 (0 - -1)	0 (0 - -1)
Chronic bronchitis (adult, age 26 and over)	-65 (-26 - -110)	-19 (-4 - -18)
Non-fatal myocardial infarction (adult, age 18 and over	-180 (-65 - -290)	-51 (-19 - -84)
Hospital admissions - respiratory (all ages)[c]	-26 (-25 - -26)	-7 (-5 - -8)
Hospital admissions - cardiovascular (adults, age >18)[d]	-55 (-44 - -70)	-12 (-9 - -16)
Emergency room visits for asthma (age 18 years and younger)	-180 (-110 - -260)	-99 (-58 - -140)
Acute bronchitis, (children, age 8-12)	-160 (0 - -330)	-50 (0 - -100)
Lower respiratory symptoms (children, age 7-14)	-1,900 (-910 - -2,900)	-600 (-290 - -910)
Upper respiratory symptoms (asthmatic children, age 9-18)	-1,400 (-450 - -2,400)	-450 (-140 - -750)
Asthma exacerbation (asthmatic children, age 6-18)	-1,700 (-190 - -4,800)	-540 (-60 - -1,500)
Work loss days	-11,000 (-10,000 - -13,000)	-3,200 (-2,800 - -3,700)
Minor restricted activity days (adults age 18-65)	-68,000 (-57,000 - -78,000)	-19,000 (-16,000 - -22,000)

[a] Note that negative incidence expressed in this table reflects "disbenefits"; in other words, an increase in total aggregated national-level ozone-related health impacts. Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.
[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope et al., 2002) and the Six-Cities Study (Laden et al., 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).[336]
[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.
[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[336] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. 1997. "The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States." *Environmental Health Perspectives* 105(6):608-612.

Table 5.4-4.
Estimated Ozone-Related Health Impacts Associated with the Mandated Renewable Fuel Volumes[a]

Health Effect	2022 RFS2 Control Case Compared to RFS1 Reference Case (5th% - 95th%ile)	2022 RFS2 Control Case compared to AEO Reference Case (5th% - 95th%ile)
Premature Mortality, All ages[b]		
Multi-City Analyses		
Bell et al. (2004) – Non-accidental	-54 (-17 - -92)	-36 (-10 - -62)
Huang et al. (2005) – Cardiopulmonary	-90 (-31 - -149)	-59 (-18 - -100)
Schwartz (2005) – Non-accidental	-83 (-24 - -140)	-55 (-13 - -97)
Meta-analyses:		
Bell et al. (2005) – All cause	-180 (-80 - -270)	-120 (-49 - -180)
Ito et al. (2005) – Non-accidental	-240 (-140 - -350)	-160 (-90 - -230)
Levy et al. (2005) – All cause	-250 (-170 - -330)	-160 (-110 - -220)
Hospital admissions- respiratory causes (adult, 6 and older)[c]	-470 (-20 - -860)	-310 (-5 - -580)
Hospital admissions -respiratory causes (childre under 2)	-83 (-24 - -140)	-190 (-52 - -330)
Emergency room visit for asthma (all ages)	-260 (0 - -740)	-180 (0 - -510)
Minor restricted activity days (adults, age 18-65)	-300,000 (-110,000 - -500,000)	-200,000 (-59,000 - -340,000)
School absence days	-110,000 (-35,000 - -180,000)	-75,000 (-19,000 - -120,000)

[a] Note that negative incidence expressed in this table reflects "disbenefits"; in other words, an increase in total aggregated national-level ozone-related health impacts. Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States. Note that negative incidence estimates represent additional cases of an endpoint related to pollution increases associated with the rule.
[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell et al. (2004); Huang et al. (2005); Schwartz (2005) ; Bell et al. (2005); Ito et al. (2005); Levy et al. (2005). The estimates of ozone-related premature mortality should therefore not be summed.
[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 5.4-5. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2022 Associated with the Mandated Renewable Fuel Volumes

Source of Mortality Estimate	2022 RFS2 Control Case Compared to the RFS1 Reference Case		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	-42	-110	-170
Laden et al. (2006)	-150	-270	-400
Expert A	-53	-290	-530
Expert B	-11	-210	-480
Expert C	-39	-220	-470
Expert D	-32	-150	-250
Expert E	-180	-360	-550
Expert F	-130	-200	-260
Expert G	0	-130	-240
Expert H	-1	-160	-380
Expert I	-34	-220	-390
Expert J	-52	-180	-390
Expert K	9	-34	-180
Expert L	4	-130	-310

Table 5.4-6. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2022 Associated with the Mandated Renewable Fuel Volumes

Source of Mortality Estimate	2022 RFS2 Control Case Compared to the AEO Reference Case		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	-13	-33	-53
Laden et al. (2006)	-46	-85	-120
Expert A	-17	-91	-170
Expert B	7	-65	-160
Expert C	-12	-68	-150
Expert D	-10	-48	-79
Expert E	-57	-110	-170
Expert F	-35	-59	-69
Expert G	0	-40	-74
Expert H	0	-51	-120
Expert I	-11	-68	-121
Expert J	-16	-55	-122
Expert K	0	-11	-54
Expert L	8	-38	-101

5.4.3 Monetized Benefits

Monetized values for each quantified health endpoint are presented in Table 5.4-7. For each endpoint presented in Table 5.4-7, we provide both the mean estimate and the 90% confidence interval. Total aggregate monetized benefits are presented in Tables 5.4-8 and 5.4-9 using either a 3 percent or 7 percent discount rate, respectively. All of the monetary benefits are in constant-year 2007 dollars.

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health impacts from the renewable fuel volumes are thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health impacts we are able to quantify plus the sum of the nonmonetized health and welfare impacts.

Our estimate of monetized adverse health impacts in 2022 for the RFS2 fuel volume scenario compared to the RFS1 reference case, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between $1.4 billion and $4.5 billion, assuming a 3 percent discount rate, or between $1.4 billion and $4.3 billion, assuming a 7 percent discount rate. When compared to the AEO reference case, we estimate the monetized adverse health impacts to be between $0.63 billion and $2.2 billion, assuming a 3 percent discount rate, or between $0.60 billion and $2.1 billion, assuming a 7 percent discount rate. The monetized impacts associated with an increase in the risk of both ozone- and $PM_{2.5}$-related premature mortality ranges between 90 to 98 percent of total monetized health impacts, in part because we are unable to quantify a number of health and environmental impact categories (see Table 5.4-2). These unquantified impacts may be substantial, although their magnitude is highly uncertain.

The next largest adverse health impact is for increased incidence of PM-related chronic illness (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for PM-related premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining adverse health impacts. The remaining categories each account for a small percentage of total adverse health impacts. A comparison of the incidence table to the monetized health impacts table reveals that there is not always a close correspondence between the number of incidences for a given endpoint and the monetary value associated with that endpoint. For example, there are over 100 times more work loss days than PM-related premature mortalities (based on the ACS study), yet work loss days account for only a very small fraction of total monetized adverse health impacts. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (e.g., cost-of-illness). As such, the true value of these effects may be different than that reported here.

Table 5.4-7.
Estimated Monetary Value of Health and Welfare Effect Incidence (in millions of 2007$) [a,b]

		2022 RFS2 Control Case Compared to RFS1 Reference Case	2022 RFS2 Control Case Compared to AEO Reference Case
$PM_{2.5}$-Related Health Effect		Estimated Mean Value of Reductions (5^{th} and 95^{th} %ile)	
Premature Mortality – Derived from Epidemiology Studies[c,d,]	Adult, age 30+ - ACS study (Pope et al., 2002)		
	3% discount rate	-$860 (-$100 - -$2,300)	-$270 (-$32 - -$700)
	7% discount rate	-$770 (-$91 - -$2,000)	-$240 (-$28 - -$630)
	Adult, age 25+ - Six-cities study (Laden et al., 2006)		
	3% discount rate	-$2,200 (-$29 - -$5,500)	-$680 (-$90 - -$1,700)
	7% discount rate	-$2,000 (-$26 - -$5,000)	-$620 (-$81 - -$1,600)
	Infant Mortality, <1 year – (Woodruff et al. 1997)	-$4.0 (-$3.0 - -$15)	-$1.7 (-$1.3 - -$6.7)
Chronic bronchitis (adults, 26 and over)		-$32 (-$2.5 - -$110)	-$9.4 (-$0.72 - -$33)
Non-fatal acute myocardial infarctions			
3% discount rate		-$23 (-$4.1 - -$58)	-$6.6 (-$1.0 - -$17)
7% discount rate		-$23 (-$3.8 - -$58)	-$6.4 (-$0.95 - -$16)
Hospital admissions for respiratory causes		-$0.39 (-$0.19 - -$0.57	-$0.11 (-$0.06 - -$0.17)
Hospital admissions for cardiovascular causes		-$1.5 (-$0.96 - -$2.1)	-$0.33 (-$0.20 - -$0.45)
Emergency room visits for asthma		-$0.07 (-$0.04 - -$0.10)	-$0.04 (-$0.02 - -$0.06)
Acute bronchitis (children, age 8–12)		-$0.01 ($0 - -$0.03)	-$0.004 ($0 - -$0.01)
Lower respiratory symptoms (children, 7–14)		-$0.04 (-$0.01 - -$0.07)	-$0.01 (-$0.004 - -$0.02)
Upper respiratory symptoms (asthma, 9–11)		-$0.04 (-$0.01 - -$0.10)	-$0.01 (-$0.004 - -$0.03)
Asthma exacerbations		-$0.09 (-$0.009 - -$0.28)	-$0.03 (-$0.003 - -$0.09)
Work loss days		-$1.7 (-$1.5 - -$1.9)	-$0.49 (-$0.42 - -$0.55)
Minor restricted-activity days (MRADs)		-$4.3 (-$2.5 - -$6.2)	-$1.2 (-$0.69 - -$1.7)
Ozone-related Health Effect			
Premature Mortality, All ages – Derived from Multi-city analyses	Bell et al., 2004	-$480 (-$51 - -$1,300)	-$320 (-$32 - -$880)
	Huang et al., 2005	-$800 (-$90 - -$2,200)	-$530 (-$56 - -$1,400)

	Schwartz, 2005	-$740 (-$76 - -$2,000)	-$490 (-$48 - -$1,300)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	-$1,600 (-$200 - -$4,000)	-$1,000 (-$130 - -$,700)
	Ito et al., 2005	-$2,200 (-$290 - -$5,400)	-$1,400 (-$190 - -$3,600)
	Levy et al., 2005	-$2,200 (-$300 - -$5,300)	-$1,400 (-$200 - -$3,500)
Hospital admissions- respiratory causes (adult, 65 and older)		-$11 (-$0.49 - -$20)	-$7.4 (-$0.13 - -$14)
Hospital admissions- respiratory causes (children, under 2)		-$3.0 (-$1.0 - -$4,9)	-$1.9 (-$0.52 - -$3.3)
Emergency room visit for asthma (all ages)		-$0.10 (-$0.009 - -$0.26)	-$0.07 (-$0.008 - -$0.18)
Minor restricted activity days (adults, age 18-65)		-$19 (-$6.4 - -$35)	-$13 (-$3.6 - -$24)
School absence days		-$10 (-$3.1 - -$16)	-$6.7 (-$1.7 - -$11)

[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Monetary impacts are rounded to two significant digits for ease of presentation and computation. PM and ozone impacts are nationwide.
[b] Monetary impacts adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2022)
[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.

Table 5.4-8. Total Monetized Impacts Associated with the Mandated Renewable Fuel Volumes – 3% Discount Rate

Total Ozone and PM Monetized Impacts (billions, 2007$) –PM Mortality Derived from the ACS and Six Cities Studies					
2022 RFS2 Control Case Compared to RFS1 Reference Case			**2022 RFS2 Control Case Compared to AEO Reference Case**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	-$1.4 to -$2.8	Multi-city	Bell et al., 2004	-$1.3 to -$1.8
	Huang et al., 2005	-$1.8 to -$3.1		Huang et al., 2005	-$0.84 to -$1.3
	Schwartz, 2005	-$1.7 to -$3.0		Schwartz, 2005	-$0.80 to -$1.2
Meta-analysis	Bell et al., 2005	-$2.5 to -$3.8	Meta-analysis	Bell et al., 2005	-$1.3 to -$1.8
	Ito et al., 2005	-$3.1 to -$4.5		Ito et al., 2005	-$1.7 to -$2.2
	Levy et al., 2005	-$3.1 to -$4.5		Levy et al., 2005	-$1.8 to -$2.2
Total Ozone and PM Monetized Impacts (millions, 2007$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2022 RFS2 Control Case Compared to RFS1 Reference Case			**2022 RFS2 Control Case Compared to AEO Reference Case**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	-$0.86 to -$3.5	Multi-city	Bell et al., 2004	-$0.45 to -$1.3
	Huang et al., 2005	-$1.2 to -$3.8		Huang et al., 2005	-$0.66 to -$1.5
	Schwartz, 2005	-$1.1 to -$3.8		Schwartz, 2005	-$0.62 to -$1.4
Meta-analysis	Bell et al., 2005	-$1.9 to -$4.6	Meta-analysis	Bell et al., 2005	-$1.2 to -$2.0
	Ito et al., 2005	-$2.5 to -$5.2		Ito et al., 2005	-$1.6 to -$2.4
	Levy et al., 2005	-$2.6 to -$5.2		Levy et al., 2005	-$1.6 to -$2.4

Table 5.4-9. Total Monetized Impacts Associated with the Mandated Renewable Fuel Volumes – 7% Discount Rate

Total Ozone and PM Monetized Impacts (billions, 2007$) – PM Mortality Derived from the ACS and Six Cities Studies					
2022 RFS2 Control Case Compared to RFS1 Reference Case			**2022 RFS2 Control Case Compared to AEO Reference Case**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	-$1.4 to -$2.6	Multi-city	Bell et al., 2004	-$0.60 to -$0.98
	Huang et al., 2005	-$1.7 to -$2.9		Huang et al., 2005	-$0.81 to -$1.2
	Schwartz, 2005	-$1.6 to -$2.8		Schwartz, 2005	-$0.77 to -$1.1
Meta-analysis	Bell et al., 2005	-$2.4 to -$3.6	Meta-analysis	Bell et al., 2005	-$1.3 to -$1.7
	Ito et al., 2005	-$3.0 to -$4.2		Ito et al., 2005	-$1.7 to -$2.1
	Levy et al., 2005	-$3.1 to -$4.3		Levy et al., 2005	-$1.7 to -$2.1
Total Ozone and PM Monetized Impacts (millions, 2007$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
2022 RFS2 Control Case Compared to RFS1 Reference Case			**2022 RFS2 Control Case Compared to AEO Reference Case**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	-$0.83 to -$3.5	Multi-city	Bell et al., 2004	-$0.44 to -$1.2
	Huang et al., 2005	-$1.1 to -$3.5		Huang et al., 2005	-$0.65 to -$1.4
	Schwartz, 2005	-$1.1 to -$3.5		Schwartz, 2005	-$0.61 to -$1.4
Meta-analysis	Bell et al., 2005	-$1.9 to -$4.3	Meta-analysis	Bell et al., 2005	-$1.1 to -$1.9
	Ito et al., 2005	-$2.5 to -$4.9		Ito et al., 2005	-$1.6 to -$2.3
	Levy et al., 2005	-$2.5 to -$4.9		Levy et al., 2005	-$1.6 to -$2.3

5.4.4 Methodology

Human Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: 1) an effect estimate from a particular study; 2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); 3) the size of the potentially affected population; and 4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. The following subsections describe: the size of the potentially affected populations; the $PM_{2.5}$ and ozone effect estimates; and the treatment of potential thresholds in $PM_{2.5}$-related health impact functions. Chapter 5.4.6 describes the ozone and PM air quality inputs to the health impact functions.

Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[1185] The Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2022 using growth factors based on economic projections.[1186]

Effect Estimate Sources

The most significant quantifiable impacts of exposure to ambient concentrations of ozone and PM are attributable to human health risks. EPA's Ozone and PM Criteria Documents[1187,1188] and the World Health Organization's 2003 and 2004[1189,1190] reports outline numerous human health effects known or suspected to be linked to exposure to ambient ozone and PM. US EPA recently evaluated the ozone and PM literature for use in the benefits analysis for the final 2008 Ozone NAAQS and final 2006 PM NAAQS analyses. We use the same literature in this analysis; for more information on the studies that underlie the health impacts quantified in this RIA, please refer to those documents.

It is important to note that we are unable to separately quantify all of the possible PM and ozone health effects that have been reported in the literature for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases versus hospital admissions for all or a sub-set of respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; or (3) the lack of an established concentration-response (CR) relationship. Table 5.4-10 lists the health endpoints included in this analysis.

Table 5.4-10. Ozone- and PM-Related Health Endpoints

Endpoint	Pollutant	Study	Study Population
Premature Mortality			
Premature mortality – daily time series	O3	Multi-city Bell et al (2004) (NMMAPS study)1191 – Non-accidental Huang et al (2005)1192 - Cardiopulmonary Schwartz (2005)1193 – Non-accidental Meta-analyses: Bell et al (2005)1194 – All cause Ito et al (2005)1195 – Non-accidental Levy et al (2005)1196 – All cause	All ages
Premature mortality — cohort study, all-cause	PM2.5	Pope et al. (2002)1197 Laden et al. (2006)1198	>29 years >25 years
Premature mortality, total exposures	PM2.5	Expert Elicitation (IEc, 2006)1199	>24 years
Premature mortality — all-cause	PM2.5	Woodruff et al. (1997)1200	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	PM2.5	Abbey et al. (1995)1201	>26 years
Nonfatal heart attacks	PM2.5	Peters et al. (2001)1202	Adults (>18 years)
Hospital Admissions			
Respiratory	O3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)1203 Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)1204,1205 Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)1206 Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)1207	<2 years
	PM2.5	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)1208 Ito (2003)—ICD 490-496 (COPD)1209	>64 years
	PM2.5	Moolgavkar (2000)—ICD 490-496 (COPD)1210	20–64 years
	PM2.5	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	PM2.5	Sheppard (2003)—ICD 493 (asthma)1211	<65 years
Cardiovascular	PM2.5	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	PM2.5	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	O3	Pooled estimate: Jaffe et al (2003)1212 Peel et al (2005)1213 Wilson et al (2005)1214	 5–34 years All ages All ages
Asthma-related ER visits (con't)	PM2.5	Norris et al. (1999)1215	0–18 years

Other Health Endpoints			
Acute bronchitis	PM2.5	Dockery et al. (1996)1216	8–12 years
Upper respiratory symptoms	PM2.5	Pope et al. (1991)1217	Asthmatics, 9–11 years
Lower respiratory symptoms	PM2.5	Schwartz and Neas (2000)1218	7–14 years
Asthma exacerbations	PM2.5	Pooled estimate: Ostro et al. (2001)1219 (cough, wheeze and shortness of breath) Vedal et al. (1998)1220 (cough)	6–18 yearsa
Work loss days	PM2.5	Ostro (1987)1221	18–65 years
School absence days	O3	Pooled estimate: Gilliland et al. (2001)1222 Chen et al. (2000)1223	5–17 yearsb
Minor Restricted Activity Days (MRADs)	O3	Ostro and Rothschild (1989)1224	18–65 years
	PM2.5	Ostro and Rothschild (1989)	18–65 years

Notes:

a The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the Science Advisory Board Health Effects Subcommittee (SAB-HES), we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

b Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.1225,1226

Treatment of Potential Thresholds in PM2.5-Related Health Impact Functions

In recent analyses, OTAQ has estimated $PM_{2.5}$-related benefits assuming that a threshold exists in the PM-related concentration-response functions (at 10 $\mu g/m^3$) below which there are no associations between exposure to $PM_{2.5}$ and health impacts. For the analysis of the final rule, however, we have revised this assumption. As explained in the recently proposed Portland Cement MACT RIA, EPA's preferred benefits estimation approach assumes a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. Based on our review of the body of scientific literature, EPA applied the no-threshold model in this analysis. EPA's draft Integrated Science Assessment,[1227,1228] which was recently reviewed by EPA's Clean Air Scientific Advisory Committee,[1229,1230] concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function.[337] Although this document does not represent final agency policy that has undergone the full agency scientific review process, it provides a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs.[338] It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis.[339,1231]

As can be seen in Table 5.4-11, we conducted a sensitivity analysis for premature mortality, with alternative thresholds at 3 $\mu g/m^3$ (the "background," or no-threshold, assumption), 7.5 $\mu g/m^3$, 10 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$. By replacing the no-threshold assumption in the ACS premature mortality function with a 10 $\mu g/m^3$ threshold model, the number of avoided incidences of premature mortality would change dramatically.

[337] It is important to note that uncertainty regarding the shape of the concentration-response function is conceptually distinct from an assumed threshold. An assumed threshold (below which there are no health effects) is a discontinuity, which is a specific example of non-linearity.
[338] The final PM ISA, which will have undergone the full agency scientific review process, is scheduled to be completed in late December 2009.
[339] In the Portland Cement RIA, EPA solicited comment on the use of the no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP closed on September 4, 2009 (Docket ID No. EPA–HQ–OAR–2002–0051 available at http://www.regulations.gov). EPA is currently reviewing those comments.

Table 5.4-11. PM-Related Mortality Impacts Associated with the Mandated Renewable Fuel Volumes: Threshold Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Level of Assumed Threshold	PM Mortality Incidence	
	2022 RFS2 Control Case Compared to RFS1 Reference Case	2022 RFS2 Control Case Compared to AEO Reference Case
15 μg/m3 [b]	9	-6
12 μg/m3	13	-14
10 μg/m3 [c]	-2	1
7.5 μg/m3 [d]	-66	-11
3 μg/m3 [e]	-110	-33

Notes:

[a] Note that this table only presents the effects of a threshold on PM-related mortality incidence based on the ACS study. Negative values indicate a disbenefit, or additional mortality incurred.
[b] Alternative annual PM NAAQS.
[c] Previous threshold assumption
[d] SAB-HES (2004)[86]
[e] NAS (2002)[87]

5.4.5 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population, while the reverse is also generally true. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993). Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987). We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 5.4-12. All values are in constant year 2006 dollars, adjusted for growth in real income out to 2022 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. For details on valuation estimates for PM-related endpoints, see the 2006 PM NAAQS RIA. For details on valuation estimates for ozone-related endpoints, see the 2008 Ozone NAAQS RIA.

Table 5.4-12. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Premature Mortality (Value of a Statistical Life): $PM_{2.5}$- and Ozone-related	$6,320,000	$7,590,000	$7,800,000	EPA currently recommends a default central VSL of $6.3 million based on a Weibull distribution fitted to twenty-six published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses. The guidelines can be accessed at: http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000	Point estimate is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., [1991][1232]) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Nonfatal Myocardial Infarction (heart attack)				Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[1233]
3% discount rate				Direct medical costs are based on simple average of estimates from Russell et al. (1998)[1234] and Wittels et al. (1990).[1235]
Age 0–24	$66,902	$66,902	$66,902	Lost earnings:
Age 25–44	$74,676	$74,676	$74,676	Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings:
Age 45–54	$78,834	$78,834	$78,834	age of onset: at 3% at 7%
Age 55–65	$140,649	$140,649	$140,649	25-44 $8,774 $7,855
Age 66 and over	$66,902	$66,902	$66,902	45-54 $12,932 $11,578
7% discount rate				55-65 $74,746 $66,920
Age 0–24	$65,293	$65,293	$65,293	Direct medical expenses: An average of:
Age 25–44	$73,149	$73,149	$73,149	1. Wittels et al. (1990) ($102,658—no discounting)
Age 45–54	$76,871	$76,871	$76,871	2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
Age 55–65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	

Table 5.4-12. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000)[1236] (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Emergency Room Visits for Asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997)[1237] and (2) $260.67, from Stanford et al. (1999).[1238]

Table 5.4-12. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994)[1239] to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the seven different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Asthma Exacerbations	$42	$45	$45	Asthma exacerbations are valued at $42 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[1240] This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma attack is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study.
Acute Bronchitis	$360	$380	$390	Assumes a 6-day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann et al. (1994).[1241]

Table 5.4-12. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median =)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.
School Absence Days	$75	$75	$75	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	Based on $68 – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States ("Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[1242]

[a] All monetized annual benefit estimates associated with the coordinated strategy are presented in year 2000 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2007 dollars from 2000 dollars.[1243] For WTP-based estimates, we use an inflation factor of 1.20 based on the CPI-U for "all items." For COI-based estimates, we use an inflation factor of 1.35 based on the CPI-U for medical care.

[b] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis. Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

5.4.6 Manipulating Air Quality Modeling Data for Health Impacts Analysis

In Chapter 3.4, we summarized the methods for and results of estimating air quality impacts for the mandated renewable fuel volumes. These air quality results are in turn associated with human populations to estimate changes in health effects. For the purposes of this analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emissions associated with the RFS2 mandated fuel volumes. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). This section describes how we converted the CMAQ modeling output into full-season profiles suitable for the health impacts analysis.

General Methodology

First, we extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[340,341] The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (i.e., BenMAP).

To estimate ozone-related health effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily maximum 8-hour average.[342,343]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2005 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating US EPA speciation network (ESPN)

[340] The ozone season for this analysis is defined as the 5-month period from May to September.
[341] Based on AIRS, there were 961 ozone monitors with sufficient data (i.e., 50 percent or more days reporting at least nine hourly observations per day [8 am to 8 pm] during the ozone season).
[342] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.
[343] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www.epa.gov/air/benmap.

ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in US EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 1999). The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the coordinated strategy to control ship emissions.

Table 5.4-13 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

Table 5.4-13.
Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Impact Endpoints Associated with the Mandated Renewable Fuel Volumes

	2022 RFS2 control case compared to the RFS1 reference case		2022 RFS2 control case compared to the AEO reference case	
Statistic[a]	Reference	Change[b]	Reference	Change[b]
Ozone Metric: National Population-Weighted Average (ppb)[c]				
Daily Maximum 8-Hour Average Concentration	44.513	-0.177	44.575	-0.116
$PM_{2.5}$ Metric: National Population-Weighted Average (ug/m^3)				
Annual Average Concentration	9.658	-0.006	9.662	-0.002

Notes:

[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (i.e., May through September).
[b] The change is defined as the reference case value minus the final rule value. A negative change means that the population-weighted average has increased from the reference scenario to the final rule scenario.
[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

5.4.7 Methods for Describing Uncertainty

The National Research Council (NRC)[1244] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that process include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, it is particularly important to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies.[344] In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs.

For premature mortality associated with exposure to PM, we follow the same approach that has been used in several recent RIAs.[1245,1246,1247] First, we use Monte Carlo methods for estimating random sampling error associated with the concentration response functions from epidemiological studies and economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. Distributions for individual effect estimates are based on the reported standard errors in the epidemiological studies. Distributions for unit values are described in Table 6-11.

Second, as a sensitivity analysis, we use the results of our expert elicitation of the concentration response function describing the relationship between premature mortality and ambient $PM_{2.5}$ concentration.[345, 1248] Incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model; whether or not a threshold may exist). This second approach attempts to incorporate these other sources of uncertainty.

Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA.[1249]

These multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

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[344] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration.
[345] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

5.5 Impacts of Increasing Volume Requirements in the RFS2 Program

The displacement of gasoline and diesel with renewable fuels has a wide range of environmental and economic impacts. As we describe in Chapters 2-6 of the RIA, we have assessed many of these impacts for the final rule. It is difficult to ascertain how much of these impacts might be due to the natural growth in renewable fuel use due to market forces as crude oil prices rise versus what might be forced by the RFS2 standards. Regardless, these assessments provide important information on the wider public policy considerations related to renewable fuel production and use, climate change, and national energy security. Where possible, we have tried to provide two perspectives on the impacts of the renewable fuel volumes mandated in EISA – both relative to the RFS1 mandated volumes, and relative to a projection from EIA (AEO 2007) of renewable fuel volumes that would have been expected without EISA.

Based on the results of our analyses, when fully phased in by 2022, the increased volume of renewable fuel required by this final rule in comparison to the AEO 2007 forecast would result in 138 million metric tons fewer CO2-equivalent GHG emissions (annual average over 30 years), the equivalent of removing 27 million vehicles from the road today. Below we report GHG benefits in the year 2022. The benefit stream from GHG reductions through time after 2022 would show increasing GHG benefits.

At the same time, increases in emissions of hydrocarbons, nitrogen oxides, particulate matter, and other pollutants are projected to lead to increases in population-weighted annual average ambient PM and ozone concentrations, which in turn are anticipated to lead to up to 245 cases of adult premature mortality. The air quality impacts, however, are highly variable from region to region. Ambient $PM_{2.5}$ is likely to increase in areas associated with biofuel production and transport and decrease in other areas; for ozone, many areas of the country will experience increases and a few areas will see decreases. Ethanol concentrations will increase substantially; for the other modeled air toxics there are some localized impacts, but relatively little impact on national average concentrations. It is important to note that these air quality results represent the impact of an incremental increase in ethanol and other renewable fuels and do not estimate the total air quality impact of the RFS2 volumes of renewable fuels as compared to near-zero levels. EPA will conduct that type of analysis as part of the “anti-backsliding” study required by Clean Air Act section 211(v), separate from this final action. The “anti-backsliding” study will use improved emissions data and consider different ethanol blend levels. Clean Air Act section 211(v) requires EPA to issue regulations that mitigate, to the greatest extent achievable, adverse impacts on air quality, considering the results of the “anti-backsliding” study.

In addition to air quality, there are also expected to be adverse impacts on both water quality and quantity as the production of biofuels and their feedstocks increase.

Also, the increased volumes of renewable fuels required by this final rule are projected to have a number of other energy and economic impacts. The increased renewable fuel use is estimated to reduce dependence on foreign sources of crude oil, increase domestic sources of energy, and diversify our energy portfolio to help in moving beyond a petroleum-based economy. The increased use of renewable fuels is also expected to have the added benefit of providing an expanded market for agricultural products such as corn and soybeans and open new markets for the development of cellulosic feedstock industries and conversion technologies.

Overall, we estimate that the renewable fuel standards will result in significant net benefits, ranging between $13 and $26 billion in 2022. Table 5.5-1 summarizes the results of our impacts analyses of the RFS2 standards relative to the AEO2007 reference case and identifies the section where you can find further explanation of it. As we work to implement the requirements of EISA, we will continue to assess these impacts.

Table 5.5-1
Impact Summary of the RFS2 Standards in 2022 Relative to the AEO2007 Reference Case (2007 Dollars)

Category	**Impact in 2022**	**Chapter Discussed**
Emissions and Air Quality		
GHG Emissions	-138 million metric tons	2.7
Non-GHG Emissions (criteria and toxic pollutants)	-1% to +10% depending on the pollutant	3.2
Nationwide Ozone	+0.12 ppb population-weighted seasonal max 8hr average	5.4
Nationwide $PM_{2.5}$	+0.002 $\mu g/m^3$ population-weighted annual average $PM_{2.5}$	5.4
Nationwide Ethanol	+0.409 $\mu g/m^3$ population-weighted annual average	3.4
Other Nationwide Air Toxics	-0.0001 to -0.023 $\mu g/m^3$ population-weighted annual average depending on the pollutant	3.4
$PM_{2.5}$-related Premature Mortality	33 to 85 additional cases of adult mortality (estimates vary by study)	5.4
Ozone-related Premature Mortality	36 to 160 additional cases of adult mortality (estimates vary by study)	5.4
Other Environmental Impacts		
Loadings to the Mississippi River from the Upper Mississippi River Basin	Nitrogen: +1.43 billion lbs. (1.2%) Phosphorus: +132 million lbs. (0.7%)	6.4
Fuel Costs		
Gasoline Costs	-2.4¢/gal	4.4
Diesel Costs	-12.1 ¢/gal	4.4
Overall Fuel Cost	-$11.8 Billion	4.4
Gasoline and Diesel Consumption	- 13.6 Bgal	4.4
Total Capital Costs Thru 2022	$90.5 Billion	4.4
Food Costs		
Corn	+8.2%	5.1
Soybeans	+10.3%	5.1
Food	+$10 per capita	5.1
Economic Impacts		

Energy Security	+$2.6 Billion	5.2
Monetized Health Impacts	-$0.63 to -$2.2 Billion	5.4
GHG Impacts (SCC)[a]	+$0.6 to $12.2 Billion (estimates vary by SCC assumption)	5.3
Oil Imports	-$41.5 Billion	5.2
Farm Gate Food	+$3.6 Billion	5.1
Farm Income	+$13 Billion (+36%)	5.1
Corn Exports	-$57 Million (-8%)	5.1
Soybean Exports	-$453 Million (-14%)	5.1
Total Net Benefits[b]	+$13 to $26 Billion (estimates vary by SCC assumption)	5.5

[a] The models used to estimate SCC values have not been exercised in a systematic manner that would allow researchers to assess the probability of different values. Therefore, the interim SCC values should not be considered to form a range or distribution of possible or likely values. See Chapter 5.3 for a complete summary of the interim SCC values.
[b] Sum of Overall Fuel Costs, Energy Security, Monetized Health Impacts, and GHG Impacts (SCC).

Chapter 6: Impacts on Water

6.1 Feedstock Production and Water Quality

As the production and price of corn and other biofuel feedstocks increase, there may be substantial impacts to both water quality and water quantity. To analyze these impacts, EPA focused on corn production for several reasons. Corn acres have increased dramatically, 20% in 2007 from 2006, an increase of over 15 million additional corn acres for a total of 93.6 million acres. Over two-thirds of the new corn acres came from soybean production. Most of the remaining acres came from the conversion to corn from cotton. Although corn acres declined to 87 million acres in 2009 due to strong prices for other commodities including soybeans, total corn acres remained the second highest since 1946.[1250]

There are three major pathways for contaminants to reach water from agricultural lands: runoff from the land's surface, subsurface tile drains, or leaching to ground water. A variety of management factors influence the potential for contaminants such as fertilizers, sediment, and pesticides to reach water from agricultural lands. These factors include nutrient and pesticide application rates and application methods, use of conservation practices and crop rotations by farmers, and acreage and intensity of tile drained lands. Additional factors outside an agricultural producers control include soil characteristics, climate, and proximity to waterbodies.

6.1.1 Corn Production and Water Quality

The rapid growth in corn acres may have major implications for water quality. Unlike soybeans and other legumes, corn needs large amounts of fertilizer, especially nitrogen fertilizer, to produce economic yields. Of all current and potential feedstocks for biofuels, corn has the greatest application rates of both fertilizer and pesticides per acre and accounts for the largest share of nitrogen use among all crops.[1251] If fertilizers are applied at rates or times when the corn cannot use them, they are available to runoff or leach to water. Corn generally utilizes only 40 to 60% of applied nitrogen. The remaining nitrogen is available to leave the field and runoff to surface waters, leach into ground water, or volatilize to the air where it can return to water through depositional processes. Farmers were expected to apply an additional one million tons of nitrogen fertilizer to the 2007 corn crop.[1252]

Historically, corn has been grown in rotation with other crops such as wheat, hay, oats, and especially soybeans. As corn prices increase relative to prices for other crops, farmers chose to grow corn every year (continuous corn). Much of the recent growth in corn acres has come from reductions in a corn-soybean rotation to continuous corn. Although the amount of losses of nitrogen fertilizers to ground and surface water vary, continuous corn loses significantly more nitrogen annually than a corn-soybean rotation.[1253] In 2005, the latest year for which data was analyzed, the U.S. average nitrogen fertilization rate for corn was 138 pounds per acre. For soybeans the average rate was 16 pounds per acre.[1254] Soybeans fix nitrogen, so they do not require as much fertilizer for adequate growth.

Continuous corn may have additional impacts on the rates of fertilizer and pesticide use. Continuous corn has lower yields per acre than corn grown in rotation. In response, farmers may add higher rates of nitrogen fertilizer to try to match yields of corn grown in rotation. Alternatively, if farmers maintain fertilization rates with these reduced yields, the amount of unused nutrients will increase and eventually be lost to the environment. Growing continuous corn also increases population densities of pests such as corn rootworm. Farmers may increase use of pesticides to control these pests. Total corn herbicide use may also increase due to the additional corn acres, especially for atrazine, the most commonly used herbicide on corn.

There are potential toxicity concerns with volatilization of pesticide active ingredients[1255] in addition to concerns with contamination of foods and drinking water. Furthermore, raising acreage under corn production will increase the quantity of pesticide products in use. Further assessment is necessary to determine whether there is the potential for adverse human health effects from any increase in pesticide use associated with increased domestic corn production.

The most commonly used types of pesticides associated with corn production and storage largely belong to two broad use categories, herbicides and insecticides. The majority of the more common corn herbicide products presently on the market contain an organochlorine-type (OC) active ingredient (AI). For the most part, OC herbicides inhibit cell division and growth while a subgroup of these products, the atrazine-containing OC herbicides, inhibit plant photosynthesis. Another type of common corn herbicide, the phosphonoglycene or glyphosate–containing organophosphate (OP) herbicides, inhibit protein synthesis in plants. Several of the common corn herbicide compounds, such as acetochlor, carbaryl and alachlor, are classified by EPA as known or likely human carcinogens and oral exposure to some of these AI compounds at high enough levels has resulted in adverse health effects, on organs such as the liver or kidney in animals.[1256, 1257, 1258]

The majority of common corn insecticides are split fairly evenly between OP- and carbamate-type AI compounds, with the top selling corn insecticide products, by sales of AI by weight, generally contain methomyl. Methomyl is an N-methyl-carbamide compound which inhibits the acetylcholinesterase enzyme, causing neurotoxicity in both insects and humans.[1259] Methomyl is classified by EPA as an E/unlikely human carcinogen[1260] and its use is regulated as a compound highly toxic to most aquatic and land animals.

High corn prices may encourage farmers to grow corn on land where row crops are not currently grown. If land is not in row crop production, it generally is an indication that the land is marginal for row crop production though the land may still be used for agriculture, such as pasture land. Typically, agricultural producers apply far less fertilizer and pesticide on pasture land than land in row crops. Corn yield on these marginal lands will be lower, limiting nutrient uptake and causing a higher percentage of nutrients under standard fertilization rates to be underutilized and ultimately lost to the environment. However since nitrogen fertilizer prices are tied to natural gas prices, fertilizer costs have increased significantly. According to U. S. Department of Agriculture (USDA) Economic Research Service (ERS), fertilizer prices have been rising steadily since 2002. Through 2008, the annual average prices paid for fertilizers rose 264%. The annual average prices paid for fertilizers were up 82% in 2008 alone. In 2009, ERS predicts that the annual average prices paid for fertilizers will fall 26.5%. In October 2009 fertilizer prices returned to the December 2007 level, when the run-up in prices started.[1261] It is unclear how agricultural producers responded to these changes in both corn and fertilizer prices.

EPA has no data indicating US farmers will increase their corn fertilization rates in response to higher corn prices. However, as demand for corn expands, additional acres panted to corn will likely results in increased amounts of fertilizer applied. The USDA National Agricultural Statistics Service has announced that it will discontinue its national Agriculture Chemical Use reports, collected since 1990, the only survey of its kind. Therefore, it will be very difficult to obtain future information on fertilizer and pesticide application rates.

Artificial drainage is another important factor in determining the losses of nutrients from cropland. Artificial drainage consists either of subsurface tiles/pipes or man-made ditches that move water from wet soils to surface waters so crops can be planted. In a few areas, drains move water to wells and then groundwater instead of to surface water. Artificial drainage has transformed large expanses of historic wetland soils into productive agriculture lands. However, the artificial drains or ditches also move nutrients and pesticides more quickly to surface waters without any of the attenuation that would occur if these contaminants moved through soils or wetlands. The highest proportion of tile drainage occurs in the Upper Mississippi and the Ohio-Tennessee River basins in areas of intensive corn production.[1262] Manmade ditches predominate in areas like the Eastern Shore of the Chesapeake Bay.

6.1.2 Impact on Farm Bill Conservation Programs

The increase in corn production and prices may also have significant impacts on conservation programs funded by the USDA. USDA funds a variety of voluntary programs to help agricultural producers implement conservation practices on their operations. These programs fall into two basic categories: land retirement and working lands.

USDA's largest land retirement program and its largest conservation program is the Conservation Reserve Program (CRP). Under CRP farmers receive annual rental payments under 10- to 15- year contracts to take land out of agricultural production and plant grasses or trees on those acres. Generally farmers put land into CRP because it is not as productive and has other characteristics that make the cropland more environmentally sensitive, such as high erosion rates. The 2008 Farm Bill (Food, Conservation and Energy Act of 2008) lowered the cap on CRP acres from 39.2 million acres to 32 million acres. Prior to the passage of the new farm bill, farmers had already not renewed their contracts on over two million acres of CRP in response to higher crop prices. USDA expects another 4.6 million acres to come out of CRP between 2007 and 2010, 1.4 million acres in major corn producing states.[1263]

CRP acres provide valuable environmental benefits both for water quality and for wildlife habitat. CRP is an important component of rare grassland habitats in the Midwest and Great Plains.[1264] CRP payments are based on the average agricultural land rental rates in the area. As land values increase due to increase in crop prices, CRP payments are not keeping up with the higher land rental rates. Farmland in Iowa increased an average of 18% in 2007 from 2006 prices.[1265] Midwestern states, where much of the nation's corn is grown, tend to have reenrollment rates lower than the national average. We note that based on input from USDA, EPA has modeled assuming the 32 million acres of eligible CRP land will remain protected.

The largest USDA conservation program on working lands is the Environmental Quality Incentives Program (EQIP). About $1 billion is given to farmers annually to implement conservation practices on their farms. Farmers are paid a percentage of the cost of installing the practices, generally ranging from 50 to 90%. Conservation practices encompass a wide range that can have a significant impact on pollutants reaching ground or surface water from crop production. EQIP cost-shares with farmers for important practices such as nutrient management, cover crops, livestock manure storage, and riparian buffers. Like CRP, high corn prices may have an impact on the willingness of agricultural producers to participate in EQIP. Producers may require higher payments to offset potential loss of profits through implementation of conservation practices.

The effectiveness of agricultural conservation practices in controlling runoff and/or leaching of nutrients, sediment, and pesticides at the field level has been established by numerous scientific studies across many geographic areas. However, the usefulness of these practices in achieving water quality goals is dependent on their placement within watersheds. To most effectively protect water quality, conservation practices should be targeted to the most vulnerable areas of watersheds. Conservation practices designed to meet wildlife goals will need different targeting mechanisms to ensure adequate habitat. USDA through the Conservation Effects Assessment Project (CEAP) is trying to evaluate the effectiveness of controlling pollution from agricultural lands at the watershed level.[346] In order to ensure that Farm Bill conservation programs meet their environmental quality goals, the EPA's Science Advisory Board report to the Gulf of Mexico Task Force (SAB) also recommends implementing the practices through competitive bidding to ensure that the highest environmental benefit is achieved at the least cost.[1266] It also warns that voluntary programs without economic incentives are unlikely to be effective to control nitrogen and phosphorus, except for a few practices.

The most cost-effective practices on working lands include: riparian buffers; crop rotation; appropriate rate, timing, and method of nutrient application; cover crops; and, on tile-drained lands, treatment wetlands and controlled drainage. These practices have significant water pollution reduction benefits that vary based on the site-specific conditions and on the implementation and operation and maintenance of the practice. For example, controlled drainage can reduce nitrogen loads by 30%; treatment wetlands by 40% to 90%; vegetative buffers by 12% to 90%.

6.1.3 Other Agricultural Biofuel Feedstocks

While corn is the most common feedstock for biofuel production by far, under this proposal, in later years other agricultural feedstocks will become increasingly important. These feedstocks will have dramatically different impacts on water quality. Biodiesel feedstocks, primarily soybeans, as well as cellulosic feedstock such as switchgrass or popular trees are not expected to have significant water quality impacts. As noted previously, soybeans require little to no additional nitrogen fertilizer. However, soybeans have less residue remaining after harvest

[346] See http://www.nrcs.usda.gov/technical/nri/ceap/index.html

compared to corn, so sediment runoff could be more of a concern, depending on how each crop is managed. Switchgrass may be a more favorable biofuels crop for reducing water impacts. It is a native plant which does not require high inputs of fertilizers or pesticides and since it is a perennial crop, there is limited sediment runoff compared to annual crops. There is very minimal acreage of switchgrass grown commercially at the present time, so it is difficult to predict what inputs farmers will use to cultivate it. Some concern has been expressed about the potential in the future for farmers to increase switchgrass fertilizer application rates and irrigation rates to dramatically increase yields.

Corn stover, at the present time, appears to be one of the more viable feedstocks for cellulosic ethanol, especially in the Corn Belt states. Corn stover is the above ground stalks, husks, and corn cobs that remain once the corn grain is harvested. Farmers keep the corn stover on their cropland to maintain the productivity of the soil. Corn stover maintains the soil organic carbon which has many benefits as a source of nutrients, preventing erosion by wind and water, and increasing soil aeration and water infiltration. Wilhelm, et al.[1267] evaluated the amount of corn stover that could be harvested for biofuel production and still maintain soil carbon. In all the soils they evaluated more stover was needed to maintain the soil carbon than for controlling erosion. For a more general discussion of cellulosic ethanol production, see Chapter 5, Section V.B.2. More research is needed to identify the amount of stover that can be removed and retain these important productivity and environmental benefits.

Different conservation systems and conservation practice standards will need to be developed and adopted for cellulosic feedstocks, such as corn stover, switchgrass, and trees for biofuels production. USDA will need to continue to adjust current standards and develop additional standards, where needed, to permit cellulosic feedstocks to be produced and utilized in a sustainable manner.

6.2 Ecological Impacts

6.2.1 Nutrients

Nitrogen and phosphorus enrichment due to human activities is one of the leading problems facing our nation's lakes, reservoirs, and estuaries. Nutrient enrichment is also a contributing factor to stream degradation. It has negative impacts on aquatic life in streams; adverse health effects on humans and domestic animals; aesthetic and recreational use impairment; and excessive nutrient input into downstream waterbodies, such as lakes. Excess nutrients in streams can lead to excessive growth of phytoplankton (free-floating algae) in slow-moving rivers, periphyton (algae attached to a surface) in shallow streams, and macrophytes (aquatic plants large enough to be visible to the naked eye) in all waters. Unsightly filamentous algae can impair the aesthetic enjoyment of streams. In more extreme situations, excessive growth of aquatic plants can slow water flow in flat streams and canals, interfere with swimming, and clog the screens on water intakes of water treatment plants and industries.

Nutrient enrichment in streams has also been demonstrated to affect animal communities in these waterbodies. For example, declines in invertebrate community structure have been correlated directly with increases in phosphorus concentration. High concentrations of nitrogen in the form of ammonia are known to be toxic to aquatic animals. Excessive levels of algae have also been shown to be damaging to invertebrates. Finally, fish and invertebrates will experience growth problems and can even die if either oxygen is depleted or pH increases are severe; both of these conditions are symptomatic of eutrophication. As a biologic system becomes more enriched by nutrients, different species of algae may spread and species composition can shift; however, unless such species shifts cause clearly demonstrable symptoms of poor water quality—such as fish kills, toxic algae, or very long streamers of filamentous algae—the general public is unlikely to be aware of this potential ecological concern.

Nutrient pollution is widespread. The most widely known examples of significant nutrient impacts include the Gulf of Mexico and the Chesapeake Bay. For these two areas alone, there are 35 states that contribute the nutrient loadings. There are also known impacts in over 80 estuaries/bays, and thousands of rivers, streams, and lakes. The significance of these impacts has led EPA, States, and the public to come together to place an unprecedented priority on public partnerships, collaboration, better science, and improved tools to reduce nutrient pollution.

Virtually every state and territory is impacted by nutrient-related degradation of our waterways. All but one state and two territories have waterbodies that are polluted by nutrients. States have listed over 10,000 waterbodies that have nutrient and nutrient-related impairments. Fifteen states have more than 200 nutrient-impaired waterbodies each. Reducing nutrient pollution is a priority for EPA.

EPA's Wadeable Streams Assessment provided the first statistically defensible summary of the condition of the nation's streams and small rivers.[1268] To perform the assessment, EPA, states, and tribes collected chemical, physical, and biological data at 1,392 perennial stream locations to determine the biological condition of these waters and the primary stressors affecting their quality. Research teams collected samples at sites chosen using a statistical design to ensure representative results. The results of the analysis provide a clear assessment of the biological quality of wadeable, perennial streams and rivers across the country.

The Wadeable Streams Assessment found that excess total nitrogen is the most pervasive biological stressor for the nation. Approximately 32% of the nation's stream length shows high concentrations of nitrogen compared to reference conditions. Phosphorus exhibits comparable patterns to nitrogen and is the second most-pervasive stressor for the nation's stream length. Streams with relatively high concentrations of nutrients or excess streambed sediments are two to four times more likely to exhibit poor biological conditions.

The *National Water Quality Inventory: Report to Congress*, prepared under section 305(b) of the Clean Water Act, summarizes water quality reports submitted by the states and territories to EPA. Historically, the National Water Quality Inventories have repeatedly shown that nutrients are a major cause of ambient water quality use impairments. In the most recent report summarizing the 2002 reports from state, nutrients are identified as the leading cause of water pollution in assessed lakes and the second leading cause of pollution in assessed estuaries and bays.[1269] Sediment is the leading cause of pollution in assessed rivers and streams.

Agriculture is the largest known source of water quality impairment to both assessed rivers and streams and lakes and reservoirs.

6.2.2 Air Deposition of Nitrogen to Water

Nitrogen oxide (NOx) emissions from fossil fuel combustion from both stationary sources and vehicles can add to the load of nitrogen to waterbodies around the country. Depending on climate and other variables, the atmospheric NOx falls back to the ground as rain, snow, fog, or dry deposition. NOx is deposited directly on waterbodies or falls on the land and can run off to waterbodies. NOx from both stationary sources and vehicles results in significant loadings of nitrogen from air deposition to waterbodies around the country[1270], including the Chesapeake Bay[1271], Long Island Sound[1272], and Lake Tahoe.[1273] The majority of the new biofuel production facilities are expected to be located in the Corn Belt in the Mississippi River Basin, therefore the NOx emissions will add to the nutrient loads to local water bodies and the Gulf of Mexico. Much of the nitrogen deposition from vehicles falls on impervious surfaces, such as roads and parking lots where it runs off into streams. Road drainage systems generally channel runoff quickly and accelerate the nitrogen loadings downstream. In the Chesapeake region, vehicle exhaust remains the single largest source of fossil-fuel derived nitrogen pollution.[1274] Air deposition of nitrogen accounts for more than half of all nitrogen loadings to Lake Tahoe.[1275]

6.3 Gulf of Mexico

Production of corn for ethanol may exacerbate existing serious water quality problems in the Gulf of Mexico. Nitrogen fertilizer applications to corn are already the major source of total nitrogen loadings to the Mississippi River.[1276] A large area of low oxygen, or hypoxia, forms in the Gulf of Mexico every year, often called the "dead zone". Hypoxia threatens commercial and recreational fisheries in the Gulf because fish and other aquatic species cannot live in the low oxygen waters. The primary cause of the hypoxia is excess nutrients (nitrogen and phosphorus) from the Upper Midwest flowing into the Mississippi River to the Gulf. These nutrients trigger excessive algal growth (or eutrophication) resulting in reduced sunlight, loss of aquatic habitat, and a decrease in oxygen dissolved in the water.

The 2008 hypoxic zone was measured at 8,000 square miles, the second largest since measurements began in 1985 and an area the size of Massachusetts.[1277] In 2009 models predicted an even larger hypoxic zone, but it was measured at only 3,000 square miles. A combination of below average high flows on the Mississippi River and winds that mixed Gulf waters are the likely causes of the reduced size of the 2009 zone. The average size of the hypoxic zone over the past five years has been 6,600 square miles.

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force's "Gulf Hypoxia Action Plan 2008" lays out two major goals for reducing water quality problems in the Mississippi River/Atchafalaya River Basin: 1) reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to 2,000 square miles by 2015 and 2) implement nutrient and sediment reductions to protect public health and aquatic life and reduce negative impacts of water pollution. The Gulf of Mexico Action Plan calls for an acceleration of actions to reduce the hypoxia in the Gulf. In order to meet these goals, the Action Plan calls for a 45% reduction in both nitrogen and phosphorus reaching the Gulf.[1278] EPA's Science Advisory Board (SAB) report to the Task Force said that an additional reduction in nitrogen and phosphorus reduction will be necessary as a result of increased corn production for ethanol and climate change impacts.[1279] The SAB also found that the Gulf of Mexico ecosystem appeared to have undergone a shift so that now the system is more sensitive to nutrient inputs than in the past, inducing a larger response in hypoxia.

Under the Gulf Hypoxia Action Plan, "USDA will encourage the increased use of its nutrient management standard to minimize nutrient loss from fields to help alleviate the impact of increased biofuels production on nutrient loads to the Gulf".[1280] The nutrient management standard requires farmers to account for all plant-available nutrient sources immediately available or rendered available throughout the crop production cycle.

6.3.1 Nutrient Loads to the Gulf of Mexico

The U.S. Geological Survey (USGS) has estimated that the spring delivery of nutrients to the Gulf of Mexico in 2008 was among the highest since the early 1980s. Spring nutrient delivery is one of the main factors that control the size of the hypoxic zone. In relation to the long-term spring average, total nitrogen was about 35 to 40% higher (817,000 tons) and total phosphorus was a record 60 to 85% higher (83,000 tons). The large nutrient contributions are primarily due to near record-breaking streamflows in spring 2008 in the Mississippi River Basin. Streamflows were about 50% higher this year compared to the long-term spring average flows since about 1980. Nutrient contributions for a given spring vary depending on the amount of flow in the Mississippi-Atchafalaya River Basin, as well as average stream water nutrient concentrations.

Alexander, et al. modeled the sources of nutrient loadings to the Gulf of Mexico using the USGS SPARROW (spatially referenced regression on watershed attributes) model.[1281] They estimated that agricultural sources contribute more than 70% of the delivered nitrogen and phosphorus. Corn and soybean production alone accounted for 52% of the total nitrogen delivery to the Gulf. Atmospheric deposition was the second largest nitrogen source at 16%. Animal manure on pasture and rangeland are the main sources of phosphorus loadings, contributing 37%. Corn and soybean contributed 25% of the phosphorus; other crops 18%, and urban areas, 12%.

6.3.2 Recent Analyses of Impact of Corn Ethanol Production on Nutrient Loadings to the Gulf

Since over 80% of corn grown in the U.S. is produced in the Gulf of Mexico watershed, concern has been expressed about the impact on Gulf hypoxia of increasing corn production for ethanol. Several recent scientific reports have estimated the water quality impact of that increase in corn production. Donner and Kucharik modeled increases in nitrogen export to the Gulf as a result of corn ethanol volumes increasing from 2007 production levels to 15 billion gallons in 2022.[1282] They concluded that the expansion of corn-based ethanol production could make it almost impossible to meet the Gulf of Mexico nitrogen reduction goals without "radical shift" in feed production, livestock diet, and management of agricultural lands. The study estimated a mean dissolved inorganic nitrogen load increase of 10 to18% from 2007 to 2022 to meet the 15 billion gallon corn ethanol goal, depending on the rate of corn yield increases and potential efficiency increases in the conversion of corn to ethanol.

EPA's Science Advisory Board (SAB) report to the Mississippi River/Gulf of Mexico Watershed Task Force estimated the additional annual nitrogen loadings to the Gulf due to the increase in corn acres from 78.3 million acres in 2006 to 93.7 million acres in 2013.[1283] The SAB estimated that this scenario will result in an additional national annual loading of almost 300 million pounds of nitrogen. An estimated 80% of that nitrogen loading or 238 million pounds will occur in the Mississippi-Atchafalaya River basin and contribute nitrogen to the "dead zone" in the Gulf of Mexico.

6.4 Upper Mississippi River Basin Analysis

To provide a quantitative estimate of the impact of this regulation and production of corn ethanol generally on water quality, EPA conducted an analysis that focused on agricultural production in the Upper Mississippi River Basin (UMRB). The UMRB drains approximately 189,000 square miles, including large parts of the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. Small portions of Indiana, Michigan, and South Dakota are also within the basin. EPA selected the UMRB because it is representative of the many potential issues associated with ethanol production, including its connection to major water quality concerns such as Gulf of Mexico hypoxia, large corn production, and numerous ethanol production plants.

In 2007, there were approximately 23.7 million acres of corn in the UMRB. About 75% of ethanol production is expected to be in the states in the Corn Belt region, of which the UMRB is a part.[1284] Additional discussion about corn production can be found in Section 1.5.1. On average the UMRB contributes about 39% of the total nitrogen loads and 26% of the phosphorus loads to the Gulf of Mexico.[1285] The Ohio/Tennessee River Basin is the highest contributor of nitrogen loads to the Gulf at 41%. The high percentage of nitrogen from these two basins is primarily due to the large inputs of fertilizer for agriculture and the extensive systems of tile drains. According to USGS, nitrogen loads to the Gulf ranged from 810,000 metric tons to 2.2 million metric tons between 1985 and 2005. Phosphorus loads to the Gulf ranged from 80,700 metric tons to 180,000 metric tons during that same 20-year period.[1286] Although nitrogen inputs to the UMRB in recent years is fairly level, there is a 21% decline in loads to the Gulf. The Science Advisory Board report attributes this decline to higher amount of nitrogen removed during harvest, due to higher crop yields.[1287] However, most of the reduction in the spring was from nitrogen forms other than nitrate. Nitrate is an important nitrogen form fueling the algal growth which leads to hypoxia.[1288] For the same period phosphorus inputs increased 12%.

In 2007, the U.S. produced approximately seven billion gallons of ethanol, mostly from corn kernels. Corn-based ethanol production is expected to reach at least 15 billion gallons in order for industry to comply with the RFS2 standards. Of the potential crops for biofuels production, corn has the highest rates of fertilizer and pesticide application, leading to the concern that higher corn production will result in increased loading of nutrients, pesticides, and sediment to water bodies, including major rivers and estuaries.

6.4.1 SWAT Model

EPA selected the SWAT (Soil and Water Assessment Tool) model to assess nutrient loads from changes in agricultural production in the UMRB. Models are the primary tool that can be used to predict future impacts based on alternative scenarios. SWAT is a physical process model developed to quantify the impact of land management practices in large, complex watersheds. SWAT, primarily developed by USDA's Agricultural Research Service and the Texas A&M University Blackland Research and Extension Center, is a public domain model.

EPA determined that SWAT was the most appropriate model to use for this analysis because it has been widely used and validated in watersheds both nationally and internationally.[1289] SWAT has been applied extensively to support water quality and Total Maximum Daily Load (TMDL) planning throughout the United States. SWAT is a basin-scale continuous simulation model that operates on a daily time step and is designed to predict the nonpoint source loadings and resulting water quality impacts of water, sediment, and agricultural chemicals (nutrients and pesticides) from a watershed. The model can assess a wide variety of impacts of alternative management practices and land use changes. The model is physically based, computationally efficient, and capable of continuous simulations over long periods of time, ranging from days to years to decades. Major model components include weather, hydrology, erosion/sedimentation, soil temperature, plant growth, nutrients, pesticides, bacteria, agricultural management, stream routing and pond/reservoir routing.

SWAT has several very important strengths that enabled EPA to develop a robust representation of the hydrology and water quality of the UMRB:

1) Watersheds can be modeled to evaluate the relative impact of changes in management practices, climate, and vegetation on water quality or other variables of interest;

2) SWAT uses readily available inputs commonly available from various government agencies;

3) It can simulate crop and plant communities and provide crop yield and plant biomass, essential to estimate past trends and project accurately into the future;

4) Simulation of very large basins or a variety of management strategies can be performed expeditiously;

5) Long-term impacts spanning several decades can be studied. Time- and climate-variable pollutant contributions can be simulated along with the impact on downstream water bodies spanning several decades; and

6) The model code has been validated on hundreds of basins throughout the United States and abroad.

In addition, prior applications of SWAT for hydrology and nutrient simulation in the UMRB had been completed and were available as a starting foundation for the modeling efforts and focus of this study.[1290] [1291] Further technical information regarding SWAT can be found at: http://www.brc.tamus.edu/swat.

6.4.1.1 AEO 2007 Reference Case

In order to assess alternative potential future conditions within the UMRB, such as alternative levels of increased corn production as feedstock for ethanol, we had to establish baseline conditions for SWAT. EPA developed a SWAT model for a reference case using the ethanol fuel volumes predicted in the AEO 2007 report through 2022 to which the results of the RFS1 mandate reference case, and the RFS2 control cases could be compared. As in the NPRM, we selected 2005 as the mid-point of the target period for baseline conditions in the watershed. However, for the analysis for this final rule, we used the 2007 corn yield value to correspond with the agricultural analysis described in Chapter 5. We assumed that 33% of corn produced in the UMRB was converted to corn ethanol, based on estimates from USDA.[1292] This baseline does not include corn ethanol produced as a result of this rulemaking.

Like most water quality modeling, we had to use a range of data sets for the base case scenario inputs. In developing this scenario, it was necessary to select a target year, or window of years, that represent the conditions on the watershed. For this study the year 2005 was selected as the target period for baseline conditions. As with most models of this scale, it was not possible to have all of the data sources come from the exact same time period. It is a common modeling practice to combine the best available data sources for model development in an attempt to characterize the baseline condition within a short time window or period. The majority of the data sources were from the years 2000 through 2006. In addition, selected assumptions about the baseline were made using 2007 as the reference year. In particular, the baseline value for average corn yield (144.2 bushels per acre) was based on the year 2007. In reality, the base case represents watershed conditions within a two to three year period.

Since one of the driving forces in the SWAT model is the water balance, climate data is key to accurately predicting the movement of nutrients and sediment. SWAT was applied (i.e. calibrated) to the UMRB using weather data from the NRCS climatic data center for a 40-year period from 1960 to 2001 and flow and water quality data from 13 USGS gauges on the mainstem of the Mississippi River, spatially distributed from the upper reaches in Minnesota and Wisconsin to the UMRB outlet below Grafton, Illinois. In addition, the weather data has been spatially interpolated to assign one weather station per subwatershed.

To establish the land use for the baseline scenario, SWAT was setup on 131 subwatersheds [8-digit Hydrologic Unit Code (HUC)] for the entire UMRB using the 2001 National Land Cover Data (NLCD)[1293] and Cropland Data Layer (CDL).[1294] The CDL contains crop specific digital data layers, suitable for us in geographic information system applications. The CDL program focuses on classifying corn/soybean/rice/cotton agricultural regions in many of the Midwestern and Mississippi delta states using remote-sensing imagery and on-the-ground monitoring. The USDA-NRCS STATSGO provided the soils data for the entire analyses. The primary input data is the USDA 1997 National Resource Inventory (NRI), which provided land use, soil, and data on management practices on the land.[1295] 1997 is the most current year for which this data is available.

In addition, information from the Conservation Tillage Information Center and USDA-NASS Census of Agriculture 2002/1997 were used to identify the cropping rotation and management practices for the agricultural land areas by these same 131 subwatersheds. Based on the management information at this level, each sub-watershed was assigned appropriate management and tillage practices.

Drainage tiles are one of the critical man-made hydrology structures that changes the natural hydrological cycle significantly at both surface and subsurface (lateral flow) levels. There are no clear records of where the tiles are within the UMRB, other than a few research articles that attempted to estimate the location and extent of the tile drainage coverage. In this study, similar literature values were used to estimate and identify the areas that have the tile system to drain the excess water and nutrients in a timely manner. First, the STATSGO database was used to identify the very poorly drained soils, somewhat poorly drained soils, and poorly drained soils. Then, slope and land use maps were overlaid on these poorly drained soils to identify the potential tile drainage system. Only slopes <1% and agricultural land uses were identified as areas that may potentially be served with tile drainage system.

The tillage practice information in the UMRB was obtained at the county level from Conservation Technology Information Center.[1296] There are five major tillage types. Three of them (no-tillage, ridge-tillage, and mulch-tillage) belong to conservation tillage, and the other two types of tillage (reduced-tillage and intensive-tillage) are non-conservation tillage. The county acreages of this tillage information were overlaid on 8-digit HUCs to estimate the percent of each tillage practices by crop within each HUC.

To estimate nutrient applications on cropland, we started by estimating the livestock and the amount of manure produced. The livestock numbers came from the agricultural statistics for each county based on the 2002 Census of Agriculture for each 8-digit HUC. (Only cattle and hogs numbers were used since they are the dominant livestock types in the UMRB.) Then, the manure production of each 8-digit HUC was obtained through multiplying the number of cattle and hogs and the manure production rates as outlined in ASABE, 2005.[1297] If the total amount of the manure production exceeded 20% of the estimated total fertilizer application in one HUC, manure application and chemical fertilizer application were used as SWAT model inputs to simulate nutrient applications in that HUC. The manure was applied to only those areas that are agricultural land use, even during rotation. For example, only hay, corn, and row crops get manure application, not legume crops such as alfalfa or soybean. So, if an area had a corn and soybean rotation, manure was only applied during the corn growing period. Even when manure was applied, chemical fertilizer was used to supplement the manure application where and when needed. In areas where the manure was not applied, chemical fertilizer was applied to grow the agricultural crops. Chemical nitrogen fertilizer at applied at 1.3 times the amount of nitrogen taken off at harvest.

For the UMRB analysis we used the auto-fertilization feature in SWAT. Any time actual plant growth fell below the specified nitrogen stress threshold, the model automatically applied fertilizer. The user specifies the type of fertilizer, the fraction of total fertilizer applied to the soil surface, the maximum amount of fertilizer that can be applied during the year, the maximum amount of fertilizer that can be applied in any one application, and the application efficiency. Fertilizer is applied to match the difference between soil available nitrogen and the crop yield nitrogen that is removed during harvest. The auto-fertilization used in the UMRB study was set up using default parameter values for fertilizer application rate (200 kg N /ha), maximum per year fertilization rate (300 kg N /ha), application efficiency (1.3, ratio, unitless), and fraction of fertilizer applied to soil surface (0.2). The nitrogen stress factor was set to 0.75 (ratio, unitless).

The 42-year SWAT model runs were performed and the results analyzed to establish runoff, sediment, nitrogen, and phosphorous loadings from each of the 131 8-digit HUC subwatersheds and the larger 4-digit subbasins, along with the total outflow from the UMRB and at the various USGS gage sites distributed along the Mississippi River mainstem. These results provided the Reference Case model values to which the RFS1 and RFS2 future alternatives are compared.

The current national average for corn yield of 150 bushels per acre (bu/ac) was used to establish baseline yield levels. The baseline average yield for the UMRB was established at 144.2 bushels per acre. This baseline yield is due to the significant amount of crop area in northern states where yield values are lower than the national average. National average corn yields have been increasing primarily due to favorable weather conditions and improvement in practices to reduce stress on the corn plants from excess water, drought, and pests.

6.4.1.2 Reference Cases and RFS2 Control Case

To assess the impacts of the increased use of corn ethanol, we modeled an RFS2 control case and compared it to both the AEO2007 reference case and the RFS1 mandate reference case. For the AEO2007[1298] reference case we modeled: 10.49 billion gallons a year (BGY) in 2010, 11.1 BGY in 2015, 11.83 BGY in 2020, and 12.29 BGY in 2022. For the RFS1 mandate reference case we modeled a constant national ethanol goal of 7.05 billion gallons a year (BGY) starting in 2012. For this analysis, the reference cases assumed that no cellulosic ethanol was produced from corn stover. For the RFS2 control case we modeled a steadily increasing volume of corn ethanol in keeping with the EISA standards; 11.24 BGY in 2010, 14.79 BGY in 2015, and 15 BGY in 2016 and beyond. We were not able to model the impacts of corn stover removal at this time, so the analysis only reflects the impacts of increased use of corn grain for renewable fuel use.

For SWAT analyses of these three scenarios, national corn ethanol volumes were adjusted for the UMRB based on a 42.3% ratio of ethanol production capacity within the UMRB compared to national capacity. This fraction was determined by overlaying coverage of nationwide ethanol plants with a coverage of the UMRB. Production from ethanol plants within the study area were totaled and then divided by the nationwide production. Both current production and planned expansion were included in the totals. Ethanol location and production information were taken from the Renewable Fuels Association table of ethanol refinery locations in April 2008.[1299] We assumed an average of 2.7 gallons of ethanol per bushed of corn and a moisture content of 20% when converting corn grain mass to bushels. The resulting UMRB ethanol production goals were converted into the corresponding required corn production acreage, i.e. the extent of corn acreage needed to meet those ethanol production goals.

The SWAT model was run with the available input climate record, 1960-2001, with the model run under conditions of the increased corn production and yields noted above. Separate model runs were performed for each of the three projection years, and the model results were analyzed to provide loadings for comparison with the baseline loadings.

6.4.1.2.1 Corn

Increases in corn yield were built into the future scenarios, with an annual increase of 1.23%. This produced yield increases to 149.6 bushels per acre (bu/ac) (3.7% in 2010), 159 bu/ac (10.3% in 2015), 169 bu/ac (17.2% in 2020), and 173.2 bu/ac (20.1% in 2022). Table 6.4-1 shows the corn acreage in the Upper Mississippi River Basin for each case. Corn acres increased 9% in 2022 between the AEO 2007 case and the RFS2 (no stover) cae.

Table 6.4-1.
Corn Acres in the Upper Mississippi River Basin for
AEO 2007, RFS1, and RFS2 Cases (millions of acres)

	AE0 2007	RFS1	RFS2 (no stover)
2010	26.83	23.65	27.61
2015	26.78	22.78	30.40
2020	26.80	22.35	29.73
2022	26.96	22.20	29.40

6.4.1.2.2 RFS2 (No Stover) Control Case Pollutant Loadings

Tables 6.4-2 through 6.4-4 compare the model outputs for nitrogen, phosphorus, and sediment between the AEO 2007 Reference Case and the RFS2 (no stover) Case scenarios for the years 2010, 2015, 2020, and 2022. Land load is the total amount of nitrogen or phosphorus that reaches a stream within the UMRB. The total outflow is the remaining amount measured at the outlet of the UMRB at Grafton, Illinois after accounting for in-stream loses due to uptake or assimilation.

These results only estimate loadings from the Upper Mississippi River basin, not the entire Mississippi River watershed. As noted earlier, the UMRB contributes about 39% of the total nitrogen loads and 26% of total phosphorus loads to the Gulf of Mexico. The decreasing nutrient load over time is likely attributable to the increased average corn yield per acre, resulting in greater plant uptake of nitrogen and fewer corn acres planted for ethanol production goals in this rule.

Table 6.4-2.
Average annual nitrogen loads: Comparison of AEO 2007 Reference Case to the 2022 RFS2 (No Stover) Case (% difference in parentheses)

	AEO 2007 Reference Case		**RFS2 (No Stover) Case**	
Model Run	Total Land Load, million lbs	Total Outflow, million lbs	Total Land Load, million lbs	Total Outflow, million lbs
2010	1948	1470	1944 (-0.21)	1467 (-0.20)
2015	1911	1441	1946 (1.83)	1469 (1.94)
2020	1887	1421	1912 (1.32)	1442 (1.48)
2022	1877	1413	1897 (1.07)	1430 (1.20)

Approximately 24 to 25% of nitrogen leaving agricultural fields was either taken up by aquatic plants or volatilized before reaching the outlet of the UMRB at Grafton, Illinois. Even though much of the nitrogen that is volatilized from streams and rivers and near-coastal waters is removed from the total loading to water, it is not necessarily eliminated as an environmental concern. Conversion of the nitrate to nitrogen gas through denitrification is generally an incomplete chemical process. 5% or more of the nitrogen can be converted to nitrous gas, a powerful greenhouse gas that is 300 times the climate-warming potential of carbon dioxide, the major greenhouse gas of environmental concern. Thus, a water pollutant becomes an air pollutant until it is either captured through biological sequestration or converted fully to elemental nitrogen.

The scenarios showed an increase in phosphorous loads at a slightly lower percentage than nitrogen.

Table 6.4-3.
Average annual phosphorus loads: Comparison of AEO 2007 Reference Case to the 2022 RFS2 (No Stover) Case (% difference in parentheses)

	AEO 2007 Reference Case		**RFS2 (No Stover) Case**	
Model Run	Total Land Load, million lbs	Total Outflow, million lbs	Total Land Load, million lbs	Total Outflow, million lbs
2010	180.0	133.8	179.9 (-0.06)	133.7 (-0.07)
2015	178.2	132.3	179.6 (0.79)	133.6 (0.98)
2020	177.0	131.3	178.2 (0.68)	132.4 (0.84)
2022	176.5	130.9	177.6 (0.62)	131.8 (0.69)

Total sediment outflow showed very little change over all scenarios. This result is primarily due to corn stover remaining on the field following harvest and therefore reducing sediment transport to water.

Table 6.4-4.
Average annual sediment loads: Comparison of AEO 2007 Reference Case to the 2022 RFS2 (No Stover) Case (% difference in parentheses)

	AEO 2007 Reference Case	**RFS2 (No Stover) Case**
Model Run	Total Outflow, million tons	Total Outflow, million tons
2010	6.231	6.232 (0.02)
2015	6.221	6.233 (0.19)
2020	6.214	6.224 (0.16)
2022	6.211	6.220 (0.14)

6.4.1.2.3 RFS1 Mandate Reference Case Pollutant Loadings

Tables 6.4-5 through 6.4-7 compare the models outputs for nitrogen, phosphorus, and sediment between the RFS1 Mandate Reference Case and the RFS2 (No Stover) Case scenarios for the years 2010, 2015, 2020, and 2022. Land load is the total amount of nitrogen or phosphorus that reaches a stream within the UMRB. The total outflow is the remaining amount measured at the outlet of the UMRB at Grafton, Illinois after accounting for in-stream loses due to uptake or assimilation.

Table 6.4-5.
Average annual nitrogen loads: Comparison of RFS1 Mandate Reference Case to the RFS2 (No Stover) Case (% difference in parentheses)

	RFS1 Mandate Reference Case		**RFS2 (No Stover) Case**	
Model Run	Total Land Load, million lbs	Total Outflow, million lbs	Total Land Load, million lbs	Total Outflow, million lbs
2010	1878	1414	1944 (3.5)	1467 (3.7)
2015	1838	1382	1946 (5.8)	1469 (6.3)
2020	1806	1357	1912 (5.9)	1442 (6.3)
2022	1794	1347	1897 (5.7)	1430 (6.2)

Table 6.4-6.
Average annual phosphorus loads: Comparison of RFS1 Mandate Reference Case to the RFS2 (No Stover) Case (% difference in parentheses)

	RFS1 Mandate Reference Case		**RFS2 (No Stover) Case**	
Model Run	Total Land Load, million lbs	Total Outflow, million lbs	Total Land Load, million lbs	Total Outflow, million lbs
2010	175.6	130.1	179.9 (2.4)	133.7 (2.8)
2015	173.5	128.4	179.6 (3.5)	133.6 (4.0)
2020	171.6	126.9	178.2 (3.8)	132.4 (4.3)
2022	170.8	126.3	177.6 (4.0)	131.8 (4.4)

Table 6.4-7.
Average annual sediment loads: Comparison of RFS1 Mandate Reference Case to the 2022 RFS2 (No Stover) Case (% difference in parentheses)

	RFS1 Mandate Reference Case	**RFS2 (No Stover) Case**
Model Run	Total Outflow, million tons	Total Outflow, million tons
2010	6.190	6.232 (.07)
2015	6.187	6.233 (.07)
2020	6.178	6.224 (.07)
2022	6.174	6.220 (.07)

6.4.1.2.4 Case Study

To evaluate local water quality impacts that are impossible to ascertain at the scale of the UMRB, we also modeled the Raccoon River watershed in central Iowa. The criteria for choosing this watershed included: percentage of corn area representative of the UMRB, stream segments included in EPA's 303(d) list of impaired waters due to high nutrient levels, biorefinery plants, drinking water intakes, and observed streamflow and water quality data. Nearly 88% of the watershed is in agriculture. 75% of the watershed produces corn and soybeans, mostly in rotation. Hay and other row crops are produced on the remaining agriculture land. The city of Des Moines makes up about 8% of the watershed. The state of Iowa has listed numerous stream segments of the Raccoon River as impaired. In particular, the two stream segments from the confluence of the North and South branches of the Raccoon River to the watershed's outlet were listed in 2006 for having more than 25% of the collected water samples exceed the drinking water standard for nitrate.

As part of the UMRB and by itself, the Raccoon River has been the focus of numerous modeling studies. As a result, there is a substantial amount of observed data throughout the watershed, primarily from the U.S. Geological Survey gaging stations.

The case study used the same assumptions and scenarios as those used for the UMRB analysis. SWAT-simulated streamflow and water quality (total nitrogen and phosphorus, and sediment loadings) were calibrated against observed data at both monthly and yearly time steps.

As in the UMRB study, nitrogen loads to water increased for the future scenarios, though at a greater rate. Future phosphorus loads decreased in the Raccoon River model, where they had shown minor increases in the UMRB model. For the Raccoon River, there was a greater decrease in sediment load, which is the likely cause for the decrease in phosphorus loadings. As with the UMRB model, there was minimal change in streamflow.

6.4.1.5 Sensitivity Analysis

Using the existing UMRB SWAT model, a sensitivity analysis was conducted on a number of important meteorological and management related factors. The goal was to further understand the model characteristics and sensitivities to parameters and input forcing functions that control the model response for the key environmental indicators of concern. Scenarios were constructed using four factors: fertilization application threshold, corn residue removal, daily air temperature, and daily precipitation. The results of the analysis showed that rainfall and temperature are the most influential factors for all model outputs: water yield, total nitrogen and phosphorus loadings, and sediment loadings. These results underscored the importance of representing these two driving factors accurately in hydrologic modeling. Corn residue removal noticeably reduced nutrient loading into streams while increasing sediment loads. However, since corn residue is the main source of organic nitrogen and phosphorus, the removal of the residue leads to the need for higher nutrient inputs in the growing season. The fertilization application threshold scenario did not tangibly impact water yield and sediment loading. The findings from this study indicated that future climate change could greatly influence water availability and pollution from corn cropland.

6.5 Climate Change Impacts

Although climate change is expected to be an important factor in future crop production in the Upper Mississippi River Basin, EPA has not modeled the impact of climate change on corn yields for a variety of reasons. Climate change requires a long period of observation. Over the short time frame reflected in this proposal, precipitation and temperature increases will be small and indistinguishable from the natural variability of the climate.

Crop yield changes resulting from climate change depend on the atmospheric carbon dioxide level, the crop, and the base temperature. Yield also depends on the characteristics of the crop relative to the timing of precipitation and of extreme temperature events. All of these variables make an estimation of actual climate-induced yield loss very difficult to develop. Farmer adaptation may mitigate the effects of climate change on agriculture to some degree. Adaptations are influenced by many unpredictable factors, including government policy, prices, research and development, and technical assistance. Climate model simulations generally indicate that most locations in the upper Midwest will warm more than the global average and will receive more precipitation than current – though estimates vary considerably depending on the model used and initial conditions.

6.6 Chesapeake Bay Watershed

The Chesapeake Bay Commission and others have expressed concerns about the water quality impact of increased corn production for ethanol may have on the Chesapeake Bay.[1300, 1301] The Chesapeake Bay watershed stretches across more than 64,000 square miles, encompassing parts of six states--Delaware, Maryland, New York, Pennsylvania, Virginia and West Virginia—and the entire District of Columbia. The Chesapeake's land-to-water ratio (14:1) is the largest of any coastal water body in the world. This is why land use and land management have such significant influences on the health of the Bay. In its annual State of the Bay report in 2007, the Chesapeake Bay Foundation gave the Bay a score of 28 on a scale where 70 means the Bay is "saved" and 100 is pristine. The Foundation said that "the health of the Chesapeake Bay is dangerously out of balance".[1302]

In 2000, Chesapeake Bay Program partners (states, federal agencies, universities, nongovernmental agencies) agreed to reduce nitrogen pollution from an estimated 285 million pounds per year to no more than 175 million pounds by 2010. Similarly they pledged to reduce phosphorus from about 19 million pounds per year to less than 13 million pounds. While there have been steady declines in nitrogen and phosphorus, they have not been adequate to meet the established goals. The watershed must essentially quadruple the pace of the Bay cleanup to meet the 2010 commitment. To restore water quality in the Bay, all of the basin's more than 87,000 farms will need to implement best management practices (BMPs) at levels never before seen in this country. The states have committed to implement close to 30 different agricultural BMPs as part of their restoration strategies.

In May 2009, President Obama issued Executive Order 13508 on Chesapeake Bay Restoration and Protection. The order established a Federal Leadership Committee, chaired by EPA, and with senior representatives from the departments of Agriculture, Commerce, Defense, Homeland Security, Interior, and Transportation. In November 2009, these federal agencies released a draft strategy which contains a range of approaches for accelerating cleanup of the nation's largest estuary and its vast watershed.[1303] The draft strategy calls for increased accountability and performance from pollution control, habitat protection and land conservation programs at all levels of government, including an expanded use of regulatory authorities to address pollution control and additional voluntary and market-based solutions – particularly when it comes to habitat protection and land conservation programs. The proposed actions are in response to overwhelming scientific evidence that the health of the Chesapeake Bay remains exceptionally poor, despite the concerted restoration efforts of the past 25 years.

Agricultural lands account for nearly a quarter of the watershed, and contribute more nutrients to the Bay than any other land use. Agricultural operations produce about 41% of the nitrogen and 47% of the phosphorus loads going to the Bay. Agriculture also contributes about 63% of the Bay's sediment. Municipal and industrial wastewater treatment plants throughout the watershed are responsible for 21% of the total nitrogen pollution and 22% of the total phosphorus pollution delivered to the Bay.

At least 25% and possibly a third of the nitrogen entering the Bay comes from air deposition. The principal sources of emissions are power plants, cars and trucks, agriculture, and off-road sources such as construction equipment, lawn mowers and aircraft. While population increased about 8% during the last decade, vehicle miles traveled rose 26%. More discussion about nitrogen oxides emission impacts can be found in Chapter 3.2.

The Bay watershed receives significant levels of nitrogen oxides and other airborne pollutants from its large airshed (which is about six and a half times the size of the watershed), as far west as Ohio and Indiana. Air deposition of nitrogen on the land adds to the burden that must be dealt with by farmers, local governments and other landowners.

6.6.1 Agricultural Production Effects

Due to the significant acreage within the Chesapeake Bay watershed that is devoted to agricultural production (approximately 22%), increases in corn acreage can potentially contribute to changes in nutrient loads to the Bay. High demand for corn reflected in record corn prices have played a substantial role in encouraging producers to alter their typical crop production rotations and crop acreage, contributing to noteworthy changes in crop acreages across the watershed. A technical review committee convened by the Chesapeake Bay Commission estimated that 300,000 new acres of corn could be added in the Bay watershed in the coming years.[1304] This new corn acreage could potentially contribute an additional five million pounds of nitrogen to the Bay. The Bay Program partners are trying to reach a 90 million pound reduction in nitrogen from all sources. However, it is estimated that 17 million pounds of nitrogen could be offset if all agriculture acres used cover crops as a conservation practice after harvest.

Strong market forces also encourage agricultural operators to increase grain production possibly by increasing the conversion of non-row crop acreage (hay, pasture and fallow or idle lands) to row crop production. Grain row crops can add more nutrients per acre to the Bay than hay and pasture due to production intensity, management systems, and nutrient efficiency of the crop.

6.6.1.1 Base Analysis Assumptions

The Chesapeake Bay Program Watershed Model Phase 4.3 (CBWM) and Vortex were utilized in the analysis of potential shifts in nutrient loading to the Bay based on reported changes to agricultural crop production from 2005 to 2008. These agricultural production changes are partially the result of the rapid expansion of biofuel production within the United States, supported by market-driven commodity price increases, government policies, or a combination of both. The CBWM is a dynamic watershed model used to characterize nutrient and sediment loads, and changes in these loads, due to management actions for decision support.[347]

[347] For more information on the CBWM see http://www.chesapeakebay.net/model.htm

In developing the agricultural production trend analysis within the Chesapeake Bay watershed, the USDA's National Agricultural Statistics Service's (NASS) 2007 and 2008 Projected Plantings report on reported crop acreages was modified to target only the Bay watershed.

6.6.1.2 Corn Production Analysis

Analyzing corn production acreage figures for the period from 2005 to 2008 from the NASS 2007 and 2008 Projected Planting reports, a measurable upward trend was evident for corn acreage plantings across the Bay watershed over the analysis period. This upward trend increased sharply between 2006 and 2007 and decreased for the 2007 and 2008 period. Despite the recent downward trend, total corn acreage increased over the analysis period by almost 66,000 acres.

6.6.1.3 Corn Nutrient Load Analysis

Employing a modeled analysis of the USDA-NASS Prospective Plantings report using the Chesapeake Bay Watershed Model Version 4.3 and Vortex, considerable increases of potential nitrogen loads to the Bay are associated with increased corn acreage. The decrease of corn acreage in the 2007 to 2008 period does not offset the total increase in acreage and nitrogen yields between 2005 and 2008. Total nitrogen loads increased by almost 2.4 million pounds.

6.6.1.4 Land Use Conversion Analysis

The agricultural production trends between 2005 and the present not only indicate an overall increase in the number of acres under corn production, but also an increase in the total acres of land under row crop production by over 355,000 acres. Since agricultural land uses within the Chesapeake Bay watershed are continuously decreasing due to urban development, the increase in row crop acreage may come at the expense of other cropping systems, or agricultural land uses such as hay, pasture or idle lands.

6.6.1.5 Land Use Conversion Nitrogen Load Analysis

The USDA-NASS Prospective Plantings reports and the Chesapeake Bay Program Watershed Model indicate a continuous total conversion of non-row crop agricultural lands over the period from 2005 to 2008 to more intensive row crop production. The non-row crop land uses typically produce less nitrogen yields to the Bay, thus additional acres converted to grain production can also increase nitrogen loads significantly. This analysis estimates that nitrogen loads increase by 8.8 million pounds.

If time and resources allow, the Chesapeake Bay Program proposes to analyze the potential impacts within the Chesapeake Bay watershed of the implementation of the RFS2 for the FRM using available systems and models at our disposal. The models that would potentially be used in the analysis would include Phase 5.2 of the Chesapeake Bay Watershed Model (CBWM), the Nutrient and Sediment Scenario Builder (NSSB), the Chesapeake Bay Estuarine

Water Quality Sediment Transport Model (CBEWQSTM) and the Chesapeake Bay Land Change Model (CBLCM). The CBWM is a dynamic watershed model used to characterize nutrient and sediment loads, and changes in these loads, due to management actions for decision support. The NSSB is being developed to determine nutrient and sediment loads under multiple land uses and crop types with variable organic and inorganic nutrient inputs. The CBEWQSTM determines the effects of nutrient and sediment load changes to the attainment of water quality standards. The CBLCM simulates changes in land use as a result of locally projected increases in population out to the year 2030.

The scope of the analysis is proposed to include incremental and delivered nitrogen, phosphorus and sediment to the Chesapeake Bay, and the effect of management changes to the attainment of water quality standards.

6.7 Ethanol Production and Distribution

Under the Clean Water Act, all point sources of pollution, including ethanol plants, must have a permit to discharge to water bodies or to municipal wastewater treatment plants for both industrial process water and stormwater. The permit regulates the amount of pollutants that can be discharged. There are three principle sources of discharges to water from ethanol plants: reject water from water purification, cooling water blowdown, and off-batch ethanol.

6.7.1 Water Discharges

Water is required at ethanol facilities for processing and for the production of steam that is typically used in biomass pretreatment and ethanol distillation processes. An ethanol plant's wastewater is typically comprised of cooling tower blowdown, boiler blowdown, and water softener discharge. The majority of the process water is lost as steam in the distillation process. In addition, stormwater runoff from the facility may be contaminated from precipitation (rain or snow) coming in contact with plant operations (industrial plant yards, material and waste handling, storage areas, shipping and receiving areas, residuals sites) and requires adequate control and management.[1305]

While some ethanol facilities get their process water from municipal water supplies, most use on-site wells to produce the process water for the ethanol process. Most groundwater sources are not suitable for process water because of their mineral content. Therefore, the water must be treated for use in ethanol production. The most common method of groundwater treatment is reverse osmosis. Reverse osmosis uses specialized filtration and pressure to produce pure water while concentrating the groundwater minerals into reject water. The minerals in the reject water are site-specific, but they can include: calcium carbonate, magnesium carbonate, sulfate, iron, and sodium. For every two gallons of pure water produced, about a gallon of brine is discharged as reject water. Most estimates of water consumption in ethanol production are based on the use of clean process water and neglect the water discharged as reject water.

The largest source of wastewater discharge is reverse osmosis reject water from process water purification. The reverse osmosis process concentrates groundwater minerals to levels where they can have water quality impacts. The concentrated minerals can show toxicity due to osmotic concentration and the presence of some ions such as sulfate or copper. There is really no means of "treating" these ions to reduce toxicity, other than further concentration and disposal, or use of in-stream dilution. Some facilities have had to construct long pipelines to get access to dilution so they can meet water quality standards.

Ethanol plants also discharge cooling water blowdown, where some cooling water is discharged to avoid the buildup of minerals in the cooling system. These brines are similar to the reject water described above. In addition, if off-batch ethanol product or process water is discharged, the waste stream can have high Biochemical Oxygen Demand (BOD) levels. BOD directly affects the amount of dissolved oxygen in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low dissolved oxygen: aquatic organisms become stressed, suffocate, and die.
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Ethanol production facilities are important transportation hubs. For instance, a facility in Iowa produces about 130 million gallons of ethanol in a year. On an average workday, 175 tractor-trailers bring in corn, ethanol goes out in 12 rail tankers, and 8 rail cars are filled with dried distillers grain to be used as animal feed. This intensity of vehicle travel can have local water impacts from stormwater runoff, spills, etc. similar to any other rail and trucking terminal.

6.7.2 Water Use

Older generation production facilities used 4-6 gallons of process water to produce a gallon of ethanol, but newer facilities use less than 3 gallons of water in the production process. Most of this water savings is gained through improved recycling of water and heat in the process: the conservation of heat energy and water go hand-in-hand. This energy savings is a key economic advantage for newer plants. A gallon of ethanol contains about 70,000 Kcal of energy. Older plants used 35-40,000 Kcal of energy to produce a gallon of ethanol, but newer facilities use only 25-28,000 Kcal per gallon.

The abundance or lack of water supply is a local issue, and there have been concerns with water consumption as new plants go online. Some facilities are tapping into deeper aquifers as a source of water. These deeper water resources tend to contain higher levels of minerals and this can further increase the concentration of minerals in reverse osmosis reject water.

6.7.3 Distillers Grain with Solubles

One important co-product of ethanol production is distillers grain with solubles (DGS). Due to the increase in ethanol production and the price of corn, DGS has become an increasing important feed component for confined livestock. About one-third of the corn processed into ethanol is converted into DGS. Therefore approximately 45 million tons of DGS will be produced for the 15 billion gallons of corn ethanol produced by 2015. Concerns have been raised about the relatively higher phosphorus content of DGS compared to traditional feeds.

Livestock producers may partially replace corn or other feeds with DGS for both economic and production reasons. Different livestock species can tolerate varying amounts of DGS in their diets. The majority of DGS are fed to beef and dairy cows. Current recommendations allow beef and dairy cows diets to include from 15 to 40% DGS. Recommendations for poultry and swine diets are generally less than 15% DGS. Although specific analysis of DGS can vary between ethanol plants, compared to corn, DGS are higher in crude protein (nitrogen) and three to four times higher in phosphorus.[1306]

The increase in nitrogen and phosphorus from DGS in livestock feed has potential implications for water quality. When nitrogen and phosphorus are fed in excess of the animal's needs, these nutrients are excreted in the manure. Most livestock manure is applied to crops, especially corn, as a source of nutrients. When manure is applied at rates above the nutrient needs of the crop or at times the crop can not use the nutrients, the nitrogen and phosphorus can runoff to surface waters or leach or ground waters. Excess nutrients from manure nutrients have the same impact on water quality as excess nutrients from other sources.

Several recent studies have indicated that DGS may have an impact on food safety. Cattle fed DGS have a higher prevalence of a major food-borne pathogen, E. coli O157, than cattle without DGS in their diets.[1307] More research is needed to confirm these studies and devise methods to eliminate the potential risks.

Livestock producers can limit the potential pollution from manure applications to crops through a variety of techniques. USDA's Natural Resources Conservation Service (NRCS) has developed a standard for a comprehensive nutrient management plan (CNMP) to address the issue of proper use of livestock manure.[1308] Agricultural producers who use manure should test the nitrogen and phosphorus content before application of the manure. Due to the substantially higher phosphorus content of manure from livestock fed DGS, producers will potentially need significantly more acres to apply the manure so that phosphorus will not be applied at rates above the needs of the crops. This is a particularly important concern in areas where concentrated livestock production already produces more phosphorus in the manure than can be taken up by crops or pasture land in the vicinity.

6.7.4 Water Quality Impact from Ethanol Leaks and Spills

The potential for exposure to fuel components and/or additives can occur when underground fuel storage tanks leak fuel into ground water that is used for drinking water supplies or when spills occur from above ground tanks or distribution systems that contaminate surface drinking water supplies or surface waters. Additionally, in surface waters, rapid biodegradation of ethanol can result in depletion of dissolved oxygen with potential mortality to aquatic life.

Regarding leaks or spills and drinking water impacts, ethanol biodegrades quickly and is not necessarily the pollutant of greatest concern in these situations. Instead, ethanol's high biodegradability shifts the subsurface geochemistry, which can cause reduced biodegradation of benzene, toluene, and xylene (up to 50% for toluene and 95% for benzene).[1309] The plume of BTEX (benzene, toluene, ethylbenzene and xylenes) compounds in gasoline from a fuel spill can extend as much as 70% farther in groundwater and can persist longer, thereby increasing potential human exposures to these compounds.[1310] Particularly large plumes of benzene can be expected when: there is a large area of the aquifer that is contaminated with liquid phase gasoline; the background concentration of sulfate-reducing bacteria (which biodegrade ethanol and benzene) in the ground water is low; the rate of ethanol biodegradation is low; and the flow velocity of the ground water is high. More detail on ethanol biodegradation and a summary of laboratory and field studies of ethanol spills will be forthcoming in the EPAct 2005 Report to Congress on Fuel Additive Replacements for MTBE in 2010.

Ethanol leak and spills from the approximately 600,000 gas stations in the U.S, could have a significant impact on water quality and drinking water supplies. Urban areas, that rely on ground water for drinking water would be affected most, especially where are existing water shortages

With the increasing use of ethanol in the fuel supply nationwide, it is important to understand the impact of ethanol on the existing tank infrastructure. Federal regulations require that underground storage tank (UST) systems be compatible with the fuel stored. Because much of the current underground storage tank equipment was designed and tested for use with petroleum fuels, there may be many UST systems currently in use that contain materials that are incompatible with ethanol blends greater than 10%. Combined with the fact that ethanol is more corrosive than petroleum, there is concern regarding the increased potential for leaks from existing distribution systems, terminals and gas stations and subsequent impacts on water supplies. Given the practical challenges of determining the age and materials of underground storage equipment at approximately 233,000 federally regulated facilities, it may be difficult or impossible to confirm the compatibility of current underground storage tanks and other tank-related hardware with ethanol blends. Further discussion of challenges in retail distribution are discussed in Section 1.6 of the RIA.

In 2007, there were 7,500 reported releases from underground storage tanks. Since approximately 50% of the gasoline used in the U.S. contains ethanol, approximately 3,750 of those releases likely contained some amount of ethanol. Therefore, EPA is undertaking analyses designed to assess the potential impacts of ethanol blends on tank infrastructure and leak detection systems and determine the resulting water quality impacts.

An additional hazard from spills from fuels containing ethanol is risk of potential explosions. Laboratory and field studies have found biodegradation of ethanol can produce concentrations of methane in excess of the water solubility of methane (i.e., more methane was produced than could be dissolved by the available water). This methane could bubble out of the ground water and enter the soil gas at explosive concentrations, although it is not possible to quantify the risk at this time. EPA is beginning development of modeling software for the assessment of fuels of varying composition on ground water, with simulation of methane production being one component of this work.

6.8 Water Use and Wastewater from Biodiesel Plants

Biodiesel plants use much less water than ethanol plants in production of biofuel. Water is not used in conversion of oil to biodiesel, but is used for washing impurities from the finished product. Water use is variable, but is usually less than one gallon of water for each gallon of biodiesel produced. Larger well-designed plants use water more sparingly, while smaller producers and hobbyists use more water. Some facilities recycle washwater, which reduces water consumption.

The strength of process wastewater from biodiesel plants is highly variable. Most production processes produce washwater that has very high BOD levels. Essentially the strength of the wastewater is based on glycerin and methanol content. Larger facilities are segregating glycerin as a side product and have efficient methanol recovery, while smaller plants are more likely to dispose of glycerin, excess methanol, and washwater as a single waste stream. Crude glycerin is an important side product from the biodiesel process and has many uses. It is about 10% of the final product. Although there is a commercial market for glycerin, the rapid development of the biodiesel industry has caused a glut of glycerin production and many facilities dispose of glycerin.

The high strength of these wastes can overload and disrupt the biological processes in municipal treatment plants. The normal wastewater going into a municipal sewage treatment plant has a BOD 200mg/l. Washwater from the biodiesel process with efficient recovery of methanol, containing small amounts of glycerin, can have a BOD of 10,000 – 15,000 mg/L. Pure glycerin has a BOD of nearly 1,000,000 mg/L. There have been several cases of wastewater treatment plant upsets due to these shock loadings from releases of glycerin from biodiesel production facilities. Unfortunately, these have been due to slug loadings to small wastewater treatment plants. Other states such as Illinois and Alabama have also had problems with discharges from small biodiesel plants. In addition, there have been incidences of outright dumping of glycerin. One such event resulted in a large fish kill in Missouri.

Producers that choose to dispose of glycerin can be regulated under several EPA programs, depending on the practice. EPA strongly supports the beneficial use of glycerin as a product. While the market for refined glycerin is glutted with an excess supply, there are many known uses for glycerin feedstock. As prices for glycerin go down, many of these known products will show a better profit margin and demand for glycerin will increase. Most larger facilities are segregating crude glycerin for refining into usable feedstock for other products. Refining can range from minimal processing up to creation of a food grade product. Nationally, there is a lot of research on the creation of new value added products (ethanol, propylene glycol, etc.) using glycerin as a feedstock. Most of these projects are in university labs, but a few are up to pilot scale. These new technologies will go online at full scale within the next few years, and are an important part of the profit stream for the industry.

6.9 Potential Impacts to Drinking Water and Public Health

Under the Safe Drinking Water Act (SDWA), EPA establishes enforceable safety standards for drinking water provided by public water systems (PWS). For chemicals, the standard is typically called a maximum contaminant level (MCL). A PWS is “a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals." If the source water for a PWS does not meet the MCL, the PWS must take measures to reduce the contamination to safe levels and that may entail installing expensive drinking water treatment technology e.g., ion exchange (IE), granulated activated carbon (GAC) or reverse osmosis (RO).

EPA anticipates that increased corn production for ethanol will increase the occurrence of nitrate, nitrite, and atrazine in sources of drinking water. New corn acreage may result in increase in the application of fertilizers and herbicides, especially on marginal lands that are not as productive. The ethanol production process may generate new or increased discharges, injection or infiltration of process waste water that could adversely affect the nation's surface water and ground water used for drinking water.

In addition to potential additional contamination of sources of drinking water, surface and ground water supplies may be strained by increased production of irrigated corn for ethanol and the ethanol production process itself in local and regional areas. Increased pumping from agricultural aquifers to support ethanol production may accelerate the long running depletion of aquifers which has been documented by the USGS. According to U. S. Geological Survey (USGS) data, more than 72 billion gallons a day are already being pumped from the "thirty regional principle aquifers with the greatest amount of ground water use", with irrigation accounting for slightly more than 75% of those withdrawals.[1311] The water table of the Ogallala aquifer has declined by over 150 feet in some areas since the 1950s due to increasingly large withdrawals.[1312] Aquifers provide water for domestic and other uses, and contribute to the base flow of many streams and lakes that support aquatic habitats and other ecosystem services such as fishing and swimming. Lower stream levels combined with the increased pollutant loadings may concentrate pollutants. Higher pollutant concentrations may require increased drinking water treatment. The accelerated depletion of agricultural aquifers and surface water supplies may be exacerbated by an increase in the incidence of droughts that are predicted under many climate change scenarios.

6.9.1 Nitrogen

The nitrogen fertilizers that are applied to corn and other agricultural crops can end up in drinking water sources where they can impact human health. The two nitrogen compounds of concern are nitrate and nitrite. Nitrate is the most stable form of nitrogen in water.

EPA has established the MCL for nitrate-nitrogen at 10 parts per million (ppm) and for nitrite at 1 ppm. Infants below six months who drink water containing nitrate and/or nitrite in excess of the MCL could become seriously ill and, if untreated, may die.[1313] Symptoms include shortness of breath and blue baby syndrome. This health effects language is not intended to catalog all possible health effects for nitrate. Rather, it is intended to inform people of the most significant and probable health effects, associated with nitrate and nitrite in drinking water.

Most nitrogen in water is converted to nitrates. Since nitrates are very soluble and do not bind to soils, they have a high potential to migrate to ground water. Because they do not evaporate, nitrates and nitrites are likely to remain in water until consumed by plants or other organisms. Primary sources of nitrate which may contaminate drinking water are human sewage, livestock manure, and fertilizers.

In 2007, there were 562 public water systems, serving 257, 558 people, reporting violations of the nitrate MCL.[1314] If a utility's routine compliance monitoring indicates that nitrate or nitrite concentrations are above the MCL, the water system must implement measures such as treatment or blending to reduce the concentration so that it is below the MCL (e.g., find a new source of water, adjust existing treatment or install new treatment). Also, utilities must monitor the finished water every quarter and provide notification to consumers of the MCL exceedance.

Since there is no nationally consistent sampling of ambient water used by public water systems, the relative contribution of nitrate detections from the various sources is generally unknown.

6.9.2 Pesticides

The U.S. Geological Survey evaluated the fate and transport of herbicides in surface water, ground water, and in precipitation in the Midwest during the 1990s. Results of these studies showed the occurrence and temporal distribution of herbicides and their associated degradation products in reservoir outflows.[1315]

Atrazine is estimated to be the most widely used herbicide in the United States for control of weeds. Atrazine was the second most frequently detected pesticide in EPA's National Survey of Pesticides in Drinking Water Wells. EPA's Pesticides in Ground Water Database indicates numerous detections of atrazine at concentrations above the MCL in ground water in several states, including Delaware, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, and New York.[1316] In 1993, EPA and the atrazine registrants initiated a monitoring program to focus on the most significant exposures associated with agricultural and residential uses -- exposures through drinking water. To this point, levels found in PWS have been low. Through the PWS monitoring program, EPA is ensuring that exposures to atrazine in drinking water do not reach levels that pose a risk to public health.

The MCL for atrazine is three parts per billion (ppb). MCL violations are not triggered by single measurement above the MCL but by the running annual average concentration from four quarterly samples in which at least one measurement during that period exceeds 3 ppb. Some people who drink water containing atrazine well in excess of the MCL over a period of many years could experience problems with their cardiovascular system or reproductive difficulties. This health effects language is not intended to catalog all possible health effects for atrazine. Rather, it is intended to inform people of the most significant and probable health effects, associated with atrazine in drinking water.

Atrazine may be released to the environment in wastewater from herbicide manufacturing facilities and through its use as an herbicide. Microbial activity and other chemicals may breakdown atrazine in soil and water, particularly in alkaline conditions. Sunlight and evaporation do not reduce its presence. It may bind to some soils, but generally tends to leach to ground water. Atrazine is not likely to be taken up in the tissues of plants or animals.[1317]

In *A Review of Contaminant Occurrence in Public Water Systems*, published in 1999, EPA found atrazine in the finished water of 21% of the surface water systems.[1318] Atrazine was found at concentrations exceeding the MCL in 10.7% of the surface water systems and, in 83% of those systems, atrazine was found at concentrations that would have been in violation of the MCL. As noted above, MCL violations are not triggered by single excursions above the MCL but by the running annual average concentration from four quarterly samples in which the measurement of at least one of those samples exceeds three ppb. However in one of the states where atrazine is widely used e.g., for corn production, the percentage of single samples exceeding the MCL was as high as 77.8% for surface water systems serving less than 500 people; see Table 6.1.

Table 6.9-1.
Percentage of Surface Water Systems with Detections of Atrazine for a High Occurrence State, 1999

POPULATION	<500	500 – 3,300	3,301 – 10,000	10,001 – 50,000	> 50,000
> MRL[a]	100%	100%	96.2%	96.3%	55.6%
> MCL[b]	77.8%	71.1%	57.7%	18.5%	22.2%

[a] The MRL, or minimum reporting level, is the lowest concentration at which the contaminant can be consistently and reliably detected. U.S. Environmental Protection Agency, *A Review of Contaminant Occurrence in Public Water Systems*, EPA 816-R-99-006, 1999, Table V.A.2, page D-2.

[b] U.S. Environmental Protection Agency, ibid, p. D-3.

In 2003, EPA estimated that single atrazine measurements greater than the MCL would be observed in 26 to 57 public water systems serving a range of 24,400 – 260,300 people.[1319]

Because atrazine is used mostly as a pre-emergent herbicide on corn, the surface water concentrations typically spike during growing season then taper off for the rest of the year. Even though many surface water systems encounter concentrations above the MCL during the growing season, very few experience MCL violations based on the average concentration over four consecutive quarters. In 2007, only one water system serving 740 people officially reported a MCL violation.[1320]

From 1992 through 2001, the USGS observed atrazine in 90% of the samples it took from 83 stream sites in agricultural areas as part of its National Water Quality Assessment (NAWQA). Although it does not target exclusively drinking water intakes or wells, the NAWQA program "provides an understanding of water-quality conditions and how those conditions may vary locally, regionally, and nationally**…".[1321]** Atrazine was observed in 71% of the samples from 30 urban stream sites during the same period. For ground water, USGS observed atrazine in 42% of the samples it took from wells in agricultural areas and in 31% of the samples from urban wells.

The detection limits for this study were very low and 95% of the sampling results from streams in agricultural areas, where the highest concentrations of atrazine were found, were below 2.4 ppb which is 80% of the MCL of 3 ppb.

6.9.3 Future availability of more recent occurrence data

EPA anticipates releasing the chemical occurrence data covering the years 1999 – 2006 from states for publication in 2010 as part of the six year review of drinking water standards. Once those data sets are publicly available, they will be useful in updating the occurrence data published here for nitrate and atrazine.

6.10 Water Quantity Concerns

Biofuel production based on current and projected approaches and processes, future alternative fuel development and production could markedly increase the demand for various fresh water resources. Two potential needs could increase water demand: quantities of water to produce biomass as a feedstock, and the additional water demand for refining of bio-ethanol and biodiesel fuels (by up to a factor of three relative to traditional refining). From a regional perspective, water demand for crop production would be relatively much larger than biorefinery demand; crop production needs would be approximately 200 times the water needed to refine biofuels.[1322]

With growth of ethanol production, water supply reliability related to crop demand for biomass feedstock will remain an issue. The amount of water needed to grow feedstocks for biofuels can be considerable – for example, the ratio of water consumed to produce the corn itself for ethanol is nearly one thousand gallons per gallon of corn ethanol. Large scale production of perennial energy crops involving tens of millions of acres, even when rain-fed, can have water resource impacts and unintended local consequences due to alterations of hydrologic flows. The timing of the water demand may also be critical; water is often plentiful in one season but scarce in another.

Growing crops for biofuel production is likely to have significant regional and local impacts, including the potential to change irrigation water use, and thus local water availability. The feasibility and sustainability of water diversions for biomass irrigation will vary depending on the region. Moreover, some ethanol plants are being sited where water resources are already under duress, for example on the High Plains aquifer.

Biofuel refineries create additional local scale demand for water withdrawals and consumption. It is difficult to generalize about the impact on local water supplies, however, some community supplies have been stressed by the water requirements of ethanol facilities. However, from a national and regional perspective, relative to the water incorporated in the feedstock, water use in biorefineries is quite small. A typical corn ethanol plant consumes slightly more than four gallons water per gallon of ethanol produced; biodiesel refining even less, about one gallon of water per gallon of biodiesel, which on an energy-equivalent basis is even less in comparison to ethanol. (Petroleum refining consumes about 1.5 gallons of water per gallon fuel produced.) Biodiesel refining consumes about one gallon water per gallon, but may be up to three gallons per gallon. However, biofuel crops may be irrigated with wastewater that is biologically and chemically unsuitable for use with food crops. On the other hand, cellulosic materials require a different process, and are thought to use 9.5 gallons water per gallon fuel produced--but this would be expected to decline as efficiency increases (currently projected to be lowered to two to six gallons per gallon).

Geographic impacts of biofuel refining vary. Currently, the Midwest and Southeast have most of the production. In Iowa, water consumption alone from ethanol refining already accounts for about 7% of all industrial water use, and is projected to be 14% by 2012--or about 50 million gallons per day. A typical ethanol plant now producing 50 million gallons per year means a minimum of 175 million gallons (nearly 480,000 per day) used in a year. In the Great Lakes-St. Lawrence region, newer facilities under construction will have capacities of 100 million gallons per year.[1323] For a 100 million gallon per year corn ethanol plant, water consumption is one million gallons of water/day (equates to daily water consumption of a town of 20,000).

Research is needed to establish water use requirements across the entire biofuel production chain. Information needs related to biomass feedstock production include the assessment and quantification of impacts of increased irrigation of energy crops and resulting biofuel cost/benefit tradeoffs for both starch/sugar/oil biofuel crops, and the lignocellulosic biofuel crops. An assessment is also needed of the impacts on hydrologic flows of regional expansion of perennial energy crop production. These include the impacts and risks tradeoffs, e.g., altered flows due to deep extensive root systems and dense canopies, as well as a need for management practices/metrics, e.g. relatively large absolute water consumption, and additional irrigation necessary. Changing climate adds an additional element of uncertainty in making assessments of water use.

Many uncertainties exist regarding estimating water needs for irrigating cellulosic feedstocks in particular. Reasons include: water data is less available for proposed cellulosic feedstock than for common crops, evapotranspiration rates of marginal lands used for these crops are unknown, and water demand by heretofore unirrigated native grasses is unknown.

Some practices can mitigate the increased demand for water by biofuels. Both the impacts and regulatory opportunities for mitigation of water impacts are likely to be at the state and local levels. For example, rainfall harvesting, efficient irrigation water transport and use of reclaimed water can lead to more efficient agricultural water use for both corn and cellulosic ethanol crops. Also, biorefineries are increasingly incorporating water recycling.

The economics of the energy-water distribution linkage are important in biofuels production. At a macroscale, the high prices of energy driving the increased production of biofuels will likely affect water availability and use, e.g., conveyance costs related to irrigation waters will also increase with energy costs, possibly leading to water conservation that may counter the expanded water use for crops. Also, the value of crops relative to their water demand matters: water rights can often be bought and sold if the value of the crop is sufficiently high.

Finally, there is the potential for a low water use alternative biomass feedstock to develop: oil-producing macro-algae. These algae can be grown without land, using nontraditional waters, and CO2 waste streams as a nutrient source. Such fuels can have significantly higher energy density and are potentially more fungible within existing transportation fuel infrastructure than ethanol.

Chapter 7: Final Regulatory Flexibility Analysis

This chapter discusses our Final Regulatory Flexibility Analysis (FRFA) which evaluates the potential impacts of the standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Prior to issuing a proposal for this rulemaking, we analyzed the potential impacts of these regulations on small entities. As a part of this analysis, we convened a Small Business Advocacy Review Panel (SBAR Panel, or 'the Panel'). During the Panel process, we gathered information and recommendations from Small Entity Representatives (SERs) on how to reduce the impact of the rule on small entities, and those comments are detailed in the Final Panel Report which is located in the public record for this rulemaking (Docket EPA-HQ-OAR-2005-0161).

7.1 Overview of the Regulatory Flexibility Act

In accordance with section 609(b) of the Regulatory Flexibility Act, we convened an SBAR Panel before conducting the FRFA. A summary of the Panel's recommendations can be found in the preamble to the proposed rule. Further, the Final Panel Report contains a detailed discussion of the Panel's advice and recommendations (as well as comments from the Small Entity Representatives (SERs)). The regulatory alternatives that are being adopted in this final rule are described below.

Section 609(b) of the Regulatory Flexibility Act further directs the Panel to report on the comments of small entity representatives and make findings on issues related to identified elements of the Regulatory Flexibility Analysis under section 603 of the Regulatory Flexibility Act. Key elements of a Regulatory Flexibility Analysis are:

- a description of and, where feasible, an estimate of the number of small entities to which the rule will apply;
- projected reporting, record keeping, and other compliance requirements of the rule, including an estimate of the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record;
- an identification, to the extent practicable, of all other relevant Federal rules which may duplicate, overlap, or conflict with the rule;
- any significant alternatives to the rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the rule on small entities.

The Regulatory Flexibility Act was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although we are not required by the Clean Air Act to provide special treatment to small businesses, the Regulatory Flexibility Act requires us to carefully consider the economic impacts that our rules may have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with Clean Air Act requirements.

7.2 Need for the Rulemaking and Rulemaking Objectives

A detailed discussion on the need for and objectives of this rule are located in the preamble to the final rule. As previously stated, section 1501 of the Energy Policy Act of 2005 (EPAct) amended section 211 of the Clean Air Act (CAA) by adding section 211(o) which required the Environmental Protection Agency (EPA) to promulgate regulations implementing a renewable fuel program. The final Renewable Fuels Standard (RFS1) program, which began on September 1, 2007, created a specific annual level for minimum renewable fuel use that increases over time — resulting in a requirement that 7.5 billion gallons of renewable fuel be blended into gasoline by 2012.

The Energy Independence and Security Act of 2007 (EISA) amended section 211(o), and the RFS program, by requiring higher volumes of renewable fuels, to result in 36 billion gallons of renewable fuel by 2022. EISA also expanded the purview of the RFS1 program by requiring that these renewable fuels be blended into diesel fuel (both highway and nonroad) in addition to gasoline. This expanded the volume obligation of parties that were already regulated under RFS1. It also expanded the pool of regulated entities, so the obligated parties under the RFS2 rule will now include certain refiners, importers, and blenders of these fuels that were not previously covered by the RFS1 program. In addition to the total renewable fuel standard required by EPAct, EISA added standards for three additional types of renewable fuels to the program (advanced biofuel, cellulosic biofuel, and biomass-based diesel) and requires compliance with all four standards.

7.3 Definition and Description of Small Entities

Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration's (SBA) size standards; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

Small businesses (as well as large businesses) would be regulated by this rulemaking, but not small governmental jurisdictions or small organizations as described above. As set by SBA, the categories of small entities that will potentially be affected by this rulemaking are defined in Table 7.3-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 7.3-1. Small Business Definitions

Industry	Defined as small entity by SBA if less than or equal to:	NAICS[a] codes
Gasoline and diesel fuel refiners	1,500 employees[b]	324110

[a] *North American Industrial Classification System*

[b] *EPA has included in past fuels rulemakings a provision that, in order to qualify for the small refiner flexibilities, a refiner must also produce no greater than 155,000 bpcd crude capacity*

EPA used a variety of sources to identify which entities are appropriately considered "small." EPA used the criteria for small entities developed by the Small Business Administration under the North American Industry Classification System (NAICS) as a guide. Information about the characteristics of refiners comes from sources including the Energy Information Administration (EIA) within the U.S. Department of Energy, oil industry literature, and previous rulemakings that have affected the refining industry. EPA then found employment information for these companies using the business information database Hoover's Online (a subsidiary of Dun and Bradstreet). These refiners fall under the Petroleum Refineries category, 324110, as defined by NAICS.

Small entities that will be subject to the renewable fuel standard include: domestic refiners that produce gasoline and/or diesel, and importers of gasoline and/or diesel into the U.S. Based on 2007 data, EPA believes that there are about 95 refiners of gasoline and diesel fuel. Of these, EPA believes that there are currently 17 refiners owning 20 refineries producing gasoline and/or diesel fuel that meet the SBA small entity definition of having 1,500 employees or less. Further, we believe that three of these refiners own refineries that do not meet the definition of a "small refinery" that Congress specified under section 211(o). It should be noted that because of the dynamics in the refining industry (i.e., mergers and acquisitions), the actual number of refiners that ultimately qualify for small refiner status under the RFS2 program could be different from this initial estimate.

7.4 Steps to Minimize Impacts on Small Entities

As a part of the SBREFA process, we conducted outreach to small refiners of gasoline and/or diesel fuels and convened a Panel to gain feedback and advice from these entities. Prior to convening the Panel, we held outreach meetings with the SERs to learn the needs of small entities and potential challenges that these entities may face. The outreach meetings also helped to provide the SERs an opportunity to gain a better understanding of the new requirements under EISA and how it would change the RFS program (including those small refiners who only produce diesel and were not regulated entities). The feedback that we received from SERs as a result of these meetings was used during the Panel process to develop regulatory alternatives to mitigate the impacts of the rulemaking on small businesses. General concerns raised by SERs during the SBREFA process were potential costs and access to RINs for compliance with the program.

The Panel consisted of members from EPA, the Office of Management and Budget (OMB), and the Small Business Administration's Office of Advocacy. Following the Panel convening, a Final Panel Report detailing all of the alternatives that were recommended by the Final Regulatory Support Document Panel (as well as individual Panel members) was issued. We either proposed or requested comment on the various recommendations put forth by the Panel. Below we discuss those flexibility options recommended in the Panel Report, our proposed regulatory alternatives, and those provisions which are being finalized.

7.4.1 Panel Recommendations

The purpose of the Panel process is to solicit information as well as suggested flexibility options from the SERs, and the Panel recommended that EPA continue to do so during the development of the RFS2 rule. Recognizing the concerns about EPA's authority to provide extensions to a subset of small refineries (i.e., those that are owned by small refiners) different from that provided to small refineries in section 211(o)(9), the Panel recommended that EPA continue to evaluate this issue, and that EPA request comment on its authority and the appropriateness of providing extensions beyond those authorized by section 211(o)(9) for small refineries operated by a small refiner. The Panel also recommended that EPA propose to provide the same extension provision of 211(o)(9) to small refiners who do not own small refineries as is provided for small refiners who do own small refineries.

7.4.2 Extensions of the Temporary Exemption Based on a Study of Small Refinery Impacts

Panel Recommendations

The Panel recommended that EPA propose in the RFS2 program the provision at 40 CFR 80.1141(e) extending the RFS1 temporary exemption for at least two years for any small refinery that DOE determines would be subject to disproportionate economic hardship if required to comply with the RFS2 requirements.

Section 211(o)(9)(A)(ii) requires DOE to perform a study of the economic impacts of the RFS requirements on small refineries. The study, which was required to be completed by December 31, 2008, must assess and determine whether the RFS requirements would impose a disproportionate economic hardship on small refineries. Small refineries that are found to be in a disproportionate economic hardship situation will receive an extension of the temporary exemption for at least two years.

The Panel also recommended that EPA work with DOE in the development of the small refinery study, specifically to communicate the comments that SERs raised during the Panel process.

What We Proposed and Public Comments Received on the NPRM

We did not propose this hardship provision given the outcome of the DOE small refinery study. In the small refinery study, "EPACT 2005 Section 1501 Small Refineries Exemption

Study", DOE's finding was that there is no reason to believe that any small refinery would be disproportionately harmed by inclusion in the proposed RFS2 program. This finding was based on the fact that there appeared to be no shortage of RINs available under RFS1, and EISA has provided flexibility through waiver authority (per section 211(o)(7)). Further, in the case of the cellulosic biofuel standard, cellulosic biofuel allowances can be provided from EPA at prices established in EISA (see regulation section 80.1455). DOE thus determined that no small refinery would be subject to disproportionate economic hardship under the proposed RFS2 program, and that the small refinery exemption should not be extended beyond December 31, 2010. DOE noted in the study that, if circumstances were to change and/or the RIN market were to become non-competitive or illiquid, individual small refineries have the ability to petition EPA for an extension of their small refinery exemption (as stated in regulation section 80.1441).

In their written comments, as well as in discussions we had with them on the proposed rule, small refiners indicated that they did not believe that EPA should rely on the results of the DOE small refinery study to inform any decisions on small refiner provisions. Small refiners generally commented that they believe that the study was flawed and that the conclusions of the study were reached without adequate analysis of, or outreach with, small refineries (as the majority of the small refiners own refineries that meet the Congressional small refinery definition). One commenter stated that such a limited investigation into the impact on small refineries could not have resulted in any in-depth analysis on the economic impacts of the program on these entities. Another commenter stated that it believes that DOE should be directed to reopen and reassess the small refinery study be June 30, 2010, as suggested by the Senate Appropriations Committee.

<u>What We're Finalizing</u>

As discussed more in section III.E of the preamble to the final rule, since the only small refinery study available for us to use as a basis for whether or not to grant small refineries an automatic two-year extension of the exemption is the study that was performed in 2008, we had to use this study to develop this final rule. EPAct directs EPA to consider the DOE small refinery study in assessing the impacts to small refineries, and we interpret this to mean that any extension past December 31, 2010 has to be tied to the DOE Study. Further, since that study found that there was no disproportionate economic impact on small refineries, we cannot grant an automatic additional extension for small refineries or small refiners (except on a case-by-case hardship basis). However, this does not preclude small refiners from applying for case-by-case extensions of the small refiner temporary exemption.

We are aware that there have been expressions of concern from Congress regarding the DOE Study. Specifically, in Senate Report 111-45, the Senate Appropriations Committee "directed [DOE] to reopen and reassess the Small Refineries Exemption Study by June 30, 2010," noting a number of factors that the Committee intended that DOE consider in the revised study. The Final Conference Report 111-278 to the Energy & Water Development Appropriations Act (H.R. 3183), referenced the language in the Senate Report, noting that the conferees "support the study requested by the Senate on RFS and expect the Department to undertake the requested economic review." The DOE study has not been revised at this time; however, if DOE prepares a revised study and the revised study finds that there is a disproportionate economic impact, we will revisit the exemption extension at that point in accordance with section 211(o)(9)(A)(ii).

7.4.3 Delay in Standards for Small Refiners

Panel Recommendations

The RFS1 program regulations provide small refiners who operate small refineries as well as small refiners who do not operate small refineries with a temporary exemption from the standard through December 31, 2010. Small refiner SERs suggested that an additional temporary exemption for the RFS2 program would be beneficial to them in meeting the RFS2 standards. EPA evaluated a temporary exemption for at least some of the four required RFS2 standards for small refiners. The Panel recommended that EPA propose a delay in the effective date of the standards until 2014 for small entities, to the maximum extent allowed by the statute. However, the Panel recognized that EPA has serious concerns about its authority to provide an extension of the temporary exemption for small refineries that is different from that provided in CAA section 211(o)(9), since Congress specifically addressed an extension for small refineries in that provision.

The Panel did recommend that EPA propose other avenues through which small refineries and small refiners could receive extensions of the temporary exemption. These avenues were a possible extension of the temporary exemption for an additional two years following a study of small refineries by the Department of Energy (DOE) (as discussed above) and provisions for case-by-case economic hardship relief.

What We Proposed and Public Comments Received on the NPRM

We proposed and took comment on the recommendations of the Panel and SERs. We proposed to continue the temporary exemption finalized in RFS1, through December 31, 2010, for small refiners (and small refineries), extending it to include an exemption for diesel volume and diesel refiners, importers, and blenders, as required by EISA.

Commenters that oppose an extension of the temporary exemption generally stated that they believe an extension is not warranted, and some of these commenters expressed concerns about allowing provisions for small refiners. One commenter also stated that the small refinery exemption should not be extended and that the small refiner exemption should be eliminated completely. A couple commenters supported the continuation of the exemption through December 31, 2010 only; one of those commenters stated that it does not support an extension as it believes that all parties have been well aware of the passage of EISA and small refineries and small refiners should have been striving to achieve compliance by the end of 2010. Two commenters also expressed views that the exemption should not have been offered to small refiners in RFS1 as this was not provided by EPAct, and that an extension of the exemption should not be finalized for small refineries at all. The commenters further commented that an economic hardship provision was included in EPAct, and any exemption extension should be limited to such cases, and only to the specific small refinery (not small refiner) that has petitioned for such an extension.

Commenters supporting an extension of the exemption commented that they believe that the statutes (EPAct and EISA) do not prohibit EPA from providing relief to regulated small entities on which the rule will have a significant economic impact, and that such a delay could lessen the burden on these entities. One commenter stated that it believes EPA denied or ignored much of the relief recommended by the Panel in the proposal. Another commenter stated that it believes EPA's concerns regarding the legal authority are unsustainable considering EPA's past exercises of discretion under the RFS1 program, and with the discretion afforded to EPA under section 211(o) of the CAA. Some commenters requested a delay until 2014 for small refiners. One additional commenter expressed support for an extension of the small refinery exemption only, and stated that these small refineries should be granted a permanent exemption.

What We're Finalizing

The RFS1 program regulations exempt gasoline produced by small refineries from the renewable fuels standard through December 31, 2010 (at 40 CFR 80.1141), per EPAct. As EISA did not alter the small refinery exemption in any way, we are retaining this small refinery temporary exemption in the RFS2 program, extending the relief to diesel fuel volumes produced or imported in addition to gasoline, and extending the relief to those small refineries of diesel fuel that were not covered under RFS1. Likewise, as we extended under RFS1 the small refinery temporary exemption to the few remaining small refiners that met the Small Business Administration's (SBA) definition of a small business (1,500 employees or less company-wide), we are also finalizing a continuation of the small refiner temporary exemption through December 31, 2010 for all gasoline and diesel small refiners.

As described in the Final Panel Report, EPA early-on identified limitations on its authority to issue additional flexibility and exemptions to small refineries. In section 211(o)(9) Congress specifically addressed the issue of an extension of time for compliance for small refineries, temporarily exempting them from renewable fuel obligations through December 31, 2010. As discussed above, the statute also includes two specific provisions describing the basis and manner in which further extensions of this exemption can be provided. In the RFS1 rulemaking, EPA considered whether it should provide additional relief to the limited number of small refiners who were not covered by the small refinery provision, by providing them a temporary exemption consistent with that provided by Congress for small refineries. EPA exercised its discretion under section 211(o)(3) and provided such relief. Thus, in RFS1, EPA did not modify the relief provided by Congress for small refineries, but did exercise its discretion to provide the same relief specified by statute to a few additional parties.

In RFS2 we are faced with a different issue—the extent to which EPA should provide additional relief to small refineries beyond the relief specified by statute, and whether it should provide such further relief to small refiners as well. There is considerable overlap between entities that are small refineries and those that are small refiners. Providing additional relief just to small refiners would, therefore, also extend additional relief to at least a number of small refineries. Congress spoke directly to the relief that EPA may provide for small refineries, including those small refineries operated by small refiners, and limited that relief to a blanket exemption through December 31, 2010, with additional extensions if the criteria specified by

Congress are met. EPA believes that an additional or different extension, relying on a more general provision in section 211(o)(3) would be inconsistent with Congressional intent. Further, we do not believe that the statute allows us the discretion to give relief to small refiners only—as this would result in a subset of small refineries (those that also qualify as small refiners) receiving relief that is greater than the relief already given to all small refineries under EISA.

EPA also notes that the criteria specified by statute for providing a further compliance extension to small refineries is a demonstration of "disproportionate economic hardship." The statute provides that such hardship can be identified through the DOE study, or in individual petitions submitted to the Agency. However, the DOE study has concluded that no disproportionate economic hardship exists, at least under current conditions and for the foreseeable future under RFS2. Therefore, absent further information that may be provided through the petition process, there does not currently appear to be a basis under the statute for granting further compliance extensions to small refineries. If DOE revises its study and comes to a different conclusion, EPA can revisit this issue.

During the development of this final rule, we again evaluated the various options recommended by the Panel, the legality of offering an extension of the exemption to small refiners only, and also comments on the proposed rule. Specifically in the case of an extension of the exemption for small refiners, we also consulted the small refinery study prepared by DOE, as the statute directs us to use this as a basis for providing an additional two year exemption. As discussed in Section III.E of the preamble to the final rule, we do not believe that we can provide an extension of the exemption considering the outcome of the DOE small refinery study, which did not find that there was a disproportionate economic hardship. Further, we do not believe that the statute allows us the discretion to give relief to a subset of small refineries (those that also qualify as small refiners) that is greater than the relief already given to all small refineries under EPAct. However, it is important to recognize that the 211(o)(9) small refinery provision does allow for extensions beyond December 31, 2010, as discussed in preamble Section III.E.2. Thus, refiners may apply for individual hardship relief.

7.4.4 Phase-in

<u>Panel Recommendations</u>

Small refiner SERs suggested that a phase-in of the obligations applicable to small refiners would be beneficial for compliance, such that small refiners would comply by gradually meeting the standards on an incremental basis over a period of time, after which point they would comply fully with the RFS2 standards, EPA has serious concerns about its authority to allow for such a phase-in of the standards. CAA section 211(o)(3)(B) states that the renewable fuel obligation shall "consist of a single applicable percentage that applies to all categories of persons specified" as obligated parties. This kind of phase-in approach would result in different applicable percentages being applied to different obligated parties. Further, such a phase-in approach would provide more relief to small refineries operated by small refiners than that provided under the small refinery provision. Thus the Panel recommended that EPA should invite comment on a phase-in, but not propose such a provision.

What We Proposed and Public Comments Received on the NPRM

While we did not propose it, we did request comment on the concept of a phase-in for small refiners only. Specifically, we requested comments on a phase-in for some or all of the applicable standards for small refiners.

With respect to our request for comments on the concept of a phase-in of the RFS standards for small refiners, some commenters stated that they believe that EPA has the ability to consider a phase-in of the standards for small refiners. One commenter suggested that a temporary phase-in could help lessen the burden of regulation on small entities and promote compliance. Another commenter stated that it believes EPA's legal concerns regarding a phase-in are unsustainable considering EPA's past exercises of discretion under the RFS1 program and with the discretion afforded to EPA under section 211(o) of the CAA.

What We're Finalizing

After considering the comments on this issue, EPA continues to believe that allowing a phase-in of regulatory requirements for small refineries and/or small refiners would be inconsistent with the statute, for the reasons mentioned above. Any individual entities that are experiencing hardship that could justify a phase-in of the standards have the ability to petition EPA for individualized relief. Therefore we are not including a phase-in of standards for small refiners in the final rule.

7.4.5 RIN-related Flexibilities

Panel Recommendations

The small refiner SERs requested that the proposed rule contain provisions for small refiners related to the RIN system, such as flexibilities in the RIN rollover cap percentage and allowing all small refiners to use RINs interchangeably. In the RFS1 program, EPA allows for 20% of a previous year's RINs to be "rolled over" and used for compliance in the following year. We noted during the Panel process that a provision to allow for flexibilities in the rollover cap could include a higher RIN rollover cap for small refiners for some period of time or for at least some of the four standards. Further, we noted our belief that since the concept of a rollover cap was not mandated by section 211(o), EPA believes that there may be an opportunity to provide appropriate flexibility in this area to small refiners under the RFS2 program but only if it is determined in the DOE small refinery study that there is a disproportionate effect warranting relief. The Panel recommended that EPA request comment on increasing the RIN rollover cap percentage for small refiners, and further that EPA should request comment on an appropriate level of that percentage. The Panel also recommended that EPA invite comment on allowing RINs to be used interchangeably for small refiners, but not propose this concept because under this approach small refiners would arguably be subject to a different applicable percentage than other obligated parties.

What We Proposed and Public Comments Received on the NPRM

We proposed a change to the RIN rollover cap for small refiners only, and we requested comment on appropriate level to set the rollover cap for these entities. We also took comment on the concept of allowing RINs to be used interchangeably for small refiners only.

We also requested comment on the concept of RIN-related flexibilities for small refiners. In their comments on the proposed rule, one small refiner commented that, in regards to small refiners' concerns about RIN pricing and availability, there is no mechanism in the rule to address the possibility that the RIN market will not be viable. The commenter further suggested that more "durable" RINs are needed for small refiners that can be carried over from year to year, to alleviate some of the potentially market volatility for renewable fuels. Another commenter suggested that RINs should be interchangeable for small refiners, or alternatively, some mechanism should be implemented to ensure that RIN prices are affordable for small refiners. Further, with regard to interchangeable RINs, one commenter stated that small refiners do not have the staff or systems to manage and account for four different categories of RINs and rural small refiners will suffer economic hardship and disadvantage because of the unavailability of biofuels. The commenter also requested an increase in the rollover cap to 50% for small refiners.

What We're Finalizing

We are not finalizing RIN-related provisions in today's action. As highlighted in the NPRM, we continue to believe that the concept of interchangeable RINs for small refiners only fails to require the four different standards mandated by Congress (e.g., conventional biofuel could not be used instead of cellulosic biofuel or biomass-based diesel). Further, given the findings from the DOE study, if small refineries and small refiners do not face disproportionate economic hardship, then we do not believe that we have the basis for granting such additional relief beyond what Congress already provided. Thus, small refiners will be held to the same RIN rollover cap as other obligated parties.

7.4.6 Program Review

Panel Recommendations

During the SBREFA process, SERs raised concerns over uncertainty with acquiring RINs, and the potential pricing of RINs. They commented that an annual program review would be beneficial to small refiners as it could provide information about the RIN system. EPA raised the concern that this could lead to some redundancy since EPA is required to publish a notice of the applicable RFS standards in the Federal Register annually, and that this annual process will inevitably include an evaluation of the projected availability of renewable fuels. Nevertheless, the SBA and OMB Panel members stated that they believe that a program review could be helpful to small entities in providing them some insight to the RFS program's progress and alleviate some uncertainty regarding the RIN system. As EPA will be publishing a Federal Register notice annually, the Panel recommended that EPA include an update of RIN system progress (e.g., RIN trading, RIN availability, etc.) in this notice and that the results of this evaluation be considered in any request for case-by-case hardship relief.

What We Proposed and Public Comments Received on the NPRM

In the NPRM, we proposed that we would include information to help inform industry about the RIN system in the annual notice of the RFS standards that EPA must publish in the Federal Register. We also proposed that information from the annual Production Outlook Reports that producers and importers must submit to EPA, as well as information required in EMTS reports, could be used in the annual Federal Register notice to update RIN system progress.

A group of commenters stated that they support the concept of an annual review. They commented that EPA should include a review of the RIN system in annual review procedures, and further suggested that EPA invite small refiner participation in the development of the review process. (For more information on the comments received on Production Outlook Reports specifically, please see Chapter 3 of the Summary and Analysis of Comments.)

What We're Finalizing

Based on comments received on the proposed rule, we believe that such information could be helpful to industry, especially to small businesses to help aid the proper functioning of the RIN market, especially in the first years of the program. However, during the development of the final rule, it became evident that there could be instances where we would want to report out RIN system information on a more frequent basis than just once a year. Thus, we are finalizing that we will report out elements of RIN system progress; but such information will be reported via other means (e.g., the RFS website (www.epa.gov/otaq/renewablefuels/index.htm), EMTS homepage, etc.). Additionally, we will also publish annual summaries of the Production Outlook Reports.

7.4.7 Extensions of the Temporary Exemption Based on Disproportionate Economic Hardship

Panel Recommendations

While SERs did not specifically comment on the concept of hardship provisions for the upcoming proposal, the Panel noted that under CAA section 211(o)(9)(B) small refineries may petition EPA for case-by-case extensions of the small refinery temporary exemption on the basis of disproportionate economic hardship. Refiners may petition EPA for this case-by-case hardship relief at any time.

The Panel recommended that EPA propose in the RFS2 program a case-by-case hardship provision for small refineries similar to that provided at 40 CFR 80.1141(e)(1). The Panel also recommended that EPA propose a case-by-case hardship provision for small refiners that do not operate small refineries that is comparable to that provided for small refineries under section 211(o)(9)(B), using its discretion under CAA section 211(o)(3)(B). This would apply if EPA does not adopt an automatic extension for small refiners, and would allow those small refiners that do not operate small refineries to apply for the same kind of extension as a small refinery. The Panel recommended that EPA take into consideration the results of the annual update of RIN system progress and the DOE small refinery study in assessing such hardship applications.

What We Proposed and Public Comments Received on the NPRM

We did propose hardship provisions for small refineries and small refiners in the RFS2 proposal program similar to those provided at 40 CFR 80.1141 and 80.1142. We propose to extend the temporary exemption for at least two years for any small refinery that DOE's small refinery study determines would face disproportionate economic hardship in meeting the requirements of the RFS2 program (per CAA section 211(o)(9)(A)(ii)(I)), and that any small refinery could apply for a case-by-case hardship at any time on the basis of disproportionate economic hardship per section 211(o)(9)(B). For those small refiners that do not operate small refineries, we also proposed the same case-by-case hardship provision using our discretion under CAA section 211(o)(3)(B).

While the findings from DOE's small refinery study indicate that no small refineries would be subject to disproportionate economic hardship under the proposed RFS2 program and that the small refinery exemption should not be extended beyond December 31, 2010, DOE noted in the study that if circumstances were to change and/or the RIN market became non-competitive or illiquid, individual small refineries have the ability to petition EPA for an extension of their small refinery exemption.

Two commenters noted that an economic hardship provision was included in EPAct, and commented that any extension of the exemption past 2010 should be limited to such cases, and only to the specific small refinery (not small refiner) that has petitioned for such an extension. A group of commenters also stated that they believe that small refiners that may be subject to disproportionate hardship should be granted a two-year extension of the existing RFS1 temporary exemption. The commenters further suggested that EPA tailor the case-by-case hardship provisions to include a general hardship exemption of up to five years for any and all small refiners meeting certain specified hardship criteria. The commenters stated that such criteria should be developed with small refiner participation.

What We're Finalizing

We believe that these avenues of relief can and should be fully explored by small refiners who are covered by the small refinery provision. In addition, we believe that it is appropriate to allow petitions to EPA for an extension of the temporary exemption based on disproportionate economic hardship for those small refiners who are not covered by the small refinery provision (again, per our discretion under section 211(o)(3)(B)); this would ensure that all small refiners have the same relief available to them as small refineries do. Thus, we are finalizing a hardship provision for small refineries in the RFS2 program, that any small refinery may apply for a case-by-case hardship at any time on the basis of disproportionate economic hardship per CAA section 211(o)(9)(B). We are also finalizing a case-by-case hardship provision for those small refiners that do not operate small refineries (section 80.1442(h)) using our discretion under CAA section 211(o)(3)(B). This provision will allow those small refiners that do not operate small refineries to apply for the same kind of extension as a small refinery. In evaluating applications for this hardship provision EPA will take into consideration information gathered from annual reports and RIN system progress updates, as recommended by the SBAR Panel.

7.5 Reporting, Recordkeeping, and Other Compliance Requirements

Registration, reporting, and recordkeeping are necessary to track compliance with the RFS standards and transactions involving RINs. As discussed in Sections II.J and III.A of the preamble to the final rule, the compliance requirements under the RFS2 rule are in many ways similar to those required under the RFS1 rule, with some modifications (e.g., those to account for the new requirements of EISA). New provisions being finalized in today's action include the new EPA Moderated Transaction System (EMTS) to aid industry in their reporting and ensure validity of RINs in the marketplace. EMTS allows for "real-time" reporting of RIN generation transactions, and the ability for small blenders to "delegate" their RIN-separation responsibilities to the party directly upstream. Please see Sections II and III of the final preamble for more detailed information on these and other registration, recordkeeping, reporting, and compliance requirements of the final rule.

7.6 Related Federal Rules

We are aware of a few other current or proposed Federal rules that are related to this rule. The primary related federal rules are: the first Renewable Fuel Standard (RFS1) rule (*72 FR 23900, May 1, 2007*), the RFS1 Technical Amendment Direct Final Rulemaking (*73 FR 57248, October 2, 2008*), and Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder (proposed rule: *74 FR 44442, August 28, 2009*; final rule: *signed December 22, 2009*).

7.7 Conclusions

Based on our outreach, fact-finding, and analysis of the potential impacts of our regulations on small businesses, we were able to estimate annual costs, and thus use this information to complete a preliminary screening analysis. To perform this analysis, we used a cost-to-sales ratio test (a ratio of the estimated annualized compliance costs to the value of sales per company). Costs were analyzed using average gasoline + diesel costs for the RFS2 program referenced to the AEO 2007 reference case for 2022, and also for 2010 and 2012.

For 2022, the cost-to-sales test indicated that all 17 small refiners would be affected at less than 1 percent of their sales (i.e., the estimated costs of compliance with the rule would be less than 1 percent, of their sales), and that these costs would actually be negative (or, a cost savings)—ranging from -3.15% to -0.94%. The gasoline and diesel costs for the 2022 scenario were estimated to be -2.35 and -12.07 cents per gallon, respectively.

Under the 2010 and 2012 scenarios, all small refiners were still affected at less than 1 percent, however the costs were no longer negative. For 2010, costs ranged from 0.24 to 0.84 percent of small refiners' sales, with estimated gasoline and diesel costs of 0.29 and 1.29 cents per gallon, respectively. For 2012, the costs were relatively similar for all small refiners—at 0.24-0.25 percent of their sales. The gasoline and diesel costs for 2012 were estimated to be 0.51 and 0.58 cents per gallon, respectively (the similarity in small refiners' costs-to-sales was due to this similarity in the estimated gasoline and diesel costs). Thus, costs for small refiners are generally anticipated to be less than one percent of their sales, and are expected to decrease over time, ultimately resulting in a cost savings by 2022. Note that while we did analyze a 2010 scenario, small refiners would not be participating in the program during this time, as the small refiner temporary exemption runs through December 31, 2010.

The cost estimates for all 3 scenarios do include the current available subsidies for the blending of ethanol of 45 cents per gallon for ethanol and $1.00 per gallon for biodiesel/renewable diesel, and the $1.01 per gallon producer credit for cellulosic biofuel, which depress the true cost of these renewable fuels in the marketplace.

For a complete discussion of the costs of the RFS2 rulemaking please see Chapter 4 of this Regulatory Impact Analysis.

Appendix A: Biodiesel Effects on Heavy-Duty Highway Engines and Vehicles

Executive Summary

Due to the continuing interest in the use of biodiesel fuels, the Environmental Protection Agency (EPA) has conducted a comprehensive analysis of the emission impacts of biodiesel using publicly-available heavy-duty, in-use diesel chassis and engine exhaust emissions data.

We investigated the emission impacts on NOx, PM, HC, and CO of 20 volume percent biodiesel fuels produced from various animal- and plant-based feedstock materials tested under several cycles in this analysis. Average NOx emissions were found to increase 2.2%, while PM, HC, and CO were found to decrease 15.6%, 14.1%, and 13.8% respectively, for all test cycles run on 20 vol% soybean-based biodiesel fuel at a significance level of $P < 0.05$ (See Table ES-A).

Table ES-A.
Emission impacts for all cycles tested on 20 vol% soybean-based biodiesel fuel relative to an average base fuel

Emissions	Percent Change in Emissions
NOx	+2.2%
PM	-15.6%
HC	-14.1%
CO	-13.8%

These results are consistent with the exhaust emission impacts for heavy-duty, in-use diesel engines found in our 2002 Draft Technical Report, entitled "*A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*."

The current analysis also found that heavy-duty engine dynamometer data was statistically indistinguishable from heavy-duty chassis dynamometer data for NOx and HC at a significance level of $p < 0.05$. Likewise, results for Detroit Diesel Corporation (DDC) engines, used in many test programs, were found to be statistically similar to results for other engines for NOx, CO, and HC at a significance level of $p < 0.05$.

The results of the current analysis also point to a load-dependence of NOx emissions for heavy-duty highway engines and chasses. The difference in NOx emissions between our results here and those of other researchers appears to be attributable to an artifact of the selected test cycle profile. Analyzing the NOx emissions data as a function of load, as we do here -- as opposed to a particular test cycle profile -- reconciles the difference and supports the NOx emission-load-dependence hypothesis for heavy-duty highway engines and chasses posited by Sze *et al*. and corroborated by Eckerle *et al*.

A1. Introduction

We investigated the emission impacts on NOx, PM, CO, and HC of 20 volume percent (vol%) biodiesel fuels produced from various feedstock materials tested under several vehicle and engine test cycles. The data used in this analysis is comprised of data used in EPA's 2002 Draft Technical Report, entitled "*A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions Draft Technical Report*", hereafter referred to as the 2002 Draft Technical Report. Data from that report was supplemented with pertinent data sources published in the scientific and automotive literature between 2002 and 2007. The supplemental data was comprised of late model year engines, vehicles, and technology groups. A list of all data sources used in this analysis appears in the appendix to this document as does the 2002 Draft Technical Report.

The focus of the analysis proceeded from general to specific terms, through seven fuel-cycle combinations, summarized below. In Case 1, the most-general fuel-cycle combination, we examined all heavy-duty engine and chassis cycles run on plant- and animal-based biodiesel fuels; in Case 5a, 5b, and 5c, the most-specific fuel-cycle combinations, we examined heavy-duty engine and chassis data for light-, medium-, and heavy-duty cycles using soybean-based biodiesel. The latter analysis was designed to examine load-dependence of NOx emissions for heavy-duty highway engines and chasses first posited by EPA in 2007 (see Sze *et al.*). This research was further elucidated by Eckerle *et al*. While feedstock materials varied for the seven fuel-cycle combinations presented here, all analyses were conducted using 20 vol% biodiesel fuels.

A summary of fuel-cycle combinations used in the analysis appears below.

- Case 1: All cycles tested on plant-based (soybean, rapeseed/canola, and coconut) and animal-based (tallow, lard, and grease) biodiesel fuels,

- Case 2: All cycles tested on soybean-based biodiesel fuel,

- Case 3: FTP and UDDS cycles tested on soybean-based biodiesel fuel,

- Case 4: Detroit Diesel Corporation (DDC) and non-DDC engines tested on soybean-based biodiesel fuel,

- Case 5a: Engines and chasses tested on soybean-based biodiesel fuel run on light-duty cycles,

- Case 5b: Engines and chasses tested on soybean-based biodiesel fuel run on medium-duty cycles, and

- Case 5c: Engines and chasses tested on soybean-based biodiesel fuel run on heavy-duty cycles.

The results of the analysis of the seven fuel-cycle combinations appear in Section A3.2. The results of the analysis of the NOx emissions load-dependence appear in Section A3.3 and a discussion of the observed load-dependence impacts in the context of relevant literature and the 2002 Draft Technical Report appear in Section A3.4.

In the 2002 Draft Technical Report, we focused our analysis on data from heavy-duty highway engines, since this data was the most abundant in our database and since it was unclear to what extent testing on a chassis dynamometer might differ from testing on an engine dynamometer. However, some researchers criticized the conclusions of the report for its disproportionate reliance on engine data. These researchers argued that these engines may not behave in a manner indicative of the actual, in-use fleet or that chassis-generated data may be better-suited for NOx emissions testing.

Some researchers also criticized the conclusions of our 2002 Draft Technical Report, citing its disproportionate reliance on DDC engine data. These researchers argued that these engines may not behave in a manner indicative of the actual, in-use fleet as a whole. To help address these concerns, we supplemented the database for the 2002 Draft Technical Report with non-DDC engine data. In the current analysis, non-DDC engines represent 59.0% of all engines present in the supplemented database.

To investigate these concerns, we carried out an analysis to determine the compatibility of heavy-duty highway engine data with heavy-duty highway chassis data. Establishing compatibility between heavy-duty highway engine data and heavy-duty highway chassis data would allow us to make more-complete use of all emissions data in the database. In turn, this would allow us to perform more robust statistical analyses. The results of this engine and chassis data compatibility analysis are presented in Section A3.1. Section A2 contains a discussion of the data screening criteria and methodology used in this analysis.

A2. Data Screening and Methodology

The data used in this analysis is comprised of data initially used in our 2002 Draft Technical Report, supplemented by pertinent data published between 2002 and 2007. The supplemental data included late model year engines, vehicles, and technology groups. A list of data sources used in this analysis appears in the appendix to this document.

A criticism raised by the 2002 Draft Technical report was that its analysis relied too heavily upon data from early model year engines and that these engines may not behave in a manner indicative of the actual, in-use fleet as a whole. To help address this concern, we supplemented the existing database of over 800 observations with approximately 560 additional observations comprised of late model year engines, vehicle, and technology groups.

Candidate data were first screened to verify that they met EPA data QC/QA requirements as well as criteria consistent with the goals of the analysis before inclusion into the database (See Section II of the 2002 Draft Technical Report for a discussion of EPA data QC/QA considerations). New data meeting these criteria were entered into the database developed for the 2002 Draft Technical Report. These criteria are described in Section A2.1.

A2.1 Criteria for Selecting Data

Candidate data were screened to verify that they met criteria consistent with the goals of the analysis before inclusion into the database. For instance, the analysis was limited to No. 1 and No. 2 diesel fuel and related blends that can be used in typical heavy-duty diesel engines without engine modifications. As a result, all emulsions and non-biodiesel oxygenated blends with more than 20 vol% oxygenate were excluded from the final database used in the analysis. Also, synthetic fuels, such as those produced using the Fischer-Tropsch process, rather than refinery streams, were excluded from the final database.

We also limited this study to vehicles and engines that had already been sold commercially or had a high probability of being sold in the future. Vehicles and engines with experimental technologies that had no immediate plans for commercialization, such as those with innovative combustion chamber geometries, were excluded from the database. Likewise, single-cylinder research engines were excluded from consideration, even though the associated full-size parent engine might have been appropriately included in the database, had it been tested. Single-cylinder engines do not appear in heavy-duty applications. By definition, such engines have lower total horsepower and displacement, both of which may influence the way in which biodiesel impacts emissions.

The pairing of diesel and biodiesel fuels used in a particular study also played a role in determining if data from that study would be included in our analysis. For example, we excluded data from all studies that did not test at least two different biodiesel concentrations on the same engine, one of which could be 0 vol% biodiesel.

There were a number of instances in which data from one study was repeated in other studies. This might occur if the authors published the same dataset in multiple scientific journals to maximize exposure, or if the authors presented a previously-published set of data in a new publication for the purposes of comparing the two datasets. Such duplicative data was also excluded from our database.

Also, each prospective data source was screened to verify that it contained raw, not aggregated, data. In cases where raw data was not published in a study, attempts were made to obtain it from the study author(s). Raw data obtained from author(s) were included in our database after successful screening.

A2.2 Criteria for Selecting Test Cycles

We selected cycles which were representative of actual, in-use operating conditions. While the Federal Test Procedure (FTP) transient cycle most-closely reflects actual, in-use operating conditions, we included data from a number of other studies that used atypical test cycles which were adequately comprehensive in their number, selection of modes, and/or in their transient speed-load traces, so that the resulting emission measurements may still be informative.

Data collected under test cycles that were unique, contained only a single steady-state mode, or used two- or three-nonstandard modes for testing, were typically excluded from the database. Non-FTP/UDDS test cycles represented about 24 percent of all data in the database.

A total of eight different cycles, with two variants, representing a variety of load levels were included in our database. A description of the test cycles included in our analysis appears below.

• AVL 8-Mode Test – An eight-mode steady-state engine test procedure, designed to correlate with FTP cycle exhaust emission results. Only NOx emissions data generated by the AVL 8-Mode test was included in our database.

• Combined International Local Cycle and Commuter (CILCC) – A transient cycle developed by NREL for testing Class 4 to Class 6 vehicles. It is intended to simulate urban delivery driving conditions for heavy-duty vehicles.

• City-Suburban Heavy-Vehicle Cycle (CSHVC) – A transient cycle developed by West Virginia University. It is intended to simulate low-speed urban/ suburban driving conditions of heavy-duty vehicles and is punctuated with frequent stops.

• Freeway Cycle – A transient cycle intended to simulate four-lane highway driving conditions of heavy-duty vehicles, including entrance and exit ramps.

• Federal Test Procedure (FTP) – The heavy-duty transient cycle currently used by EPA for emission, certification, and other testing of heavy-duty on-road engines; the cycle most-closely reflects actual, in-use operating conditions and was developed to simulate a variety of heavy-duty truck and bus driving conditions in cities and on expressways.

• Highway Cycle (HWY) – A high-speed highway cruise cycle based on the Heavy Heavy-Duty Diesel Truck chassis cycle developed by the California Air Resources Board and previously used in the Coordinating Research Council E-55 program.

• Rowan University Composite School Bus Cycle (RUCSBC) – A school bus cycle developed by Rowan University.

• Urban Dynamometer Driving Schedule (UDDS) – A heavy-duty chassis dynamometer test. Our database includes data from the UDDS cycle and two variants simulating light (6,000 lbs) and heavy (28,000 lbs) test weight conditions.

The summary of the test cycles included in our analysis appears in Table A2-A.

Table A2-A. Test cycles included in this analysis

Test Cycle	Description	Duration
AVL 8	Eight-mode steady-state cycle	n/a
CILCC	Heavy-duty urban delivery cycle	53 min 12 sec
CSHVC	Heavy-duty city-suburb low-speed cycle	28 min 20 sec
Freeway	Heavy-duty highway cycle	27 min 20 sec
FTP	Heavy-duty engine certification cycle	20 min
HWY	High-speed cruise cycle from CRC E-55	12 min 40 sec
RUCSBC	School bus cycle	21 min 50 sec
UDDS	Heavy-duty chassis cycle	17 min 40 sec
UDDS 6k	UDDS variant based on EPA data	17 min 40 sec
UDDS 28k	UDDS variant based on CRC E-55 data	17 min 40 sec

A2.3 Criteria for Selecting Feedstock Materials

Biodiesel fuel can be produced from a wide variety of feedstock materials. While the studies that comprise our database included only a portion of the many feedstock materials possible, they do represent the most-common feedstock materials. The biodiesel feedstock materials found in our database and their percentages are listed in Table A2-B.

Table A2-B.
Biodiesel feedstock material observations in the database

Feedstock Materials	Number of Observations	Percentage of Observations
Soybean	556	77.1%
Rapeseed/Canola	95	13.2%
Grease*	42	5.8%
Tallow	19	2.6%
Coconut	6	0.8%
Lard	3	0.4%

* Includes high free fatty acid (HFFA) and low free fatty acid (LFFA)

Given the limited data available for some feedstock materials, we aggregated all biodiesel feedstock materials into three general categories: plant-based biodiesel, soybean-based biodiesel (a subset of plant-based biodiesel), and animal-based biodiesel (See Table A2-C for a listing of biodiesel feedstock materials aggregated into the categories used in our database).

Table A2-C.
Biodiesel feedstock materials aggregated into categories used in the database

Aggregated Feedstock Material Category	Number of Observations in Category
Plant-based	657
Soybean-based	556
Animal-based	64

A2.4 Overview of methodology

This section summarizes the statistical approach used in this analysis, which employed the SAS/STAT software procedure PROC MIXED. This procedure can treat some variables as fixed-effects and others as random-effects.

For instance, the NOx fixed-effect was expressed as a function of percent biodiesel (0 or 20 vol%), vehicle class (Class 1-2a or Class 2b-8), the interaction of percent biodiesel and vehicle class, test cell type (chassis test cell or engine test cell), and the interaction between test cell type and percent biodiesel. Each fixed-effect term is tested and removed if found not significant. Additional fixed-effect terms were added to the model when examining DDC and non-DDC engines. The random-effects examined were the test cell type and its interaction with percent biodiesel, test cycle, and the biodiesel source.

After creating the initial model, the distribution of mixed-model residuals are examined; residuals with absolute values greater than four standard deviations from a mean of 0 are considered outliers and removed from further consideration.

The final model evaluates the statistical significance of the difference between fuels containing 20 vol% biodiesel and the base fuel, containing no biodiesel. A significance criterion of $p < 0.05$ was used for all analysis. See Section II of the 2002 Draft Technical Report for additional discussion and derivations.

A3. Results

This section contains the results of the biodiesel emissions impact analysis described in Section A2. The results of the analysis of the compatibility of heavy-duty highway chassis and engine data appear in Section A3.1. The results of the analysis of the seven fuel-cycle combinations appear in Section A3.2, including the analysis of DDC engines versus non-DDC engines. The results of the analysis of the NOx emissions load-dependence appear in Section A3.3 and a discussion of the observed load-dependence impacts placed in the context of relevant literature and the 2002 Draft Technical Report appear in Section A3.4.

A3.1 Compatibility of Heavy-duty Highway Chassis and Engine Data

The primary objective of the analysis was to quantify the impacts of biodiesel fuels. One aspect of the analysis was to determine if heavy-duty highway emissions engine data in our database was comparable to heavy-duty highway chassis data for purposes of our statistical analysis. Much of the database (66%) consisted of heavy-duty highway engine data, with the balance of the data comprising heavy-duty highway chassis data. Establishing compatibility between engine and chassis data would allow us to make more complete use of all emissions data in the database, which, in turn, would allow us to perform more robust statistical analyses.

Moreover, some researchers criticized the conclusions of our 2002 Draft Technical Report, citing its disproportionate reliance on engine data. These researchers argued that these engines may not behave in a manner indicative of the actual, in-use fleet as a whole or that chassis-generated data might be better-suited for purposes of biodiesel emissions testing. To investigate these claims, we undertook an analysis to determine the compatibility of heavy-duty highway engine data with heavy-duty highway vehicle data.

Using a significance level of $p < 0.05$ for all statistical analysis, engine data was found to be statistically comparable to chassis data for NOx and CO emissions. This finding is supported by the research of NREL, whose examination of published data suggests that there exists no discrepancy between engine and vehicle testing data (See NREL Milestone 10.4). See Table A3-

A for a summary of fuel-cycle combinations for which heavy-duty highway engine data was statistically comparable to heavy-duty highway chassis data for regulated pollutants.

Table A3-A.
Fuel-cycle combinations for which heavy-duty highway engine data was statistically comparable to heavy-duty highway chassis data for regulated pollutants

		Regulated Pollutants			
		NOx	**PM**	**CO**	**HC**
Fuel-Cycles	Case 1	**x**			**x**
	Case 2	**x**			**x**
	Case 3	**x**			**x**
	Case 4	**x**			**x**
	Case 5a	**x**			**x**
	Case 5b	**x**			**x**
	Case 5c	**x**			**x**

x Denotes heavy-duty highway engine data that is statistically comparable to heavy-duty highway chassis data.

Emissions of PM and CO for heavy-duty highway engines and chasses were not found to be statistically comparable to each other for any of the seven fuel-cycle combinations. Based upon our experience with chassis test cells, it is difficult to accurately quantify PM exhaust emissions, as chassis-based testing is often deficient and non-standardized vis-à-vis 40CFR86-2007 and 40CFR1065 for test specification and test equipment, respectively. Deficiencies associated with non-standardized chassis test cells may produce high test-to-test variability. Likewise, CO emissions are difficult to accurately quantify on both heavy-duty engine and chassis test cells and may also produce high test-to-test variability.

High test-to-test variability curtails the ability to accurately capture and discern small differences in exhaust emissions, particularly PM and CO exhaust emissions. This variability may help to explain why engine and chassis data are not comparable in our analysis for CO and PM emissions.

In cases where heavy-duty highway engine data is statistically comparable to heavy-duty highway chassis data, engine and chassis data are pooled to produce the appropriate statistic. In other cases, we believe that the use of engine data alone results in a more-representative statistic, which we report here. The results for the following analysis reflect this approach.

A3.2 Fuel-cycle Results

Seven fuel-cycle combinations were identified for our statistical analysis, ranging from a general case, combining testing of all test cycles and all cycles and on all biodiesel fuel feedstock materials to cycles aggregated into light-, medium-, and heavy-duty test cycle categories, which were run exclusively on 20 vol% soybean-based biodiesel fuel. Heavy-duty highway engine and chassis emissions data were statistically comparable for NOx and HC and were subsequently pooled for our analysis. Heavy-duty highway engine and chassis emissions data were not statistically comparable for PM and CO, so only engine results are presented here. The results for each of the seven fuel-cycle combinations appear below. All results presented are statistically significant at a significance level of $p < 0.05$.

<u>Case 1: All cycles tested on all biodiesel fuels</u>

Our first fuel-cycle combination examined data collected on all cycles included in the database and from all vehicles and engines tested on both plant-based (soybean, rapeseed/canola and coconut) and animal-based (tallow, lard, and grease) biodiesel fuels (See Table A2-A for a listing of all cycles used in the Case 1, Case 2, and Case 4 analyses).

For plant-based and animal-based biodiesel fuels, NOx emissions were found to increase a statistically-significant 2.0% relative to the base fuel, whereas, PM, CO, and HC emissions were found to decrease by 13.6%, 13.5%, and 18.7%, respectively, relative to the base fuel.

<u>Case 2: All cycles tested on soybean-based biodiesel fuels</u>

Our second fuel-cycle combination examined all cycles specified in Case 1, but only involved vehicles and engines tested on soybean-based biodiesel fuels.

For soybean-based biodiesel, NOx emissions were found to increase by 2.2%, whereas PM, CO, and HC emissions were found to decrease by 15.6%, 13.8%, and 14.1%%, respectively, relative to the base fuel. Case 1 and Case 2 differ in their fuel composition. The biodiesel tested in Case 1 is composed of 20 vol% animal- and plant-based biodiesel, whereas in Case 2, the fuel is composed of 20 vol% soybean-based biodiesel only. The results suggest that the removal of animal-based and/or rapeseed/canola/coconut-based biodiesel fuel feedstock materials may have a slight impact on some exhaust emissions. Increases in emissions of 0.2 %, 2.0%, and 0.3% are observed for NOx, PM, and CO, respectively, relative to a soybean-based biodiesel discussed in Case 2. HC emissions decrease by 4.6% relative to a soybean-based biodiesel.

Several hypotheses have been advanced by researchers in an attempt to help explain the differences in exhaust emissions between plant-based and animal-based biodiesel feedstock materials (See Graboski *et al*. and Goetz); these are, however, outside the scope of the current analysis and are not discussed here.

<u>Case 3: FTP and UDDS cycles tested on soybean-based biodiesel fuels</u>

Our third fuel-cycle combination examined only engines and vehicles tested on soybean-based biodiesel fuel over only the FTP and UDDS cycles. Together, FTP and UDDS cycles comprise 76% of the database observations.

For soybean-based biodiesel, NOx emissions were found to increase by 3.2%, whereas PM, CO, and HC emissions were found to decrease by 15.6%, 15.9%, and 13.7%, respectively, relative to the base fuel.

The results of this analysis suggest that the emission impacts associated with heavy-duty highway engines and chasses tested on 20 vol% soybean-based biodiesel and run on FTP/UDDS cycles produce an increase in exhaust emissions of 1.0% for NOx and 2.1% for CO, relative to all engine and chassis cycles run on the same fuels. HC emissions decrease by 0.4% relative to all engine and chassis cycles and PM emissions appear to be relatively unaffected. These results were statistically significant at a significance level of $p < 0.05$.

As the FTP and UDDS cycles may more-closely represent actual, in-use operating conditions encountered by heavy-duty highway engines and vehicles, it is possible that the Case 3 results may be a better indicator of actual, in-use biodiesel emissions impacts.

Case 4: DDC vs. non-DDC engines tested on soybean-based biodiesel fuels

Our fourth fuel-cycle combination separately examined DDC and non-DDC engines tested on the cycles specified in Case 1 and Case 2 using soybean-based biodiesel fuel.

Our analysis found that DDC heavy-duty engine data was statistically comparable to non-DDC heavy-duty engine data for NOx, CO, and HC emissions at a significance level of $p < 0.05$. DDC heavy-duty engines and non-DDC heavy-duty engines did not behave in a statistically similar manner for PM emissions, however. In this regard, the results of our analysis suggest that DDC heavy-duty engines behave in the same manner in which non-DDC heavy-duty engines behave in our database for NOx, CO, and HC emissions. As such, this finding should help alleviate earlier concerns that the disproportionate representation of DDC engines may produce results which are not indicative of the database as a whole or the in-use fleet.

Case 5a: Light-duty cycles tested on soybean-based biodiesel fuels

Our fifth fuel-cycle combination examined heavy-duty engine and chassis data for light-duty cycles specified in Table A3-B and tested on soybean-based biodiesel fuel.

For soybean-based biodiesel tested on light-duty cycles, NOx, PM, CO, and HC emissions were found to decrease by 1.0%, 19.0%, 9.9%, and 14.2% respectively, relative to the base fuel.

Table A3-B. Cycle composition by case

Case Number	Case Description	Individual Cycles
Case 5a	Light-duty cycles	CILCC CSHVC UDDS6k
Case 5b	Medium-duty cycles	AVL8 (NOx) Freeway FTP RUCSBC UDDS UDDS28k
Case 5c	Heavy-duty cycles	HWY55

Case 5b: Medium-duty cycles tested on soybean-based biodiesel fuels

Our sixth fuel-cycle combination examined heavy-duty engine and chassis data for medium-duty cycles specified in Table A3-B and tested on soybean-based biodiesel fuel.

For soybean-based biodiesel tested on medium-duty cycles, NOx emissions were found to increase by 2.5%, relative to the base fuel, whereas PM, CO, and HC emissions were found to decrease by 19.0%, 14.0%, and 14.2%, and respectively, relative to the base fuel.

Case 5c: Heavy-duty cycles tested on soybean-based biodiesel fuels

Our seventh fuel-cycle combination examined heavy-duty engine and chassis data for heavy-duty cycles specified in Table A3-B and tested on soybean-based biodiesel fuel.

For soybean-based biodiesel tested on heavy-duty cycles, NOx emissions were found to increase by 5.1%, relative to the base fuel, whereas PM, CO, and HC emissions were found to decrease by 32.6%, 22.0%, and 14.2%, respectively, relative to the base fuel. Unlike Case 5a and 5b, the PM emissions results were significant and greater than those of the light-duty and medium-duty cases. A summary of these results appears in Table A3-C.

Table A3-C.
Summary of emissions results for seven fuel-cycle combinations for heavy-duty highway engines and chasses

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="4">Regulated Pollutants</th></tr>
<tr><th>NOx</th><th>PM*</th><th>CO*</th><th>HC</th></tr>
<tr><th rowspan="7">Fuel-Cycles</th><td>Case 1</td><td>+2.0%</td><td>-13.6%</td><td>-13.5%+</td><td>-18.7%</td></tr>
<tr><td>Case 2</td><td>+2.2%</td><td>-15.6%</td><td>-13.8%</td><td>-14.1%</td></tr>
<tr><td>Case 3</td><td>+3.2%</td><td>-15.6%</td><td>-15.9%</td><td>-13.7%</td></tr>
<tr><td>Case 4</td><td>+2.4%</td><td>-16.9%</td><td>-13.9%</td><td>-14.3%</td></tr>
<tr><td>Case 5a</td><td>-1.0%</td><td rowspan="2">-19.0%</td><td>-9.9%</td><td rowspan="3">-14.2%</td></tr>
<tr><td>Case 5b</td><td>+2.5%</td><td>-14.0%</td></tr>
<tr><td>Case 5c</td><td>+5.1%</td><td>-32.6%</td><td>-22.0%</td></tr>
</table>

* Only engine data.
+ Not significant.

A3.3 Load-dependent Emissions Impacts

We initially identified the load-dependence of NOx emissions in heavy-duty highway engines in 2007 (See Sze *et al*.) and these results were later corroborated by Eckerle *et al*. The results of Sze *et al*. and Eckerle *et al*. were based largely upon new engine and chassis studies (as well as modeling efforts), which were aimed specifically at examining the load-dependent NOx emissions phenomenon.

In the current research, however, our work is retrospective insofar as we examined data from a broad array of pre-existing studies, none of which were designed to examine the load-dependent NOx emissions impacts. As such, this analysis occasionally suffers from the experimental design limitations associated with the pre-existing studies. One such limitation is the use of test cycles which do not realistically reflect actual, in-use operating conditions. Such data can skew results and obscure evidence of the load-dependence of NOx emissions. Such a situation is discussed in Case 5a.

<u>Case 5a, 5b, and 5c: Load-dependent emissions impact on NOx</u>

The load-dependence of NOx emissions observed in this analysis is apparent when comparing Case 5a (light-load cycles) to Case 5b (medium-load cycles) to Case 5c (heavy-load cycles). However, results for the light-load conditions in Case 5a may not be representative of in-use vehicle operation.

<u>Case 5a: Confounding effects of lightly-loaded conditions</u>

The load-dependence of NOx emissions evident in the research of Sze *et al*. and Eckerle *et al*. was based upon medium- and heavy-duty cycles, not lightly-loaded cycles as in Case 5a.

We believe that our current findings for NOx emissions under lightly-loaded conditions may not be representative of the operating conditions typically encountered in actual, in-use fleet operations. As in-use heavy-duty highway engines and vehicles do not typically operate under the lightly-loaded conditions encountered in the cycles which comprise our light-duty category, the practical significance of the NOx emissions results for Case 5a is questionable.

Further, the NOx emissions results for Case 5a are also suspect when compared to Cases 1-4 and 5b-5c, all of which indicate that there is a statistically-significant increase in NOx emissions of between 2.0% and 5.1%.

As such, we place greater significance on the results obtained under medium- (Case 5b) and heavy-load (Case 5c) conditions, since they more-accurately mirror typical, in-use fleet operations and, as a result, provide a more realistic representation of operating conditions encountered in-use.

<u>Case 5b vs. Case 5c: Load-dependent NOx emission impacts</u>

Since the medium-loading conditions associated with these cycles are typical of actual, in-use fleet operations, these cycles provide a more realistic representation of operating conditions encountered by actual fleet usage. As such, we place greater significance on these results.

The difference in NOx emissions between our results here and those of other researchers appears to be attributable to an artifact of the selected test cycle profile. Analyzing the NOx emissions data as a function of load, as we do here -- as opposed to a particular test cycle profile -- reconciles the difference and supports the NOx emission-load-dependence hypothesis for heavy-duty highway engine and chasses posited by Sze *et al*. and corroborated by Eckerle *et al*. The discussion of load-dependent NOx emission impacts in the context of our research appears in Section A3.4.

A3.4 Relevant Studies

We initially identified the load-dependence of NOx emissions in heavy-duty highway engines in 2007 (See Sze *et al*.) and these results were later corroborated by Eckerle *et al*. The results of Sze *et al*. and Eckerle *et al*. were based largely upon new engine and chassis studies (as well as modeling efforts), which were aimed specifically at examining the load-dependent NOx emissions phenomenon.

In the current research, however, our work is retrospective insofar as we examined data from a broad array of pre-existing studies, none of which were designed to examine the load-dependent NOx emissions impacts. As such, this analysis occasionally suffers from the experimental design limitations associated with the pre-existing studies. One such limitation is the use of test cycles which do not realistically reflect actual, in-use operating conditions. Such data can skew results and obscure evidence of the load-dependence of NOx emissions. Such a situation is discussed in Case 5a.

2002 Draft Technical Report

In 2002, the EPA conducted a comprehensive analysis of the emission impacts of biodiesel using publicly available data. Entitled "*A Comprehensive Analysis of Biodiesel Emissions Impacts on Exhaust Emissions*," the 2002 Draft Technical Report made use of statistical regression analysis to correlate the concentration of biodiesel in conventional diesel fuel with changes in regulated and unregulated pollutants for heavy-duty highway engines.

Figure A3-A presents basic emission correlations for NOx, PM, CO, and HC developed in the 2002 Draft Technical Report as a function of soybean-based biodiesel concentration. Table A3-D presents results specifically for 20 vol% soybean-based biodiesel.

Figure A3-A.
Emission impacts from the 2002 Draft Technical Report by percent biodiesel content for soybean-based biodiesel added to an average base fuel

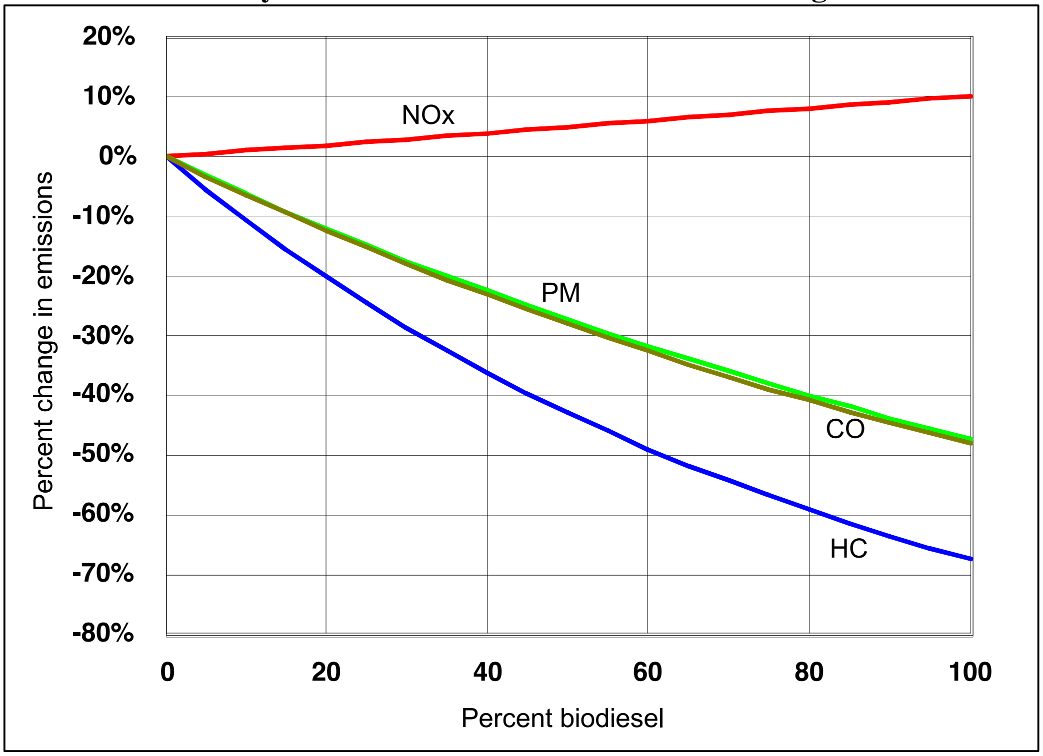
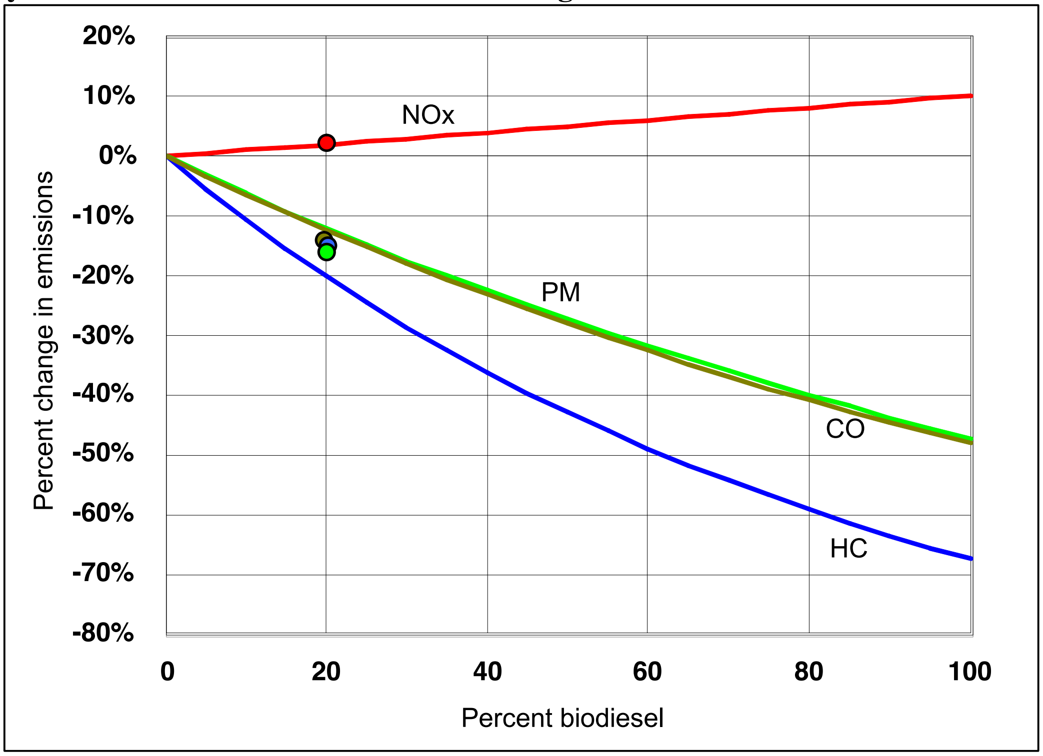


Table A3-D.
Emission impacts from the 2002 Draft Technical Report for 20 vol% soybean-based biodiesel added to an average base fuel

Emissions	Percent Change in Emissions
NOx	+2.0%
PM	-10.1%
HC	-21.1%
CO	-11.0%

We found that the results of the current analysis, which examined heavy-duty highway engine and chassis data, are consistent with the findings of our 2002 Draft Technical Report, which examined heavy-duty highway engine data only. Compared to the 2002 Draft Technical Report, NOx emissions were found to increase 2.2% while PM, HC, and CO emissions were found to decrease by 15.6%, 14.1%, and 13.8%, respectively, in the current study. These are shown in Figure A3-B as points overlaid on the results of the 2002 Draft Technical Report.

Figure A3-B.
Emission impacts from the 2002 Draft Technical Report by percent biodiesel content for soybean-based biodiesel added to an average base fuel with new results overlaid

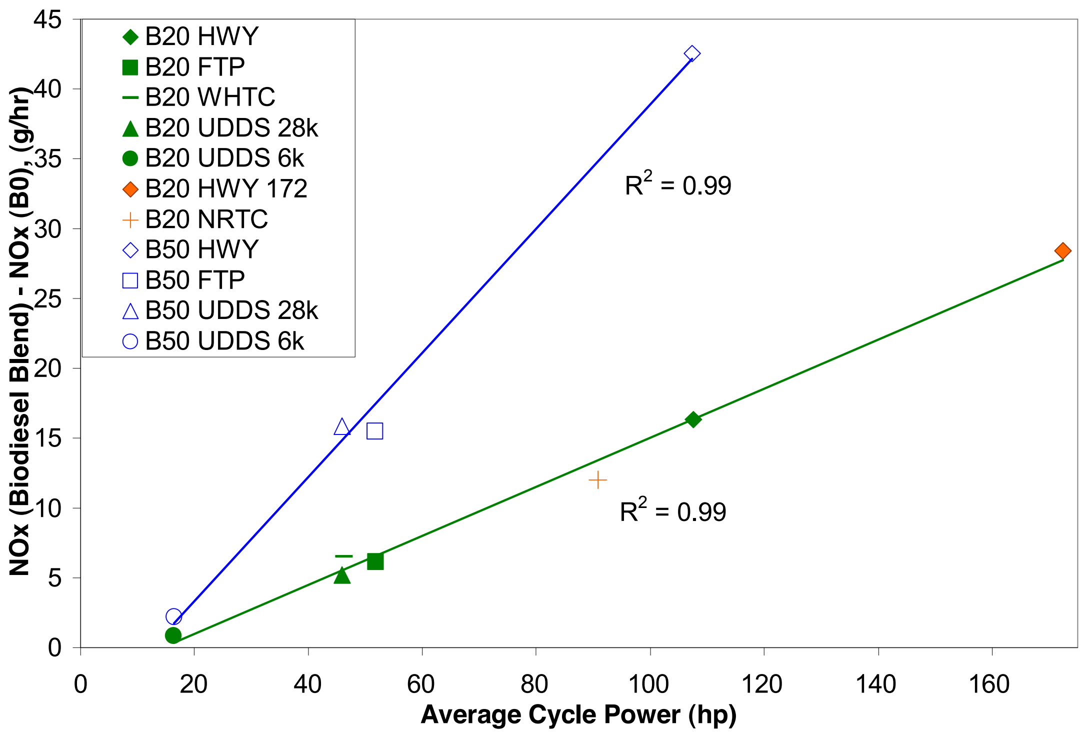


SAE paper by Sze et al.

Sze *et al*. conducted a series of paired fuel tests comparing certification-grade highway diesel fuels with 5 to 50 vol% soybean-based biodiesel blends. Each fuel pair was tested for up to seven transient cycles representing various load conditions, using a 2006 model year Cummins ISB compression ignition engine.

The authors concluded that biodiesel NOx impact on the test engine is directly proportional to average cycle power or fuel consumption and biodiesel content (See Figure A3-C).

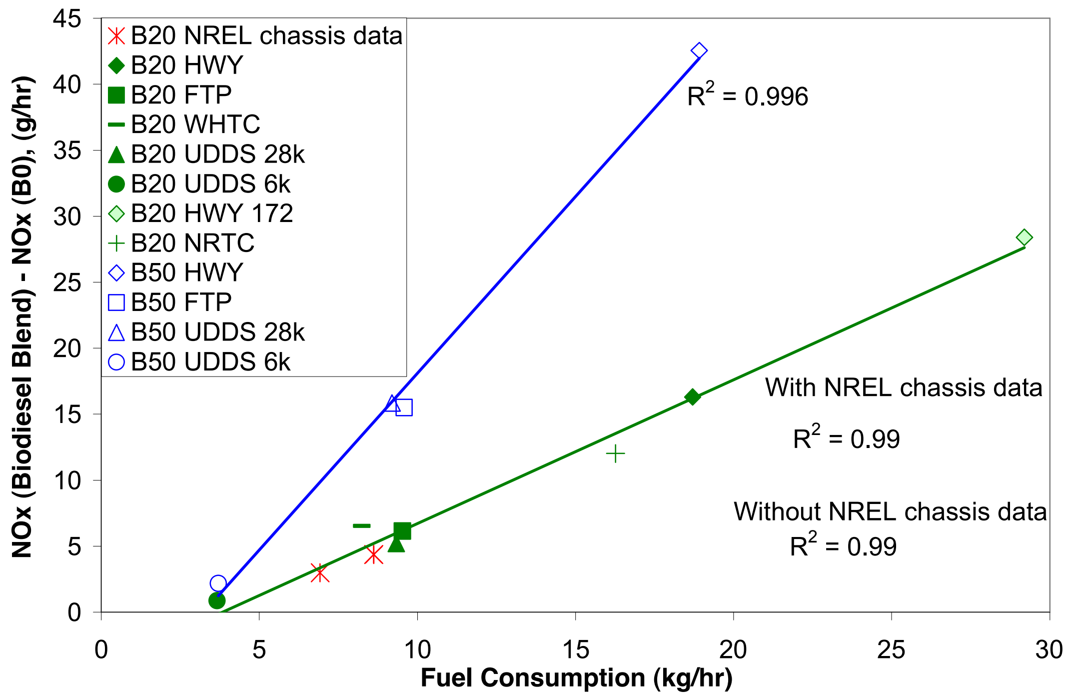
Figure A3-C.
NOx emissions for 20 vol% and 50 vol% soybean-based biodiesel fuel versus average cycle power for various heavy-duty highway engine and chassis cycles



Except for the most lightly-loaded cycle, the results show statistically significant differences in NOx emissions for all fuel pairs. The average NOx emissions due to biodiesel were found to increase over each cycle, ranging from 0.9 to 6.6% for 20 vol% and 2.2 to 17.2% for 50 vol% biodiesel fuels. The load-dependence of NOx emissions observed by Sze *et al*. is consistent with the findings presented in this report for Cases 5a, 5b, and 5c as well as those of Eckerle *et al*.

To further elucidate the load-dependent nature of NOx emissions, Sze *et al*. reanalyzed chassis-generated NOx emissions data from NREL as a function of fuel consumption (a surrogate for average cycle power) and found it to be in close agreement with EPA engine test data. This is depicted in Figure A3-D. Data from NREL using the same engines tested instead on a chassis dynamometer are also shown in the figure and follow the same trend, with an R^2 = 0.99 with and without the inclusion of the NREL dataset.

Figure A3-D.
NOx emissions for 20 vol% soybean-based biodiesel fuel versus average cycle power for various heavy-duty highway engine and chassis cycles, including NREL chassis testing data



SAE paper by Eckerle et al.

The load-dependence of NOx emissions was also examined by Eckerle *et al*., who generated engine data using 20 vol% soybean-based biodiesel to calibrate chemical kinetic models. These models were used to examine NOx production during the combustion process. The authors concluded that the NOx effect associated with burning biodiesel blends over a duty cycle depends, in part, on the duty cycle average power and that higher duty cycle average power corresponded to larger increases in NOx emissions.

References

Studies included in database
Aako P. *et al.*, "Emission Performance of Selected Biodiesel Fuels - VTT's Contribution" Research Report ENE/33/2000, October 2000

Alam M. *et al.*, "Combustion and Emissions Performance of Low Sulfur, Ultra Low Sulfur and Biodiesel Blends in a DI Diesel Engine," SAE paper no. 2004-01-3024

Bouché, T., M. Hinz, R. Pitterman, "Optimising Tractor CI Engines for Biodiesel Operation," SAE paper no. 2000-01-1969

Callahan, T.J., C.A. Sharp, "Evaluation of Methyl Soyate/Diesel Fuel Blends as a Fuel for Diesel Engines," Southwest Research Institute Final Report to the American Biofuels Association, December 1993

Clark, N.N., C.M. Atkinson, G.J. Thompson, R.D. Nine, "Transient Emissions Comparisons of Alternative Compression Ignition Fuels," SAE paper no. 1999-01-1117

Clark N. N. *et al.*, "Class 8 Truck Emission Testing: Effects of Test Cycles and Data on Biodiesel Operation," ASAE, 1999, 42(5), 1211-1219

Durbin, T.D., J.R. Collins, J.M. Norbeck, M.R. Smith, "Evaluation of the Effects of Alternative Diesel Fuel Formulations on Exhaust Emissions Rates and Reactivity," Final Report from the Center for Environmental Research and Technology, University of California, April 1999

Durbin, T.D., *et al.*, Final Report: "Evaluation of the Effects of Biodiesel and Biodiesel Blends on Exhaust Emission Rates and Reactivity - 2", Center for Environmental Research and Technology; College of Engineering; University of California, Riverside, August 2001

Durbin, T.D., J.M. Norbeck, "Effects of Biodiesel Blends and Arco EC-Diesel on Emissions from Light Heavy-Duty Diesel Vehicles," Environ. Sci. Technol., 2002, 36, 1686-1691

Durbin T. D. *et al.*, "Effects of Biodiesel, Biodiesel Blends, and a Synthetic Diesel on Emissions from Light Heavy-Duty Diesel Vehicles," Environ. Sci. Technol., 2000, 34, 349-355

Environment Canada, "Emissions Characterization of a Caterpillar 3126E Equipped with a Prototype SCRT System with Ultra Low Sulfur Diesel and a Biodiesel Blend," ERMD Report #2005-32, 2005

Eckerle, W., Lyford-Pike, E., Stanton, D., LaPointe, L., Whitacre, S., Wall, J., "Effects of Methyl Ester Biodiesel Blends on NOx Emissions," SAE paper no. 2008-01-0078.

Fosseen, D., "DDC 6V-71N Emission Testing on Diesel and Biodiesel Blend," Fosseen Manufacturing and Development, Ltd., report no. NSDB4F15, July 14, 1994

Fosseen, D., "DDC 6V-92TA MU1 Coach Upgrade Emission Optimization on 20%/80% Soy/Diesel Blend," Fosseen Manufacturing & Development, Ltd., report no. 260-2 and 24 1-1, September 30, 1994

Frank B.P. *et al*., "A Study of the Effects of Fuel Type and Emission Control Systems on Regulated Gaseous Emissions from Heavy-Duty Diesel Engines," SAE paper no. 2004-01-1085

Goetz, W., "Evaluation of Methyl Soyate/Diesel Blend in a DDC 6V-92TA Engine: Optimization of NOx Emissions," Ortech International, Report No. 93-E14-36, July 20, 1993

Goetz, W., "Evaluation of a Tallow/Diesel Blend in a DDC 6V-92TA Engine," Ortech International report no. 93-E14-37, July 21, 1993

Graboski, M.S., J.D. Ross, R.L. McCormick, "Transient Emissions from No. 2 Diesel and Biodiesel Blends in a DDC Series 60 Engine," SAE paper no. 961166

Graboski, M.S., R.L. McCormick, T.L. Alleman, A.M. Herring, "The Effect of Biodiesel Composition on Engine Emissions from a DDC Series 60 Diesel Engine," Colorado School of Mines, Final Report to National Renewable Energy Laboratory, June 8, 2000

Hansen, K.F., M.G. Jensen, "Chemical and Biological Characteristics of Exhaust Emissions from a DI Diesel Engine Fuelled with Rapeseed Oil Methyl Ester (RME)," SAE paper no. 971689

Holden, Bruce *et al*., Final Report: "Effect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions," Naval Facilities Engineering Command (NAVFAC) Technical Report TR-2275-ENV, May 2006

Howes, P., G. Rideout, "Evaluation of Biodiesel in an Urban Transit Bus Powered by a 1988 DDECII6V92 TA Engine," National Biodiesel Board, MSED Report # 96-26743-1, June 1995

Howes, P., G. Rideout, "Evaluation of Biodiesel in an Urban Transit Bus Powered by a 1981 DDCC8V71 Engine," National Biodiesel Board, MSED Report # 95-26743-2

Liotta, F.J., D.M. Montalvo, "The Effect of Oxygenated Fuels on Emissions from a Modern Heavy-Duty Diesel Engine," SAE paper no. 932734

Lyons D. W., "Biodiesel Fuel Comparison Final Data Report for Washington Metropolitan Area Transit Authority," West Virginia University, August 2002

Manicom, B., C. Green, W. Goetz, "Methyl Soyate Evaluation of Various Diesel Blends in a DDC 6V-92 TA Engine," Ortech International, April 21, 1993

Marshall, W., L.G. Schumacher, S. Howell, "Engine Exhaust Emissions Evaluation of a Cummins L10E When Fueled With a Biodiesel Blend," University of Missouri

McCormick, R.L., J.D. Ross, M.S. Graboski, "Effect of Several Oxygenates on Regulated Emissions from Heavy-Duty Diesel Engines," Environ. Sci. Technol., 1997, 31, 1144-1150

McCormick, R.L., J.R. Alvarez, M.S. Graboski, "NOx Solutions for Biodiesel," Colorado School of Mines, August 31, 2001

McCormick R.L. *et al.*, "Fuel Additive and Blending Approaches to Reducing NOx Emissions from Biodiesel," SAE paper no. 2002-01-1658

McCormick R.L. *et al.*, "Regulated Emissions from Biodiesel Tested in Heavy-Duty Engines Meeting 2004 Emission Standards," SAE paper no. 2005-01-2200

McCormick, R.L. *et al.*, "Effects of Biodiesel Blends on Vehicle Emissions, FY 2006 Annual Operating Plan Milestone 10.4," October 2006

McDonald, J.F., D.L. Purcell, B.T. McClure, D.B. Kittelson, "Emissions Characteristics of Soy Methyl Ester Fuels in an IDI Compression Ignition Engine," SAE paper no. 950400

McGill, R., Storey, J., Wagner, R., Irick, D., Aakko, P., Westerholm, M., Nylund, N., Lappi, M., "Emission Performance of Selected Biodiesel Fuels," SAE paper no. 2003-01-1866

National Resources Canada, "National Resources Canada/Fiba Canning - Biodiesel Freightliners," National Resources Canada draft report, October 24, 2006

National Institute for Petroleum and Energy Research, "Effects of Methyl Esters of Tallow and Grease on Exhaust Emissions and Performance of a Cummins L10 Engine," September 16, 1993

ORYXE Energy International, Inc., Biodiesel Emissions Test Summary, ORYXE presentation, 2006

Peterson, C., D. Reece, J. Thompson, S. Beck, C. Chase, "Development of Biodiesel for Use in High Speed Diesel Engines," University of Idaho, presentation at Sixth National Bioenergy Conference, Oct. 2-6, 1994

Peterson, C.L., D.L. Reece, "Emissions Tests with an On-Road Vehicle Fueled with Methyl and Ethyl Esters of Rapeseed Oil," ASAE paper no. 946532

Peterson C. L., *et al.*, "The Effect of Biodiesel Feedstock on Regulated Emissions in Chassis Dynamometer Tests of a Pickup Truck," ASAE, 2000, 43 (6), 1371-1381

Peterson, C.L., D.L. Reece, "Emissions Testing with Blends of Esters of Rapeseed Oil Fuel With and Without a Catalytic Converter," SAE paper no. 961114

Peterson, C.L., "Truck-In-The-Park Biodiesel Demonstration with Yellowstone National Park," University of Idaho, August 1999

Rantanen, L., S. Mikkonen, L. Nylund, P. Kociba, M. Lappi, N. Nylund, "Effect of Fuel on the Regulated, Unregulated and Mutagenic Emissions of DI Diesel Engines," SAE paper no. 932686

Schumacher, L.G., S.C. Borgelt, W.G. Hires, D. Fosseen, W. Goetz, "Fueling Diesel Engines with Blends of Methyl Ester Soybean Oil and Diesel Fuel," University of Missouri. See http://web.missouri.edu/~pavt0689/ASAED94.htm.

Schumacher, L., S.C. Borgelt, W.G. Hires, W. Wetherell, A. Nevils, "100,000 Miles of Fueling 5.9L Cummins Engines with 100% biodiesel," SAE paper no. 962233

Schumacher, L., N.N. Clark, D.W. Lyons, W. Marshall, "Diesel Engine Exhaust Emissions Evaluation of Biodiesel Blends Using a Cummins L10E Engine," ASAE, 44(6), 1461-1464

Sharp, C.A., "Transient Emissions Testing of Biodiesel in a DDC 6V-92TA DDEC Engine," Southwest Research Institute, Final Report to the National Biodiesel Board, October 1994

Sharp, C.A., "Transient Emissions Testing of Biodiesel and Other Additives in a DDC Series 60 Engine," Southwest Research Institute, Final Report to the National Biodiesel Board, December 1994

Sharp, C.A., "Emissions and Lubricity Evaluation of Rapeseed Derived Biodiesel Fuels," Southwest Research Institute, Final Report for Montana Department of Environmental Quality, November 1996

Sharp, C.A., "Characterization of Biodiesel Exhaust Emissions for EPA 211(b)," Southwest Research Institute report no. 08-1039A, January 1998

Sharp, C.A., S.A. Howell, J. Jobe, "The Effect of Biodiesel Fuels on transient Emissions from Modern Diesel Engines, Part I Regulated Emissions and Performance," SAE paper no. 2000-01-1967

Sirman, M.B., E.C. Owens, K.A. Whitney, "Emissions Comparison of Alternative Fuels in an Advanced Automotive Diesel Engine," Southwest Research Institute, AD A353968/PAA, November 1998

Smith, J.A., D.L. Endicott, R.R. Graze, "Biodiesel Engine Performance and Emissions Testing," Caterpillar Technical Center, May 1998

Souligny M. *et al.*, "Heavy-Duty Engine Performance and Comparative Emission Measurements for Different Biodiesel Blends Used in the Montreal Project," SAE paper no. 2004-01-1861

Spataru, A., C. Romig, "Emissions and Engine Performance from Blends of Soya and Canola Methyl Ester with ARB #2 Diesel in a DDC 6V92TA MUI Engine," SAE paper no. 952388

Starr, M.E., "Influence on Transient Emissions at Various Injection Timings, Using Cetane Improvers, Bio-Diesel, and Low Aromatic Fuels," SAE paper no. 972904

Stotler, R.W., D.M. Human, "Transient Emission Evaluation of Biodiesel Fuel Blend in a 1987 Cummins L10 and DDC 6V-92-TA," Engineering Test Services, report no. ETS-95-128, Nov. 30, 1995.

Sze, C., Whinihan, J, Olson, B., Schenk, C., Sobotowski, R., "Impact of Test Cycle and Biodiesel Concentration on Emissions," SAE paper no. 2007-01-4040.

Ullman, T.L., C.T. Hare, T.M. Baines, "Heavy-Duty Diesel Emissions as a Function of Alternate Fuels," SAE paper no. 830377.

Wang W. G., "Emissions from Nine Heavy-Duty Trucks Fueled by Diesel and Biodiesel Blend Without Engine Modification," Environ. Sci. Technol., 2000, 34, 933-939.

Studies not included because data collected on single cylinder/experimental engine

Murayama, T., Y. Oh, A. Kido, T. Chikahisa, N. Miyamoto, K. Itow, "Effects of Super Heating of Heavy Fuels on Combustion and Performance in DI Diesel Engines," SAE paper no. 860306

Murayama, T., Y. Oh, N. Miyamoto, T. Chikahisa, N. Takagi, K. Itow, "Low Carbon Flower Buildup, Low Smoke, and Efficient Diesel Operation with Vegetable Oils by Conversion to Mono-Esters and Blending with Diesel Oil or Alcohols," SAE paper no. 841161

Shaheed, A., E. Swain, "Performance and Exhaust Emission Evaluation of a Small Diesel Engine Fuelled with Coconut Oil Methyl Esters," SAE paper no. 981156

Suda, K.J., "Vegetable Oil or Diesel Fuel - A Flexible Option," SAE paper no. 840004

Ziejewski, M., H.J. Goettler, "Comparative Analysis of the Exhaust Emissions for Vegetable Oil Based Alternative Fuels," SAE paper no. 920195

Studies not included because data not readily available

Alfuso. S., M. Auriemma, G. Police, M.V. Prati, "The Effect of Methyl-Ester of Rapeseed Oil on Combustion and Emissions of DI Diesel Engines," SAE paper no. 932801

Hemmerlain, N., V. Korte, H. Richter, G. Schröder, "Performance, Exhaust Emissions and Durability of Modern Diesel Engines Running on Rapeseed Oil," SAE paper no. 910848

Humke, A.L., N.J. Barsic, "Performance and Emissions Characteristics of a Naturally Aspirated Diesel Engine with Vegetable Oil Fuels - (Part 2)," SAE paper no. 810955

Knothe, G., C.A. Sharp, T.W Ryan, "Exhaust Emissions of Biodiesel, Petrodiesel, Neat Methly Esters, and Alkanes in a New Technology Engine," Energy and Fuels, 2006, 20, 403-408

Lapuerta, M., Armas, O., Ballesteros, R., Fernandez, J., "Diesel Emissions from Biofuels Derived from Spanish Potential Vegetable Oils," Fuel, 2005, 84(6), 773-780

Last, R.J., M. Krüger, M. Dürnholz, "Emissions and Performance Characteristics of a 4-Stroke, Direct Injected Diesel Engine Fueled with Blend of Biodiesel and Low Sulfur Diesel Fuel," SAE paper no. 950054

Ma, W., L.I. Leviticus, F.G. Ullman, "On-Line Measurement of Formaldehyde in Tailpipe Emissions by Tunable Diode Laser Spectroscopy," SAE paper no. 941702

Martin, B., P. Aakko, D. Beckman, N. D. Giacomo, F. Giavazzi, "Influence of Future Fuel Formulations on Diesel Engine Emissions - A Joint European Study," SAE paper no. 972966

McDonald, J.F., "Evaluation of a Yellow Grease Methyl Ester and Petroleum Diesel Fuel Blend," University of Minnesota Final Report to the Agricultural Utilization Research Institute, August 11, 1997

Montagne, X., "Introduction of Rapeseed Methyl Ester in Diesel Fuel - The French National Program," SAE paper no. 962065

Reece, D.L., C.L. Peterson, "Biodiesel Testing in Two On-Road Pickups," SAE paper no. 952757

Staat, F., P. Gateau, "The Effects of Rapeseed Oil Methyl Ester on Diesel Engine Performance, Exhaust Emissions and Long-Term Behavior - A Summary of Three Years of Experimentation," SAE paper no. 950053

Wang, W.G., D.W. Lyons, N.N. Clark, M. Gautam, "Emissions from Nine Heavy Trucks Fueled by Diesel and Biodiesel Blend without Engine Modification," Environ. Sci. Technol., 2000, 34, 933-939

Studies not included because test cycle nonstandard/unrepresentative

Adelman, A.J., "Emission Evaluation Test Report for a Comparative Analysis of Emissions Among Petroleum Diesel and Biodiesel Blends fired in a Large Diesel Engine," AirNova, Inc., January 1998

Akasaka, Y., T. Suzuki, Y. Sakurai, "Exhaust Emissions of a DI Diesel Engine Fueled with Blends of Biodiesel and Low Sulfur Diesel Fuel," SAE paper no. 972998

Bagley, S.T., L.D. Gratz, J.H. Johnson, J.F. McDonald, "Effects of an Oxidation Catalytic Converter and a Biodiesel Fuel on the Chemical, Biological, and Particulate Size Characteristics of Emissions from an IDI Diesel Engine," Michigan Technological University, December 1995

Chang, D.Y.Z., J.H. Van Gerpen, "Fuel Properties and Engine Performance for Biodiesel Prepared from Modified Feedstocks," SAE paper no. 971684

Chang, D.Y., J.H. Van Gerpen, "Determination of Particulate and Unburned Hydrocarbon Emissions from Diesel Engines Fueled with Biodiesel," SAE paper no. 982527

Choi, C.Y., G.R. Bower, R.D. Reitz, "Effects of Biodiesel Blended Fuels and Multiple Injections on D.I. Diesel Engines," SAE paper no. 970218

Czerwinski, J., "Performance of HD-DI-Diesel Engine with Addition of Ethanol and Rapeseed Oil," SAE paper no. 940545

Desantes, J.M., J. Arrègle, S. Ruiz, A. Delage, "Characterization of the Injection-Combustion Process in a D.I. Diesel Engine Running with Rape Oil Methyl Ester," SAE paper no. 1999-01-1497

Fort, E.F., P.N. Blumberg, H.E. Staph, J.J. Staudt, "Evaluation of Cottonseed Oil as Diesel Fuel," SAE paper no. 820317

Jacobus, M.J., S.M. Geyer, S.S. Lestz, W.D. Taylor, T.H. Risby, "Single-Cylinder Diesel Engine Study of Four Vegetable Oils," SAE paper no. 831743

Masjuki, H., M.Z. Abdulmuin, H.S. Sii, "Investigations on Pre-Heated Palm Oil Methyl Esters in the Diesel Engine," IMechE 1996, Part A: Journal of Power and Energy

Needham, J.R., D.M. Doyle, "The Combustion and Ignition Quality of Alternative Fuels in Light Duty Diesels," SAE paper no. 852101

Schmidt, K., J. Van Gerpen, "The Effect of Biodiesel Fuel Composition on Diesel Combustion and Emissions," SAE paper no. 961086

Scholl, K.W., S.C. Sorenson, "Combustion of Soybean Oil Methyl Ester in a Direct Injection Diesel Engine," SAE paper no. 930934

Schramm, J., I. Foldager, N. Olsen, L. Gratz, "Emissions from a Diesel Vehicle Operated on Alternative Fuels in Copenhagen," SAE paper no. 1999-01-3603

Schröder, O., J. Krahl, A. Munack, J. Krahl, J. Bünger, "Environmental and Health Effects Caused By the Use of Biodiesel," SAE paper no. 1999-01-3561

Senatore, A., M. Cardone, V. Rocco, M.V. Prati, "A Comparative Analysis of Combustion Process in D.I. Diesel Engine Fueled with Biodiesel and Diesel Fuel," SAE paper no. 2000-01-0691

Uchida, M., Y. Akasaka, "A Comparison of Emissions from Clean Diesel Fuels," SAE paper no. 1999-01-1121

Zhang, Y., J.H. Van Gerpen, "Combustion Analysis of Esters of Soybean Oil in a Diesel Engine," SAE paper no. 960765

Studies not included because they lack new emissions data for regulated pollutants

Culshaw, F.A., "The Potential of 'Biodiesel' from Oilseed Rape," IMechE 1993, Part A: Journal of Power and Energy

Durbin, T.D., J.R. Collins, H. Galdamez, J.M. Norbeck, M.R. Smith, R.D. Wilson, T. Younglove, "Evaluation of the Effects of Biodiesel Fuel on Emissions from Heavy-Duty Non-Road Engines," University of California Final Report submitted to South Coast Air Quality Management District, May 2000

Peterson, C.L., D.L. Auld, "Technical Overview of Vegetable Oil as a Transportation Fuel," University of Idaho, 1991

Sharp, C.A., S.A. Howell, J. Jobe, "The Effect of Biodiesel Fuels on Transient Emissions from Modern Diesel Engines, Part II Unregulated Emissions and Chemical Characterization," SAE paper no. 2000-01-1968

Exclusion of duplicate datasets

Colorado Institute for Fuels and High Altitude Engine Research, "Emissions from Biodiesel Blends and Neat Biodiesel from a 1991 Model Series 60 Engine Operating at High Altitude," Final Report to National Renewable Energy Laboratory, September 1994

Note: CO_2 values were not duplicative.

Peterson, C.L., D.L. Reece, "Emissions Testing with Blends of Esters of Rapeseed Oil Fuel With and Without a Catalytic Converter," SAE paper no. 961114

Note: Only Table 6 data is duplicative.

Taberski, J.S., C.L. Peterson, "Dynamometer Emissions test Comparisons on a 5.9L Direct Injected Diesel Powered Pickup," BioEnergy '98: Expanding BioEnergy Partnerships

Taberski, J.S., C.L. Peterson, J. Thompson, H. Haines, "Using Biodiesel in Yellowstone National Park - Final Report of the Truck in the Park Project," SAE paper no. 1999-01-2798

McCormick, R.L., M.S. Graboski, T.L. Alleman, A.M. Herring, "Impact of Biodiesel Source Material and Chemical Structure on Emissions of Criteria Pollutants from a Heavy-Duty Engine," Environ. Sci. Technol., 2001, 35, 1742-1747

Studies not included for other reasons

Watts, W.F., M. Spears, J Johnson, "Evaluation of Biodiesel Fuel and Oxidation Catalyst in an Underground Metal Mine," University of Minnesota, September 24, 1998

Reason: Emission measurements were made in the field with portable emission measurement devices

Yoshimoto, Y., M. Onodera, H. Tamaki, "Reduction of NOx, Smoke, and BSFC in a Diesel Engine Fueled by Biodiesel Emulsion with Used Frying Oil," SAE paper no. 1999-01-3598

Reason: Biodiesel blend included water in an emulsion

Frank B.P. *et al*., "A Study of the Effects of Fuel Type and Emission Control Systems on Regulated Gaseous Emissions from Heavy-Duty Diesel Engines," SAE paper no. 2004-01-1085

Reason: Effect of oxycat & CRDPF greater than effect of B20.

Durbin T. D. *et al*., "Evaluation of the Effects of Biodiesel Fuel on Emissions from Heavy-Duty Non-Road Vehicles", Final Report for the SCAQMD under contract No. 99132 by the University of California, Riverside, May 2000

Reason: Non-road vehicles not considered here.

Guerra S. A. *et al*., "Comparison Study of NOx and CO_2 Emissions from an Off-Road Diesel Compactor Running on Regular Diesel, Biodiesel and Ultra-Low Sulfur Diesel," University of Kansas draft report, March 17, 2006

Reason: Non-road equipment not considered here.

Endnotes

[1] See the following documents: Iowa State University Center for Agricultural Research and Development, "Emerging Biofuels: Outlook of Effects on U.S. Grain, Oilseed, and Livestock Markets," May 2007 (a revised version is available from July 2007); USDA Agricultural Projections to 2018, Report OCE-2009-1, February 2009 (also USDA Agricultural Projections to 2016, Report OCE-2007-1, February 2007 for details on ethanol conversion yield); NCGA, "How Much Ethanol Can Come From Corn?" 2006; USDA, "An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture," May 2007.
[2] USDA/NASS. "Quick Stats: U.S. and All States Data- Corn field"
[3] USDA/NASS. "Corn: Yield by year, US," http://www.nass.usda.gov/Charts_and_Maps/Field_Crops/cornyld.asp, November 10, 2009.
[4] USDA Agricultural Projections to 2018, Report OCE-2009-1, February 2009
[5] USDA, National Agricultural Statistics Service, Crop Production and Grain Stocks; USDA, World Agricultural Outlook Board, World Supply and Demand Estimates; and U.S. Department of Commerce, Bureau of the Census.
[6] USDA Agricultural Projections to 2016, Report OCE-2007-1, February 2007, page 22.
[7] Shapouri, H., Gallagher, P., "USDA's 2002 Ethanol Cost-of-Production Survey," July 2005, p.11.
[8] F.O. Licht, "World Ethanol Markets: The Outlook to 2015," 2006, page 45.
[9] Renewable Fuels Association. "2008 World Fuel Ethanol Production". http://www.ethanolrfa.org/industry/statistics/
[10] "Sugarcane Industry in Brazil: Ethanol, Sugar, Bioelectricity" brochure from UNICA
[11] UNICA. "Sugarcane Production – Brazil" Spreadsheet available http://english.unica.com.br/dadosCotacao/estatistica/, Accessed December 8, 2009.
[12] Agra FNP. "Sugar and Ethanol in Brazil: A Study of the Brazilian Sugarcane, Sugar and Ethanol Industries," 2007.
[13] "Sugarcane Industry in Brazil: Ethanol, Sugar, Bioelectricity" brochure from UNICA
[14] Scaramucci, Jose & Cunha, Marcelo, "Bioethanol as Basis for Regional Development in Brazil: An Input-Output Model with Mixed Technologies."
[15] CGEE, ABDI, Unicamp, and NIPE, "Scaling Up the Ethanol Program in Brazil," n.d. cited in Rothkopf, Garten, "A Blueprint for Green Energy in America," 2006.
[16] CGEE, ABDI, Unicamp, and NIPE, "Scaling Up the Ethanol Program in Brazil," n.d. cited in Rothkopf, Garten, "A Blueprint for Green Energy in America," 2006.
[17] USDA, "The Economic Feasibility of Ethanol Production from Sugar in the United States," July 2006.
[18] Kline, K. et. al., "Biofuel Feedstock Assessment for Selected Countries," Oak Ridge National Laboratory, February 2008.
[19] USDA, "The Economic Feasibility of Ethanol Production from Sugar in the United States," July 2006.
[20] Personal communication with Nathalie Hoffman, Managing Member of California Renewable Energies, LLC, August 27, 2008.
[21] Christiansen, Ryan, "Analysis: Sugarcane Ethanol Has 95% Less Emissions," Ethanol Producer Magazine, March 2009.
[22] Voegele, Erin, "Sugarcane Economics," Ethanol Producer Magazine, March 2009.

[23] Voegele, Erin, "Sugarcane plays role in development of green polyethylene, Sugarcorn," Ethanol Producer Magazine, March 2009.
[24] Saballos, Ana. in W. Vermerris (ed.), (2008) "Development and Utilization of Sorghum as a Bioenergy Crop," Genetic Improvement of Bioenergy Crops DOI: 10.1007/978-0-387-70805-8_8
[25] W. W. Wilhelm, USDA-ARS, Univ. of Nebraska, Lincoln, NE 68583-0934, J. M. F. Johnson, USDA-ARS, Morris, MN 56267-1065, J. L. Hatfield, 108 Natl. Soil Tilth Lab., Ames, IA 50011-3120, W. B. Voorhees, USDA-ARS (retired), Morris, MN 56267-1065, and D. R. Linden, USDA-ARS (retired), St. Paul, MN 55108-0000, Crop and Soil Productivity Response to Corn Residue Removal A Literature Review; FORUM, © American Society of Agronomy, Madison, WI 53711 USA, Published in Agron. J. 96:1-17 (2004)
[26] Predicting Soil Erosion by Water. A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agricultural Research Service, Agricultural Handbook Number 703, 1997.
[27] Richard G. Nelson, Enersol Resources, Manhattan, KS 66502, USA, Resource Assessment and Removal Analysis for Corn Stover and Wheat Straw in the Eastern and Midwestern United States—Rainfall and Wind-induced Soil Erosion Methodology, Biomass and Bioenergy 22 (2002) 349 – 363, Published by Elsevier Science Ltd
[28] Linda Mann, Virginia Tolbert, Janet Cushman, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6038, Potential Environmental Effects of Corn Stover Removal With Emphasis on Soil Organic Matter and Erosion, Agriculture, Ecosystems and Environment 89: 149-166, ISSN 0167-8809 Elsevier Science, Amsterdam. June 2002.
[29] http://www.nrcs.usda.gov/technical/Standards/nhcp.html
[30] Richard G. Nelson, Enersol Resources, Manhattan, KS 66502, USA, Resource Assessment and Removal Analysis for Corn Stover and Wheat Straw in the Eastern and Midwestern United States—Rainfall and Wind-induced Soil Erosion Methodology, Biomass and Bioenergy 22 (2002) 349 – 363, Published by Elsevier Science Ltd.
[31] W.W. Wilhelm, USDA-ARS; J.M.F. Johnson, USDA-ARS; D.L. Karlen, USDA-ARS; D.T. Lightle, National Soil Survey; Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply, Published in Agron. J. 99:1665–1667 (2007); American Society of Agronomy, Madison, WI 53711.
[32] Susan S. Andrews, Ph.D., Leader, Soil Quality National Technology Development Team USDA-Natural Resource Conservation Service Crop, White Paper: Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations, Updated February 22, 2006
[33] Graham, R.L. et. al., "Current and Potential U.S. Corn Stover Supplies," *American Society of Agronomy* 99:1-11, 2007.
[34] Perlack, Robert D.; Biomass as Feedstocks for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Annual Supply; Sponsored by the U.S. Department of Energy and the U.S. Department of Agriculture; April 2005.
[35] Elbehri, Aziz. USDA, ERS, "An Evaluation of the Economics of Biomass Feedstocks: A Synthesis of the Literature," Prepared for the Biomass Research and Development Board, 2007.
[36] Milbrandt, A., "Geographic Perspective on the Current Biomass Resource Availability in the United States," NREL Report No. TP-560-39181, 2005.
[37] Gallagher, P. et. al., "Supply and Social Cost Estimates for Biomass from Crop Residues in the United States," *Environmental and Resource Economics* 24: 335-358, 2003.

[38] Walsh, Marie, "U.S. Cellulosic Biomass Feedstock Supplies and Distribution," Unpublished Manuscript, January 10, 2008.
[39] Graham, R.L. et. al., "Current and Potential U.S. Corn Stover Supplies," *American Society of Agronomy* 99:1-11, 2007.
[40] Wright, Lynn. (July 2007) "Historical Perspective on How and Why Switchgrass was Selected as a "Model" High-Potential Energy Crop," Oak Ridge National Laboratory.
[41] U.S Department of Energy. "Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda." (2006).
[42] Kumar, A., & Sokhansanj, S., "Switchgrass (Panicum vigratum, L.) delivery to a biorefinergy using integrated biomass supply analysis and logistics (IBSAL) model." *Bioresource Technology*, (2006).
[43] McLaughlin, S.B. & Adams Kszos, L., "Development of switchgrass (Panicum virgatum) as a bioenergy feedstock in the United States," *Biomass and Bioenergy*, 28: 515-535, 2005.
[44] Kumar, *op. cit.*
[45] McLaughlin, *op. cit.*
[46] Lewandowski, I., Clifton-Brown, J.C., Scurlock, J.M.O., & Huisman, W., "Miscanthus: European experience with a novel energy crop," *Biomass and Bioenergy*, 19: 209-227, 2000.
[47] Pyter, R., Voigt, T., Heaton, H., Dohleman, F., & Long, S. Growing giant miscanthus in Illinois. University of Illinois. (2006).
[48] *Ibid.*
[49] *Ibid.*
[50] Lewandowski, *op. cit.*
[51] Pyter, *op. cit.*
[52] Pyter, *op. cit.*
[53] Lewandowski, *op. cit.*
[54] Pyter, *op. cit.*
[55] U.S Department of Energy. "Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda," 2006.
[56] Saballos, *op. cit.*
[57] McCutchen, Bill et. al. High-Tonnage Dedicated Energy Crops: The Potential of Sorghum and Energy Cane.
[58] U.S Department of Energy. "Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda," 2006.
[59] *Ibid.*
[60] Campbell, J.E. at al., "The Global Potential of Bioenergy on Abandoned Agriculture Lands," *Environ. Sci. Technology*, 2008.
[61] Adapted from additional information received from J. Elliot Campbell. "The Global Potential of Bioenergy on Abandoned Agriculture Lands," *Environ. Sci. Technology*, 2008.
[62] USDA, Farm Services Agency, "Conservation Reserve Program Summary and Enrollment Statistics," FY 2008.
[63] USDA, Farm Services Agency, "Conservation Reserve Program Statistics: Monthly Summary November 2009."
[64] *Ibid.*
[65] Perlack, R.D., Wright, L.L., Turhollow, A.F, Graham, R.L., Environmental Sciences Division, Oak Ridge National Laboratory; Stokes, B.J., Forest Service, USDA.; Erbach, D.C., Agricultural

Research Service, USDA, "Biomass as Feedstock for a Bioenergy & Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply (A Joint Study Sponsored by DOE and USDA, Prepared by Oak Ridge National Laboratory)," 2005

[66] Walsh, M.E. (2007) Sungrant Bioweb. Forest Resources. http://bioweb.sungrant.org/Technical/Biomass+Resources/Forest+Resources/Default.htm

[67] *Ibid*.

[68] Perlack, R.D., Wright, L.L., Turhollow, A.F, Graham, R.L., Environmental Sciences Division, Oak Ridge National Laboratory; Stokes, B.J., Forest Service, USDA.; Erbach, D.C., Agricultural Research Service, USDA, "Biomass as Feedstock for a Bioenergy & Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply (A Joint Study Sponsored by DOE and USDA, Prepared by Oak Ridge National Laboratory)," 2005.

[69] *Ibid*.

[70] Dickerson, K., et. al. (revised November 2007). *Biomass and Biofuels in Maine: Estimating Supplies for Expanding the Forest Products Industry*. Margaret Chase Smith Policy Center.

[71] Puttock, G.D. (1995). Estimating cost for integrated harvesting and related forest management activities. *Biomass and Bioenergy 8*(2), 73-79.

[72] Perlack, R.D., Wright, L.L., Turhollow, A.F, Graham, R.L., Environmental Sciences Division, Oak Ridge National Laboratory; Stokes, B.J., Forest Service, USDA.; Erbach, D.C., Agricultural Research Service, USDA, "Biomass as Feedstock for a Bioenergy & Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply (A Joint Study Sponsored by DOE and USDA, Prepared by Oak Ridge National Laboratory)," 2005.

[73] Dickerson, K., et. al. (revised November 2007). *Biomass and Biofuels in Maine: Estimating Supplies for Expanding the Forest Products Industry*. Margaret Chase Smith Policy Center.

[74] *Ibid*.

[75] Timko, B., 2003. USDA, Forest Service, personal communication as noted in the "Billion-ton Study" by Perlack, R.D., et. al.

[76] F. Bohlin and A. Roos, Wood fuel supply as a function of forest owner preferences and management styles, *Biomass & Bioenergy* **22** (2002), pp. 237–249.

[77] Sanchez, Felipe G., Effects of organic matter removal and soil compaction on fifth-year mineral soil carbon and nitrogen contents for sites across the United States and Canada, Canadian Journal of Forestry Research, 36;:565 – 576, 2006.

[78] Powers, Robert F., The North American long-term soil productivity experiment: Findings from the first decade of research, Forest Ecology and Management, 220: 31 – 50, 2005.

[79] Zobrist, K.W.; T. M. Hinckley; M.G. Andreu. A literature review of management practices to support increased biodiversity in intensively managed loblolly pine plantations. Final Technical Report to the National Commission on Science for Sustainable Forestry (NCSSF). July 31, 2005. 16 p.

[80] Jonsell, M. 2007. Effects on Biodiversity of Forest Fuel Extraction, Governed by Processes Working on a Large Scale. Biomass and Bioenergy, Issue 31 pg. 726-732.

[81] T.B. Wigley and T. H. Roberts. 1994. Forest management and wildlife in forested wetlands of the southern Appalachians. *Water, Air and Soil Pollution* 77: 445--456.

[82] Kozlowski, T.T., 1999. Soil Compaction and Growth of Woody Plants. Scandinavian Journal of Forest Research, Volume 14, Number 6. Taylor and Francis Ltd.

[83] Rummer, B.; Len, D.; and O'Brien, O. (2004). *Forest Residues Bundling Project-New Technology for Residue Removal*. USDA Forest Service, Southern Research Station

[84] Energy content of hardwood; www.eere.energy.gov/biomass/progs/search3.cgi?8828; Biomass Feedstock Composition and Property Database; Energy Efficiency and Renewable Energy, U.S. Department of Energy.
[85] Aden, Andy. December 10, 2009. "Feedstock Considerations and Impacts on Biorefining." National Renewable Energy Laboratory
[86] Perlack, Robert D.; Biomass as Feedstocks for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Annual Supply; Sponsored by the U.S. Department of Energy and the U.S. Department of Agriculture; April 2005.
[87] Walsh, Marie E., U.S. Cellulosic Biomass Feedstock Supplies and Distribution; January 10, 2008.
[88] Gordon, Gayle of the Western Governors Association; Strategic Assessment of Bioenergy Development in the West, Kansas State University and the US Forest Service, multiple reports dated September 1, 2008.
[89] Data provided by e-mail by Perlack, Robert D., May 2008.
[90] EPA. "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008,"
[91] USEPA. "Municipal Solid Waste in the United States," 2007; See Tables 1-3.
[92] Biocycle, "The State of Garbage in America," Vol. 49, No. 12, December 2008, page 22.
[93] Midwest Assistance Program, Inc. "The 2006-2007 Missouri Municipal Solid Waste Composition Study," October, 2007.
[94] R. W. Beck, "Georgia Statewide Characterization Study," June 2005.
[95] Engineering Solutions and Design, Inc., "State of Ohio Waste Characterization Study," April 2004.
[96] NYC Department of Sanitation, "2004-2005 NYC Waste Characterization Study."
[97] R.W. Beck, "Statewide MSW Composition Study: A Study of Discards in the State of Minnesota," 2000.
[98] R.W. Beck, "Statewide Waste Composition Study: Pennsylvania State-wide Waste Composition," April 2003.
[99] DSM Environmental Services, Inc, "Vermont Waste Composition Study," June 2002.
[100] R.W. Beck, "1992 Washington State Waste Characterization Study."
[101] R.W. Beck, "Wisconsin Statewide Waste Characterization Study," May 2003.
[102] Department of Environmental Quality, "Oregon 2002 Waste Composition Study," 2002.
[103] Williams, Robert and California Biomass Collaborative, "Biofuels from Municipal Wastes-Background Discussion Paper," March 28, 2007.
[104] *Ibid*.
[105] Walsh, Marie, "U.S. Cellulosic Biomass Feedstock Supplies and Distribution," Unpublished Manuscript, January 10, 2008.
[106] Falk, Robert and McKeever, David. 2004. "Recovering Wood for Reuse and Recycling A United States Perspective" USDA Forest Service
[107] Fricke, K. (1989). "Technology and undesirable components on compost of separately collected organic wastes" *Agriculture, Ecosystem, Environment*.
[108] McKeever, David. (December 1999). "How Woody Residues Are Recycled in the United States" *BioCycle*
[109] Center for Sustainable Systems "U.S. Food System Fact Sheets,"2008

[110] USEPA, Construction and Demolition (C&D) Materials. http://www.epa.gov/osw/nonhaz/industrial/cd/basic.htm Accessed August 10, 2008.
[111] Fehrs, J., "Secondary Mill Residues and Urban Wood Waste Quantities in the United States-Final Report," Northeast Regional Biomass Program Washington, D.C., December 1999.
[112] Wiltsee, G., "Urban Wood Waste Resource Assessment," Appel Consultant, Inc. Valencia, CA. November, 1998.
[113] Seabra, Joaquim. (July 2009). "Comparison of options for advanced ethanol production in Brazilian sugarcane biorefineries" draft manuscript, anticipated to be available in Biomass and Bioenergy soon.
[114] Kline, K. et. al. Biofuel Feedstock Assessment for Selected Countries. Oak Ridge National Laboratory. February 2008.
[115] See F.O. Licht World Ethanol and Biofuels Report, vol 7, no 21, p 434 (July 8, 2009).
[116] Mueller, Steffen. An analysis of the projected energy use of future dry mill corn ethanol plants (2010-2030). October 10, 2007. Available at http://www.chpcentermw.org/pdfs/2007CornEethanolEnergySys.pdf
[117] "Essential Rendering", published by the National Renderer's Association, edited by David Meeker. 2006. Available at http://nationalrenderers.org/assets/essential_rendering_book.pdf
[118] "Statewide Feasibility Study for a Potential New York State Biodiesel Industry", prepared by LECG, LLC. Report number 04-02, April 2004. Available at http://www.nyserda.org/publications/biodieselreport.pdf
[119] A copy of this letter is available in the docket.
[120] Sheehan, John, Terri Dunahay, John Benemann, and Paul Roessler, "A Look Back at the U.S. Department of Energy's Aquatic Species Program—Biodiesel from Algae," National Renewable Energy Laboratory. Office of Fuels Development. Golden, Colorado, 1998.
[121] *Ibid*.
[122] Ryan, Catie. *op. sit*.
[123] Ryan, Catie, "Cultivating Clean Energy: The Promise of Algae Biofuels," NRDC and Terrapin Bright Green, LLC. October 2009.
[124] Davis, Ryan. November 2009. Techno-economic analysis of microalgae-derived biofuel production. National Renewable Energy Laboratory. Technical Memorandum to EPA.
[125] Davis, Ryan. *op. sit*.
[126] Chisti, Yusuf, "Biodiesel from Microalgae." *Biotechnology Advances* 25, 294-306, 2007.
[127] Schenider, David, "Grow Your Own?" *American Scientist*, Sept.-Oct. 2006.
[128] Campbell, Matthew N., "Biodiesel: Algae as a Renewable Source for Liquid Fuel." *Guelph Engineering Journal*, 1, 2-7, 2008.
[129] Chisti, *op. sit*.
[130] Pienkos, Philip T., "The Potential for Biofuels from Algae," Algae Biomass Summit. San Francisco, CA. Nov. 15, 2007.
[131] Campbell, *op. sit*.
[132] Pienkos, *op. sit*.
[133] Pienkos, *op. sit*.
[134] Campbell, *op. sit*.
[135] Putt, Ron. "Algae as a Biodiesel Feedstock," Nov. 20, 2007.
[136] Sheehan, *op. sit*.
[137] "Algae Bloom Again." *Nature*, 447, 520-21 2007.

[138] Deshayes, Pierre-Henry, "As planet swelters, are algae unlikely saviour?" *AFP,* July 10, 2008.
[139] Sheehan, *op. sit*.
[140] Pienkos, *op. sit*.
[141] "PV Solar Radiation," Digital image. National Renewable Energy Laboratory. May 2004.
[142] Bullock, Cary, "Algae Corrals Carbon Dioxide," *EnergyBiz Magazine*, 68-70, Mar.-Apr. 2007.
[143] Chisti, *op. sit*.
[144] Sheehan, *op. sit*.
[145] Davis, Ryan. *op sit*.
[146] Ryan, Catie, op. sit.
[147] Jongschaap, R.E.E, W.J. Corre, P.S Bindraban, and W.A. Brandenburg, "Claims and Facts on Jatropha curcas L," *Plant Research International*, Vers. Report 158, Oct. 2007.
[148] Euler, Hartlieb, and David Gorriz, "Case Study "Jatropha Curcas"" *Rep. No. Global Facilitation Unit for Underutilized Species*, Frankfurt, 2004.
[149] Jongschaap, *op. sit*.
[150] *Ibid*.
[151] Fairless, Daemon. "The little shrub that could - maybe." Nature 449 (2007): 652-55.
[152] Francis, G., R. Edinger, and K. Becker. "A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of Jatropha plantations." Natural Resources Forum 29 (2005): 12-24. As sited in Jongschaap, R.E.E, W.J. Corre, P.S Bindraban, and W.A. Brandenburg, "Claims and Facts on Jatropha curcas L," *Plant Research International*, Vers. Report 158, Oct. 2007.
[153] Woltjer, Lyanne. Size does matter. Expertise Centrum voor Duurzame Ontwikkeling (ECDO). Dec. 2006.
[154] Jongschaap, *op. sit*.
[155] Li Guo, T. "The photosynthesis and water use efficiency of eight garden tree species." *Forest Research* 15 (2002): 291-96. As sited in Jongschaap, R.E.E, W.J. Corre, P.S Bindraban, and W.A. Brandenburg, "Claims and Facts on Jatropha curcas L," *Plant Research International*, Vers. Report 158, Oct. 2007.
[156] Jongschaap, *op. sit*.
[157] Fairless, *op. sit*.
[158] Jongschaap, *op. sit*.
[159] Ghosh, A., J.S. Patolia, D.R. Chaudharry, J. Chikara, S.N. Rao D. Kumar, G.N. Boricha, and A. Zala. Response of Jatropha curcas under different spacing to Jatropha de-oiled cake. Discipline of Phytosalinity, Central Salt and Marine Chemicals Research Institute. 2007.
[160] Jongschaap, *op. sit*.
[161] Kumar, *op. sit*.
[162] *Ibid*.
[163] Pant, K.S., V. Khosla, D. Kumar, and S. Gairola, "Seed oil content variation in Jatropha curcas Linn. in different altitudinal ranges and site conditions in H.P. India," *Lyonia* 11 (2006): 31-34.
[164] Jongschaap, *op. sit*.
[165] USDA, "PLANTS Profile for Jatropha curcas L." USDA Natural Resources Conservation Service. http://plants.usda.gov/java/profile?symbol=jacu2, November 3, 2008.
[166] Jongschaap, *op. sit*.

[167] Oregon Climate Service, “State Annual Precip Maps,” http://www.ocs.oregonstate.edu., November 3, 2008.
[168] Carney, Dan. "Second-generation biodiesel." *Automotive Engineering*, May 2008: 20-22.
[169] Koch, Blair. “Canola yield light, but growers pleased with first crop.” Ag Weekly August 21, 2007. <http://www.agweekly.com/articles/2007/09/10/news/ag_news/news32.txt>
[170] W.M. Breene, J.T. Budin, L.A. Field, and D.H. Putnam. “Camelina: A Promising Low-Input Oilseed.” New Crops. 1993. 314-322. < http://www.hort.purdue.edu/newcrop/proceedings1993/v2-314.html>
[171] Great Plains: The Camelina Company < https://www.camelinacompany.com/marketing/agronomics.aspx#Facts>
[172] W.M. Breene, et. al. *op sit*.
[173] McCormick, Margaret. “Oral Comments of Targeted Growth, Incorporated” Submitted to the EPA on June 9, 2009.
[174] Schill, Susanne R. “Making Pennycress Pay Off.” Biodiesel Magazine February 2008.
[175] Biofuel Manufacturers of Illinois. http://www.growpennycress.com/
[176] Schill, Susanne R. *op sit*.
[177] Figures taken from European Biodiesel Board website as of December 2009. See http://www.ebb-eu.org/stats.php.
[178] Food and Agricultural Policy Research Institute, 2009 Agricultural Outlook. See http://www.fapri.iastate.edu/outlook/2009/text/14WorldBiofuels.pdf.
[179] Biofuels Barometer. Eurobserv’er, July 2009. See http://www.eurobserv-er.org/pdf/baro192.pdf
[180] DTN Ethanol Center, ”EU Biodiesel Feedstock Challenge,” October 11, 2007, http://www.dtnethanolcenter.com/index.cfm?show=10&mid=66&pid=27
[181] Food and Agricultural Policy Research Institute, 2009 Agricultural Outlook. See http://www.fapri.iastate.edu/outlook/2009/text/14WorldBiofuels.pdf.
[182] National Renewable Energy Laboratory estimate based on biomass portion available at $45-$55/dry ton.. Using POLYSYS Policy Analysis System, Agricultural Policy Analysis Center, University of Tennessee. http://www.agpolicy.org/polysys.html. Accessed May 2008.
[183] Milbrandt, A. (2005). “Geographic Perspective on the Current Biomass Resource Availability in the United States.” 70 pp.; NREL Report No. TP-560-39181
[184] Kerstetter, J. and Lyons, J., (2001) *Logging and Agricultural Residue Supply Curves for the Pacific Northwest*. Washington State University Energy Program for U.S. DOE.
[185] Rummer, B.; Len, D.; and O’Brien, O. (2004). *Forest Residues Bundling Project-New Technology for Residue Removal*. USDA Forest Service, Southern Research Station
[186] *Ibid*.
[187] Rawlings, C., et. al. (2004). *A Study of How to Decrease the Costs of Collecting, Processing and Transporting Slash*. USDA Forest Service.
[188] D. Montross, Associate Professor, Scott A. Shearer, Professor, Timothy S. Stombaugh, Associate Extension Professor, Stephen F. Higgins, Research Specialist, and Samuel G. McNeill, Associate Extension Professor, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, Kentucky; and Shahab Sokhansanj, Professor, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tennessee, Corn Stover Availability and Collection Efficiency Using Typical Hay Equipment, This article is published with the approval of the Director of the Kentucky Agricultural Experiment Station and

designated Paper No. 04-05-066. Transactions of the ASABE, Vol. 50(3): 705−711 – 2007 American Society of Agricultural and Biological Engineers, ISSN 0001−2351.

[189] S. Sokhansanj1, A. Turhollow, and R. Perlack, Oak Ridge National Laboratory, Tennessee, USA 37830, Stochastic Modeling of Costs of Corn Stover Costs Delivered to an Intermediate Storage Facility, Paper Number: 024190, Presented at: 2002 ASAE Annual International Meeting / CIGR XVth World Congress, Sponsored by ASAE and CIGR, Hyatt Regency Chicago, Chicago, Illinois, USA, July 28-July 31, 2002

[190] P. Savoie, L. D'Amours, F. Lavoie, G. Lechasseur, H. Joannis. Development of a Cutter-Shredder-Baler to Harvest Long-Stem Willow. Paper Number: 061016, Presented at: 2006 ASABE Annual International Meeting, Sponsored by ASABE, Portland Convention Center, Portland, Oregon, USA, July 9 – July 12, 2006

[191] Kevin J. Shinners, Professor of Agricultural Engineering, Ben N. Binversie, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Madison, WI, Philippe Savoie, Research Scientist, Agriculture and Agri-Food Canada, Quebec, Canada; Harvest and Storage Of Wet and Dry Corn Stover As A Biomass Feedstock, Paper Number: 036088, 2003 ASAE Annual International Meeting
Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003

[192] Christopher T. Wright, Peter A. Pryfogle, Nathan A. Stevens, J. Richard Hess, Corey W. Radtke, Idaho National Laboratory, Idaho Falls, ID, USA, Value of Distributed Preprocessing of Biomass Feedstocks to a Bioenergy Industry, Paper No: 066151, 2006 ASABE Annual International Meeting, Oregon Convention Center, Portland, Oregon, 9 - 12 July 2006

[193] Biomass Research Development Board. The Economics of Biomass Feedstocks in the United States. Occasional Paper 1, October 2008.

[194] ICM website, Ethanol Production Process, http://www.icminc.com/ethanol/production_process (Supplemented with information provided by EPA's Region 7).

[195] Renewable Fuels Association website, How Ethanol is Made: The Ethanol Production Process –Wet Milling, http://www.ethanolrfa.org/resource/made.

[196] Renewable Fuels Association, Annual Energy Outlook 2006 (http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2006.pdf)

[197] POET website, Technology - BPX™, http://www.poetenergy.com/learn/bpx.asp.

[198] Kirkbride McElroy, Anduin , "Poet, ISU partner for BPX research," *Ethanol Producer Magazine,* http://www.ethanol-producer.com/article.jsp?article_id=3770, March 2008.

[199] U.S. Environmental Protection Agency, Combined Heat & Power Partnership website, Basic Information, http://www.epa.gov/chp/basic/index.html.

[200] Smeets, Edward, et. al. "Sustainability of Brazilian bio-ethanol". August 2006

[201] Saeman, J.F., *Kinetics of Wood Saccharification: Hydrolysis of Cellulose and Decomposition of Sugars in dilute Acid at High Temperature*, Industrial and Engineering Chemistry, 37(1): 43–52 (1945).
http://pubs3.acs.org/acs/journals/toc.page?incoden=iechad&indecade=3&involume=37&inissue=1]

[202] Harris, E.E., Beglinger, E., Hajny, G.J., and Sherrard, E.C., , Industrial and Engineering Chemistry, 37(1): 12–23 (1945)
http://pubs3.acs.org/acs/journals/toc.page?incoden=iechad&indecade=3&involume=37&inissue=1]

[203] DOE National Laboratories. "30x30 A Scenario for Supplying 30% of 2004 Motor Gasoline with Ethanol by 2030: A Production Scenario for Cellulosic Ethanol from Corn Stover," June 23, 2006.

[204] LaMonica, Martin. "Investor Vinod Khosla: Advanced biofuels are closer than you think". Accessed at: http://www.news.com/8301-11128_3-9811702-54.html

[205] DOE. "Biomass Program: ABC's of Biofuels". Accessed at: http://www1.eere.energy.gov/biomass/abcs_biofuels.html#content

[206] Starch Hydrolysis; http://www.bio-link.org/pdf/starch.pdf

[207] Glossary of Biomass Terms, National Renewable Energy Laboratory, Golden, CO. http://www.nrel.gov/biomass/glossary.html

[208] Glossary of Biomass Terms, National Renewable Energy Laboratory, Golden, CO. http://www.nrel.gov/biomass/glossary.html

[209] Condensation and Hydrolysis; http://www.biotopics.co.uk/as/disaccharideformation.html

[210] BlueFire Ethanol. "Review of Competing Processes," May 2006. Accessed at: http://www.bluefireethanol.com/images/Technology_Comparison_051206.ppt#295,1, 31 Musick Irvine, California 92618.

[211] Stephanopoulos, Gregory, et. al., "Challenges in Engineering Microbes for Biofuels Production," *Science*, 315, 801, February 9, 2007.

[212] Dipardo, Joseph, "Outlook for Biomass Ethanol Production and Demand," Energy Information Administration, 2002.

[213] Tao, Ling and Aden, Andy. November 2008. Techno-economic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR). National Renewable Energy Laboratory (NREL)

[214] Aden, Andy, Ethanol Process Design and Economics Utilizing Co-current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover, Contract DE-AC36-99-GO10337, National Renewable Energy Laboratory, June 2002.

[215] Kim S, Holtzapple MT., "Effect of Structural Features on Enzyme Digestibility of Corn Stover," *Bioresource Technology*, 97: 583-591, 2006. As sited in Gray, Kevin, et. al., "Bioethanol," *Current Opinion in Chemical Biology*, 10:141-146, 2006.

[216] A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace National Renewable Energy Laboratory (NREL); L. Montague, A. Slayton, and J. Lukas Harris Group, Seattle, Washington, Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover; June 2002;NREL is a U.S. Department of Energy Laboratory Operated by Midwest Research Institute • Battelle • Bechtel; Contract No. DE-AC36-99-GO10337

[217] Graf, Angela, et. al., "Oregon Cellulose-Ethanol Study: An evaluation of the potential for ethanol production in Oregon using cellulose-based feedstocks," Bryan & Bryan Inc and Oregon Office of Energy, 2000.

[218] Tim Eggeman, Neoterics International, Lakewood, CO 80228, USA, Richard T. Elander, National Renewable Energy Laboratory, Golden, CO 80401, USA, Process and economic analysis of pretreatment technologies, Bioresource Technology 96 (2005) 2019–2025

[219] Gray, K., et. al., "Bioethanol," *Current Opinion in Chemical Biology*, 10:141-146, 2006.

[220] Graf, *op. sit*.

[221] Aden, Andy. December 10, 2009. "Feedstock Considerations and Impacts on Biorefining." National Renewable Energy Laboratory

[222] DOE, "From Biomass to Biofuels: A Roadmap to the Energy Future." based on a workshop held in Rockville, MD, on December 7-9, 2005. As sited in Stephanopoulos, Gregory, et. al., "Challenges in Engineering Microbes for Biofuels Production," *Science*, 315, 801, February 9, 2007.

[223] Presentations of K.C. McFarland (Novozymes) and G. Anderl (Genencor International) at the World Congress on Industrial Biotechnology and Bioprocessing, Orlando, FL, July 2006. As sited in Stephanopoulos, Gregory, et. al., "Challenges in Engineering Microbes for Biofuels Production," *Science*, 315, 801, February 9, 2007.

[224] Genencor Launches First Ever Commercial Enzyme Product for Cellulosic Ethanol, Rochester, NY, World-Wire, October 22, 2007 Copyright © 2007,. All rights reserved. World-Wire is a resource provided by Environment News Service. http://world-wire.com/news/0710220001.html

[225] Purdue yeast makes ethanol from agricultural waste more effectively, Purdue News, June 28, 2004
http://www.purdue.edu/UNS/html4ever/2004/040628.Ho.ethanol.html

[226] Stephanopoulos, *op. sit.*

[227] US. DOE. Technologies: Processing and Conversion. Accessed at: http://www1.eere.energy.gov/biomass/processing_conversion.html on October 28, 2008

[228] EERE, DOE, Thermochemical Conversion, & Biochemical Conversion, *Biomass Program Thermochemical R&D* .
http://www1.eere.energy.gov/biomass/thermochemical_conversion.html
http://www1.eere.energy.gov/biomass/biochemical_conversion.html

[229] Aden, Andy, Mixed Alcohols from Woody Biomass – 2010, 2015, 2022, National Renewable Energy Laboratory (NREL), September, 23 2009.

[230] Lin Wei, Graduate Research Assistant, Lester O. Pordesimo, Assistant Professor Willam D. Batchelor, Professor, Department of Agricultural and Biological Engineering, Mississippi State University, MS 39762, USA, Ethanol Production from Wood: Comparison of Hydrolysis Fermentation and Gasification Biosynthesis, Paper Number: 076036, Written for presentation at the 2007 ASABE Annual International Meeting. Minneapolis Convention Center, Minneapolis, MN, 17 - 20 June 2007

[231] J. Phillips, "Different Types of Gasifiers and Their Integration with Gas Turbines," EPRI/Advanced Coal Generation,
http://www.netl.doe.gov/technologies/coalpower/turbines/refshelf/handbook/1.2.1.pdf, October 30, 2008.

[232] Ciferno, Jared P., Benchmarking Biomass Gasification Technologies for Fuels, Chemicals and Hydrogen Production, National Energy Technology Laboratory, Department of Energy, June 2002.

[233] S. Phillips, A. Aden, J. Jechura, and D. Dayton, National Renewable Energy Laboratory, Golden, Colorado 80401-3393, T. Eggeman, Neoterics International, Inc., Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass, Technical Report, NREL/TP-510-41168, April 2007

[234] Aden, Andy, Mixed Alcohols from Woody Biomass – 2010, 2015, 2022, National Renewable Energy Laboratory (NREL), September, 23 2009.

---

235 BRI Energy Bioengineering Resources for Renewable Energy. "The Co-Production of Ethanol and Electricity From Carbon-based Wastes," A Report from BRI Energy, Inc. Regarding a New Technology That Addresses Multiple Energy and Waste Disposal Solutions, March 2006.
236 DOE EERE. "Biomass Program: Thermochemical Conversion of Corn Stover," April 2006. Accessed at: http://www1.eere.energy.gov/biomass/pdfs/thermochemical_stover.pdf.
237 S. Phillips, A. Aden, J. Jechura, and D. Dayton, National Renewable Energy Laboratory, Golden, Colorado 80401-3393, T. Eggeman, Neoterics International, Inc., Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass, Technical Report, NREL/TP-510-41168, April 2007
238 Davis, Ryan; Techno-economic analysis of current technology for Fischer-Tropsch fuels production, National Renewable Energy Laboratory for EPA, August 14, 2009.
239 DOE EERE Biomass Program. "Thermochemical Conversion Processes: Pyrolysis" http://www1.eere.energy.gov/biomass/thermochemical_processes.html, November 6, 2008.
240 Zeman, Nicholas, "Thermochemical Versus Biochemical," *Biomass Magazine*, June 2007.
241 Information derived from staff-level communication with National Biodiesel Board personnel.
242 "Tyson ConocoPhillips Venture in Jeopardy." The Morning News, article dated 9/26/08. http://www.nwaonline.net/articles/2008/09/26/business/092708fuelcredits.txt
243 See Syntroleum Investor Presentation, dated November 2009. Available here: http://www.syntroleum.com/Presentations/SyntroleumInvestorPresentation.November%205.2009.FINAL.pdf. Accessed December 16, 2009.
244 "Tyson's Fats to Fuel Plant on Schedule." The Morning News, article dated 10/6/08. http://www.nwaonline.net/articles/2008/10/06/business/100708tysonfuelplant.txt
245 Based on presentation materials by Lars Peter Lindfors dated 29 September 2009, available here: http://www.nesteoil.com/default.asp?path=1,41,538,2496,12947. Accessed December 16, 2009.
246 Total ethanol usage from EIA, Monthly Energy Review, September 2009 (Table 10.2) and EIA imports reported online at: http://tonto.eia.doe.gov/dnav/pet/hist/mfeimus1a.htm.
247 Total projected ethanol consumption according to a letter from Richard Newell, EIA Administrator to Lisa Jackson, EPA Administrator dated October 29, 2009 (Table 1) and projected imports according to 2009 YTD reported online at: http://tonto.eia.doe.gov/dnav/pet/hist/mfeimus1a.htm.
248 110th Congress of the United States of America, First Session, *The Energy Independence and Security Act of 2007, House Rule 6* (December 19, 2007) available at: http://www.govtrack.us/congress/billtext.xpd?bill=h110-6.
249 Total ethanol usage from EIA, Monthly Energy Review, September 2009 (Table 10.2) and EIA imports reported online at: http://tonto.eia.doe.gov/dnav/pet/hist/mfeimus1a.htm.
250 Sources include Renewable Fuels Association (RFA), Ethanol Biorefinery Locations (updated October 22, 2009) and Ethanol Producer Magazine (EPM), Producing plant list (last modified on October 22, 2009) in addition to information gathered from producer websites and follow-up correspondence.
251 Form 10-Q/A submitted by Greenshift Corporation to the United States Securities and Exchange Commission for the quarterly period ending June 30, 2009. The Q2 2009 SEC filing can be found at: http://www.greenshift.com/pdf/GERS_Form10Q_Q209_FINAL.pdf

[252] Spreadsheet provided to EPA by Neeharika Naik-Dhungel at EPA's Combined Heat & Power Partnership on December 17, 2009.
[253] Spreadsheet provided to EPA by Bruce Woerner at Airgas on August 14, 2009.
[254] Total plants less those denoted as "farmer owned" *b*ased on Renewable Fuels Association (RFA) Ethanol Biorefinery Locations (updated October 22, 2009).
[255] "Valero Renewables to Purchase Three Ethanol Plants," December 15, 2009. Valero press release available at: http://www.valero.com/NewsRoom/Pages/PR_20091215_0.aspx
[256] Based on Valero refinery information provided at http://www.valero.com/OurBusiness/OurLocations/
[257] EIA, Annual Energy Outlook 2009 – ARRA Update (Table 12).
[258] Sources include Renewable Fuels Association (RFA), Ethanol Biorefinery Locations (updated October 22, 2009) and Ethanol Producer Magazine (EPM), Producing, Not Producing, Under Construction, and Expansions lists (last modified on October 22, 2009) in addition to information gathered from producer websites and follow-up correspondence.
[259] Data based on "An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)"; Steffen Mueller, University of Illinois at Chicago Energy Resource Center, October 10, 2007, Available online at: http://www.chpcentermw.org/pdfs/2007CornEethanolEnergySys.pdf
[260] Data based on "An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)"; Steffen Mueller, University of Illinois at Chicago Energy Resource Center, October 10, 2007
[261] Data based on "An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)"; Steffen Mueller, University of Illinois at Chicago Energy Resource Center, October 10, 2007, with the exception of Membrane Separation data based on conversation with Leland Vane, EPA
[262] According to an e-mail from ADM's Dean Frommelt dated May 7, 2009, "The new dry mills for Cedar Rapids, IA and Columbus, NE commenced construction July 2007 and October 2006, respectively." According to information posted on Riverland Biofuels website, the Canton, IL plant broke ground in October 2006. According to the Southwest Iowa Renewable Energy website, the Council Bluffs, IA plant had a groundbreaking ceremony on November 11, 2006 (plant was assumed to break ground sometime shortly after that).
[263] Ministry of Agriculture in Brazil (MAPA), http://www.agricultura.gov.br/ Accessed: April 3, 2009
[264] F.O. Licht's, "World Ethanol Markets: The Outlook to 2015," pg. S-22 to S-23, 2006.
[265] F.O. Licht's, "World Ethanol and Biofuels Report," Vol. 5, No. 22, July 23, 2007.
[266] Agra FNP, "Sugar and Ethanol in Brazil: A Study of the Brazilian Sugar Cane, Sugar and Ethanol Industries," 2007.
[267] Agra FNP, *op. sit*.
[268] ANFAVEA (Associação Nacional dos Fabricantes de Veículos Automotores Assessoria de Planejamento Econômico e Estatístico Indústria Automobilística Brasileira - Empresas Associadas). Internal Sales in Brazil 2009. http://www.anfavea.com.br/tabelas.html, November 24, 2009.
[269] Ministerio da Agricultura, Pecularia E Abastecimento (MAPA), "Brazilian Ethanol Production,"

http://www.agricultura.gov.br/pls/portal/docs/PAGE/MAPA/ESTATISTICAS/PRODUCAO/06-PROD.%20BR%20%C1LCOOL.PDF, December 9, 2009.
[270] Ewing, Elizabeth, "Pipeline Projects on Hold." *Ethanol Producer Magazine*, July 2008.
[271] Rothkopf, Garten, "A Blueprint for Green Energy in the Americas," 2006.
[272] *Ibid*.
[273] FAPRI 2009 U.S. and World Agricultural Outlook; OECD-FAO Agricultural Outlook 2007-2016, 2007 (note: this was interpreted from a graph); Bioenergia: Liquid Biofuels, "18 Billion Liters a Year!" March 2007; Rothkopf, *op. sit*. (note: years 2007-2019 were interpreted from a graph); EPE, "Plano National de Energia 2030," Presentation from Mauricio Tolmasquim, 2007 (note: years were interpreted from a graph); UNICA, "Sugarcane Industry in Brazil: Ethanol, Sugar, Bioelectricity" brochure, 2008.
[274] Agra FNP, *op. sit*.
[275] Carpenter, Claudia, "Sugar Gains Capped by Brazil Ethanol Expansion, Czarnikow Says," *Bloomberg*, June 19, 2008.
[276] UNICA, "Sugarcane as a key element against Global Warming to be highlighted at Green Week in Brussels," Press Release on June 23, 2009.
[277] F.O. Licht GmbH, "89 New Ethanol Facilities to Come Online in 2007-11 – BNDES," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 22, July 23, 2007.
[278] AFP, "Brazil says biofuel production not to blame for food crisis," June 1, 2008.
[279] Business News Americas, "Odebrecht to invest US$2.6 bn to Lead Ethanol Sector – Brazil," June 28, 2007.
[280] The Wall Street Journal, "ADM Plans Entry Into Sugar-Cane Ethanol in Brazil," June 22, 2007.
[281] Agra FNP, *op. sit*.
[282] Petrobras Magazine No. 122. "Ethanol: From Brazil to the World," August 13, 2007.
[283] *Ibid*.
[284] Ewing, *op. sit*.
[285] Rothkopf, *op. sit*.
[286] *Ibid*.
[287] F.O. Licht GmbH. "Ethanol Blend Rose to 25% on July 1, 2007," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 21, July 9, 2007.
[288] Agra FNP, *op. sit*.
[289] F.O. Licht GmbH. "Sobering Times for Biofuels in Seville," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 20, June 19, 2007. (note: only 2006, 2015 & 2025 values were reported, other values are interpolated); FAPRI 2009 U.S. and World Agricultural Outlook; EPE, *op. sit*. (note: years were interpreted from a graph); UNICA, "Sugarcane Industry in Brazil: Ethanol, Sugar, Bioelectricity" brochure, 2008.
[290] Ewing, *op. sit*.
[291] European Bioethanol Fuel Association (eBio), "The Industry, Statistics: Production Data," http://www.ebio.org/statistics.php?id=4, September, 2009.
[292] Walter, A. et. al., "Perspectives on Fuel Ethanol Consumption and Trade," *Biomass and Bioenergy*, 32, 730-748, 2008.
[293] Flach, Bob, "EU-27 Biofuels Annual: Annual Report 2009," USDA FAS GAIN Report, June 15, 2009.
[294] *Ibid*.

[295] Energy Information Administration (EIA), "Delivered Energy Consumption in OECD Europe by End-Use Sector and Fuel, 2006-2030: Table F6," *International Energy Outlook 2009*, http://www.eia.doe.gov/oiaf/ieo/index.html
[296] BP, "BP Statistical Review of World Energy 2007 (revised with 2008 statistics) Historical Data," http://www.bp.com/statisticalreview.
[297] Walter, A., *op. sit.*
[298] Ayoub PM. Biofuels for Shell-biomass based blending components for transport fuels (gasoline and diesel). In: World biofuels symposium-China, Beijing, 2006. As sited in Walter, *op. sit.*
[299] European Bioethanol Fuel Association (eBio), "Production Capacity Installed" and "Production Capacity Under Construction," http://www.ebio.org/statistics.php?id=5 and http://www.ebio.org/statistics.php?id=6, September 9, 2009.
[300] F.O. Licht GmbH. "Sobering Times for Biofuels in Seville," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 20, June 19, 2007.
[301] Fukuda, Hisao, et. al.,"Japan Bio-fuels Production Report," USDA, FAS, May 26, 2006. http://www.fas.usda.gov/gainfiles/200605/146197881.pdf
[302] Iijima, Midori. (2009) "Japan to Focus on Next Generation Biofuels," USDA FAS GAIN Report, June 1, 2009.
[303] Rothkopf, *op. sit.*
[304] Fukuda, *op. sit.*
[305] *Ibid.*
[306] Rothkopf, *op. sit.*
[307] Jolly, Lindsay, "World Fuel Ethanol Outlook: Can ethanol be traded globally in a large proportion?," International Sugar Organization, Presentation to 9th World Beet and Cane Growers Conference, 9-12 July 2007.
[308] Fukuda, *op. sit.*
[309] Rothkopf, *op. sit.*
[310] Iijima, *op sit.*
[311] Iijima, Midori. *op. sit.*
[312] Ferreira, Lenilson, "Brazil Priming Ethanol Initiative to Supply Fuel-Thirsty Japan," *The Japan Times*, August 22, 2007. http://search.japantimes.co.jp/print/nb20070822a3.html
[313] Ewing, *op. sit.*
[314] Iijima, *op sit.*
[315] Rothkopf, *op. sit.*
[316] Singh, Santosh, "India: Biofuels Annual 2009," USDA FAS GAIN Report, June 15, 2009.
[317] *Ibid.*
[318] Jagannathan, Prabha, "Fuel doping: Govt to rework pricing formula for ethanol" *The Economic Times*, December, 23, 2009.
[319] Nayak, D., "Weak Crude, Cane Shortage Hit India Ethanol Expansion" *Wall Street Journal*, April, 1, 2009.
[320] Renewable Fuels Association (RFA), "2008 World Fuel Ethanol Production, " http://www.ethanolrfa.org/industry/statistics/#E, December 23, 2009.
[321] Ohga K. & Tatsuji K. Biofuels Policies in Asia: Trade effects on World Agricultural and Biofuels Trade. Presentation to USDA Agricultural Outlook Forum, March 2, 2007.

[322] Beckman, Chanda et. al., "China-Peoples Republic of: Biofuels Annual" USDA FAS GAIN Report, July 17, 2009.
[323] Rothkopf, *op. sit*.
[324] AFX News Limited, Forbes, "China to Freeze Approvals for Corn Processing Projects for 3 Years," September 21, 2007.
http://www.forbes.com/markets/feeds/afx/2007/09/21/afx4142281.html
[325] F.O. Licht GmbH, "New Ethanol Plants Will Rely on Non-Grain Feedstocks," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 22, July 23, 2007.
[326] Rothkopf, *op. sit*.
[327] Beckman, *op. sit*. Conversions assume 1 million tonnes of ethanol equals 330 million gallons.
[328] Rothkopf, *op. sit*.
[329] *Ibid*.
[330] Ohga, *op. sit*.
[331] F.O. Licht GmbH, "New Ethanol Plants Will Rely on Non-Grain Feedstocks," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 22, July 23, 2007.
[332] Rothkopf, *op. sit*.
[333] F.O. Licht GmbH, "New Ethanol Plants Will Rely on Non-Grain Feedstocks," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 22, July 23, 2007.
[334] EIA, "U.S. Oxygenates: Fuel Ethanol Imports," Last updated on October 10, 2008.
http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_EPOOXE_im0_mbbl_m.htm
[335] Joseph, Ken, "Argentina Biofuels Annual," USDA FAS GAIN Report, June 19, 2009.
[336] Deborah O'Connell, et. al., "Biofuels in Australia - Issues and Prospects. A Report for the Rural Industries Research and Development Corporation," CSIRO Australian Government Rural Industries Research and Development Corporation, May 2007.
[337] Roberts, Greg, "Rees scraps biofuel mandates," *The Australian: Online Newspaper of the Year*, September 20, 2008. http://www.theaustralian.news.com.au/story/0,25197,24373888-11949,00.html
[338] Sobolik, Jessica, "Canadian Government Passes Renewable Fuels Standard," *Ethanol Producer Magazine*, August 2008.
[339] Pinzon, L., "Colombia Bio-fuels Annual 2008," USDA FAS GAIN Report, August 20, 2008.
[340] Chavez, L., "Mexico Biofuels Annual," USDA FAS GAIN Report, June 15, 2009.
[341] Darby, Mike, "Australia Biofuels Annual," USDA FAS GAIN Report, June 1, 2009.
[342] Dessureault, Darlene, "Canada Biofuels Annual," USDA FAS GAIN Report, June 30, 2009.
[343] Office of the United States Trade Representative (USTR), "Caribbean Basin Initiative," November 12, 2008.
http://www.ustr.gov/Trade_Development/Preference_Programs/CBI/Section_Index.html
[344] Bryan, Tom, "Entering Tariff-Free," Ethanol Producer Magazine, January 2004.
[345] Office of the United States Trade Representative (USTR), "Ethanol Provisions in the CAFTA-DR," July 2007.
[346] Bryan, *op. sit*.
[347] Rapoza, Kenneth, "UPDATE: Tax Loophole Helps US Import Ethanol 'Duty Free'- ED&F," *INO News*, *Dow Jones Newswires*, March 2008. http://news.ino.com/
[348] Peter Rohde, "Senate Finance May Take Up Drawback Loophole As Part of Energy Bill," *EnergyWashington Week*, April 18, 2007. As sited in Yacobucci, Brent, "Ethanol Imports and

the Caribbean Basin Initiative," CRS Report for Congress, Order Code RS21930, Updated March 18, 2008.
[349] Perkins, Jerry, "BRAZIL: Loophole Hurt U.S. Ethanol Prices," DesMoinesRegister.com, October 18, 2007.
[350] Public Law Version 6124 of the Farm Bill. 2008. http://www.usda.gov/documents/Bill_6124.pdf.
[351] Lundell, Drake, "Brazilian Ethanol Export Surge to End; U.S. Customs Loophole Closed Oct. 1," Ethanol and Biodiesel News, Issue 45, November 4, 2008.
[352] MacDonald, T., et. al., "Ethanol Supply Outlook for California," California Energy Commission, October 2003. http://www.ethanolrfa.org/objects/documents/100/castaffreport.pdf
[353] Petrojam Limited, "Official Opening of Petrojam Ethanol Limited," November 12, 2008. http://www.pcj.com/petrojam/whats_new.htm
[354] Petrojam Limited, "About Us," November 12, 2008. http://www.petrojambunkering.com/petrojam_aboutb.htm
[355] F.O. Licht GmbH, "Company News- JBG Commences Fuel Ethanol Production," *F.O. Licht's World Ethanol & Biofuels Report*, Vol. 5, No. 22, July 23, 2007.
[356] Email Correspondence with Jeffrey Tuite, ED&F Man, September 6, 2007.
[357] Yacobucci, Brent, "Ethanol Imports and the Caribbean Basin Initiative," CRS Report for Congress, Order Code RS21930, Updated March 18, 2008.
[358] Email Correspondence with Jeffrey Tuite, ED&F Man, September 6, 2007.
[359] Ethanol Producer Magazine, "Ethanol Dehydration Facility to be Built in Trinidad," December 2006.
[360] Etter, Lauren, and Millman, Joel, "Ethanol Tariff Loophole Sparks a Boom in Caribbean Islands Build Plants To Process Brazil's Fuel; Farm Belt Cries Foul," *Wall Street Journal*, March 9, 2007.
[361] Homer, Louis, "Another Energy Sector Stimulus," PetroleumWorld.com. November 22, 2006. http://www.petroleumworldtrinidad.com/storytrini06112606.htm
[362] Etter, *op. sit.*
[363] Browne, J., "Angostura Launches US$11m Ethanol Plant," *The Trinidad Guardian*. August 6, 2004. http://www.guardian.co.tt/archives/2004-08-06/business1.html
[364] Email Correspondence with Jeffrey Tuite, ED&F Man, September 6, 2007.
[365] Ramjeet, Oscar, "Barbados to Build $72 Million Ethanol Dehydration Plant," Caribbean Net News, August 22, 2008.
[366] Jamaica Gleaner News, "US$36m Ethanol Plant for Barbados," August 23, 2008. http://www.jamaica-gleaner.com/gleaner/20080823/business/business1.html
[367] Email Correspondence with Jeffrey Tuite, ED&F Man, September 6, 2007.
[368] Bryan, *op. sit.*
[369] Etter, *op. sit.*
[370] *Ibid.*
[371] Email Correspondence with Jeffrey Tuite, ED&F Man, September, 7, 2007.
[372] Etter, *op. sit.*
[373] 110th Congress of the United States of America, Second Session, *The Food, Conservation, and Energy Act of 2008, House Rule 6124* (June 18, 2008) available at: http://www.usda.gov/documents/Bill_6124.pdf.

[374] Bell Bio-Energy funding based on Press Release, "Defense Energy Support Center and Army Test Turning Waste into Fuel," (October 2, 2008) available at: http://www.bellbioenergy.com/html/newsletter/Press%20Releases/DLA_PR_10-3-08.pdf. Clearfuels Technology funding based on DOE Press Release, "Recovery Act Announcement: Secretaries Chu and Vilsack Announce More than $600 Million in Advanced Biorefinery Projects," (December 4, 2009) available at: http://www.energy.gov/8352.htm. Verenium funding based on DOE Press Release, "DOE to Provide up to $40 Million in Funding for Small-Scale Biorefinery Projects in Wisconsin and Louisiana," (July 14, 2008) available at: http://www.energy.gov/news/6413.htm.

[375] Letter from Richard Newell, EIA Administrator to Lisa Jackson, EPA Administrator dated October 29, 2009 (Table 2).

[376] http://www.iogen.ca/company/demo_plant/index.html

[377] DOE Press Release, "Recovery Act Announcement: Secretaries Chu and Vilsack Announce More than $600 Million in Advanced Biorefinery Projects," (December 4, 2009) available at: http://www.energy.gov/8352.htm.

[378] Based on the following DOE press releases, "U.S. Department of Energy Selects First Round of Small-Scale Biorefinery Projects for Up to $114 Million in Federal Funding," (January 29, 2008) available at: http://www.energy.gov/news/5903.htm; "DOE Selects 3 Small-Scale Biorefinery Projects for Up to $86 Million of Federal Funding in Maine, Tennessee and Kentucky," (April 18, 2008) available at: http://www.energy.gov/news/6164.htm; "DOE to Provide up to $40 Million in Funding for Small-Scale Biorefinery Projects in Wisconsin and Louisiana," (July 14, 2008) available at: http://www.energy.gov/news/6413.htm; "Recovery Act Announcement: Secretaries Chu and Vilsack Announce More than $600 Million in Advanced Biorefinery Projects," (December 4, 2009) available at: http://www.energy.gov/8352.htm.

[379] DOE Press Release, "DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding," (February 28, 2007) available at: http://www.energy.gov/news/4827.htm.

[380] 109th Congress of the United States of America, First Session, *The Energy Policy Act of 2005, House Rule 6* (January 4, 2005) available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h6enr.txt.pdf

[381] DOE Press Release, "DOE Announces Final Rule for Loan Guarantee Program," (October 4, 2007) available at: http://www.energy.gov/print/5568.htm.

[382] 111th Congress of the United States of America, First Session, *The American Recovery and Reinvestment Act of 2009, House Rule 1* (January 6, 2009) available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf.

[383] DOE Press Release, "Department of Energy Issues Final Rule on Loan Guarantees," (December 7, 2009) available at: http://www.energy.gov/news2009/8369.htm

[384] USDA Press Release, "USDA Approves First Ever Guaranteed Loan for Commercial-Scale Cellulosic Ethanol Plant," (January 16, 2009) available at: http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1RD?printable=true&contentidonly=true&contentid=2009/01/0024.xml

[385] DOE Press Release, "DOE Selects Five Ethanol Conversion Projects for $23 Million in Federal Funding," (March 27, 2007) available at: http://www.energy.gov/print/4896.htm.

[386] DOE Press Release, "Energy and Agriculture Depts. Provide $8.3 Million in Funding for Biofuels Research," (June 7, 2007) available at: http://www.energy.gov/print/5115.htm.

[387] DOE Press Release, "Energy Department Selects Three Bioenergy Research Centers for $375 Million in Federal Funding," (June 26, 2007), http://www.energy.gov/print/5172.htm.
[388] DOE Press Release, "Department of Energy to Invest up to $7.7 Million for Four Biofuels Projects," (December 4, 2007) available at: http://www.energy.gov/print/5757.htm.
[389] DOE Press Release, "U.S. Department of Energy to Invest up to $33.8 Million to Further Development of Commercially Viable Renewable Fuels," (February 26, 2008) available at: http://www.energy.gov/print/6015.htm.
[390] DOE Press Release, "USDA, DOE to Invest up to $18.4 Million for Biomass Research, Development and Demonstration Projects," (March 4, 2008) available at: http://www.energy.gov/print/6035.htm.
[391] DOE Press Release, "DOE and USDA Announce More than $10 Million in Bioenergy Plant Feedstock Research," (July 31, 2008) available at: http://www.energy.gov/print/6444.htm
[392] DOE Press Release, "DOE Announces Up to $7 Million for Technology Commercialization Acceleration," (August 29, 2008) available at: http://www.energy.gov/news/6493.htm
[393] DOE Press Release, "DOE to Invest up to $4.4 Million in Six Innovative Biofuels Projects at U.S. Universities," (September 10, 2008) available at: http://www.energy.gov/print/6525.htm.
[394] DOE Press Release, "USDA & DOE Release National Biofuels Action Plan," (October 7, 2008) available at: http://www.energy.gov/print/6633.htm.
[395] DOE Press Release, "DOE Announces Additional Steps in Developing Sustainable Biofuels Industry," (October 7, 2008) available at: http://www.energy.gov/print/6638.htm.
[396] DOE Press Release, "Energy Secretary Chu, Agriculture Secretary Vilsack Announce $6.3 million for Biofuels Research," (July 22, 2009) available at: http://www.energy.gov/news2009/7683.htm.
[397] DOE Press Release, "DOE Awards $377 Million in Funding for 46 Energy Frontier Research Centers," (August 6, 2009) available at: http://www.energy.gov/news2009/7768.htm.
[398] DOE Press Release, "DOE Selects Biofuels Projects to Receive up to $21 Million in Funding," (August 31, 2009) available at: http://www.energy.gov/news2009/7848.htm).
[399] DOE Press Release, "DOE and USDA Select Projects for more than $24 Million in Biomass Research and Development Grants," (November 12, 2009) available at: http://www.energy.gov/news2009/print2009/8283.htm
[400]Midwest Governors Association, "Energy Security and Climate Stewardship Platform for the Midwest 2007," (November 2007) available at: http://www.midwesterngovernors.org/resolutions/Platform.pdf.
[401] Midwest Governors Association, "The Midwestern Energy Infrastructure Accord," (October 2009) available at: www.midwesterngovernors.org/publications.htm.
[402] Plant information taken from Nation Biodiesel Board website as of November 2009.
[403] Capacity data taken from National Biodiesel Board as of November 2009. Production, import, and export figures taken from EIA Monthly Energy Review, Table 10.4 as of December 2009.
[404] See http://www.biodiesel.org/buyingbiodiesel/plants/showall.aspx and http://www.afdc.energy.gov/afdc/incentives_laws.html. Tax incentive information used here was current as of October 2008, and plant statistics as of October 2009.
[405] Industry data for 2008 taken from National Biodiesel Board fact sheets available at that time (see docket for historical lists) and

http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_graph_slide.pdf (accessed April 27, 2009).
[406] "Tyson ConocoPhillips Venture in Jeopardy." The Morning News, article dated 9/26/08. Available in the docket.
[407] See Syntroleum Investor Presentation, dated November 2009. Available here: http://www.syntroleum.com/Presentations/SyntroleumInvestorPresentation.November%205.2009.FINAL.pdf. Accessed December 16, 2009.
[408] "Tyson's Fats to Fuel Plant on Schedule." The Morning News, article dated 10/6/08. Available in the docket.
[409] Syntroleum Investor Presentation dated November 5, 2009. Available in the docket or at: http://www.syntroleum.com/Presentations/SyntroleumInvestorPresentation.November%205.2009.FINAL.pdf
[410] Ethanol and Pipeline Transportation Policy Paper, Association of Oil Pipelines (AOPL and American Petroleum Institute (API), February 2007, http://www.aopl.org/pdf/AOPL_API_Ethanol_Transportation_Final144839.pdf
[411] Testimony of Tim Felt President and CEO Explorer Pipeline On Behalf of and the Association of Oil Pipe Lines (AOPL) and API Before the House Committee on Energy and Commerce Subcommittee on Energy and Air Quality March 12, 2008, http://www.aopl.org/pdf/felt-testimony.pdf
[412] Kinder Morgan announcement that their Central Florida Pipeline from Tampa to Orlando ships batches of ethanol along with batches of gasoline. http://www.kindermorgan.com/business/products_pipelines/
[413] "POET Joins Magellan Midstream Partners to Assess Dedicated Ethanol Pipeline", March 2009, http://www.poet.com/news/showRelease.asp?id=155
[414] Kinder Morgan announcement that their Central Florida Pipeline from Tampa to Orlando ships batches of ethanol along with batches of gasoline. http://www.kindermorgan.com/business/products_pipelines/
[415] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[416] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[417] "The Importance of Adequate Rail Investment", Association of American Railroads, http://www.aar.org/GetFile.asp?File_ID=150
[418] American Association of State Highway and Transportation Officials (AASHTO) Freight-Rail Bottom-Line Report, 2003.
[419] Association of American Railroads (AAR), National Rail Freight Infrastructure Capacity and Investment Study, September 2007.
[420] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[421] Transportation activity data output spreadsheet that accompanied the report entitled "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[422] "Kinder Morgan Announces $195 Million Acquisition and new Ethanol Venture", download from Kinder Morgan website.

[423] Transportation activity data output spreadsheet that accompanied the report entitled "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[424] "Barge Transportation in the United States". Timothy Casey, Presentation at the MARE Forum USA, 2006, http://www.mareforum.com/ENERGY_TRANSPORTATION_USA_2006_PRESENTATIONS_files/CASEY.pdf
[425] Energy Information Administration (EIA) historical company level ethanol and gasoline import data: http://www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli_historical.html
[426] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009. The list of projected ethanol import locations is contained in Table 3 in Section 3.3.2 of this report.
[427] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[428] Transportation activity data output spreadsheet that accompanied the report entitled "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[429] "The U.S. Truck Driver Shortage: Analysis and Forecasts", Prepared by Global Insights for the American Trucking Association, May 2005. http://www.truckline.com/NR/rdonlyres/E2E789CF-F308-463F-8831-0F7E283A0218/0/ATADriverShortageStudy05.pdf
[430] Our projections of the motor fuel demand can be found in chapter 1.2 of this RIA.
[431] "Renewable Fuel Standard Challenges Faced by Terminals", Andrea Grant, Independent Fuel Terminal Operators Association, May, 13, 2008, presentation at the 2008 Society of Automotive Engineers Government-Industry Meeting.
[432] "Infrastructure Requirements for an Expanded Fuel Ethanol Industry", Downstream Alternative Incorporated, January 15, 2002.
[433] A discussion of the volumes of biofuels we estimate would be used absent the RFS2 standards is located in Section 1.2 of this RIA.
[434] A discussion of the estimated number of terminals that carry diesel fuel is contained in Chapter V of the Regulatory Impact Analysis to the final highway diesel fuel rule http://www.epa.gov/otaq/highway-diesel/regs/ria-v.pdf, EPA Docket A-99-06.
[435] "Renewable Fuel Standard Challenges Faced by Terminals", Andrea Grant, Independent Fuel Terminal Operators Association, May, 13, 2008, presentation at the 2008 Society of Automotive Engineers Government-Industry Meeting.
[436] "Renewable Fuel Standard Challenges Faced by Terminals", Andrea Grant, Independent Fuel Terminal Operators Association, May, 13, 2008, presentation at the 2008 Society of Automotive Engineers Government-Industry Meeting.
[437] Section 1.7 of this RIA contains a discussion of our projections regarding the prevalence of flexible fuel vehicles in the vehicle fleet and the relative volumes of E85 versus E10 that would be used in these vehicles.
[438] "Summary Data on Diesel Fuel Retailers", Memorandum to the Docket, Jeffery Herzog, U.S. EPA, March 23, 2000, EPA Docket A-99-06, Docket Item II-B-07.

[439] 2007 National Association of Convenience Stores State of the Industry survey data www.nacsonline.com as reported in the National Petroleum News MarketFacts 2007, October 2007.
[440] "Diesel Throughput Volume by Percentage of Diesel Fuel Retailers", Memorandum to the Docket, Jeffery Herzog, U.S. EPA, May 05, 2000, EPA Docket A-99-06, Docket Item II-B-14.
[441] National Petroleum News, "2008 marketfacts", www.npnweb.com
[442] National Petroleum News, "2007 marketfacts", Volume 99, Number 10, October 2007, www.npnweb.com
[443] The National Ethanol Vehicle Coalition estimate of E85 refueling facilities is located at http://www.e85refueling.com/ estimates http://www.e85refueling.com/
[444] The "NEAR85" estimate of E85 retail facilities is located at http://www.neare85.com/
[445] Letter from Richard Newell, EIA Administrator to Lisa Jackson, EPA Administrator dated October 29, 2009 (Table 1).
[446] Based on comments provided by NPRA (EPA-HQ-OAR-2005-0161-2124.1)
[447] Hart Energy Consulting, North American Ethanol Database Service, Revised November 2009. Included under the permission of Fred Potter, Executive VP at Hart.
[448] Quadrillion BTUs based on EIA, AEO 2007 (Table 2), EIA, AEO 2008 Final Release (Table 2), and EIA, AEO 2009 – ARRA Update (Table 2).
[449] http://www.growthenergy.org/2009/e15/Waiver%20Cover%20Letter.pdf
[450] 1998-2005 FFV sales based on DOE's EERE data available at: www.eere.energy.gov/afdc/data/index.html
[451] EIA, Annual Energy Outlook 2009 – ARRA Update (Table 57).
[452] Rulemaking to Establish Light-Duty Vehicle GHG Emission Standards and Corporate Average Fuel Economy Standards, 74 FR 49454 (September 28, 2009).
[453] Historical car and light truck sales taken from ORNL, Transportation Energy Data Book, Edition 28-2009 (Tables 4.5 and 4.6).
[454] Vehicle survival rates taken from Rulemaking to Establish Light-Duty Vehicle GHG Emission Standards and Corporate Average Fuel Economy Standards, 74 FR 49454 (September 28, 2009).
[455] EIA, Annual Energy Outlook 2009 – ARRA Update (Table 57).
[456] Ethanol Producer Magazine, "Automakers Maintain FFV Targets in Bailout Plans." February 2009. FFV commitments reiterated in Chrysler Restructuring Plan for Long-Term Viability and General Motors Corp. 2009-2014 Restructuring Plan presented to the U.S. Department of Treasury on February 17, 2009.
[457] 111th Congress of the United States of America, First Session, *The Open Fuel Standard Act of 2009, House Rule 1476* (March 12, 2009) available at: http://www.opencongress.org/bill/111-h1476/text.
[458] EIA, Annual Energy Outlook 2007 (Table 47).
[459] For more information, visit: http://www.afdc.energy.gov/afdc/ . The $100 per FFV estimate is also cited by others, including Growth Energy: http://www.growthenergy.org/2009/Brochures/Fueling_Ethanol.pdf.
[460] National Ethanol Vehicle Coalition, 2009 FFV Purchasing Guide.
[461] NEVC website, accessed on November 23, 2009
[462] For more information, visit: http://www.midwesterngovernors.org/resolutions/Platform.pdf

[463] 111th Congress of the United States of America, First Session, *The American Recovery and Reinvestment Act of 2009, House Rule 1* (January 6, 2009) available at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h1enr.pdf.
[464] Proposed Rulemaking to Establish Light-Duty Vehicle GHG Emission Standards and Corporate Average Fuel Economy Standards, 74 FR 49454 (September 28, 2009).
[465] EIA, Annual Energy Outlook 2009 - ARRA Update (Table 17).
[466] NEVC, "2008 Purchasing Guide for Flexible Fuel Vehicles." Refers to all mass produced 3.5 and 3.9L Impalas. However, it is our understanding that consumers may still place special orders for non-FFVs.
[467] Based on average E85 and regular unleaded gasoline prices reported at http://www.fuelgaugereport.com/ on November 23, 2009.
[468] 110th Congress of the United States of America, Second Session, *The Food, Conservation, and Energy Act of 2008, House Rule 6124* (June 18, 2008) available at: http://www.usda.gov/documents/Bill_6124.pdf,
[469] EIA, Annual Energy Outlook 2009 - ARRA Update (Table 17).
[470] Brownstone, D., Small, K.A., Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstrations, Transportation Research Part A 39, 2005 (pages 293-279).
[471] Greene, David, Survey Evidence on the Importance of Fuel Availability to Choice of Alternative Fuels and Vehicles, Prepared by Oak Ridge National Laboratory (November 11, 1997), available at: http://ntl.bts.gov/lib/000/700/723/survey.pdf.
[472] http://www.dtnethanolcenter.com/index.cfm?show=10&mid=32
[473] http://www.growthenergy.org/2009/e15/Waiver%20Cover%20Letter.pdf. Additional supporting documents are available on the Growth Energy website.
[474] Refer to 74 FR 18228 (April 21, 2009).
[475] Refer to 74 FR 23704 (May 20, 2009).
[476] http://www.epa.gov/OMS/regs/fuels/additive/lettertogrowthenergy11-30-09.pdf
[477] Highway and non-road gasoline information taken from ORNL, Transportation Energy Data Book, Edition 28-2009 (Table 2.5). Off-road gasoline information taken from ORNL, Transportation Energy Data Book, Edition 26-2007 (Table 2.5). This was the last year ORNL reported. All calculations exclude aviation gasoline.
[478] Ethanol Producer Magazine website, Ethanol Plant Lists (Producing, Not Producing, Under Construction, Expansions), http://www.ethanolproducer.com/plant-list.jsp, Modified on April 14, 2008.
[479] Renewable Fuels Association (RFA) website, Ethanol Biorefinery Locations, http://www.ethanolrfa.org/industry/locations, Updated on April 2, 2008.
[480] International Trade Commission 2005-2007 historical ethanol import data as reported by the Renewable Fuels Association, http://www.ethanolrfa.org/industry/statistics/
[481] Communication from Douglas Newman, International Trade Commission to Doris Wu, EPA, May 20, 2008.
[482] Energy Information Administration historical gasoline and ethanol import data: http://www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli_historical.html
[483] NASS database. http://www.nass.usda.gov/
[484] USDA, WGA, Bioenergy Strategic Assessment project findings upcoming as noted in report WGA. Transportation Fuels for the Future Biofuels: Part I. 2008.

[485] NASS database. http://www.nass.usda.gov/
[486] U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Transportation Energy Book: Edition 26*, Prepared by Oak Ridge National Laboratory, ORNL-6978, 2007 (Table 2.5).
[487] U.S. Department of Energy, Energy Information Administration, *Petroleum Marketing Annual 2006*, http://tonto.eia.doe.gov/FTPROOT/petroleum/048706.pdf, August 2007 (Tables 31, 34 & 48).
[488] U.S. Environmental Protection Agency, *Draft Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources,* EPA420 D-06-004, http://www.epa.gov/otaq/regs/toxics/chapter9.pdf, February 2006 (Chapter 9).
[489] American Petroleum Institute, Gasoline Tax Report, http://www.api.org/statistics/fueltaxes/upload/January_2008_gasoline_and_diesel_summary_pages-2.pdf, January 2008.
[490] See http://www.afdc.energy.gov/afdc/fuels/biodiesel_laws.html. Incentives were evaluated as of October 2008.
[491] Status taken from the online plant database as of October 2009. Current data is available at http://www.biodiesel.org/buyingbiodiesel/plants/showall.aspx
[492] Industry data for 2008 taken from National Biodiesel Board fact sheets no longer available (see docket for historical versions) and http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_graph_slide.pdf (accessed April 27, 2009).
[493] Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, Biodiesel Incentives and Laws. Accessed July 2008. http://www.afdc.energy.gov/afdc/fuels/biodiesel_laws.html
[494] Energy Information Administration, 2005 Prime Supplier Sales Volumes for No. 2 Diesel. Accessed 10/7/2008. http://tonto.eia.doe.gov/dnav/pet/pet_cons_prim_a_EPD2D_P00_Mgalpd_a.htm
[495] Energy Information Administration, Fuel Oil and Kerosene Sales 2006, Table 16. 2005 data column used. http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/fuel_oil_and_kerosene_sales/current/pdf/table16.pdf
[496] Product Life Cycle Accounting and Reporting Standard, Review Draft for Stakeholder Advisory Group, November 2009, World Resources Institute & World Business Council for Sustainable Development, 2009
[497] Clean Air Act Section 211(o)(1)
[498] Delucchi, M. 2005. Incorporating the Effect of Price Changes on CO_2-Equivalent Emissions from Alternative Fuel Lifecycles: Scoping the Issues. Working Paper UCD—ITS—RR—05—19. http://pubs.its.ucdavis.edu/publication_detail.php?id=62
[499] http://www.epa.gov/sequestration/greenhouse_gas.html
[500] Heffer, Patrick (2009). Assessment of Fertilizer Use by Crop at the Global Level, 2006/07 – 2007/08. International Fertilizer Industry Association. Paris, France.
[501] http://faostat.fao.org/
[502] Macedo I.C., Seabra J.E.A., Silva J.E.A.R. (2008) "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020." Biomass and Bioenergy.

[503] Argonne Laboratory. 2008. Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis by Arora, Wu, and Wang

[504] Shurson, J. 2009. Analysis of Current Feeding Practices of Distiller's Grains with Solubles in Livestock and Poultry Feed Relative to Land Use Credits Associated with Determining the Low Carbon Fuel Standard for Ethanol. Dr. Jerry Shurson, Professor, Department of Animal Science, University of Minnesota, March 25, 2009

[505] Energy Life-Cycle Assessment of Soybean Biodiesel, A. Pradhan, D.S. Shrestha, A. McAloon, W. Yee, M. Haas, J.A. Duffield, H. Shapouri, USDA, Agricultural Economic Report Number 845, September 2009

[506] Davis, Ryan. November 2009. Techno-economic analysis of microalgae-derived biofuel production. National Renewable Energy Laboratory (NREL)

[507] Aden, Andy. September 2009. Mixed Alcohols from Woody Biomass – 2010, 2015, 2022. National Renewable Energy Laboratory (NREL)

[508] Davis, Ryan. August 2009. Techno-economic analysis of current technology for Fischer-Tropsch fuels. National Renewable Energy Laboratory (NREL)

[509] An Analysis Of Modern Corn Ethanol Technologies, February 16, 2009, Energy Resources Center, 1309 South Halsted Street, Chicago, IL 60607

[510] The MODerate resolution Imagin Spectoradiometer (MODIS) land Products (MCD12Q1) Land Cover Type Product (Land Cover Type 1), https://lpdaac.usgs.gov/lpdaac/products/modis_products_table/land_cover/yearly_l3_global_500_m/mcd12q1

[511] FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

[512] Lewis et al. 2009. Increasing carbon storage in intact African tropical forests. Nature. 457(19): 1003-1006

[513] Phillips et al. 2008. The changing Amazon forest. Phil. Trans. R. Soc. (363): 1819-1827

[514] Department of Energy: National Energy Technology Laboratory. 2009. NETL: Petroleum-Based Fuels Life Cycle Greenhouse Gas Analysis - 2005 Baseline Model.

[515] "N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" P.J. Crutzen, A.R. Mosier, K.A. Smith, and W. Winiwarter, Atmospheric Chemistry and Physics, 8, 389–395, 2008.

[516] U.S. Environmental Protection Agency. 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. EPA 430-R-05-003. Available at http://www.epa.gov/climatechange/emissions/downloads06/05CR.pdf.

[517] U.S. Environmental Protection Agency. 2005. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003. EPA 430-R-05-003. Available at http://www.epa.gov/climatechange/emissions/downloads06/05CR.pdf.

[518] U.S. Environmental Protection Agency. 2005. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003. EPA 430-R-05-003. Available at http://www.epa.gov/climatechange/emissions/downloads06/05CR.pdf.

[519] Heffer, Patrick (2009). Assessment of Fertilizer Use by Crop at the Global Level, 2006/07 – 2007/08. International Fertilizer Industry Association. Paris, France.

[520] Venezia, John et. al. Notable Revisions and Recalculations: International Agriculture GHG Emissions and GHG Metrics. Memorandum to EPA on September 30, 2009.

[521] Ross and Associates Environmental Consulting, Ltd (2009). Peer Review of International Greenhouse Gas Emissions and Factors as provided to EPA to support its RFS2 rulemaking.
[522] Venezia, John et. al. Notable Revisions and Recalculations: International Agriculture GHG Emissions and GHG Metrics. Memorandum to EPA on September 30, 2009.
[523] FAO (2009). FAOStat Production (Crops). Retrieved Sept. 25, 2009 from http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. Assumes FAO definitions for seed cotton, maize, sunflower seed, groundnuts, in shell, and rice, paddy equal cotton; corn; sunflower; peanut; and rice, respectively.
[524] Venezia, John et. al. Notable Revisions and Recalculations: International Agriculture GHG Emissions and GHG Metrics. Memorandum to EPA on September 30, 2009.
[525] USDA Economic Research Service. China Agricultural and Economic Data: National Data Results. Retrieved from http://www.ers.usda.gov/Data/China/NationalResults.aspx?DataType=6&DataItem=160&StrDatatype=Agricultural+inputs&ReportType=0 on Sept 15, 2009.
[526] Faroni, C.E.; Penatti, C.P.; Donzelli, J.L.; Paes, L.A.D. Simulação CTC para o uso de fertilizantes pela cana-de-açúcar no ano de 2020. Relatório Técnico de Pesquisa e Desenvolvimento (Planilha Microsoft Excel). CTC – Centro de Tecnologia Canavieira, Piracicaba-SP, 2009.
[527] 2006 IPCC Guidelines for National Inventories, Volume 4, Chapter 11: N_2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application
[528] http://wds.iea.org/wds/default.aspx
[529] Macedo I.C., Seabra J.E.A., Silva J.E.A.R. (2008) "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020." Biomass and Bioenergy.
[530] International Rice Research Institute. www.iri.org. Last accessed: October 15, 2008.
[531] UNICA. (August 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-1761.1, pg. 20-21
[532] Michael Wang, May Wu, Hong Huo and Jiahong Liu (2008) Life-cycle energy use and greenhouse gas emissions implications of Brazilian sugarcane ethanol simulated with the GREET model. International Sugar Journal 2008, Vol. 110, No. 1317.
[533] Salil Arora, May Wu, and Michael Wang, "Update of Distillers Grains Displacement Ratios for Corn Ethanol Life-Cycle Analysis," September 2008. See http://www.transportation.anl.gov/pdfs/AF/527.pdf
[534] West, T.O., and W.M. Post. 2002. "Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation." *Soil Science Society of America Journal* 66:1930-1936.
[535] See Adams et al. (2005) for additional detail on the FASOM forest carbon accounting procedures.
[536] Smith, J., L.S. Heath, and J. Jenkins. 2003. Forest Volume-to-Biomass Models and Estimates of Mass for Live and Standing Dead Trees of U.S. Forests. Newton Square, PA: USDA Forest Services.
[537] Haynes, R.W. (Technical coordinator). 2003. *An Analysis of the Timber Situation in the United States: 1952 to 2050*. General Technical Report PNW-GTR-560. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 254 p.
[538] Birdsey, R.A. 1996a. "Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management after Cropland and Pasture Revision to Forest." In

Forests and Global Change. Volume II: Forest Management Opportunities for Mitigating Carbon Emissions, D. Hair, and Neil R. Sampson, eds., Washington, DC: American Forests: 309-333.

[539] Birdsey, R.A. 1996b. "Carbon Storage for Major Forest Types and Regions in the Conterminous United States." In *Forests and Global Change. Volume II: Forest management opportunities for mitigating carbon emissions, Chapter 1,* D. Hair and Neil R. Sampson, eds. Washington, DC: American Forests: 1-25.

[540] Smith, J., L.S. Heath, and J. Jenkins. 2003. Forest Volume-to-Biomass Models and Estimates of Mass for Live and Standing Dead Trees of U.S. Forests. Newton Square, PA: USDA Forest Services.

[541] Ibid.

[542] Miles, P., U.S. Forest Service, electronic file 2002_RPA_Tables.xls to Brooks Depro, RTI International, July 30, 2003.

[543] Birdsey, R.A. 1992. Changes in forest carbon storage from increasing forest area and timber growth. In: Sampson, R.N.; Dwight, H.; eds. *Forest and Global Change, Volume 1: Opportunities for Increasing Forest Cover*. Washington, DC: American Forests: 23-29.

[544] Birdsey, R.A. 1996a. "Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management after Cropland and Pasture Revision to Forest." In *Forests and Global Change. Volume II: Forest Management Opportunities for Mitigating Carbon Emissions*, D. Hair, and Neil R. Sampson, eds., Washington, DC: American Forests: 309-333.

[545] Birdsey, R.A. 1996b. "Carbon Storage for Major Forest Types and Regions in the Conterminous United States." In *Forests and Global Change. Volume II: Forest management opportunities for mitigating carbon emissions, Chapter 1,* D. Hair and Neil R. Sampson, eds. Washington, DC: American Forests: 1-25.

[546] Heath, L.S.; Birdsey, R.A.; Williams, D.W. 2002. "Methodology for estimating soil carbon for the forest carbon budget model of the United States, 2001." *Environmental Pollution*, 116: 373-380.

[547] Birdsey, R.A. 1996a. "Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management after Cropland and Pasture Revision to Forest." In *Forests and Global Change. Volume II: Forest Management Opportunities for Mitigating Carbon Emissions*, D. Hair, and Neil R. Sampson, eds., Washington, DC: American Forests: 309-333.

[548] Birdsey, R.A. 1996b. "Carbon Storage for Major Forest Types and Regions in the Conterminous United States." In *Forests and Global Change. Volume II: Forest management opportunities for mitigating carbon emissions, Chapter 1,* D. Hair and Neil R. Sampson, eds. Washington, DC: American Forests: 1-25.

[549] Heath, L.S.; Birdsey, R.A.; Williams, D.W. 2002. "Methodology for estimating soil carbon for the forest carbon budget model of the United States, 2001." *Environmental Pollution*, 116: 373-380.

[550] Birdsey, R.A. 1996a. "Regional Estimates of Timber Volume and Forest Carbon for Fully Stocked Timberland, Average Management after Cropland and Pasture Revision to Forest." In *Forests and Global Change. Volume II: Forest Management Opportunities for Mitigating Carbon Emissions*, D. Hair, and Neil R. Sampson, eds., Washington, DC: American Forests: 309-333.

[551] Birdsey, R.A. 1996b. "Carbon Storage for Major Forest Types and Regions in the Conterminous United States." In *Forests and Global Change. Volume II: Forest management opportunities for mitigating carbon emissions, Chapter 1,* D. Hair and Neil R. Sampson, eds. Washington, DC: American Forests: 1-25.
[552] Smith, J., and L.S. Heath. 2002. A Model of Forest Floor Carbon Mass for United States Forest Types. Newton Square, PA: USDA Forest Service.
[553] Smith, J., USDA Forest Service, email communication to Brian Murray, RTI International. August 11, 2004.
[554] U.S. Environmental Protection Agency. 2003. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2001*. Annex O.
[555] U.S. Environmental Protection Agency. 2003. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2001*. Annex O.
[556] Skog, K, and G. Nicholson. 2000. Carbon Sequestration in Wood and Paper Products. In *The Impact of Climate Change on American Forests, Chapter 5,* L. Joyce and R. Birdsey, eds. USDA Forest Service, General Technical Report RMRS-GTR-59, Chap. 5:79-88.
[557] Adams, D., R. Alig, B.A. McCarl, and B.C. Murray. 2005. "FASOMGHG Conceptual Structure and Specification: Documentation." Available at http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/1212FASOMGHG_doc.pdf.
[558] Skog, K, and G. Nicholson. 2000. Carbon Sequestration in Wood and Paper Products. In *The Impact of Climate Change on American Forests, Chapter 5,* L. Joyce and R. Birdsey, eds. USDA Forest Service, General Technical Report RMRS-GTR-59, Chap. 5:79-88.
[559] Skog, K, and G. Nicholson. 2000. Carbon Sequestration in Wood and Paper Products. In *The Impact of Climate Change on American Forests, Chapter 5,* L. Joyce and R. Birdsey, eds. USDA Forest Service, General Technical Report RMRS-GTR-59, Chap. 5:79-88.
[560] Source: Adams, D., R. Alig, B.A. McCarl, and B.C. Murray. 2005. "FASOMGHG Conceptual Structure and Specification: Documentation." Available at http://agecon2.tamu.edu/people/faculty/ mccarl-bruce/papers/1212FASOMGHG_doc.pdf.
[561] Source: Adams, D., R. Alig, B.A. McCarl, and B.C. Murray. 2005. "FASOMGHG Conceptual Structure and Specification: Documentation." Available at http://agecon2.tamu.edu/people/faculty/ mccarl-bruce/papers/1212FASOMGHG_doc.pdf.
[562] Smith, W.B., J.S. Vissage, D.R. Darr, and R.M. Sheffield. 2001. Forest Resources of the United States, 1997. US Forest Service General Technical Report NC-219. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Research Station.
[563] Smith, J. and L.S. Heath. 2002. A Model of Forest Floor Carbon Mass for United States Forest Types. Newton Square, PA: USDA Forest Service.
[564] Ramankutty, N., A. T. Evan, C. Monfreda, and J. A. Foley (2008), Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000, Global Biogeochem. Cycles, 22, GB1003, doi:10.1029/2007GB002952.
[565] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National
Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds)., Ch. 10

[566] Global cattle density (2005): The Gridded Livestock of the World FAO (2007). Predicted-2005 (adjusted to match FAOSTAT 2005 national totals). http://kids.fao.org/glipha/
[567] Ramankutty et al., 2008
[568] MODIS/Terra Land Cover Type Yearly L3 Global 1km SIN Grid (MOD12Q1) version 4
[569] Friedl, M.A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A., Huang, X., 2010, MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets, Remote Sensing of Environment, 114: 168-182
[570] ICF International, Inc. 2009. Biofuels Stochastic International Land Use Lifecycle Analysis Model. Report submitted to U.S. EPA
[571] Friedl, Mark, Validation of the Consistent-Year V003 MODIS Land Cover Product, MODIS Land Team Internal PI Document, http://landval.gsfc.nasa.gov/Results.php?TitleID=mod12_valsup1, accessed December 2009
[572] ICF International, Inc. 2009. Biofuels Stochastic International Land Use Lifecycle Analysis Model. Report submitted to U.S. EPA
[573] ICF International, Inc. 2009. Biofuels Stochastic International Land Use Lifecycle Analysis Model. Report submitted to U.S. EPA
[574] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National
Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).
Published: IGES, Japan.
[575] Harris, NL, S. Grimland and S. Brown. 2009. Land Use Change and Emission Factors: Updates since Proposed RFS Rule. Report submitted to EPA.
[576] U.S. EPA. 2009. Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program. EPA-420-D-09-001
[577] Ruesch, A. and H.K. Gibbs. 2008. New IPCC Tier-1 Global Biomass Carbon Map For the Year 2000. Available online from the Carbon Dioxide Information Analysis Center [http://cdiac.ornl.gov], Oak Ridge National Laboratory, Oak Ridge, Tennessee.
[578] Saatchi, S.S., N.L. Harris, S. Brown, M. Lefsky and S. Petrova. New benchmark map of tropical forest carbon stocks. In preparation, Science.
[579] Mokany, K., R.J. Raison, and A.S. Prokushkin. 2006. Critical analysis of root:shoot ratios in terrestrial biomes. Global Change Biology 12: 84-96.
[580] Brown, S. L.R. Iverson and A. Prasad. 2001. Geographical distribution of biomass carbon in tropical southeast Asian forests: a database. Available at http://cdiac.ornl.gov/epubs/ndp/ndp068/ndp068.html from the Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee. NDP-068.
[581] Myneni, R.B., D. Jong, C.J. Tucker, R.K. Kaufmann, P.E. Kauppi, J. Liski, L. Zhou, V. Alexeyev, and M.K. Hughes. 2001. A large carbon sink in the woody biomass of Northern forests. PNAS 98: 14784-14789.
[582] Blackard, J.A., M.V. Finco, E.H. Helmer, G.R. Holden, M.L. Hoppus, D.M. Jacobs, A.J. Lister, G.G. Moisen, M.D. Nelson, R. Riemann, B. Ruefenacht, D. Salajanu, D.L. Weyermann, K.C. Winterberger, T.J.
[583] Brandeis, R.L. Czaplewski, R.E. McRoberts, P.L. Patterson, and R.P. Tymcio. 2008. Mapping U.S. forest biomass using nationwide forest inventory data and moderate resolution information. Remote Sensing of Environment 112: 1658-1677.

[584] Houghton, R.A., D. Butman, A.G. Bunn, O.N. Krankina, P. Schlesinger and T.A. Stone. 2007. Mapping Russian forest biomass with data from satellites and forest inventories. Environmental Research Letters 2:
045032.
[585] Nabuurs, G.J., M.J. Schelhaas, G.M.J. Mohren, C.B. Field. 2003. Temporal evolution of the European forest sector carbon sink from 1950 to 1999. Global Change Biology 9: 152-160.
[586] Piao, S., J. Fang, B. Zhu, and K. Tan. 2005. Forest biomass carbon stocks in China over the past 2 decades: estimation based on integrated inventory and satellite data. Journal of Geophysical Research 110:
GO1006.
[587] Mokany, K., R.J. Raison, and A.S. Prokushkin. 2006. Critical analysis of root:shoot ratios in terrestrial biomes. Global Change Biology 12: 84-96.
[588] Amaral W. A. N., J.P. Marinho, R. Tarasantchi, A. Beber, and E. Giuliani. 2008, Environmental sustainability of sugarcane ethanol in Brazil. In: Zuurbier P.; van de Vooren J. (eds) Sugarcane ethanol: Contribution to climate change mitigation and the environment. Wageningen Academic, Wageningen, pp 121-124.
[589] Smith, D.M., N.G. Inman-Bamber and P.J. Thorburn. 2005. Growth and function of the sugarcane root system. Field Crops Research 92: 169-183.
[590] deCastro, E.A. and J.B. Kaufmann. 1998. Ecosystem structure in the Brazilian Cerrado: a vegetation gradient of aboveground biomass, root mass and consumption by fire. Journal of Tropical Ecology 14: 263-283.
[591] Coutinho, L.M. 1978. O conceito de Cerrado. Revista Brasileira de Botanica 1: 17-23.
[592] Eiten, G. 1972. The Cerrado vegetation of Brazil. Botanical Review 38: 201-341.
[593] Goodland, R. and Pollard. 1973. The Brazilian Cerrado vegetation: a fertility gradient. Journal of Ecology 61: 219-224.
[594] FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.
[595] Winjum, J.K., S. Brown and B. Schlamadinger. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. Forest Science 44: 272-284.
[596] PINGOUD, K, A.-L. PERÄLÄ and A. PUSSINEN. 2001. CARBON DYNAMICS IN WOOD PRODUCTS. Mitigation and Adaptation Strategies for Global Change 6: 91–111, Kluwer Academic Publishers. Printed in the Netherlands.
[597] Micales, J.A. and Skog, K.E.: 1997, 'The decomposition of forest products in landfills', Int. Biodet.Biodeg. 39(2), 145–158.
[598] Lewis, S.L., G. Lopez-Gonzalez, B. Sonké, K. Affum Bafoe, T.R. Baker, L.O. Ojo, O.L. Phillips, J.M. Reitsma, L. White, J.A. Comiskey, et al. 2009. Increasing carbon storage in intact African tropical forests. Nature 457: 1003-1006.
[599] Stehman, S. 1997, Estimating Standard Errors of Accuracy Assessment Statistics under Cluster Sampling, *Remote Sensing of the Environment*, (60): 258-269
[600] Macedo I.D.C., Leal M.R.L.V. and Seabra J.E.A. (2004) "Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil." Prepared for the State of Sao Paulo, Brazil.
[601] Macedo I.C., Seabra J.E.A., Silva J.E.A.R. (2008) "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020." Biomass and Bioenergy.

[602] Michael Wang, May Wu, Hong Huo and Jiahong Liu (2008) "Life-cycle energy use and greenhouse gas emissions implications of Brazilian sugarcane ethanol simulated with the GREET model." International Sugar Journal 2008, Vol. 110, No. 1317.

[603] UNICA. (August 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-1761.1

[604] Version 1.8c of the GREET model, released in March, 2009, was utilized to estimate GHG emissions associated with sugarcane transport. Information on this release can be found at: http://www.transportation.anl.gov/modeling_simulation/GREET/

[605] Davis, Ryan. November 2009. Techno-economic analysis of microalgae-derived biofuel production. National Renewable Energy Laboratory. Technical Memorandum to EPA.

[606] Ryan, Catie, "Cultivating Clean Energy: The Promise of Algae Biofuels," NRDC and Terrapin Bright Green, LLC. October 2009.

[607] Davis, Ryan. November 2009. Techno-economic analysis of microalgae-derived biofuel production. National Renewable Energy Laboratory. Technical Memorandum to EPA.

[608] A. Pradhan, D.S. Shrestha, A. McAloon, W. Yee, M. Haas, J.A. Duffield, H. Shapouri, September 2009, "Energy Life-Cycle Assessment of Soybean Biodiesel", United States Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses, Agricultural Economic Report Number 845

[609] Tao, Ling and Aden, Andy. November 2008. Techno-economic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR). National Renewable Energy Laboratory (NREL)

[610] Aden, Andy. September 2009. Mixed Alcohols from Woody Biomass – 2010, 2015, 2022. National Renewable Energy Laboratory (NREL)

[611] Davis, Ryan. August 2009. Techno-economic analysis of current technology for Fischer-Tropsch fuels. National Renewable Energy Laboratory (NREL)

[612] Aden, Andy. December 10, 2009. Feedstock Considerations and Impacts on Biorefining. National Renewable Energy Laboratory (NREL)

[613] Michael Wang, May Wu, Hong Huo and Jiahong Liu (2008) Life-cycle energy use and greenhouse gas emissions implications of Brazilian sugarcane ethanol simulated with the GREET model. International Sugar Journal 2008, Vol. 110, No. 1317.

[614] Macedo I.C., Seabra J.E.A., Silva J.E.A.R. (2008) "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020." Biomass and Bioenergy.

[615] Swain, R.L., Molecular sieve dehydrators. How they became the industry standard and how they work. Chapter 19, Alcohol Textbook.

[616] Kaminski, W. (2008) Renewable energy source- Dehydrated ethanol. Chemical Engineering Journal 135: 95-102.

[617] Roy, Suzanne. Fuel Production: Using membrane integration for plant expansion. Vaperma handout.

[618] Vane, Leland. (2008). Separation technologies for the recovery and dehydration of alcohols from fermentation broths. Biofuels, Bioproducts, and Biorefining 2.6: 553-588.

[619] Kawaitkowski, J.R., McAloon, A., Taylor, F., Johnston, D.B., Modeling the process and costs of fuel ethanol production by the corn dry grind process. Industrial Crops and Products 23 (2006) 288-296. A copy of the current USDA model can be obtained by contacting the corresponding author. Model was adjusted based on conversations with technology providers.

[620] Fitch, George (2009) Caribbean Basin Ethanol Producers Group email correspondence, "Caribbean Basin Ethanol Dehydration Energy Usage and CO2 Emissions”.
[621] Fitch, George (2009) Caribbean Basin Ethanol Producers Group email correspondence, "Caribbean Basin Ethanol Dehydration Energy Usage and CO2 Emissions”.
[622] Fitch, George (2009) Caribbean Basin Ethanol Producers Group email correspondence, "Caribbean Basin Ethanol Dehydration Energy Usage and CO2 Emissions”.
[623] UNICA. (September 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-2137.1, pg. 21-29
[624] Government of Brazil, “Executive Summary-National Plan on Climate Change”, pg. 10.
[625] UNICA. (September 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-2137.1, pg. 28
[626] Version 1.8c of the GREET model, released in March, 2009, was utilized to estimate the GHG emissions associated with the transportation of domestic and imported ethanol. Information on this release can be found at: http://www.transportation.anl.gov/modeling_simulation/GREET/ The method used to estimate the GHG impacts associated with biodiesel transportation has not been changed since the proposal. This method utilized an earlier version of the GREET model.
[627] “Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints," prepared for EPA by Oak Ridge National Laboratory, March 2009. Data files that support this report are available in the docket.
[628] Energy Information Administration (EIA) historical company level ethanol and gasoline import data:
http://www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli_historical.html
[629] UNICA. (August 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-1761.1
[630] UNICA. (September 2009) Submission of comments document # EPA-HQ-OAR-2005-0161-2137.1
[631] https://www.gtap.agecon.purdue.edu. Accessed on January 14, 2010.
[632] See Burniaux, Jean-Marc & T. Truong, 2002. "GTAP-E: An Energy-Environmental Version of the GTAP Model," GTAP Technical Papers #16, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. Available at https://www.gtap.agecon.purdue.edu/resources/download/1203.pdf.
[633] See Lee H, Hertel T, Sohngen B, Ramankutty N. Towards an Integrated Land Use Data Base for Assessing the Potential for Greenhouse Gas Mitigation. GTAP Technical Paper # 25, Center for Global Trade Analysis, Purdue University: 2005. Available at https://www.gtap.agecon.purdue.edu/resources/download/2375.pdf
[634] See Birur D, Hertel T, Tyner W. Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis. GTAP Working Paper # 53, Department of Agricultural Economics, Purdue University. Available at https://www.gtap.agecon.purdue.edu/resources/download/4034.pdf.
[635] See Kløverpris J., H. Wenzel, and A. Nielsen (2008) “Life Cycle Inventory Modeling of Land Use Induced by Crop Consumption.” *International Journal of Life Cycle Analysis,* 13(1): 13-21.
[636] Lee, H.-L., T.W. Hertel, S. Rose and M. Avetisyan (2009) “An Integrated Global Land Use Data Base for CGE Analysis of Climate Change Policy Options.” Chapter 4 in T. Hertel, S. Rose and R. Tol (eds.) Economic Analysis of Land Use in Global Climate Policy, Routledge

Publishing, London, New York, pp: 72-88. Also available as GTAP Working Paper # 42 (2008), Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA. Available at: https://www.gtap.agecon.purdue.edu/resources/download/3673.pdf.

[637] See https://www.gtap.agecon.purdue.edu/models/cge_gtap_n.asp. Accessed on January 14, 2010.

[638] See http://www.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol1.pdf

[639] See Taheripour, Farzad, T.W. Hertel, W.E. Tyner, J. F. Beckman, and D.K. Birur (2009). "Biofuels and their By-Products: Global Economic and Environmental Implications." Biomass and Bioenergy, in press.

[640] See Taheripour et al, (2009).

[641] Villoria, Nelson and T. Hertel (2009). Geography Matters: International Trade Patterns and the Indirect
Land Use Effects of Biofuels. Under review at American Journal of Agricultural Economics.

[642] See Arndt, C. and K.R. Pearson (1998) "How to Carry Out Systematic Sensitivity Analysis via Gaussian Quadrature and GEMPACK." GTAP Technical Paper No. 3, Center for Global Trade Analysis, Purdue University, West Lafayette, IN. Available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=474; See also Keeney, Roman, and T.W. Hertel, The Indirect Land Use Impacts of United States Biofuel Policies: The Importance of Acreage, Yield, and Bilateral Trade Responses (2009-01). American Journal of Agricultural Economics, Vol. 91, Issue 4, pp. 895-909, November 2009. Available at SSRN: http://ssrn.com/abstract=1483971.

[643] See Keeney & Hertel (2009).

[644] See FAPRI (2004) "Documentation the FAPRI Modeling System." FAPRI-UMC Report #12-04, Food and Agricultural Policy Research Institute, Iowa State University, University of Missouri-Columbia, Ames, IA, USA. December 2004.

[645] These values are based on the 2008 Ahmed, Hertel, and Lubowski paper. See Ahmed, Syud Amer. T. Hertel & R. Lubowski, 2008. "Calibration of a Land Cover Supply Function Using Transition Probabilities," GTAP Research Memoranda 14, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. Available at https://www.gtap.agecon.purdue.edu/resources/download/4199.pdf.

[646] The MODerate resolution Imagin Spectoradiometer (MODIS) land Products (MCD12Q1) Land Cover Type Product (Land Cover Type 1), https://lpdaac.usgs.gov/lpdaac/products/modis_products_table/land_cover/yearly_l3_global_500_m/mcd12q1

[647]http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/TriDecadal_Global_Landsat_Orthorectified_Overview

[648] https://lpdaac.usgs.gov/lpdaac/get_data/data_pool

[649] Integrity Applications Incorporated. 2009. Renewable Fuel Lifecycle Analysis – High Resolution Land Use Change Analysis, Final Report, BPA-09-03/GS-23F-0076M

[650] Available in the docket, EPA-HQ-OAR-2005-0161, or on the NETL website at http://www.netl.doe.gov/energy-analyses/pubs/NETL%20LCA%20Petroleum-Based%20Fuels%20Nov%202008.pdf

[651] Alex D. Charpentier, Joule A. Bergerson and Heather L. MacLean, "Understanding the Canadian Oil Sands Industry's Greenhouse Gas Emissions," Environmental Research Letters 4 (2009).

[652] International Energy Outlook 2007, Report #:DOE/EIA-0484(2007), Release Date: May 2007, Tables G1 and G3.
[653] U.S. EPA 2008, Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA 430-R-08-005), Tables 3-23 and3-24 http://www.epa.gov/climatechange/emissions/usinventoryreport.html
[654] U.S. EPA 2008, Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA 430-R-08-005), Table ES-1 http://www.epa.gov/climatechange/emissions/usinventoryreport.html
[655] Department of Energy: National Energy Technology Laboratory. 2009. NETL: Petroleum-Based Fuels Life Cycle Greenhouse Gas Analysis - 2005 Baseline Model. www.netl.doe.gov/energy-analyses.
[656] IPCC WGI, 2007.
[657] "Summary of recent findings for fuel effects of a 10% ethanol blend on light duty exhaust emissions", Memo from Aron Butler to Docket EPA-HQ-OAR-2005-0161.
[658] "MOVES runs performed to support RFS2 final rule emission inventories", Memo from John Koupal to Docket EPA-HQ-OAR-2005-0161
[659] MOVES (Motor Vehicle Emission Simulator) http://www.epa.gov/otaq/models/moves/index.htm
[660] U. S. EPA. 2007. Final Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources; EPA420-R-07-002; Office of Transportation and Air Quality, Ann Arbor, MI. http://www.epa.gov/otaq/toxics.htm
[661] U. S. EPA. 2007. Regulatory Impact Analysis: Renewable Fuel Standard Program; EPA420-R-07-004; Office of Transportation and Air Quality, Ann Arbor, MI. http://www.epa.gov/otaq/renewablefuels/index.htm
[662] Overview Presentation to CRC on EPACT Testing (September 2008)
[663] CRC E-74b report
[664] Haskew, Harold M., Thomas F. Liberty and Dennis McClement, "Fuel Permeation from Automotive Systems," Final Report, for the Coordinating Research Council and the California Air Resources Board, CRC Project E-65, September 2004. Available in Docket EPA-HQ-OAR-2005-0161.
[665] "Analysis of ethanol evaporative permeation effects from CRC E-77 and E-65 programs", Memo from David Hawkins to Docket EPA-HQ-OAR-2005-0161
[666] Southwest Research Institute. 2007. Flex Fuel Vehicles (FFVs) VOC/PM Cold Temperature Characterization When Operating on Ethanol (E10, E70, E85). Prepared for U. S. Environmental Protection Agency. Available in Docket EPA-HQ-OAR-2005-0161.
[667] Environment Canada. 2007. Comparison of Emissions from Conventional and Flexible Fuel Vehicles Operating on Gasoline and E85 Fuels. ERM Report No. 05-039, Emissions Research Division. Available in Docket EPA-HQ-OAR-2005-0161.
[668] EPA Certification and Fuel Economy Information System. http://www.epa.gov/otaq/cfeis.htm
[669] Southwest Research Institute. 2007. Flex Fuel Vehicles (FFVs) VOC/PM Cold Temperature Characterization When Operating on Ethanol (E10, E70, E85). Prepared for U. S. Environmental Protection Agency. Available in Docket EPA-HQ-OAR-2005-0161.
[670] Graham, L. A.; Belisle, S. L. and C. Baas. 2008. Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85. Atmos. Environ. 42: 4498-4516.
[671] Environment Canada. 2007. Comparison of Emissions from Conventional and Flexible Fuel Vehicles Operating on Gasoline and E85 Fuels. ERM Report No. 05-039, Emissions Research Division. Available in Docket EPA-HQ-OAR-2005-0161.

[672] Auto/Oil Air Quality Improvement Research Program. 1996. Phase I and II Test Data. Prepared by Systems Applications International, Inc.
[673] U.S. EPA, 2007. Modeling of Ethanol Blend Effects on Nonroad Fuel Hose and Tank Permeation. Memorandum from Craig Harvey, U. S. EPA, March 26, 2007.
[674] U.S. EPA. 2008. Work Plan for Work Assignment 1-07, Amendment 1, "Ethanol Evaluation on Non-road Engines," Contract EP-C-07-028, October 3, 2008.
[675] U.S. EPA. 2008. Work Plan for Work Assignment 1-07, Amendment 2, "Ethanol Evaluation on Nonroad Engines," Contract EP-C-07-028, October 22, 2008.
[676] "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated," National Renewable Energy Laboratory, NREL/TP-540-43543, ORNL/TM-2008/117, February 2009.
[677] U.S. EPA, 2008. Control of Emissions From Nonroad Spark-Ignition Engines and Equipment; Final Rule, 73 FR 59034, Oct. 8, 2008.
[678] U.S. EPA, 2008. Biodiesel Effects on Heavy-Duty Highway Engines and Vehicles; Office of Transportation and Air Quality, Ann Arbor, MI.
[679] U.S. EPA 2002 A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions: Draft Technical Report (EPA420-P-02-001)
[680] U.S. EPA, 2008. Development of MOVES Rates for HC, CO and NOx Exhaust Emissions from Light-duty Vehicles for use in the RFS2 NRPM, Memorandum from James Warila, U. S. EPA, November 2008.
[681] U.S. EPA. 2008. Kansas City Characterization Study: Final Report (EPA420-R-08-009) http://www.epa.gov/otaq/emission-factors-research/420r08009.pdf
[682] U.S. EPA. 2008. Analysis of Particulate Matter Emissions from Light-Duty Vehicles in Kansas City (EPA420-R-08-010) http://www.epa.gov/otaq/emission-factors-research/420r08010.pdf
[683] U.S. EPA, 2008. Modeling Evaporative Emissions in MOVES for the RFS2 NPRM. Memorandum from Prashanth Gururaja, U.S. EPA, November 2008.
[684] U.S. EPA. 2002. Technical Description of the Toxics Module for MOBILE6.2 and Guidance on Its Use for Emission Inventory Preparation. (EPA420-R-02-029) http://www.epa.gov/otaq/models/mobile6/r02029.pdf
[685] Details about NMIM are available at http://www.epa.gov/otaq/nmim.htm.
[686] Information about the 2005 NEI may be found at http://www.epa.gov/ttn/chief/net/2005inventory.html.
[687] Details concerning the Final Rule: Control of Emissions of Air Pollution from New Nonroad Spark-Ignition Engines, Equipment, and Vessels may be found at http://www.epa.gov/otaq/equip-ld.htm#.
[688] Sze, C., Whinihan, J., Olson, B., Schenk, C., Sobotowski, R. Impact of Test Cycle and Biodiesel Concentration of Emissions, SAE report 2007-01-4040 (2007).
[689] U. S. EPA. 2007. Final Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources; EPA420-R-07-002; Office of Transportation and Air Quality, Ann Arbor, MI. http://www.epa.gov/otaq/toxics.htm
[690] Landman, L. C. (2007) Estimating Emissions Associated with Portable Fuel Containers (PFCs). U. S. EPA, Assessment and Standards Division, National Vehicle and Fuel Emissions Laboratory, Ann Arbor, MI, Report No. EPA420-R-07-001. http://www.epa.gov/otaq/toxics.htm

[691] U. S. EPA. 2007. Regulatory Impact Analysis: Renewable Fuel Standard Program; EPA420-R-07-004; Office of Transportation and Air Quality, Ann Arbor, MI. http://www.epa.gov/otaq/renewablefuels/index.htm

[692] U. S. EPA. 1993. Final Regulatory Impact Analysis for Reformulated Gasoline. December 13, 1993. http://www.epa.gov/otaq/regs/fuels/rfg/

[693] Haskew, H. M.; Liberty, T. F.; McClement, D. 2004. Fuel Permeation from Automotive Systems. Prepared for the Coordinating Research Council by Harold Haskew and Associates and Automotive Testing Laboratories, Inc. September 2004. CRC Project No. E-65. http://www.crcao.com. This document is available in Docket EPA-HQ-OAR-2005-0036.

[694] Hester, Charles. 2006. Review of Data on HAP Content in Gasoline. Memorandum from MACTEC to Steve Shedd, U. S. EPA, March 23, 2006. This document is available in Docket EPA-HQ-OAR-2003-0053.

[695] U. S. EPA. 2006. Determination that Gasoline Distribution Stage 1 Area Source (GD AS) Category Does Not Need to Be Regulated Under Section 112(c)6. Memoradum from Stephen Shedd to Kent Hustvedt, May 9, 2006. This document is available in Docket EPA-HQ-OAR-2005-0036.

[696] U. S. EPA. SPECIATE Version 4.0. http://www.epa.gov/ttn/chief/software/speciate/index.html

[697] Haskew, H. M., Liberty, T. F., McClement, D. 2004. Fuel Permeation from Automotive Systems. Report No. CRC E-65, Prepared for California Air Resources Board and Coordinating Research Council. http://www.crcao.org/

[698] United States Department of Agriculture, Amber Waves, February 2004, page 9, U.S. Increasingly Imports Nitrogen and Potash Fertilizer. http://www.ers.usda.gov/amberwaves/February04/

[699] Wen Huang, United States Department of Agriculture, Economic Research Service, personal communication to Craig Harvey, US EPA, November 9, 2007.

[700] U.S. EPA. 2009. RFS2 Final Fuel Production/Distribution Emission Impacts Calculation Spreadsheet, 12/23/2009.

[701] 40 CFR Part 63 National Emission Standards for Hazardous Air Pollutants for Source Categories: Gasoline Distribution Bulk Terminals, Bulk Plants, Pipeline Facilities, and Gasoline Dispensing Facilities; Proposed Rule, Thursday, November 9, 2006, 66064-66092.

[702] E. H. Pechan. Documentation For The Final 2002 Nonpoint Sector (Feb 06 Version) National Emission Inventory For Criteria And Hazardous Air Pollutants, Appendix A, pp. A-89 to A-105. Prepared for Emissions Inventory and Analysis Group (C339-02) Air Quality Assessment Division Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711, Report No. 05.10.001/9014.401 Jul-06. Available at ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/2002nei_final_nonpoint_documentation0206version.pdf.

[703] Energy Information Administration. 2007. Product Supplied, Petroleum Supply Reporting System. http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm

[704] EPA. 1994. Final Regulatory Impact Analysis: Refueling Emission Regulations for Light Duty Vehicles and Trucks and Heavy Duty Vehicles. Office of Mobile Sources, Ann Arbor, MI. Available at http://www.epa.gov/otaq/orvr.htm.

[705] U. S. EPA. 2001. Final Rule: Control of Air Pollution From New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, January 18, 2001.
[706] U. S. EPA. 2008. Final Rule: Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder, Regulatory Impact Analysis, June 30, 2008.
http://www.epa.gov/otaq/locomotv.htm
[707] U.S. EPA. 2008. RFS2 Modified version of GREET1.7 Upstream Emissions Spreadsheet, October 31, 2008.
[708] U.S. EPA. 2009. RFS2 FRM modified version of GREET1.8c Upstream Emissions Spreadsheet, October 30, 2009.
[709] Emission Inventories for Ocean-Going Vessels Using Category 3 Propulsion Engines In or Near the United States, Draft Technical Support Document, EPA420-D-07-007, December 2007. This is available in Docket OAR-2007-0121at http://www.regulations.gov/ .
[710] U. S. EPA. 2009. National-Scale Air Toxics Assessment for 2002. http://www.epa.gov/ttn/atw/nata2002.
[711] U. S. EPA. 2007. Approach for Developing 2002 and Future Emission Summaries. Memorandum from Madeleine Strum to Docket, November 26, 2007. This document is available in Docket EPA-HQ-OAR-2007-0491.
[712] Federal Register. 2007. National Emission Standards for Hazardous Air Pollutants From Petroleum Refineries. 72(170): 50715-50742. http://www.epa.gov/EPA-AIR/2007/September/Day-04/a17009.htm.
[713] Energy Information Administration. 2007. Product Supplied, Petroleum Supply Reporting System. http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm
[714] Brady, D. and Pratt, G. C. 2007. Volatile Organic Compound Emissions from Dry Mill Fuel Ethanol Production. J. Air & Waste Manage. Assoc. 57: 1091-1102.
[715] Prevention of Significant Deterioration Construction Permit Application. Prepared for Verasun Fort Dodge, LLC, Fort Dodge Iowa, by Barr, Minneapolis, MN, December, 2007.
[716] See Chapter 1.5 of the Draft Regulatory Impact Assessment of this rulemaking.
[717]U. S. EPA. 2007. Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. Federal Register, 72: 8428-8570.
[718] U. S. EPA. 2007. Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program; Final Rule. Federal Register, 72: 23900-24014.
[719] U. S. EPA. 2007. Final Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources; EPA420-R-07-002; Office of Transportation and Air Quality, Ann Arbor, MI. http://www.epa.gov/otaq/toxics.htm
[720] Energy Information Adminstration. 1999. Petroleum Marketing Annual. Report No. DOE/EIA-0487(99).
http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_annual/historical/1999/pma_1999.html
[721] Energy Information Administration. 2007. Annual Energy Outlook 2007 with Projections to 2030. U.S. Department of Energy, Report # DOE/EIA-0383.
http://www.eia.doe.gov/oiaf/aeo/index.html
[722] U. S. EPA. SPECIATE Version 4.0.
http://www.epa.gov/ttn/chief/software/speciate/index.html

[723] [723] Auto/Oil Air Quality Improvement Research Program. 1996. Phase I and II Test Data. Prepared by Systems Applications International, Inc.
[724] Diesel Locomotives, Marine Distillate, Residual Boiler -- E. H. Pechan. 2005. Documentation For Aircraft, Commercial Marine Vessel, Locomotive, And Other Nonroad Components Of The National Emissions Inventory, Volume I - Methodology.
Prepared for U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/chief/net/2002inventory.html
[725] HDD Trucks -- R. Cook, E. Glover. 2002. Technical Description of the Toxics Module for MOBILE6.2 and Guidance on Its Use for Emission Inventory Preparation. U. S. Environmental Protection Agency, Office of Transportation and Air Quality. Report No. EPA420-R-02-011. http://www.epa.gov/otaq/m6.htm
[726] Natural Gas Turbines -- U. S. EPA. 2000. AP-42, 5th Edition, Volume 1. Chapter 3: Stationary Internal Combustion Sources. http://www.epa.gov/ttn/chief/ap42/ch03/index.html
[727] U.S. EPA. 2010. "RFS2 Emissions Inventory for Air Quality Modeling Technical Support Document," January 2010.
[728] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints," Oak Ridge National Laboratory, U.S. Department of Energy, March 2009.
[729] U.S. EPA. 2009. spreadsheet tool, "2022 Ethanol Vapor Losses during Transport" 12/4/2009.
[730] U.S. EPA. 2008. spreadsheet tool, "Ethanol Transport/Distribution VOC Emissions for RFS2 2022 AQ Modeling: RFS1 Case," 12/15/2008.
[731] U.S. EPA. 2008. spreadsheet tool, "Ethanol Transport/Distribution VOC Emissions for RFS2 2022 AQ Modeling: AEO Case," 12/11/2008.
[732] U.S. EPA. 2008. spreadsheet tool, "Ethanol Transport/Distribution VOC Emissions for RFS2 2022 AQ Modeling: EISA (RFS2) Case," 12/15/2008.
[733] U. S. EPA. 2008. AP-42, 5th Edition, Volume 1. Chapter 5.2: Transportation And Marketing Of Petroleum Liquids, July 2008.
[734] U.S. EPA. 2009. "Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines (Chapter 3: Emission Inventory)," EPA-420-D-09-002, June 2009.
[735] U.S. Army Corps of Engineers Principal Ports file for 2006 (PPORTS06.xls)
[736] U.S. EPA. 2008. Spreadsheet file: "RFS2 Ethanol Usage & Constraint Analysis Inputs.6.23.08.xls"
[737] "Annual Energy Outlook 2008," Table 7 (Transportation Sector Key Indicators and Delivered Energy Consumption), DOE/EIA-0383(2008), June 2008.
[738] The three cases and their corresponding Excel files are as follows:
RFS1: County_To_CountyRefNew_RFS1_1116.xls
AEO: County_To_CountyRefOld_1113R2.xls
EISA: County_To_County2022_Controlled_1114.xls
[739] U.S. EPA. 2009. "Ethanol Plant inventory inputs for RFS2 2005 AQ model run," Spreadsheet file: "Corn_EtOH_Plant_Inv_2005c.xls"
[740] U.S. EPA. 2009. "Ethanol Plant inventory inputs for RFS2 2022 RFS1 reference case AQ model run," Spreadsheet file: "Corn_EtOH_Plant_Inv_2022-rfs1-fixC.xls"
[741] U.S. EPA. 2009. "Ethanol Plant inventory inputs for RFS2 2022 AEO reference case AQ model run," Spreadsheet file: "Corn_EtOH_Plant_Inv_2022-aeo-fixC.xls"

[742] U.S. EPA. 2009. "Ethanol Plant inventory inputs for RFS2 2022 EISA reference case AQ model run," Spreadsheet file: "Corn_EtOH_Plant_Inv_2022-eisa-fixC.xls"
[743] U.S. EPA. 2009. Spreadsheet file: Cellulosic Ethanol Plant inventory inputs for RFS2 2022 EISA control case AQ model run," 2/25/2009.
[744] U.S. EPA. 2009. "Biodiesel Plant inventory inputs for RFS2 2022 RFS1 reference AQ model run," Spreadsheet file: "Biodsl_Plant_Inv_2022-rfs1-fixC.xls," 2/25/2009.
[745] U.S. EPA. 2009. "Biodiesel Plant inventory inputs for RFS2 2022 AEO reference AQ model run," Spreadsheet file: Biodsl_Plant_Inv_2022-aeo-fixC.xls," 2/25/2009.
[746] U.S. EPA. 2009. "Biodiesel Plant inventory inputs for RFS2 2022 EISA control case AQ model run," Spreadsheet file: Biodsl_Plant_Inv_2022-eisa-fixC.xls," 2/25/2009.
[747] U.S. EPA. 2008. "Agricultural SCCs and Emissions Affected by RFS2 in Air Quality Modeling," spreadsheet file: "otaq_upstream_2020cc_2020ce_2005ag_tox-docket.xls" 11/5/2008.
[748] U.S. EPA. 2008. "Refinery Emission Adjustments for RFS2 Air Quality Modeling," spreadsheet file: "RFS2_Refinery_Adjust-docket.xls," 11/25/2008.
[749] U.S. EPA. 2008. "Adjustments to 2022 Platform Gasoline transp & distrib emissions for RFS2 AQ," spreadsheet file: "2005ai_tox_SCC_50state_CAPHAP-20081216.xls" 12/16/2008.
[750] See http://www.epa.gov/ttn/chief/emch/index.html#2002.
[751] Final Rule: Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder (published May 6, 2008 and republished June 30, 2008). For details, see http://www.epa.gov/otaq/locomotives.htm#2008final.
[752] U.S. EPA, 2010. NMIM and MOVES Runs for RFS2 Air Quality Modeling: Memorandum, January 2010.
[753] Details concerning the Final Rule: Control of Emissions of Air Pollution from New Nonroad Spark-Ignition Engines, Equipment, and Vessels may be found at http://www.epa.gov/otaq/equip-ld.htm#.
[754] Sze, C., Whinihan, J., Olson, B., Schenk, C., Sobotowski, R. Impact of Test Cycle and Biodiesel Concentration of Emissions, SAE report 2007-01-4040 (2007).
[755] Byun, D.W., Ching, J. K.S. (1999). *Science algorithms of the EPA models-3 community multiscale air quality (CMAQ) modeling system*. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.
[756] Byun, D.W., Schere, K.L. (2006). Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. *Journal of Applied Mechanics Reviews, 59(2),* 51-77.
[757] Dennis, R.L., Byun, D.W., Novak, J.H., Galluppi, K.J., Coats, C.J., and Vouk, M.A. (1996). The next generation of integrated air quality modeling: EPA's Models-3, *Atmospheric Environment, 30,* 1925-1938.
[758] Hogrefe, C., Biswas, J., Lynn, B., Civerolo, K., Ku, J.Y., Rosenthal, J., et al. (2004). Simulating regional-scale ozone climatology over the eastern United States: model evaluation results. *Atmospheric Environment, 38(17),* 2627-2638.
[759] Lin, M., Oki, T., Holloway, T., Streets, D.G., Bengtsson, M., Kanae, S. (2008). Long-range transport of acidifying substances in East Asia-Part I: Model evaluation and sensitivity studies. *Atmospheric Environment, 42(24),* 5939-5955.

[760] United States Environmental Protection Agency. (2008). *Technical support document for the final locomotive/marine rule: Air quality modeling analyses*. Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division.
[761] Grell, G., Dudhia, J., Stauffer, D. (1994). *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR*., 138 pp, National Center for Atmospheric Research, Boulder CO.
[762] Grell, G., Dudhia, J., Stauffer, D. (1994). *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR*., 138 pp, National Center for Atmospheric Research, Boulder CO.
[763] U.S. Environmental Protection Agency, Byun, D.W., and Ching, J.K.S., Eds, 1999. *Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ) modeling system*, EPA/600/R-99/030, Office of Research and Development). Please also see: http://www.cmascenter.org/
[764] Yantosca, B. (2004). *GEOS-CHEMv7-01-02 User's Guide*, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, October 15, 2004.
[765] U.S. EPA, (2004), *Procedures for Estimating Future PM2.5 Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)- Updated 11/8/04*.
[766] U.S. EPA, (2008), *Control of Emissions from Nonroad Spark-Ignition Engines and Equipment, Technical Support Document*. EPA 454/R-08-005
[767] U.S. EPA (2007) *Guidance on the Use of Models and Other Analyses For Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze;* EPA-454/B-07-002; Research Triangle Park, NC; April 2007.
[768] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the US EPA, RT-0400675, December 8, 2005. http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf.
[769] 74 FR 24904. Regulation of fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. Notice of Proposed Rulemaking.
[770] Dodge, M.C., 2000. Chemical oxidant mechanisms for air quality modeling: critical review. Atmospheric Environment 34, 2103-2130.
[771] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[772] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[773] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.

[774] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[775] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html.
[776] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html.
[777] Yarwood, G., Rao, S., Yocke, M., Whitten, G.Z., 2005. Updates to the Carbon Bond Mechanism: CB05. Final Report to the US EPA, RT-0400675. Yocke and Company, Novato, CA.
[778] Luecken, D.J., Phillips, S., Sarwar, G., Jang, C., 2008b. Effects of using the CB05 vs. SAPRC99 vs. CB4 chemical mechanism on model predictions: Ozone and gas-phase photochemical precursor concentrations. Atmospheric Environment 42, 5805-5820.
[779] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory.
[780] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory.
[781] Atkinson R, Arey J (2003) Atmospheric Degradation of Volatile Organic Compounds. Chem Rev 103: 4605-4638.
[782] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[783] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[784] Edney, E. O., T. E. Kleindienst, M. Lewandowski, and J. H. Offenberg, 2007. Updated SOA chemical mechanism for the Community Multi-Scale Air Quality model, EPA 600/X-07/025, U.S. EPA, Research Triangle Park, NC.
[785] Carlton, A.G., B. J. Turpin, K. Altieri, S. Seitzinger, R. Mathur, S. Roselle, R. J. Weber, (2008), CMAQ model performance enhanced when in-cloud SOA is included: comparisons of OC predictions with measurements, Environ. Sci. Technol. 42 (23), 8798–8802.

[786] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html

[787] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location, Atmos Environ 41(37):8288-8300.

[788] Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of Toluene and -pinene to SOA Formed in an Irradiated Toluene/ -pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976.

[789] Pandis, S.N., Harley, R.A., Cass, G.R., Seinfeld, J.H. (1992) Secondary organic aerosol formation and transport. Atmos Environ 26, 2269–2282.

[790] H Takekawa, H Minoura, S Yamazaki (2003) Temperature dependence of secondary organic aerosol formation by photo-oxidation of hydrocarbons. Atmos Environ 37: 3413–3424.

[791] M J. Kleeman, Q Ying, Jin Lu, M J. Mysliwiec, R J. Griffin, Jianjun Chen, Simon Clegg (2007) Source apportionment of secondary organic aerosol during a severe photochemical smog episode. Atmos Environ 41: 576–591.

[792] Robinson, A. L.; Donahue, N. M.; Shrivastava, M.; Weitkamp, E. A.; Sage, A. M.; Grieshop, A. P.; Lane, T. E.; Pierce, J. R.; Pandis, S. N. (2007) Rethinking organic aerosol: Semivolatile emissions and photochemical aging. Science 315: 1259-1262.

[793] Byun DW, Schere, KL (2006) Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, J Applied Mechanics Reviews 59: 51-76.

[794] U. S. EPA (2002) National Air Quality and Emissions Trends Report, 2001. EPA 454/K-02-001, September 2002. http://www.epa.gov/air/airtrends/aqtrnd01/summary.pdf

[795] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html

[796] U. S. EPA (2007) Regulatory Impact Analysis for the Control of Hazardous Air Pollutants from Mobile Sources Rule, Chapter 3, Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources. 72 FR 8428, February 26, 2007. http://www.epa.gov/otaq/regs/toxics/420r07002.pdf

[797] TE Kleindienst (2008) Hypothetical SOA Production from Ethanol Photooxidation. Memo to the Docket EPA-HQ-OAR-2005-0161.

[798] BJ Turpin, JJ Huntzicker, SM Larson, GR Cass (1991) Los Angeles Summer Midday Particulate Carbon: Primary and Secondary Aerosol. Environ Sci Technol 25: 1788-1793.

[799] BJ Turpin, JJ Huntzicker (1995) Identification of Secondary Organic Aerosol Episodes and Quantitation of Primary and Secondary Organic Aerosol Concentrations During SCAQS. Atmos Environ 29(23): 3527-3544.

[800] Bae M-S, Schauer JJ, Turner JR (2006) Estimation of the Monthly Average Ratios of Organic Mass to Organic Carbon for Fine Particulate Matter at an Urban Site, Aerosol Sci Technol 40(12): 1123-1139. http://dx.doi.org/10.1080/02786820601004085.

[801] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300.

[802] Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of Toluene and -pinene to SOA Formed in an Irradiated Toluene/ -pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976.
[803] Claeys M, R Szmigielski, I Kourtchev, P Van der Veken, R Vermeylen, W Maenhaut, M Jaoui, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2007) Hydroxydicarboxylic acids: Markers for secondary organic aerosol from the photooxidation of -pinene. Environ Sci Technol 41(5): 1628-1634.
[804] Edney EO, TE Kleindienst, M Jaoui, M Lewandowski, JH Offenberg, W Wang, M Claeys (2005) Formation of 2-methyl tetrols and 2-methylglyceric acid in secondary organic aerosol from laboratory irradiated isoprene/NO_X/SO_2/air mixtures and their detection in ambient $PM_{2.5}$ samples collected in the Eastern United States. Atmos Environ 39: 5281-5289.
[805] Jaoui M, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2005) Identification and quantification of aerosol polar oxygenated compounds bearing carboxylic or hydroxyl groups. 2. Organic tracer compounds from monoterpenes. Environ Sci Technol 39: 5661-5673.
[806] Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implications in ambient $PM_{2.5}$. J Atmos Chem 47: 70-100.
[807] Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implication in ambient $PM_{2.5}$, J Atmos Chem 47: 70-100.
[808] Izumi L, T Fukuyama (1990) Photochemical aerosol formation from aromatic hydrocarbons in the presence of NO_x, Atmos Environ 24A: 1433.
[809] Martin-Reviego M, K Wirtz (2005) Is benzene a precursor for secondary organic aerosol? Environ Sci Technol 39: 1045-1054.
[810]Ng, N. L., Kroll, J. H., Chan, A. W. H., Chabra, P. S., Flagan, R. C., Seinfield, J. H., Secondary organic aerosol formation from *m*-xylene, toluene, and benzene, Atmospheric Chemistry and Physics Discussion, 7, 3909-3922, 2007.
[811] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309.
http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html.
[812] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300.
[813] Henze DK, JH Seinfeld (2006) Global secondary organic aerosol from isoprene oxidation. Geophys Res Lett 33: L09812. doi:10.1029/2006GL025976.
[814] Henze DK.;J Seinfeld (2006) Global secondary organic aerosol from isoprene oxidation. Geophys. Res. Lett 33 L09812. doi:10.1029/2006GL025976.
[815] Jaoui M, M Lewandowski, TE Kleindienst, JH Offenberg, EO Edney (2007) β - Caryophyllinic acid: An atmospheric tracer for β-caryophyllene secondary organic aerosol. Geophys Res Lett 34: L05816. doi:10.1029/2006GL028827.
[816] Griffin RJ, DR Cocker III, RC Flagan, JH Seinfeld (1999) Organic aerosol formation from oxidation of biogenic hydrocarbons, J Geophys Res 104: 3555-3567.

[817] Ng NL, JH Kroll, AWH Chan, PS Chabra, RC Flagan, JH Seinfeld (2007) Secondary organic aerosol formation from m-xylene, toluene, and benzene. Atmos Chem Phys 7: 3909-3922.
[818] Hildebrandt1, L., Donahue1, N. M, Pandis1, S. N. (2009) High formation of secondary organic aerosol from the photo-oxidation of toluene. Atmos Chem Phys 9: 2973-2986.
[819] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[820] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory. http://jpldataeval.jpl.nasa.gov/index.html.
[821] Finlayson-Pitts BJ, Pitts JN Jr. (1986) Atmospheric Chemistry: Fundamentals and Experimental Techniques, Wiley, New York.
[822] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the US EPA, RT-0400675, December 8, 2005. http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf.
[823] EPA (2009). Exhaust Emission Profiles for EPA SPECIATE Database: Engery Policy Act (EPAct) Low-Level Ethanol Fuel Blends and Tier 2 Light-Duty Vehicles. EPA-20-R-09-002, June 2009.
[824] http://www.epa.gov/ttn/chief/software/speciate/
[825] Ewell, .H., Harrison J.M., and Berg, L., (1944), Azeotropic distillation, Industrial and Engineering Chemistry, 40, 3, 871.
[826] Skolnik, H., (1948), Correlation of azeotropic data, Industrial and Engineering Chemistry, 40, 3, 442.
[827] U.S. EPA. 2010. Hydrocarbon Composition of Gasoline Vapor Emissions from Enclosed Fuel Tanks. Draft Report EPA-420-D-10-001, January 2010.
[828] U.S. EPA. 2010. Hydrocarbon Composition of Gasoline Vapor Emissions from Enclosed Fuel Tanks. Draft Report EPA-420-D-10-001, January 2010.
[829] http://www.cmascenter.org/help/model_docs/cmaq/4.7/RELEASE_NOTES.txt
[830] "Summary of recent findings for fuel effects of a 10% ethanol blend on light duty exhaust emissions", Memo from Aron Butler to Docket EPA-HQ-OAR-2005-0161
[831] Hannigan, Michael P., William F. Busby, Jr., Glen R. Cass (2005) Source Contributions to the Mutagenicity of Urban Particulate Air Pollution. J Air Waste Mgmt 55: 399-410.
[832] Zheng M, GR Cass, JJ Schauer, ES Edgerton (2002) Source Apportionment of $PM_{2.5}$ in the Southeastern United States Using Solvent-Extractable Organic Compounds as Tracers. Environ Sci Technol 36: 2631-2371.
[833] U.S. EPA (2002) National Air Quality and Emission Trends Report, 2001. EPA 454/K-02-001, September 2002. http://www.epa.gov/air/airtrends/aqtrnd01/summary.pdf
[834] Schauer JJ, GR Cass (2000) Source Apportionment of Wintertime Gas-Phase and Particle-Phase Air Pollutants Using Organic Compounds as Tracers, Environ Sci Technol 34(9): 1821-1832. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2000/34/i09/pdf/es981312t.pdf

[835] Kleeman MJ, GR Cass (1999) Identifying the Effect of Individual Emission Sources on Particulate Air Quality Within a Photochemical Aerosol Processes Trajectory Model. Atmos Environ 33: 4597-4613.
[836] Watson J, Fujita E, Chow J, Zielinska B, Richards L, Neff W, Dietrich D (1998) Northern Front Range Air Quality Study Final Report: Volume 1. June 30, 1998. For Colorado State University, Cooperative Institute for Research in the Atmosphere, by Desert Research Institute, Reno, NV. This document is available in EPA Docket EPA-HQ-OAR-2005-0161.
[837] Schauer JJ, WF Rogge, LM Hildemann, MA Mazurek, GR Cass, B Simoneit (1996) Source Apportionment of Airborne Particulate Matter Using Organic Compounds as Tracers. Atmos Environ 30: 3837-3855.
[838] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.
[839] Niven, R. (2005) Ethanol in Gasoline: environmental impacts and sustainability review article. Renewable & Sustainable Energy Reviews 9: 535-555.
[840] U. S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007.
[841] U. S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007.
[842] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/
[843] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html
[844] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/
[845] U. S. Environmental Protection Agency (2009). Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program. Assessment and Standards Division, Office of Transportation and Air Quality, Ann Arbor, MI. Report No. EPA-420-D-09-001. http://www.epa.gov/otaq/renewablefuels/420d09001.pdf
[846] Anderson LG, Lanning JA, Wilkes E, Wolfe P, Jones RH (1997) Effects of Using Oxygenated Fuels on Carbon Monoxide, Formaldehyde and Acetaldehyde Concentrations in Denver. Paper 97-RP139.05, Air & Waste Management Association 90th Annual Meeting & Exhibition, June 8-13, 1997, Toronto, Ontario, Canada.
[847] Jeffrey S. Gaffney, Nancy A. Marley, Randal S. Martin, Roy W. Dixon, Luis G. Reyes, and Carl J. Popp (1997) Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ Sci Technol 31(11): 3053 - 3061; DOI: 10.1021/es9610388.
[848] Allen P, R Bradley, BE Croes, J DaMassa, R Effa, M Fuentes, A Hebert, D Luo, R Vincent, L Woodhouse, E Yang (1999) Analysis of the Air Quality Impacts of the Use of Ethanol in Gasoline. California Air Resources Board, November 18, 1999.
[849] U.S. EPA. 2010. Hydrocarbon Composition of Gasoline Vapor Emissions from Enclosed Fuel Tanks. Draft Report EPA-420-D-10-001, January 2010.
[850] "Summary of recent findings for fuel effects of a 10% ethanol blend on light duty exhaust emissions", Memo from Aron Butler to Docket EPA-HQ-OAR-2005-0161

[851] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/02pdfs/health_effects.pdf

[852] U.S. EPA. U.S. EPA's 2008 Report on the Environment (Final Report). U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-07/045F Available electronically from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=190806. Date accessed 12/31/09

[853] Anderson LG, Lanning JA, Wilkes E, Wolfe P, Jones RH (1997) Effects of Using Oxygenated Fuels on Carbon Monoxide, Formaldehyde and Acetaldehyde Concentrations in Denver. Paper 97-RP139.05, Air & Waste Management Association 90th Annual Meeting & Exhibition, June 8-13, 1997, Toronto, Ontario, Canada.

[854] Anderson, L.G., P. Wolfe, R.A. Barrell, and J.A. Lanning (1994) "The Effects of Oxygenated Fuels on the Atmospheric Concentrations of Carbon Monoxide and Aldehydes in Colorado," In Alternative Fuels and the Environment, Lewis Publishers, Boca Raton, Florida, pp. 75 103.

[855] Anderson, Larry G., Lanning, John A., Barrell, R., Miyagishima, Joyce, and Jones, Richard (1996) Sources and sinks of formaldehyde and acetaldhde: an analysis of Denver's ambient concentration data, Atmospheric Environment, 12, 2113-2133.

[856] Altshuller, A. P. 1993. Production of Aldehydes as Primary Emissions and from Secondary Atmospheric Reactions of Alkenes and Alkanes During the Night and Early Morning Hours. Office of Research and Development, Research Triangle Park, North Carolina. Report No. EPA--600/J-93/467.

[857] Altshuller A. P. (1991a) Chemical reactions and transport of alkanes and their products in the troposphere. J. Atmos. Chem. 12, 19-61.

[858] Altshuller A. P. (1991b) Estimating product yields of carbon-containing products from the atmospheric photooxidation of ambient air alkenes. J. Atmos. Chem. 13, 131-154.

[859] Jeffrey S. Gaffney, Nancy A. Marley, Randal S. Martin, Roy W. Dixon, Luis G. Reyes, and Carl J. Popp (1997) Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ Sci Technol 31(11): 3053 - 3061; DOI: 10.1021/es9610388.

[860] Gaffney, J.S., N.A. Marley, R.S. Martin, R.W. Dixon, L.G. Reyes, and C.J. Popp (1998) Response to Comment on 'Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ. Sci.Technol., 32**:** 3842-3833.

[861] Grosjean D (1999) Ambient levels of peroxyacetyl nitrate in southern California, Report from DGA, Inc., Ventura, CA to California Air Resources Board, Sacramento, CA, Agreement 99-703, Draft, August 31.

[862] Allen P, R Bradley, BE Croes, J DaMassa, R Effa, M Fuentes, A Hebert, D Luo, R Vincent, L Woodhouse, E Yang (1999) Analysis of the Air Quality Impacts of the Use of Ethanol in Gasoline. California Air Resources Board, November 18, 1999.

[863] Jacobson M (2007) Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States, Environ Sci Technol 41: 4150-4157.

[864] Grosjean D (1997) Atmospheric Chemistry of Alcohols. J Braz Chem Soc 8(4): 433-442.

[865] Andrade JB de, Andrade MV, Pinheiro HLC (1998) Atmospheric levels of formaldehyde and acetaldehyde and their relationship with the vehicular fleet composition in Salvador, Bahia, Brazil. J Braz Chem Soc 9(3): 219-223.

[866] Montero L, Vasconcellos PC, Souza SR, Pires MAF, Sanchez-Ccoyllo OR, Andrade MF, Carvalho LRF (2001) Measurements of Atmospheric Carboxylic Acids and Carbonyl Compounds in Sao Paulo City, Brazil. Environ Sci Technol 35: 3071-3081.

[867] Colon M, Pleil JD, Hartlage TA, Guardani ML, Martins MH (2001) Survey of volatile organic compounds associated with automotive emissions in the urban airshed of Sao Paulo, Brazil. Atmos Environ 35: 4017–4031.
[868] Tanner R, Miguel A, deAndrade J, Gaffney J, Streit G (1988) Atmospheric Chemistry of Aldehydes, Enhanced Peroxyacetyl Nitrate Formation from Ethanol-Fueled Vehicles. Envion Sci Technol 22(9): 1026-1037.
[869] Grosjean E, Grosjean D, Woodhouse L, Yang Y, (2002) Peroxyacetyl nitrate and peroxypropionyl nitrate in Porto Alegre, Brazil, Atmos Environ 36: 2405-2419.
[870] Grosjean D, Grosjean E, Moreira LFR (2002) Speciated Ambient Carbonyls in Rio de Janeiro, Brazil. Environ Sci Technol 36: 1389-1395.
[871] EM Martins, G Arbilla (2003) Computer modeling study of ethanol and aldehyde reactivities in Rio de Janeiro urban air. Atmos Environ 37: 1715–1722.
[872] Niven, R. (2005) Ethanol in Gasoline: environmental impacts and sustainability review article. Renewable & Sustainable Energy Reviews 9: 535-555.
[873] Kleindienst, T. E., W.A. Lonnman (2009) Chamber irradiations to measure acetaldehyde concentrations from fuels with and without 10% ethanol, EPA memo.
[874] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf. Section 2.2.
[875] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.
[876] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf.
[877] U.S. EPA. (2006). *Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure*. EPA/600/R-06/063. Retrieved on March 19, 2009 from http://www.epa.gov/air/particlepollution/pdfs/ord_report_20060720.pdf.
[878] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-305.
[879] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 9-93.
[880] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.3.1.
[881] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Table 8-34.
[882] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.1.3.4.

[883] U.S. EPA. (2006). *National Ambient Air Quality Standards for Particulate Matter*. 71 FR 61144, October 17, 2006.
[884] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.4.
[885] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-85.
[886] Laden, F., Neas, L.M., Dockery D.W., et al. (2000). Association of fine particulate matter from different sources with daily mortality in six U.S. cities. *Environ Health Perspectives, 108(10),* 941-947.
[887] Schwartz, J., Laden, F. Zanobetti, A. (2002). The concentration-response relation between PM(2.5) and daily deaths. *Environ Health Perspect, 110(10),* 1025-1029.
[888] Mar, T.F., Ito, K., Koenig, J.Q., Larson, T.V., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Neas, L., Stölzel, M., Paatero, P., Hopke, P.K., Thurston, G.D. (2006). PM source apportionment and health effects. 3. Investigation of inter-method variations in associations between estimated source contributions of PM2.5 and daily mortality in Phoenix, AZ. *J. Exposure Anal. Environ. Epidemiol, 16,* 311-320.
[889] Ito, K., Christensen, W.F., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Larson, T.V., Neas, L., Hopke, P.K., Thurston, G.D. (2006). PM source apportionment and health effects: 2. An investigation of intermethod variability in associations between source-apportioned fine particle mass and daily mortality in Washington, DC. *J. Exposure Anal. Environ. Epidemiol., 16,* 300-310.
[890] Janssen N.A., Schwartz J., Zanobetti A., et al. (2002). Air conditioning and source-specific particles as modifiers of the effect of PM10 on hospital admissions for heart and lung disease. *Environ Health Perspect, 110(1),* 43-49.
[891] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-307.
[892] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-313, 8-314.
[893] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p.8-318.
[894] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-306.
[895] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf. p.3-18.
[896] Dockery, D.W., Pope, C.A. III, Xu, X, et al. (1993). An association between air pollution and mortality in six U.S. cities. *N Engl J Med, 329,*1753-1759. Retrieved on March 19, 2009 from http://content.nejm.org/cgi/content/full/329/24/1753.

[897] Pope, C.A., III, Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W., Jr. (1995). Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *Am. J. Respir. Crit. Care Med, 151*, 669-674.
[898] Pope, C. A., III, Burnett, R.T., Thun, M. J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc, 287*,1132-1141.
[899] Krewski, D., Burnett, R.T., Goldberg, M.S., et al. (2000). *Reanalysis of the Harvard Six Cities study and the American Cancer Society study of particulate air pollution and mortality*. A special report of the Institute's Particle Epidemiology Reanalysis Project. Cambridge, MA: Health Effects Institute. Retrieved on March 19, 2009 from http://es.epa.gov/ncer/science/pm/hei/Rean-ExecSumm.pdf
[900] Jerrett, M., Burnett, R.T., Ma, R., et al. (2005). Spatial Analysis of Air Pollution and Mortality in Los Angeles. *Epidemiology, 16(6)*,727-736.
[901] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter. Volume I* EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 9.2.2.1.2.
[902] Künzli, N., Jerrett, M., Mack, W.J., et al. (2005). Ambient air pollution and atherosclerosis in Los Angeles. *Environ Health Perspect.,113*,201-206
[903] Riediker, M.; Cascio, W.E.; Griggs, T.R.; et al. 2004. "Particulate matter exposure in cars is associated with cardiovascular effects in healthy young men." Am J Respir Crit Care Med 169: 934-940.
[904] Maynard, D.; Coull, B.A.; Gryparis, A.; Schwartz, J. (2007) Mortality risk associated with short-term exposure to traffic particles and sulfates. Environmental Health Perspectives 115: 751-755.
[905] Ryan, P.H.; LeMasters, G.K.; Biswas, P.; Levin, L.; Hu, S.; Lindsey, M.; Bernstein, D.I.; Lockey, J.; Villareal, M.; Khurana Hershey, G.K.; Grinshpun, S.A. (2007) A comparison of proximity and land use regression traffic exposure models and wheezing in infants. Environ Health Perspect 115: 278-84.
[906] Morgenstern, V.; Zutavern, A.; Cyrys, J.; Brockow, I.; Gehring, U.; Koletzko, S.; Bauer, C.P.; Reinhart, D; Wichmann, H-E.; Heinrich, J. (2007) Respiratory health and individual estimated expousure to traffic-related air pollutant in a cohort of young children. Occupational and Environmental Medicine 64: 8-16.
[907] Franco Suglia, S.; Gryparis, A.; Wright, R.O.; Schwartz, J.; Wright, R.J. (2007) Association of black carbon with cognition among children in a prospective birth cohort study. American Journal of Epidemiology 167: 280-286.
[908] U.S. EPA. (2006*). Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.
[909] U.S. EPA. (2007*). Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-07-003. Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.
[910] National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution*. The National Academies Press: Washington, D.C.

[911] Bates, D.V., Baker-Anderson, M., Sizto, R. (1990). Asthma attack periodicity: a study of hospital emergency visits in Vancouver. *Environ. Res., 51*,51-70.
[912] Thurston, G.D., Ito, K., Kinney, P.L., Lippmann, M. (1992). A multi-year study of air pollution and respiratory hospital admissions in three New York State metropolitan areas: results for 1988 and 1989 summers. *J. Exposure Anal. Environ. Epidemiol, 2*,429-450.
[913] Thurston, G.D., Ito, K., Hayes, C.G., Bates, D.V., Lippmann, M. (1994) Respiratory hospital admissions and summertime haze air pollution in Toronto, Ontario: consideration of the role of acid aerosols. *Environ. Res., 65,* 271-290.
[914] Lipfert, F.W., Hammerstrom, T. (1992). Temporal patterns in air pollution and hospital admissions. *Environ. Res., 59*,374-399.
[915] Burnett, R.T., Dales, R.E., Raizenne, M.E., Krewski, D., Summers, P.W., Roberts, G.R., Raad-Young, M., Dann,T., Brook, J. (1994). Effects of low ambient levels of ozone and sulfates on the frequency of respiratory admissions to Ontario hospitals. *Environ. Res., 65*, 172-194.
[916] U.S. EPA. (2006*). Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.
[917] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.
[918] Devlin, R. B., McDonnell, W. F., Mann, R., Becker, S., House, D. E., Schreinemachers, D., Koren, H. S. (1991). Exposure of humans to ambient levels of ozone for 6.6 hours causes cellullar and biochemical changes in the lung. *Am. J. Respir. Cell Mol. Biol., 4,* 72-81.
[919] Koren, H. S., Devlin, R. B., Becker, S., Perez, R., McDonnell, W. F. (1991). Time-dependent changes of markers associated with inflammation in the lungs of humans exposed to ambient levels of ozone. *Toxicol. Pathol., 19*, 406-411.
[920] Koren, H. S., Devlin, R. B., Graham, D. E., Mann, R., McGee, M. P., Horstman, D. H., Kozumbo, W. J., Becker, S., House, D. E., McDonnell, W. F., Bromberg, P. A. (1989). Ozone-induced inflammation in the lower airways of human subjects. *Am. Rev. Respir. Dis., 39,* 407-415.
[921] Schelegle, E.S., Siefkin, A.D., McDonald, R.J. (1991). Time course of ozone-induced neutrophilia in normal humans. *Am. Rev. Respir. Dis., 143*,1353-1358.
[922] U.S. EPA. (1996). *Air Quality Criteria for Ozone and Related Photochemical Oxidants*. EPA600-P-93-004aF. Washington. D.C.: U.S. EPA. Retrieved on March 19, 2009 from EPA-HQ-OAR-2005-0161. p. 7-171.
[923] Hodgkin, J.E., Abbey, D.E., Euler, G.L., Magie, A.R. (1984). COPD prevalence in nonsmokers in high and low photochemical air pollution areas. *Chest, 86*, 830-838.
[924] Euler, G.L., Abbey, D.E., Hodgkin, J.E., Magie, A.R. (1988). Chronic obstructive pulmonary disease symptom effects of long-term cumulative exposure to ambient levels of total oxidants and nitrogen dioxide in California Seventh-day Adventist residents. *Arch. Environ. Health, 43*, 279-285.
[925] Abbey, D.E., Petersen, F., Mills, P.K., Beeson, W.L. (1993). Long-term ambient concentrations of total suspended particulates, ozone, and sulfur dioxide and respiratory symptoms in a nonsmoking population. *Arch. Environ. Health, 48*, 33-46.
[926] U.S. EPA. (2007). *Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-07-003.

Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[927] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[928] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[929] Avol, E.L., Trim, S. C., Little, D.E., Spier, C.E., Smith, M. N., Peng, R.-C., Linn, W.S., Hackney, J.D., Gross, K.B., D'Arcy, J.B., Gibbons, D., Higgins, I.T.T. (1990 June). *Ozone exposure and lung function in children attending a southern California summer camp*. Paper no. 90-150.3. Paper presented at the 83rd annual meeting and exhibition of the Air & Waste Management Association, Pittsburgh, PA.

[930] Higgins, I. T.T., D'Arcy, J. B., Gibbons, D. I., Avol, E. L., Gross, K.B. (1990). Effect of exposures to ambient ozone on ventilatory lung function in children. *Am. Rev. Respir. Dis., 141*, 1136-1146.

[931] Raizenne, M.E., Burnett, R.T., Stern, B., Franklin, C.A., Spengler, J.D. (1989) Acute lung function responses to ambient acid aerosol exposures in children. *Environ. Health Perspect., 79,*179-185.

[932] Raizenne, M.; Stern, B.; Burnett, R.; Spengler, J. (1987 June) *Acute respiratory function and transported air pollutants: observational studies*. Paper no. 87-32.6. Paper presented at the 80th annual meeting of the Air Pollution Control Association, New York, NY.

[933] Spektor, D. M., Lippmann, M. (1991). Health effects of ambient ozone on healthy children at a summer camp. In: Berglund, R. L.; Lawson, D. R.; McKee, D. J., eds. *Tropospheric ozone and the environment: papers from an international conference*; March 1990; Los Angeles, CA. Pittsburgh, PA: Air & Waste Management Association; pp. 83-89. (A&WMA transaction series no. TR-19).

[934] Spektor, D. M., Thurston, G.D., Mao, J., He, D., Hayes, C., Lippmann, M. (1991). Effects of single- and multiday ozone exposures on respiratory function in active normal children. *Environ. Res, 55,*107-122.

[935] Spektor, D. M., Lippman, M., Lioy, P. J., Thurston, G. D., Citak, K., James, D. J., Bock, N., Speizer, F. E., Hayes, C. (1988). Effects of ambient ozone on respiratory function in active, normal children. *Am. Rev. Respir. Dis., 137*, 313-320.

[936] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[937] Hazucha, M. J., Folinsbee, L. J., Seal, E., Jr. (1992). Effects of steady-state and variable ozone concentration profiles on pulmonary function. *Am. Rev. Respir. Dis., 146,* 1487-1493.

[938] Horstman, D.H., Ball, B.A., Folinsbee, L.J., Brown, J., Gerrity, T. (1995) Comparison of pulmonary responses of asthmatic and nonasthmatic subjects performing light exercise while exposed to a low level of ozone. *Toxicol. Ind. Health., 11(4),* 369-85.

[939] Horstman, D.H.,; Folinsbee, L.J., Ives, P.J., Abdul-Salaam, S., McDonnell, W.F. (1990). Ozone concentration and pulmonary response relationships for 6.6-hour exposures with five hours of moderate exercise to 0.08, 0.10, and 0.12 ppm. *Am. Rev. Respir. Dis., 142*, 1158-1163.

[940] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[941] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[942] Coburn, R.F. (1979) Mechanisms of carbon monoxide toxicity. Prev. Med. 8:310-322.

[943] Helfaer, M.A., and Traystman, R.J. (1996) Cerebrovascular effects of carbon monoxide. In: Carbon Monoxide (Penney, D.G., ed). Boca Raton, CRC Press, 69-86.

[944] Benignus, V.A. (1994) Behavioral effects of carbon monoxide: meta analyses and extrapolations. J. Appl. Physiol. 76:1310-1316.

[945] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[946] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[947] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[948] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[949] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html

[950] U.S. EPA (2007) Control of Hazardous Air Pollutants from Mobile Sources. 72 FR 8428; February 26, 2007.

[951] U.S. EPA (2003) Integrated Risk Information System File of Acrolein. National Center for Environmental Assessment, Office of Research and Development, Washington, D.C. 2003. This material is available electronically at http://www.epa.gov/iris/subst/0364.htm.

[952] U.S. EPA (2009) National-Scale Air Toxics Assessment for 2002. This material is available electronically at http://www.epa.gov/ttn/atw/nata2002/risksum.html.

[953] U.S. EPA (2009) National-Scale Air Toxics Assessment for 2002. http://www.epa.gov/ttn/atw/nata2002.
[954] U.S. EPA. 2000. Integrated Risk Information System File for Benzene. This material is available electronically at: http://www.epa.gov/iris/subst/0276.htm.
[955] International Agency for Research on Cancer, IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France, p. 345-389, 1982.
[956] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. (1992) Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691-3695.
[957] International Agency for Research on Cancer (IARC). 1987. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Supplement 7, Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France.
[958] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.
[959] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193-197.
[960] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541-554.
[961] Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes (1996) Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236-246.
[962] U.S. EPA 2002 Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at http://www.epa.gov/iris/subst/0276.htm.
[963] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003). HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China.
[964] Qu, Q., R. Shore, G. Li, X. Jin, L.C. Chen, B. Cohen, et al. (2002). Hematological changes among Chinese workers with a broad range of benzene exposures. Am. J. Industr. Med. 42: 275-285.
[965] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004). Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774-1776.
[966] Turtletaub, K.W. and Mani, C. (2003). Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No.113.
[967] U.S. EPA. 2002. Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600-P-98-001F. This document is available electronically at http://www.epa.gov/iris/supdocs/buta-sup.pdf.
[968] U.S. EPA. 2002 "Full IRIS Summary for 1,3-butadiene (CASRN 106-99-0)" Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development,

National Center for Environmental Assessment, Washington, DC http://www.epa.gov/iris/subst/0139.htm.

[969] International Agency for Research on Cancer (IARC) (1999) Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide and Volume 97 (in preparation), World Health Organization, Lyon, France.

[970] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[971] Bevan, C.; Stadler, J.C.; Elliot, G.S.; et al. (1996) Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1-10.

972 International Agency for Research on Cancer (IARC). 1988. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 44, Alcohol Drinking, World Health Organization, Lyon, France.

[973] U.S. Department of Health and Human Services. 2005. National Toxicology Program 11th Report on Carcinogens available at: ntp.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932.

[974] U.S. Department of Health and Human Services. 2000. 10th Special Report to the U.S. Congress on Alcohol and Health. June. 2000.

[975] Goodlett CR, KH Horn, F Zhou. 2005. Alcohol teratogeniesis: mechanisms of damage and strategies for intervention. Exp. Biol. Med. 230:394-406.

[976] Riley EP, CL McGee. 2005. Fetal alcohol spectrum disorders: an overview with emphasis on changes in brain and behavior. Exp. Biol. Med. 230:357-365.

[977] Zhang X, JH Sliwowska, J Weinberg. 2005. Prenatal alcohol exposure and fetal programming: effects on neuroendocrine and immune function. Exp. Biol. Med. 230:376-388.

[978] Riley EP, CL McGee, ER Sowell. 2004. Teratogenic effects of alcohol: a decade of brain imaging. Am. J. Med. Genet. Part C: Semin. Med. Genet. 127:35-41.

[979] Gunzerath L, V Faden, S Zakhari, K Warren. 2004. National Institute on Alcohol Abuse and Alcoholism report on moderate drinking. Alcohol. Clin. Exp. Res. 28:829-847.

[980] World Health Organization (WHO). 2004. Global status report on alcohol 2004. Geneva, Switzerland: Department of Mental Health and Substance Abuse. Available: http://www.who.int/substance_abuse/publications/global_status_report_2004_overview.pdf

[981] Chen W-JA, SE Maier, SE Parnell, FR West. 2003. Alcohol and the developing brain: neuroanatomical studies. Alcohol Res. Health 27:174-180.

[982] Driscoll CD, AP Streissguth, EP Riley. 1990. Prenatal alcohol exposure comparability of effects in humans and animal models. Neurotoxicol. Teratol. 12:231-238.

[983] U.S. EPA. 1987. Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde, Office of Pesticides and Toxic Substances, April 1987.

[984] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615-1623.

[985] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117-1130.

[986] Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in

formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751-761.
[987] Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193-200.
[988] Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608-1615.
[989] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2003. Biologically motivated computational modeling of formaldehyde carcinogenicity in the F344 rat. Tox Sci 75: 432-447.
[990] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2004. Human respiratory tract cancer risks of inhaled formaldehyde: Dose-response predictions derived from biologically-motivated computational modeling of a combined rodent and human dataset. Tox Sci 82: 279-296.
[991] Chemical Industry Institute of Toxicology (CIIT).1999. Formaldehyde: Hazard characterization and dose-response assessment for carcinogenicity by the route of inhalation. CIIT, September 28, 1999. Research Triangle Park, NC.
[992] U.S. EPA. Analysis of the Sensitivity and Uncertainty in 2-Stage Clonal Growth Models for Formaldehyde with Relevance to Other Biologically-Based Dose Response (BBDR) Models. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-08/103, 2008
[993] Subramaniam, R; Chen, C; Crump, K; .et .al. (2008) Uncertainties in biologically-based modeling of formaldehyde-induced cancer risk: identification of key issues. Risk Anal 28(4):907-923.
[994] Subramaniam, R; Chen, C; Crump, K; .et .al. (2007). Uncertainties in the CIIT 2-stage model for formaldehyde-induced nasal cancer in the F344 rat: a limited sensitivity analysis-I. Risk Anal 27:1237
[995] Crump, K; Chen, C; Fox, J; .et .al. (2008) Sensitivity analysis of biologically motivated model for formaldehyde-induced respiratory cancer in humans. Ann Occup Hyg 52:481-495.
[996] Crump, K; Chen, C; Fox, J; .et .al. (2008) Sensitivity analysis of biologically motivated model for formaldehyde-induced respiratory cancer in humans. Ann Occup Hyg 52:481-495.
[997] Subramaniam, R; Chen, C; Crump, K; .et .al. (2007). Uncertainties in the CIIT 2-stage model for formaldehyde-induced nasal cancer in the F344 rat: a limited sensitivity analysis-I. Risk Anal 27:1237
[998] International Agency for Research on Cancer (2006) Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Monographs Volume 88. World Health Organization, Lyon, France.
[999] Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/toxprofiles/tp111.html
[1000] WHO (2002) Concise International Chemical Assessment Document 40: Formaldehyde. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva.
[1001] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.

[1002] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.
[1003] International Agency for Research on Cancer (IARC). 1999. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France.
[1004] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.
[1005] U.S. EPA. 2003. Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0364.htm.
[1006] Appleman, L.M., R.A. Woutersen, and V.J. Feron. (1982). Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. Toxicology. 23: 293-297.
[1007] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. (1993) Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. Am. Rev. Respir.Dis.148(4 Pt 1): 940-943.
[1008] Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www.epa.gov/iris/subst/0364.htm
[1009] International Agency for Research on Cancer (IARC). 1995. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 63, Dry cleaning, some chlorinated solvents and other industrial chemicals, World Health Organization, Lyon, France.
[1010] Sim VM, Pattle RE. Effect of possible smog irritants on human subjects JAMA165: 1980-2010, 1957.
[1011] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. Available online at: http://www.epa.gov/ncea/iris.
[1012] Weber-Tschopp, A; Fischer, T; Gierer, R; et al. (1977) Experimentelle reizwirkungen von Acrolein auf den Menschen. Int Arch Occup Environ Hlth 40(2):117-130. In German
[1013] Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www.epa.gov/iris/subst/0364.htm
[1014] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. Available online at: http://www.epa.gov/ncea/iris.
[1015] Morris JB, Symanowicz PT, Olsen JE, et al. 2003. Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563-1571.
[1016] U.S. EPA. 2006. Air quality criteria for ozone and related photochemical oxidants (Ozone CD). Research Triangle Park, NC: National Center for Environmental Assessment; report no. EPA/600/R-05/004aF-cF.3v. page 5-78 Available at http://cfpub.epa.gov/ncea/.
[1017] U.S. EPA Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, D.C., EPA 600/R-05/004aF-cF, 2006. page 5-

63. This document is available in Docket EPA-HQ-OAR-2005-0161. This document may be accessed electronically at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_cd.html

[1018] U.S. EPA Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. Environmental Protection Agency, Washington, D.C., EPA 600/R-05/004aF-cF, 2006. page 5-78. This document is available in Docket EPA-HQ-OAR-2005-0161. This document may be accessed electronically at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_cd.html

[1019] U. S. EPA. 2004. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0436.htm.

[1020] Oak Ridge Institute for Science and Education. (2004). External Peer Review for the IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene. August 2004. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=84403

[1021] National Toxicology Program (NTP). (2004). 11th Report on Carcinogens. Public Health Service, U.S. Department of Health and Human Services, Research Triangle Park, NC. Available from: http://ntp-server.niehs.nih.gov.

[1022] International Agency for Research on Cancer (IARC). (2002). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France.

[1023] U. S. EPA. 1998. Toxicological Review of Naphthalene, Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0436.htm

[1024] EPA. 2005. Full IRIS Summary for n-Hexane (CASRN 11054-3). Integrated Risk Information System (IRIS), Office of Research and Development, National Center for Environmental Assessment, Washington, DC. Available at www.epa.gov/iris/subst/0486.htm.

[1025] Inhalation health effect concerns for volatilized a.i. compounds are discussed for individual products, e.g., oxydimeton-methyl, carbaryl (and carbamates,generally), diazinon, at http://www.epa.gov/pesticides/reregistration/status.htm . A.I. vapor pressure and a discussion of product volatilization can be found at http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s02-2.pdf

[1026] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris

[1027] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-179.

[1028] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-236.

[1029] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-182.

[1030] Sisler, J.F. (1996) *Spatial and seasonal patterns and long term variability of the composition of the haze in the United States: an analysis of data from the IMPROVE network*. CIRA Report, ISSN 0737-5352-32, Colorado State University.

[1031] U.S. EPA (2004) Air Quality Criteria for Particulate Matter (Oct 2004), Volume I Document No. EPA600/P-99/002aF and Volume II Document No. EPA600/P-99/002bF. This document is available in Docket EPA-HQ-OAR-2005-0161.
[1032] U.S. EPA (2005) Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. EPA-452/R-05-005. This document is available in Docket EPA-HQ-OAR-2005-0161.
[1033] U.S. EPA, 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur-Ecological Criteria (Final). U.S. EPA, Washington D.C., EPA/600/R-08/082F.
[1034] Environmental Protection Agency (2003). Response Of Surface Water Chemistry to the Clean Air Act Amendments of 1990. National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Research Triangle Park, NC. EPA 620/R–03/001.
[1035] Fenn, M.E. and Blubaugh, T.J. (2005) Winter Deposition of Nitrogen and Sulfur in the Eastern Columbia River Gorge National Scenic Area, USDA Forest Service.
[1036] Galloway, J. N.; Cowling, E. B. (2002). Reactive nitrogen and the world: 200 years of change. Ambio 31: 64–71.
[1037] Bricker, Suzanne B., et al., National Estuarine Eutrophication Assessment, Effects of Nutrient Enrichment in the Nation's Estuaries, National Ocean Service, National Oceanic and Atmospheric Administration, September, 1999.
[1038] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1039] Winner, W.E., and C.J. Atkinson. 1986. "Absorption of air pollution by plants, and consequences for growth." Trends in Ecology and Evolution 1:15-18.
[1040] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1041] Tingey, D.T., and Taylor, G.E. 1982. "Variation in plant response to ozone: a conceptual model of physiological events." In: Effects of Gaseous Air Pollution in Agriculture and Horticulture (Unsworth, M.H., Omrod, D.P., eds.) London, UK: Butterworth Scientific, pp.113-138.
[1042] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1043] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.
[1044] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1045] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.

[1046] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1047] Ollinger, S.V., J.D. Aber and P.B. Reich. 1997. "Simulating ozone effects on forest productivity: interactions between leaf canopy and stand level processes." Ecological Applications 7:1237-1251.
[1048] Winner, W.E., 1994. "Mechanistic analysis of plant responses to air pollution." Ecological Applications, 4(4):651-661.
[1049] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1050] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1051] Fox, S., and R. A. Mickler, eds. 1996. Impact of Air Pollutants on Southern Pine Forests. Springer-Verlag, NY, Ecol. Studies, Vol. 118, 513 pp.
[1052] De Steiguer, J., J. Pye, C. Love. 1990. "Air Pollution Damage to U.S. Forests." Journal of Forestry, Vol 88 (8) pp. 17-22.
[1053] Pye, J.M. 1988. "Impact of ozone on the growth and yield of trees: A review." Journal of Environmental Quality 17 pp.347-360.
[1054] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1055] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1056] McBride, J.R., P.R. Miller, and R.D. Laven. 1985. "Effects of oxidant air pollutants on forest succession in the mixed conifer forest type of southern California." In: Air Pollutants Effects On Forest Ecosystems, Symposium Proceedings, St. P, 1985, p. 157-167.
[1057] Miller, P.R., O.C. Taylor, R.G. Wilhour. 1982. Oxidant air pollution effects on a western coniferous forest ecosystem. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory (EPA600-D-82-276).
[1058] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket EPA-HQ-OAR-2005-0161.
[1059] Kopp, R. J.; Vaughn, W. J.; Hazilla, M.; Carson, R. 1985. "Implications of environmental policy for U.S. agriculture: the case of ambient ozone standards." J. Environ. Manage. 20:321-331.
[1060] Adams, R. M.; Hamilton, S. A.; McCarl, B. A. 1986. "The benefits of pollution control: the case of ozone and U.S. agriculture." Am. J. Agric. Econ. 34: 3-19.
[1061] Adams, R. M.; Glyer, J. D.; Johnson, S. L.; McCarl, B. A. 1989. "A reassessment of the economic effects of ozone on U.S. agriculture." JAPCA 39:960-968.
[1062] Abt Associates, Inc. 1995. Urban ornamental plants: sensitivity to ozone and potential economic losses. U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park. Under contract to RADIAN Corporation, contract no. 68-D3-0033, WA no. 6. pp. 9-10.

[1063] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.This document is available in Docket EPA-HQ-OAR-2005-0036

[1064] Grulke, N.E. (2003). The physiological basis of ozone injury assessment attributes in Sierran conifers. In A. Bytnerowicz, M.J. Arbaugh, & R. Alonso (Eds.), *Ozone air pollution in the Sierra Nevada: Distribution and effects on forests*. (pp. 55-81). New York, NY: Elsevier Science, Ltd.

[1065] White, D., Kimerling, A.J., Overton, W.S. (1992). Cartographic and geometric component of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems, 19*, 5-22.

[1066] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[1067] White, D., Kimerling, A.J., Overton, W.S. (1992). Cartographic and geometric component of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems, 19,* 5-22.

[1068] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[1069] Coulston, J.W., Riitters, K.H., Smith, G.C. (2004). A preliminary assessment of the Montréal process indicators of air pollution for the United States. *Environmental Monitoring and Assessment, 95,* 57-74.

[1070] U.S. EPA (United States Environmental Protection Agency). 2006. *Air quality criteria for ozone and related photochemical oxidants*. EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>

[1071] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[1072] U.S. EPA (United States Environmental Protection Agency). 2006. *Air quality criteria for ozone and related photochemical oxidants*. EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>

[1073] US EPA. (2207) *Review of the National Ambient Air Quality Standards for Ozone: Policy assessment of scientific and technical information*. Office of Air Quality Planning and Standards staff paper. EPA-452/R-07-003.

[1074] Chappelka, A.H., Samuelson, L.J. (1998). Ambient ozone effects on forest trees of the eastern United States: a review. New Phytologist, 139, 91-108.

[1075] Nouchi I, S Toyama. 1998. Effects of ozone and peroxyacetyl nitrate on polar lipids and fatty acids in leaves of morning glory and kidney bean. Plant Physiol. 87:638-646.

[1076] Oka E, Y Tagami, T Oohashi, N Kondo. 2004. A physiological and morphological study on the injury caused by exposure to the air pollutant, peroxyacetyl nitrate (PAN), based on the quantitative assessment of the injury. J Plant Res. 117:27-36.

[1077] Sun E-J, M-H Huang. 1995. Detection of peroxyacetyl nitrate at phytotoxic level and its effects on vegetation in Taiwan. Atmos. Env. 29:2899-2904.

[1078] Koukol J, WM Dugger, Jr., RL Palmer. 1967. Inhibitory effect of peroxyacetyl nitrate on cyclic photophosphorylation by chloroplasts from black valentine bean leaves. Plant Physiol. 42:1419-1422.

[1079] Thompson CR, G Kats. 1975. Effects of ambient concentrations of peroxyacetyl nitrate on navel orange trees. Env. Sci. Technol. 9:35-38.
[1080] Bytnerowicz A, ME Fenn. 1995. Nitrogen deposition in California forests: A Review. Environ. Pollut. 92:127-146.
[1081] US EPA. 1991. Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3-91/001.
[1082] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.
[1083] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.
[1084] Viskari E-L. 2000. Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327-337.
[1085] Ugrekhelidze D, F Korte, G Kvesitadze. 1997. Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24-29.
[1086] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. 1987. Toxic components of motor vehicle emissions for the spruce Pciea abies. Environ. Pollut. 48:235-243.
[1087] Kwaitkowski, J.R., McAloon, A., Taylor, F., Johnston, D.B., Modeling the process and costs of fuel ethanol production by the corn dry-grind process. *Industrial Crops and Products* 23 (2006) 288-296. A copy of the current USDA model can be obtained by contacting the corresponding author.
[1088] See Tables 4.1-21 and 4.1-22 of this section for biomass costs. Coal costs taken from EIA Annual Energy Outlook 2008 Table 15.
[1089] Bioenergy Feedstock Characteristics from Jonathan Scurlock, Oak Ridge National Laboratories, available at http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html (accessed October 1, 2008)
[1090] Gallagher, P.W., Brubaker, H., and Shapouri, H. "Plant Size: Capital Cost Relationships in the Dry Mill Ethanol Industry," *Biomass and Bioenergy* Vol. 28. 2005. Pp. 565-7.
[1091] Isben, Kelly. Opportunities to add cellulosic feedstocks to the corn dry milling industry. Subcontractor to NREL. Technical Monitors: Mike Cleary and Andy Aden. Received December 2, 2009.
[1092] Corn Stover Collection Project, David A. Glassner, National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401, James R. Hettenhaus, Chief Executive Assistance, 3211 Trefoil Ave, Charlotte, NC 28226, and Thomas M. Schechinger, Iron Horse Custom Farming, 816 Iron Horse Rd, Harlan, IA 51537; in BioEnergy '98: Expanding BioEnergy Partnerships
[1093] Abhijith Mukunda, Graduate Student School of Industrial Engineering, Purdue University, West Lafayette IN 47907, Klein E Ileleji, Assistant Professor, School of Agricultural & Biological Engineering, Purdue University, West Lafayette IN 47907, Hong Wan, Assistant Professor, School of Industrial Engineering, Purdue University, West Lafayette IN47906, Simulation of Corn Stover Logistics from On-farm Storage to an Ethanol Plant, Paper Number: 0661772006, ASABE Annual International Meeting, Portland Convention Center, Portland, Oregon, 9 - 12 July 2006
[1094] Shahab Sokhansanj, , Anthony Turhollow, Oak Ridge National Laboratory, North Logan, UT 84341-8804, Janet Cushman, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6422,

John Cundiff, Biological Systems Engineering, Virginia Technical University, Blacksburg, VA 24061-0303, Engineering aspects of collecting corn stover for bioenergy, Biomass and Bioenergy 23 (2002) 347 – 355; Received 15 October 2001; received in revised form 15 April 2002; accepted 3 May 2002; 2002 Published by Elsevier Science Ltd.

[1095] David A. Glassner, National Renewable Energy Laboratory, Golden, CO 80401, James R. Hettenhaus, Chief Executive Assistance, Charlotte, NC 28226, and Thomas M. Schechinger, Iron Horse Custom Farming, Harlan, IA 51537; Corn Stover Collection Project, in BioEnergy '98: Expanding BioEnergy Partnerships

[1096] J.E. Atchison, Atchison Consultants, Inc., J. R. Hettenhaus, Chief Executive Assistance, Inc. Charlotte, North Carolina, National Renewable Energy Laboratory Golden, Colorado, .Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting, March 2003.

[1097] Daniel R. Petrolia, Department of Applied Economics, College of Food, Agriculture, and Natural Resources Sciences, University of Minnesota, The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota, Staff Paper P06-12 August 2006

[1098] Renee Sayler & Kenneth Von Bargen, Principal Investigators, Feasibility of Corn Residue Collection in Kearney, Nebraska Area, for Western Regional Biomass Energy Program, Report of findings, by University of Nebraska-Lincoln, Industrial Agricultural Products Center, Lincoln, NE 68583, September 1993.

[1099] John S. Cundiff, Professor, Robert D. Grisso, Professor, Biological Systems Engineering Dept(MS 0303), Virginia Tech, Blacksburg, VA 24061, Hosein Shapouri, Senior Agricultural Economist, U.S.D.A., Office of Energy Policy and New Uses, Washington DC 20250-3815, Economic Analysis of two Receiving Facility Designs for a Bioenergy Plant, Paper Number: 076051,2007 ASABE Annual International Meeting, Sponsored by ASABE, Minneapolis Convention Center, Minneapolis, Minnesota, 17 - 20 June 2007

[1100] Kevin J. Shinners – Professor of Agricultural Engineering, Ben N. Binversie – Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Madison, WI, Philippe Savoie – Research Scientist, Agriculture and Agri-Food Canada, Quebec, Canada, Whole-Plant Corn Harvesting for Biomass: Comparison of Single-Pass and Multiple-Pass Harvest Systems, Paper Number: 036089 2003 ASAE Annual International Meeting, Sponsored by ASAE, Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003.

[1101] S. Sokhansanj1, A. Turhollow, and R. Perlack, Oak Ridge National Laboratory, Tennessee, USA 37830, Stochastic Modeling of Costs of Corn Stover Costs Delivered to an Intermediate Storage Facility, Paper Number: 024190, Presented at: 2002 ASAE Annual International Meeting / CIGR XVth World Congress, Sponsored by ASAE and CIGR, Hyatt Regency Chicago, Chicago, Illinois, USA, July 28-July 31, 2002

[1102] D. Montross, Associate Professor, Scott A. Shearer, Professor, Timothy S. Stombaugh, Associate Extension Professor, Stephen F. Higgins, Research Specialist, and Samuel G. McNeill, Associate Extension Professor, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, Kentucky; and Shahab Sokhansanj, Professor, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tennessee, Corn Stover Availability and Collection Efficiency Using Typical Hay Equipment, This article is published with the approval of the Director of the Kentucky Agricultural Experiment Station and

designated Paper No. 04-05-066. Transactions of the ASABE, Vol. 50(3): 705−711 – 2007 American Society of Agricultural and Biological Engineers, ISSN 0001−2351.
[1103] American Society of Agricultural and Biological Engineers (ASABE), ASABE Standards, 2007, 54th Edition, Standards, Engineering Practices, Data, 2950 Niles Road, St. Joseph, MI 49085-9659.
[1104] William Edwards, extension economist, Machinery Management: Estimating Farm Machinery Costs, PM 710 Paper version, Revised November 2001; Electronic version Revised August 2005, University Extension, Iowa State University.
[1105] Mark Hanna, Extension Engineer, University Extension, Iowa State University, Ames Iowa, Estimating the Field Capacity of Farm Machines, File A3-24, April 2002.
[1106] Terry Kastens, Extension Agricultural Economist, Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Farm Machinery Operation Cost Calculations, MF-2244 May 1997
[1107] Machinery Cost Estimates: Forage Field Operations, University of Illinois Farm Business Management Handbook, University of Illinois Extension FBM 0203 Department of Agricultural and Consumer Economics • College of Agricultural, Consumer and Environmental Sciences, University of Illinois at Urbana-Champaign
[1108] Tim Cross, Agricultural Economics, Agriculture Machinery Cost Calculation Methods, E12-2015-00-032-98, Agricultural Extension Service, The University of Tennessee Institute of Agriculture.
[1109] Agricultural Prices 2006 Summary, July 2007 United States, Department of Agriculture National Agricultural Statistics Service, Pr 1-3 (07)
[1110] National Agricultural Statistics Service, Quick Stats (Agricultural Statistics Data Base, State and County Data), USDA, http://www.nass.usda.gov/
[1111] L. O. Pordesimo, W. C. Edens, The University of Tennessee, Dept. of Biosystems Engineering and Environmental Science, Knoxville, TN, U.S.A., S. Sokhansanj Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, U.S.A., Distribution of Above Ground Biomass in Corn , Stover, Paper Number: 02-6059; 2002 ASAE Annual International Meeting/CIGR XVth World Congress, Hyatt Regency Chicago, Chicago, Illinois, USA,; July 29-31, 2002.
[1112] Kevin J. Shinners, Professor of Agricultural Engineering, Ben N. Binversie, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Madison, WI, Philippe Savoie, Research Scientist, Agriculture and Agri-Food Canada, Quebec, Canada; Harvest and Storage Of Wet and Dry Corn Stover As A Biomass Feedstock, Paper Number: 036088, 2003 ASAE Annual International Meeting Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003
[1113] R.L. Graham, R.D. Perlack, and L.L. Wright, Environ. Sci. Div., Oak Ridge National Lab., Oak Ridge, TN 37831-6407; R. Nelson, Engineering Extension Programs, Kansas State Univ., Manhattan, KS 66506, and J. Sheehan, National Renewable Energy Lab., Golden, CO 80401. Current and Potential U.S. Corn Stover Supplies, Agronomy Journal 99:1–11, American Society of Agronomy, Madison, WI 53711 USA; doi:10.2134/agronj2005.0222 prepared 2005; published online 1 January 2007
[1114] Ron Kotrba, Ethanol Producer Magazine staff writer, The Great Biomass Inquisition, Ethanol Producer Magazine, January 2007.
http://ethanolproducer.com/article.jsp?article_id=2621&q=&page=all

[1115] Kevin J. Shinners, Professor of Agricultural Engineering, Ben N. Binversie, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Madison, WI, Philippe Savoie, Research Scientist, Agriculture and Agri-Food Canada, Quebec, Canada; Harvest and Storage Of Wet and Dry Corn Stover As A Biomass Feedstock, Paper Number: 036088, 2003 ASAE Annual International Meeting Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003.
[1116] William Edwards, Extension Economist, Estimating Farm Machinery Costs, PM710, Machinery Management, University Extension, Iowa State University, revised November 2001
[1117] Renee Sayler & Kenneth Von Bargen, Principal Investigators, Feasibility of Corn Residue Collection in Kearney, Nebraska Area, for Western Regional Biomass Energy Program, Report of findings, by University of Nebraska-Lincoln, Industrial Agricultural Products Center, Lincoln, NE 68583, September 1993.
[1118] Robert D. Grisso , Professor, Virginia Tech, Department of Biological Systems Engineering, Blacksburg, Virginia; Paul J. Jasa , Extension Engineer, Biological Systems Engineering Department, University of Nebraska, Lincoln, Nebraska; and Dale E. Rolofson , Farm Manager, Agri-Cross Farms, Inc. Greenwood, Nebraska. Corresponding author : Paul J. Jasa, Biological Systems Engineering Dept., University of Nebraska, Lincoln, Analysis of Traffic Patterns and Yield Monitor Data for Field Efficiency Determination, Paper No. 011013, Presented at the 2000 ASAE Annual Meeting, Applied Engineering in Agriculture Vol. 18(2): 171-178 (© 2002 American Society of Agricultural Engineers). A contribution of the University of Nebraska Agricultural Research Division, Lincoln, Nebraska. Journal Series No. 13335. Mention of trade and company names are for the reader and do not infer endorsement or preferential treatment of the products by the University of Nebraska, Lincoln.
[1119] Robert "Bobby" Grisso, Professor, and John C. Cundiff, Professor; and David H. Vaughan, Professor, Department of Biological Systems Engineering, Virginia Tech, Blacksburg, VA., Investigating Machinery Management Parameters with Computer Tools, Paper Number: 071030, Presented at 2007 ASABE Annual International Meeting, Minneapolis Convention Center, Minneapolis, Minnesota, 17 - 20 June 2007. Mention of trade and company names are for the reader and do not infer endorsement or preferential treatment of the products by Virginia Tech.
[1120] Poorna P. Ravula, Robert D. Grisso and John S. Cundiff, Biological Systems Engineering Department, Virginia Tech, Blacksburg, VA 24061-0303, Comparison between Two Policy Strategies for Scheduling in a Biomass Logistic System, Paper Number: 071095, Presented at the 2007 ASABE Annual International Meeting, Sponsored by ASABE, Minneapolis Convention Center
[1121] International Fire Code 2903.4: Agricultural Products. Hay, straw or similar agricultural products shall not be stored adjacent to structures of combustible materials. Storage shall be limited to stacks of 100 tons (91 metric tons) each. Stacks shall be separated by a minimum of 20 feet (6096 mm) of clear space. Quantities of hay, straw and other agricultural products shall not be limited where stored in or near farm structures located outside closely built areas. A permit shall not be required for agricultural storage.
[1122] Daniel R. Petrolia, Department of Applied Economics, College of Food, Agriculture, and Natural Resources Sciences, University of Minnesota, The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota, Staff Paper P06-12 August 2006

[1123] Ron Kotrba, staff writer, The Great Biomass Inquisition, Ethanol Producer Magazine. January 2007 Issue. Reach him at rkotrba@bbibiofuels.com, © 2007 BBI International http://ethanolproducer.com/article.jsp?article_id=2621&q=&page=all
[1124] Ron Kotrba, staff writer, The Great Biomass Inquisition, Ethanol Producer Magazine. January 2007 Issue. Reach him at rkotrba@bbibiofuels.com, © 2007 BBI International http://ethanolproducer.com/article.jsp?article_id=2621&q=&page=all
[1125] Graeme R Quick, Single-pass Corn and Stover Harvesters: Development and Performance. Proceedings of the International Conference on Crop Harvesting and Processing, 9-11 February 2003, Louisville, Kentucky USA, ASABE, St. Joseph, Mich.; ASAE Publication Number 701P1103e
[1126] A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace National Renewable Energy Laboratory (NREL); L. Montague, A. Slayton, and J. Lukas Harris Group, Seattle, Washington, Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover; June 2002;NREL is a U.S. Department of Energy Laboratory Operated by Midwest Research Institute • Battelle • Bechtel; Contract No. DE-AC36-99-GO10337
[1127] Robert M. Prewitt, Graduate Research Assistant, Michael D. Montross, Associate Professor, Scott A. Shearer, Professor, Timothy S. Stombaugh, Associate Extension Professor, Stephen F. Higgins, Research Specialist, Samuel G. McNeill, Associate Extension Professor, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, KY; Shahab Sokhansanj, Professor, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, Corn Stover Availability and Collection Efficiency Using Typical Hay Equipment, Transactions of the American Society of Agricultural and Biological Engineers (ASABE), Vol. 50(3): 705−711, 2007, ISSN 0001−2351; Publication of this article approved by the Director of the Kentucky Agricultural Experiment Station and designated Paper No. 04-05-066.
[1128] Graeme R Quick, Single-pass Corn and Stover Harvesters: Development and Performance. Proceedings of the International Conference on Crop Harvesting and Processing, 9-11 February 2003, Louisville, Kentucky USA, ASABE, St. Joseph, Mich.; ASAE Publication Number 701P1103e
[1129] Kevin J. Shinners, Professor of Agricultural Engineering, Graham S. Adsit, Graduate Research Assistant, Benjamin N. Binversie, Graduate Research Assistant, Matthew F. Digman, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Richard E. Muck, Research Scientist, Paul. J. Weimer, Research Scientist, US Dairy Forage Research Center – USDA-ARS, Madison, WI, Characteristic Performance and Yields using a Single-Pass, Split- Stream Maize Grain and Stover Harvester, Paper Number: 056051, presented at the 2004 ASAE/CSAE Annual International and the 2005 ASAE Annual International Meeting, Sponsored by ASAE, Tampa Convention Center, Tampa, Florida 17 - 20 July 2005
[1130] Shahab Sokhansanj, , Anthony Turhollow, Oak Ridge National Laboratory, North Logan, UT 84341-8804, Janet Cushman, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6422, John Cundiff, Biological Systems Engineering, Virginia Technical University, Blacksburg, VA 24061-0303, Engineering aspects of collecting corn stover for bioenergy, Biomass and Bioenergy 23 (2002) 347 – 355; Received 15 October 2001; received in revised form 15 April 2002; accepted 3 May 2002; 2002 Published by Elsevier Science Ltd.

[1131] Kevin J. Shinners, Professor of Agricultural Engineering, Garrit C. Boettcher, Graduate Research Assistant, Jesse T. Munk, Graduate Research Assistant, Matthew F. Digman, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin; Richard E. Muck, Research Engineer, Paul. J. Weimer, Research Scientist, US Dairy Forage Research Center, USDA-ARS, Madison, WI, Single-Pass, Split-Stream of Corn Grain and Stover: Characteristic Performance of Three Harvester Configurations, Presented at: ASABE Annual International Meeting, 2006; Oregon Convention Center, Portland, Oregon, 9 – 12 July 2006.

[1132] W. C. Edens, L. O. Pordesimo, The University of Tennessee, Dept. of Biosystems Engineering and Environmental Science, Knoxville, TN, S. Sokhansanj, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, Field Drying Characteristics and Mass Relationships of Corn Stover Fractions, Presented at the ASAE Annual International Meeting/ CIGR XVth World Congress, 2002, Hyatt Regency Chicago, Chicago, Illinois, USA, July 28-31, 2002.

[1133] Richard Hess, Idaho National Laboratory, Uniform Format Feedstock Supply System Design for Lignocellulosic Biomass, Western Region Biomass Workshop August 27, 2007 http://sungrant.oregonstate.edu/workshop/HESS_Western_RP_workshop.pdf

[1134] Kevin J. Shinners, Professor of Agricultural Engineering, Ben N. Binversie, Graduate Research Assistant, Department of Biological Systems Engineering, University of Wisconsin, Madison, WI, Philippe Savoie, Research Scientist, Agriculture and Agri-Food Canada, Quebec, Canada; Harvest and Storage Of Wet and Dry Corn Stover As A Biomass Feedstock, Paper Number: 036088, 2003 ASAE Annual International Meeting Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003.

[1135] Shahab Sokhansanj and Janet Cushman, Bioenergy Feedstock Development Program Oak Ridge National Laboratory (ORNL), Feedstock Engineering, Presentation, Lincoln, NB, December 12, 2001 ORNL, Energy Efficiency and Renewable Energy, US DOE, USA

[1136] Sudhagar Mani, Ph.D. Candidate, Shahab Sokhansanj, Adjunct Professor, Xiaotao Bi, Associate Professor, Department of Chemical & Biological Engineering, University of British Columbia, Vancouver, BC CANADA V6T 1Z4, Modeling of Forage Drying in Single and Triple Pass Rotary Drum Dryers, Paper Number: 056082, 2005 ASAE Annual International Meeting, Tampa Convention Center, Tampa, Florida, 17 - 20 July 2005

[1137] Xianzhe Zheng, Professor, Yiyuan Jiang, Professor, College of Engineering, North East Agricultural University, Harbin, China; Yubin Lan, Associate Professor, Agricultural Engineering Technology, Fort Valley State University, University Systems of Georgia, Fort Valley, GA 31030, Determination of Parameters for an Alfalfa Rotary Dryer, Paper Number: 056186, 2005 ASAE Annual International Meeting, Tampa Convention Center, Tampa, Florida, 17 - 20 July 2005

[1138] This information came in a confidential, personal communication.

[1139] Christopher T. Wright , Peter A. Pryfogle, Nathan A. Stevens , J. Richard Hess , Corey W. Radtke , Idaho National Laboratory , Idaho Falls, ID, Value of Distributed Preprocessing of Biomass Feedstocks to a Bioenergy Industry, Paper No: 066151 Presented at the ASABE Annual International Meeting, 2006, Oregon Convention Center Portland, Oregon, 9 - 12 July 2006

[1140] Roger G. Ginder, Professor of Economics, Department of Economics, Iowa State University, Ames, Iowa 50011, Potential Infrastructure Constraints on Current Corn Based and Future Biomass Based U.S. Ethanol Production, Working Paper # 07018 , July 2007
[1141] E-mailed file from Robert Perlack, U.S. Department of Agriculture, May 2008.
[1142] Phillips, S, Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass; NREL, April, 2007.
[1143] Aden, Andy, Mixed Alcohols from Woody Biomass – 2010, 2015, 2022, National Renewable Energy Laboratory (NREL), September, 23 2009.
[1144] OECD, "Biofuels: Linking Support to Performance," ITF Round Tables No. 138, March 2008.
[1145] International Energy Agency (IEA), "Biofuels for Transport: An International Perspective," 2004.
[1146] Goldemberg, J. as sited in Rothkopf, Garten, "A Blueprint for Green Energy in the Americas," 2006.
[1147] Unicamp, "A Expansão do Proalcool como Programa de Desenvolvimento Nacional," Powerpoint presentation at *Ethanol Seminar* in BNDES, 2006. As quoted in OECD, "Biofuels: Linking Support to Performance," ITF Round Tables No. 138, March 2008.
[1148] *Ibid*.
[1149] *Ibid*.
[1150] *Ibid*.
[1151] Macedo. I.C., "Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 Averages and a Prediction for 2020," *Biomass and Bioenergy*, 2008.
[1152] *Ibid*.
[1153] Smeets E, Junginger M, Faaij A, Walter A, Dolzan P, Turkenburg W, "The sustainability of Brazilian ethanol-An Assessment of the possibilities of certified production," *Biomass and Bioenergy*, 2008.
[1154] Official Statistics of the U.S. Department of Commerce, USITC
[1155] Davis, Ryan. November 2009. Techno-economic analysis of microalgae-derived biofuel production. National Renewable Energy Laboratory. Technical Memorandum to EPA.
[1156] Sun, A. et al., "Techno-Economic Analysis of Algae Biofuel Deployment." Presented at the 2009 Algae Biomass Summit, San Diego, CA (October 2009) as noted in report by Davis, Ryan, op. sit.
[1157] Haas, M.J, A process model to estimate biodiesel production costs, Bioresource Technology 97 (2006) 671-678.
[1158] Capital cost and other details taken from Syntroleum Corp Investor Presentation materials dated November 2009, available in the docket or at http://www.syntroleum.com/Presentations/SyntroleumInvestorPresentation.November%205.2009.FINAL.pdf
[1159] A New Development in Renewable Fuels: Green Diesel, AM-07-10 Annual Meeting NPRA, March 18-20, 2007.
[1160] Per EPA phone discussion July 23, 2007.
[1161] Ryan Davis, National Renewable Energy Laboratory, Golden Colorado 80401-3392, Technical Memo to EPA " Techno-economic Analysis of Current Technology for Fischer Tropsch Fuels Production. August 2009.

[1162] "Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints", prepared for EPA by Oak Ridge National Laboratory, March 2009.
[1163] BNSF railway biodiesel freight cost information can be found at http://www.bnsf.com/markets/agricultural/bnsf4024/cur/itm31001.txt
[1164] 2007 National Association of Convenience Stores State of the Industry survey data www.nacsonline.com as reported in the National Petroleum News MarketFacts 2007, October 2007.
[1165] National Petroleum News, "2008 marketfacts", www.npnweb.com
[1166] Table 12, Reference and High Price Cases, Annual Energy Outlook 2009; Energy Information Administration, Department of Energy, April 2009.
[1167] Table 2, Reference Case, Annual Energy Outlook 2007; Energy Information Administration, Department of Energy, February 2007.
[1168] Table 2, Reference Case, Annual Energy Outlook 2009; Energy Information Administration, Department of Energy, April 2009.
[1169] D5798-99 (Reapproved 2004), ASTM International.
[1170] National Association of Convenience Stores (NACS) online annual price resource kit, NACS, February 2, 2006.
[1171] Combined local, state and federal gasoline taxes, American Petroleum Institute, January 2008.
[1172] Greene, David L.; Alternative Fuel Market Share as a Function of Fuel Availability and Price Advantage, 1997.
[1173] Brownstone, D., Small, K., 2005. Valuing time and reliability: assessing the evidence from road pricing demonstrations. Trans. Res. Part A 39, 279-293.
[1174] Brownstone, D., Ghose, D., Golob, T., Kazimi, C., Van Amelsfort, D., 2003. Driver's willingness-to-pay to reduce travel time: evidence from the San Diego I-15 Congestion Pricing Project. Trans. Res. Part A 37, 373-387.
[1175] Lam, T., Small, K., 2001. The value of time and reliability: measurement from a value pricing experiment. Trans. Res. Part E 37 (2-3), 231-251.
[1176] Steimetz, S., Brownstone, D., 2005. Estimating consumers' 'Value of time' with noisy data: a multiple imputation approach. Trans. Res. Part B 39, 865-889.
[1177] Spot Annual Crude Oil Prices for Western Texas Intermediate (WTI), Cushing Oklahoma; http://tonto.eia.doe.gov/dnav/pet/hist/rwtca.htm; Energy Information Adminstration, 2008.
[1178] National Annual Average Gasoline and Diesel Fuel Prices (all grades); http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm; Energy Information Adminstration, 2008.
[1179] Weis, Daniel J., Flex-Fuel Bait and Switch, Center for American Progress, June 18, 2007 available on the Web at: http://www.americanprogress.org/issues/2007/06/flexfuel.html.
[1180] U.S. Environmental Protection Agency. (2006). *Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter*. Prepared by: Office of Air and Radiation. Retrieved March, 26, 2009 at http://www.epa.gov/ttn/ecas/ria.html
[1181] U.S. Environmental Protection Agency. (2008). *Final Ozone NAAQS Regulatory Impact Analysis*. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved March, 26, 2009 at http://www.epa.gov/ttn/ecas/ria.html
[1182] U.S. Environmental Protection Agency (U.S. EPA). 2009a. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement

Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf>.

[1183] U.S. Environmental Protection Agency (U.S. EPA). 2009b. Proposed NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/proposedno2ria.pdf. Note: The revised NO2 NAAQS may be final by the publication of this action.

[1184] U.S. Environmental Protection Agency (U.S. EPA). 2009c. Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines. Office of Transportation and Air Quality, June. Available on the Internet at http://www.epa.gov/otaq/regs/nonroad/420d09002.htm. Note: The C3 rule may be final by the publication of this action.

[1185] GeoLytics Inc. (2002). Geolytics CensusCD® 2000 Short Form Blocks. CD-ROM Release 1.0. GeoLytics, Inc. East Brunswick, NJ. Available: http://www.geolytics.com/ [accessed 29 September 2004]

[1186] Woods & Poole Economics Inc. 2008. Population by Single Year of Age CD. CD-ROM. Woods & Poole Economics, Inc. Washington, D.C.

[1187] U.S. Environmental Protection Agency. (2006). *Air quality criteria for ozone and related photochemical oxidants (second external review draft)*. Research Triangle Park, NC: National Center for Environmental Assessment; report no. EPA/600R-05/004aB-cB, 3v. Available: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=137307[March 2006]

[1188] U.S. Environmental Protection Agency, 2004. *Air Quality Criteria for Particulate Matter Volume II of II*. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC EPA/600/P-99/002bF.

[1189] World Health Organization (WHO). (2003). *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide: Report on a WHO Working Group*. World Health Organization. Bonn, Germany. EUR/03/5042688.

[1190] Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. (2004). *Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3): Report of a WHO task group*. Copenhagen, Denmark: World Health Organization.

1191 Bell, M.L., et al. (2004). Ozone and short-term mortality in 95 US urban communities, 1987-2000. JAMA, 2004. 292(19): p. 2372-8.

1192 Huang, Y.; Dominici, F.; Bell, M. L. (2005) Bayesian hierarchical distributed lag models for summer ozone exposure and cardio-respiratory mortality. Environmetrics. 16: 547-562.

1193 Schwartz, J. (2005) How sensitive is the association between ozone and daily deaths to control for temperature? Am. J. Respir. Crit. Care Med. 171: 627-631.

1194 Bell, M.L., F. Dominici, and J.M. Samet. (2005). A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. Epidemiology. 16(4): p. 436-45.

1195 Ito, K., S.F. De Leon, and M. Lippmann (2005). Associations between ozone and daily mortality: analysis and meta-analysis. Epidemiology. 16(4): p. 446-57.
1196 Levy, J.I., S.M. Chemerynski, and J.A. Sarnat. (2005). Ozone exposure and mortality: an empiric bayes metaregression analysis. Epidemiology. 16(4): p. 458-68.
1197 Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. (2002). "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132-1141.
1198 Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. (2006). Reduction in Fine Particulate Air Pollution and Mortality. American Journal of Respiratory and Critical Care Medicine. 173: 667-672.
1199 Industrial Economics, Incorporated (IEc). (2006). Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Peer Review Draft. Prepared for: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. August.
1200 Woodruff, T.J., J. Grillo, and K.C. Schoendorf. (1997). The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. Environmental Health Perspectives. 105(6):608-612.
1201 Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancuren, and P.K. Mills. (1995). Estimated Long-Term Ambient Concentrations of PM(10) and Development of Respiratory Symptoms in a Nonsmoking Population. Archives of Environmental Health. 50(2): 139-152.
1202 Peters, A., D.W. Dockery, J.E. Muller, and M.A. Mittleman. (2001). Increased Particulate Air Pollution and the Triggering of Myocardial Infarction. Circulation. 103:2810-2815.
1203 Schwartz J. (1995). Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. Thorax. 50(5):531-538.
1204 Schwartz J. (1994a). PM(10) Ozone, and Hospital Admissions For the Elderly in Minneapolis St Paul, Minnesota. Arch Environ Health. 49(5):366-374.
1205 Schwartz J. (1994b). Air Pollution and Hospital Admissions For the Elderly in Detroit, Michigan. Am J Respir Crit Care Med. 150(3):648-655.
1206 Moolgavkar SH, Luebeck EG, Anderson EL. (1997). Air pollution and hospital admissions for respiratory causes in Minneapolis St. Paul and Birmingham. Epidemiology. 8(4):364-370.
1207 Burnett RT, Smith-Doiron M, Stieb D, Raizenne ME, Brook JR, Dales RE, et al. (2001). Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. Am J Epidemiol. 153(5):444-452.
1208 Moolgavkar, S.H. (2003). "Air Pollution and Daily Deaths and Hospital Admissions in Los Angeles and Cook Counties." In Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Boston, MA: Health Effects Institute.
1209 Ito, K. (2003). "Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan." In Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Health Effects Institute, Boston, MA.
1210 Moolgavkar, S.H. (2000). Air Pollution and Hospital Admissions for Diseases of the Circulatory System in Three U.S. Metropolitan Areas. Journal of the Air and Waste Management Association 50:1199-1206.
1211 Sheppard, L. (2003). Ambient Air Pollution and Nonelderly Asthma Hospital Admissions in Seattle, Washington, 1987-1994. In Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Boston, MA: Health Effects Institute.

1212 Jaffe DH, Singer ME, Rimm AA. (2003). Air pollution and emergency department visits for asthma among Ohio Medicaid recipients, 1991-1996. Environ Res 91(1):21-28.
1213 Peel, J. L., P. E. Tolbert, M. Klein, et al. (2005). Ambient air pollution and respiratory emergency department visits. Epidemiology. Vol. 16 (2): 164-74.
1214 Wilson, A. M., C. P. Wake, T. Kelly, et al. (2005). Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environ Res. Vol. 97 (3): 312-21.
1215 Norris, G., S.N. YoungPong, J.Q. Koenig, T.V. Larson, L. Sheppard, and J.W. Stout. (1999). An Association between Fine Particles and Asthma Emergency Department Visits for Children in Seattle. Environmental Health Perspectives 107(6):489-493.
1216 Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne, and F.E. Speizer. (1996). Health Effects of Acid Aerosols On North American Children-Respiratory Symptoms. Environmental Health Perspectives 104(5):500-505.
1217 Pope, C.A., III, D.W. Dockery, J.D. Spengler, and M.E. Raizenne. (1991). Respiratory Health and PM10 Pollution: A Daily Time Series Analysis. American Review of Respiratory Diseases 144:668-674.
1218 Schwartz, J., and L.M. Neas. (2000). Fine Particles are More Strongly Associated than Coarse Particles with Acute Respiratory Health Effects in Schoolchildren. Epidemiology 11:6-10.
1219 Ostro, B., M. Lipsett, J. Mann, H. Braxton-Owens, and M. White. (2001). Air Pollution and Exacerbation of Asthma in African-American Children in Los Angeles. Epidemiology 12(2):200-208.
1220 Vedal, S., J. Petkau, R. White, and J. Blair. (1998). Acute Effects of Ambient Inhalable Particles in Asthmatic and Nonasthmatic Children. American Journal of Respiratory and Critical Care Medicine 157(4):1034-1043.
1221 Ostro, B.D. (1987). Air Pollution and Morbidity Revisited: A Specification Test. Journal of Environmental Economics Management 14:87-98.
1222 Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, et al. (2001). The effects of ambient air pollution on school absenteeism due to respiratory illnesses. Epidemiology 12(1):43-54.
1223 Chen L, Jennison BL, Yang W, Omaye ST. (2000). Elementary school absenteeism and air pollution. Inhal Toxicol 12(11):997-1016.
1224 Ostro, B.D. and S. Rothschild. (1989). Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants. Environmental Research 50:238-247.
1225 U.S. Science Advisory Board. (2004). Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004.
1226 National Research Council (NRC). (2002). Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.
[1227] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Particulate Matter (External Review Draft). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201805>.
[1228] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Second External Review Draft). National Center for Environmental

Assessment, Research Triangle Park, NC. EPA/600/R-08/139B. July. Available on the Internet at <http://cfint.rtpnc.epa.gov/ncea/prod/recordisplay.cfm?deid=210586>.

[1229] U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2009. Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008). EPA-COUNCIL-09-008. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf>.

[1230] U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2009. Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment. EPA-COUNCIL-09-009. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf>.

[1231] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

[1232] Viscusi, W.K., W.A. Magat, and J. Huber. (1991). Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis. *Journal of Environmental Economics and Management* 21:32-51.

[1233] Cropper, M.L., and A.J. Krupnick. (1990). *The Social Costs of Chronic Heart and Lung Disease*. Resources for the Future. Washington, DC. Discussion Paper QE 89-16-REV.

[1234] Russell, M.W., D.M. Huse, S. Drowns, E.C. Hamel, and S.C. Hartz. (1998). Direct Medical Costs of Coronary Artery Disease in the United States. *American Journal of Cardiology* 81(9):1110-1115.

[1235] Wittels, E.H., J.W. Hay, and A.M. Gotto, Jr. (1990). Medical Costs of Coronary Artery Disease in the United States. *American Journal of Cardiol*ogy 65(7):432-440.

[1236] Agency for Healthcare Research and Quality (AHRQ). (2000). HCUPnet, Healthcare Cost and Utilization Project. Rockville, MD. Accessed April 10, 2009, from http://hcupnet.ahrq.gov/

[1237] Smith, D.H., D.C. Malone, K.A. Lawson, L.J. Okamoto, C. Battista, and W.B. Saunders. (1997). A National Estimate of the Economic Costs of Asthma. *American Journal of Respiratory and Critical Care Medicine* 156(3 Pt 1):787-793.

[1238] Stanford, R., T. McLaughlin, and L.J. Okamoto. (1999). The Cost of Asthma in the Emergency Department and Hospital. *American Journal of Respiratory and Critical Care Medicine* 160(1):211-215.

[1239] Industrial Economics, Incorporated (IEc). (1994). Memorandum to Jim DeMocker, Office of Air and Radiation, Office of Policy Analysis and Review, U.S. Environmental Protection Agency. March 31.

[1240] Rowe, R.D., and L.G. Chestnut. (1986). *Oxidants and Asthmatics in Los Angeles: A Benefits Analysis—Executive Summary*. Prepared by Energy and Resource Consultants, Inc. Report to the U.S. Environmental Protection Agency, Office of Policy Analysis. EPA-230-09-86-018. Washington, DC.

[1241] Neumann, J.E., M.T. Dickie, and R.E. Unsworth. (1994). *Linkage Between Health Effects Estimation and Morbidity Valuation in the Section 812 Analysis—Draft Valuation Document*. Industrial Economics Incorporated (IEc) Memorandum to Jim DeMocker, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy Analysis and Review. March 31.

[1242] Tolley, G.S. et al. January (1986). *Valuation of Reductions in Human Health Symptoms and Risks*. *University of Chicago*. Final Report for the U.S. Environmental Protection Agency.

[1243] Council of Economic Advisors. (2005). *The Annual Report of the Council of Economic Advisors*. *In: Economic Report of the President*. Table B-60. U.S. Government Printing Office: Washington, DC.

[1244] National Research Council (NRC). (2002). *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. The National Academies Press: Washington, D.C.

[1245] U.S. Environmental Protection Agency, (2004a). *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf

[1246] U.S. Environmental Protection Agency, (2005). *Regulatory Impact Analysis for the Clean Air Interstate Rule*. EPA 452/-03-001. Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/interstateairquality/tsd0175.pdf

[1247] U.S. Environmental Protection Agency, (2006). *Regulatory Impact Analysis for the PM NAAQS*. EPA Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

[1248] Industrial Economics, Inc. (2006). *Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality*. Prepared for EPA Office of Air Quality Planning and Standards, September. Retrieved on April 10, 2009, from http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf

[1249] U.S. Environmental Protection Agency, (2006). *Regulatory Impact Analysis for the PM NAAQS*. EPA Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

[1250] U.S. Department of Agriculture, National Agricultural Statistics Service, ''Crop Production'', August 12, 2009, available online at: *http://usda.mannlib.cornell.edu/usda/current/CropProd/CropProd-08-12-2009.pdf*

[1251] Committee on Water Implications of Biofuels Production in the United States, National Research Council, *Water Implications of Biofuels Production in the United States*, The National Academies Press, 2008, page 3.

[1252] Huang , Wen-yuan, "Tight Supply and Strong Demand May Raise U.S. Nitrogen Fertilizer Prices", *Amber Waves,* November 2007, page 7, available online at: http://www.ers.usda.gov/AmberWaves/November07/PDF/TightSupply.pdf.

[1253] U. S. Environmental Protection Agency, EPA Science Advisory Board, "Hypoxia in the Northern Gulf of Mexico", EPA-SAB-08-003, December 2007, available on line at: http://yosemite.epa.gov/sab/sabproduct.nsf/C3D2F27094E03F90852573B800601D93/$File/EPA-SAB-08-003complete.unsigned.pdf.

[1254] U. S. Department of Agriculture, Economic Research Service, "U.S. Fertilizer Use and Price", http://www.ers.usda.gov/Data/FertilizerUse, April 2008.
[1255] Inhalation health effect concerns for volatilized a.i. compounds are discussed for individual products, e.g., oxydimeton-methyl, carbaryl (and carbamates generally), diazinon, at http://www.epa.gov/pesticides/reregistration/status.htm . A.I. vapor pressure and a discussion of product volatilization can be found at http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s02-2.pdf
[1256] A discussion of acetochlor toxicity can be found in EPA's Re-registration Eligibility Document (RED) for this product at http://www.epa.gov/IRIS/subst/0521.htm.
[1257] A discussion of carbaryl toxicity can be found in EPA's Re-registration Eligibility Document (RED) for this product at http://www.epa.gov/IRIS/subst/0019.htm.
[1258] A discussion of alachlor toxicity can be found in EPA's Re-registration Eligibility Document (RED) for this product at http://www.epa.gov/IRIS/subst/0129.htm
[1259] See http://www.irac-online.org/ , Insecticide Resistance Action Committee, for toxicity classifications and toxicity mode of action definitions used.
[1260] See carcinogen weight of evidence (WoE) determination and description of toxicity for methomyl at
http://www.epa.gov/pesticides/reregistration/REDs/0028red.pdf
[1261] U. S. Department of Agriculture, Economic Research Service, "Farm Income and Costs: 2009 Farm Sector Income Forecast", http://www.ers.usda.gov/Briefing/FarmIncome/nationalestimates.htm, updated November 24, 2009.
[1262] U.S. Environmental Protection Agency, EPA Science Advisory Board, Hypoxia in the northern Gulf of Mexico, EPA–SAB–08–003, 275 p, available online at: *http://yosemite.epa.gov/sab/sabproduct.nsf/C3D2F27094E03F90852573B800601D93/$File/EPA–SAB–08–003complete.unsigned.pdf*
[1263] Secchi, S., J. Tyndall, L. Schulte, and H. Asbjornsen. "Raising the Stakes", *Journal of Soil and Water Conservation*, Volume 63, Number. 3, 2008, pages 68A-73A.
[1264] McLachlan, M., M. Carter, C. Rustay, Effects of the Conservation Reserve Program on Priority Mixed-grass Prairie Birds: A Conservation Effects Assessment Project, 2007, available online at: ftp://ftpfc.sc.egov.usda.gov/NHQ/nri/ceap/Final%20BCR19%20CRP%20Report.pdf .
[1265] Iowa State University Extension, *2007 Iowa Land Value Survey*, 2008, available online at: http://www.extension.iastate.edu/Publications/FM1825.pdf.
[1266] U. S. Environmental Protection Agency, EPA Science Advisory Board, op. cit., p. 177.
[1267] Wilhelm, W. W., J. M. F. Johnson, D. L. Karlen, and D. T. Lightle, "Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply", *Agronomy Journal*, Volume 99, 2007, pages 1665–1667.
[1268] U.S. Environmental Protection Agency, Office of Water, *Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams,* EPA 841-B-06-002, 2006, available online at: http://www.epa.gov/owow/streamsurvey.
[1269] U. S. Environmental Protection Agency, Office of Water, *National Water Quality Inventory: Report to Congress 2002 Reporting Cycle,* U.S. EPA 841-R-07-001, 2007, available online at http://www.epa.gov/305b/2002report/.
[1270] Paerl, H.W., D. Robin, D. R. Whitall , "Atmospheric Deposition of Nitrogen: Implications for Nutrient Over-Enrichment of Coastal Waters", *Estuaries*, Volume 25, Number 4B, 2002, pages 677-693.

[1271] Chesapeake Bay Program, *Sources of Nitrogen Loads to the Bay,* available online at:
http://www.chesapeakebay.net/status_nitrogensources.aspx?menuitem=19797
[1272] New York State Department of Environmental Conservation and Connecticut Department of Environmental Protection, A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolved Oxygen in Long Island Sound, December 2000, available online at: http://www.longislandsoundstudy.net/pubs/reports/tmdl.pdf .
[1273] Roberts, D. M., and J. E. Reuter, DRAFT Lake Tahoe Total Maximum Daily Load Technical Report: California and Nevada, California Regional Water Quality Control Board, Lahontan Region and Nevada Division of Environmental Protection, September 2007, available online at: http://www.waterboards.ca.gov/lahontan/water_issues/programs/tmdl/lake_tahoe/docs/laketahoe_tmdl_techrpt.pdf .
[1274] Chesapeake Bay Program, Science and Technical Advisory Committee, *Workshop on Atmospheric Deposition of Nitrogen: Media Brief*, May 30, 2007, available online at: http://www.chesapeake.org/stac/Press/AtmoNmediabrief.pdf
[1275] Roberts, D. M., op.cit., page 4-164.
[1276] Committee on Water Implications of Biofuels Production in the United States, National Research Council, op. cit.
[1277] Louisiana Universities Marine Consortium, 2009, 'Gulf of Mexico Dead Zone Surprising Small, but Severe, available online at:
http://www.gulfhypoxia.net/Research/Shelfwide%20Cruises/2009/Files/Press_Release.pdf
[1278] Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, "Gulf Hypoxia Action Plan 2008 for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin", 2008, page 22, available online at: http://www.epa.gov/msbasin/actionplan.htm.
[1279] U. S. Environmental Protection Agency, EPA Science Advisory Board, op.cit.
[1280] Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, op.cit., page 37.
[1281] Alexander, R.B., Smith, R.A., Schwarz, G.E., Boyer, E.W., Nolan, J.V., and Brakebill, J.W., "Differences in Phosphorus and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin", *Environmental Science and Technology*, Volume 42, Number 3, 2008, pages 822–830, available online at: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/2008/42/i03/abs/es0716103.html**.**
[1282] Donner, S. D. and Kucharik, C. J., 2008, "Corn-based Ethanol Production Compromises Goal of Reducing Nitrogen Export by the Mississippi River", *PNAS*, Volume 105, Number 11, 2008, pages 4513–4518, available online at: http://www.pnas.org/content/105/11/4513.full.
[1283] U. S. Environmental Protection Agency, EPA Science Advisory Board, op.cit. page 205.
[1284] Institute for Agriculture and Trade Policy, *Staying home: How ethanol will change U.S. corn exports, 2006*, Minneapolis, MN, 26 pp., available online at: http://www.agobservatory.org/library.cfm?refid=96658 .
[1285] Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, op.cit., page 15.
[1286] Aulenbach, B.T., Buxton, H.T., Battaglin, W.A., and Coupe, R.H., Streamflow and Nutrient Fluxes of the Mississippi-Atchafalaya River Basin and Subbasins for the Period of Record Through 2005: U.S. Geological Survey Open-File Report 2007-1080, 2007, available online at: http://toxics.usgs.gov/pubs/of-2007-1080/index.html.
[1287] U. S. Environmental Protection Agency, EPA Science Advisory Board, op. cit., p. 89.

[1288] Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, op. cit., page 16.
[1289] Gassman, P.W., Reyes, M. R., Green, C. H. , Arnold, J. G. , "The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions", *Transactions of the American Society of Agricultural and Biological Engineers*, Volume 50, Number 4, 2007, pages 1211-1240, available online at:. http://www.card.iastate.edu/environment/items/asabe_swat.pdf.
[1290] Arnold, J. G., R. S. Muttiah, R. Srinivasan, and P. M. Allen, "Regional Estimation of Base Flow and Groundwater Recharge in the Upper Mississippi Basin", *Journal of Hydrology*, Volume 227, 2000, pages 21-40, available online at: http://ssl.tamu.edu/media/2900/regional%20estimation%20of%20base%20flow%20and%20groundwater%20recharge%20in%20the%20upper%20mississippi%20river%20basin.pdf
[1291] Jha, M., P. W. Gassman, S. Secchi, and J. Arnold, "Upper Mississippi River Basin Modeling System Part 2: Baseline Simulation Results", in: *Coastal Hydrology and Processes* (Eds. V.P. Singh and Y.J. Xu), Water Resources Publications, Highland Ranch, CO, 2006, pages. 117-126.
[1292] U.S. Department of Agriculture, USDA Agricultural Projections to 2018, February 2009, available on-line at: *http://www.ers.usda.gov/Publications/OCE091/*
[1293] Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. "Development of a 2001 National Landcover Database for the United States". *Photogrammetric Engineering and Remote Sensing*, Volume 70, Number 7, 2004, pages 829-840, available online at http://www.mrlc.gov/pdf/July_PERS.pdf .
[1294] U.S. Department of Agriculture, National Agricultural Statistic Service, http://www.nass.usda.gov/research/Cropland/SARS1a.htm.
[1295] U.S. Department of Agriculture, Natural Resources Conservation Service, http://www.nrcs.usda.gov/techical/NRI.
[1296] Conservation Technology Information Center, http://www.ctic.purdue.edu/.
[1297] American Society of Agricultural and Biological Engineers, *Manure Production and Characteristics*. ASAE D384.2 MAR2005, available online at: http://asae.frymulti.com/abstract.asp?aid=19432&t=1.
[1298] U. S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2007 With Projections to 2030, February 2007, available on-line at: *http://tonto.eia.doe.gov/ftproot/forecasting/0383(2007).pdf*
[1299] Renewable Fuels Association, "Ethanol Biorefinery Locations," http://www.ethanolrfa.org/industry/locations, April 2008.
[1300] Chesapeake Bay Commission, *Biofuels and the Bay: Getting It Right to Benefit Farms, Forests and the Chesapeake*, Chesapeake Bay Commission, Annapolis, Maryland, 2007, 32 pages, available online at: http://www.chesbay.state.va.us/Publications/BiofuelsAndTheBay1.pdf
[1301] Simpson, T. W., A. N. Sharpley, R.W. Howarth, H.W. Paerl, and K. R. Mankin, "The New Gold Rush: Fueling Ethanol Production while Protecting Water Quality", *Journal of Environmental Quality*, Volume 37, 2008, pages 318-324.
[1302] Chesapeake Bay Foundation, 2007 State of the Bay, 2007, available online at: http://www.cbf.org/site/DocServer/2007SOTBReport.pdf?docID=10923.

[1303] Federal Leadership Committee for the Chesapeake Bay, November 9, 2009, Executive Order 13508: Draft Strategy for Protecting and Restoring the Chesapeake Bay, available on-line at: http://executiveorder.chesapeakebay.net/
[1304] Chesapeake Bay Commission, op. cit., page 11.
[1305] U.S. Environmental Protection Agency, Region 7, *Environmental Laws Applicable to Construction and Operation of Ethanol Plants*, EPA-907-B-07-001, November 2007,104 pages, available online at:
http://www.epa.gov/region07/priorities/agriculture/ethanol_plants_manual.pdf

[1306] Regassa, T., Koelsch, R., Erickson, G., *Impact of Feeding Distillers Grains on Nutrient Planning for Beef Cattle Systems*, University of Nebraska-Lincoln Extension—RP190, 2008, 8 pages, available online at: http://www.ianrpubs.unl.edu/epublic/live/rp190/build/rp190.pdf
[1307] Jacob, M. D., Fox, J. T., Drouillard, J. S., Renter, D. G., Nagaraja, T. G., 2008, Effects of dried distillers' grain on fecal prevalence and growth of *Escherichia coli* O157 in batch culture fermentations from cattle, Applied and Environmental Microbiology, v. 74, no. 1, p. 38–43, available online at: *http://aem.asm.org/cgi/content/abstract/74/1/38*

[1308] U.S. Department of Agriculture, Natural Resources Conservation Service, "Comprehensive Nutrient Management Planning Technical Guidance", *National Planning Procedures Handbook,* Part 600.5, available online at: http://policy.nrcs.usda.gov/17088.wba.
[1309] Mackay, D.M., de Sieyes, N. R.., Einarson, M.D., Feris, K.P., Pappas, A.A., Wood, I.A., Jacobson, L., Justice, L.G., Noske, M.N., Scow, K.M., and Wilson, J.T., 2006, Impact of ethanol on the natural attenuation of benzene, toluene, and o-Xylene in a normally sulfate-reducing aquifer, Environmental Science & Technology, v. 40, p. 6123-6130.
[1310] Ruiz-Aguilar, G. M. L.; O'Reilly, K.; Alvarez, P. J. J, "Forum: A Comparison of Benzene and Toluene Plume Lengths for Sites Contaminated with Regular vs. Ethanol-amended Gasoline", *Ground Water Monitoring and Remediation*, Volume 23, 2003, pages 48-53.
[1311] Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., *Ground-Water Availability in the United States: U.S. Geological Survey Circular 1323*, 2008, page 33, available online at http://pubs.usgs.gov/circ/1323/
[1312] McGuire, V.L, Changes in Water Level and Storage in the High Plains Aquifer, Predevelopment to 2005: U.S. Geological Survey Fact Sheet 2007-3029, 2007, available online at http://pubs.usgs.gov/fs/2007/3029/ .
[1313] U.S. Environmental Protection Agency, *Consumer Fact Sheet on Nitrates/Nitrites*, available online at: http://www.epa.gov/safewater/dwh/c-ioc/nitrates.html
[1314] U.S. Environmental Protection Agency, Office of Water, *FACTOIDS: Drinking Water and Ground Water Statistics for 2007,* EPA 816-K-07-004, 2008, available online at: http://www.epa.gov/safewater/data/pdfs/data_factoids_2007.pdf
[1315] Scribner, E.A., Thurman, E.M., Goolsby, D.A., Meyer, M.T., Battaglin, W.A., and Kolpin, D.W., 2005, Summary of significant results from studies of triazine herbicides and their degradation products in surface water, ground water, and precipitation in the Midwestern United States during the 1990s: U.S. Geological Survey Scientific Investigations Report 2005–5094, 27 p.
[1316] U.S. Environmental Protection Agency, *Consumer Fact Sheet on Atrazine*, available online at: http://www.epa.gov/safewater/contaminants/dw_contamfs/atrazine.html

[1317] See 40 CFR, Part 141, Subpart O, App. A.

[1318] U.S. Environmental Protection Agency, *A Review of Contaminant Occurrence in Public Water Systems*, EPA 816-R-99-006, 1999, available online at: http://www.epa.gov/OGWDW/occur/nov99_lo.pdf

[1319] U.S. Environmental Protection Agency, of *Occurrence Estimation Methodology and Occurrence Findings Report for the Six-Year Review of Existing National Primary Drinking Water Regulations*, Office of Water, EPA-815-R-03-006, 2003, pages 38 and 40, available online at http://epa.gov/OGWDW/standard/review/pdfs/support_6yr_occurancemethods_final.pdf.

[1320] U.S. Environmental Protection Agency, Safe Drinking Water Information System (SDWIS) End of Year data for FY 2007, 2007.

[1321] Gilliom, R. J., *The Quality of Our Nation's Waters* Pesticides in the Nation's Streams and Ground Water, 1992-2001: U.S. Geological Survey Circular 129, 2006, Tables 7A-1 to 7A-4, available online at: http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix7/7a.html

[1322] Committee on Water Implications of Biofuels Production in the United States, op.cit.

[1323] Great Lakes Commission, *The Potential Impacts of Increased Corn Production for Ethanol in the Great Lakes-St. Lawrence River Region*, 2007, available online at: http://www.glc.org/tributary/pubs/documents/EthanolPaper121807FINAL.pdf.

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Annual Energy Outlook 2011

with Projections to 2035

Independent Statistics & Analysis
U.S. Energy Information Administration

For further information . . .

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The *Annual Energy Outlook 2011* is available on the EIA website at www.eia.gov/forecasts/aeo/. Assumptions underlying the projections, tables of regional results, and other detailed results will also be available, at www.eia.gov/forecasts/aeo/assumptions/. Model documentation reports for the National Energy Modeling System are available at website www.eia.gov/analysis/model-documentation.cfm and will be updated for the *Annual Energy Outlook 2011* during 2011.

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Annual Energy Outlook 2011

With Projections to 2035

April 2011

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Preface

The *Annual Energy Outlook 2011* (*AEO2011*), prepared by the U.S. Energy Information Administration (EIA), presents long-term projections of energy supply, demand, and prices through 2035, based on results from EIA's National Energy Modeling System (NEMS). EIA published an "early release" version of the *AEO2011* Reference case in December 2010.

The report begins with an *Executive summary* that highlights key aspects of the projections. It is followed by a *Legislation and regulations* section that discusses evolving legislative and regulatory issues, including a summary of recently enacted legislation and regulations, such as a recently announced (October 13, 2010) EPA waiver, which allows the use of motor gasoline blends containing 15 percent ethanol in newer vehicles (model year 2007 or later), or the 7-year moratorium on offshore drilling in the Atlantic and Pacific that was announced by the U.S. Department of the Interior on December 1, 2010. The *Issues in focus* section contains discussions of selected energy topics, including a discussion of the results in two cases that adopt different assumptions about the future course of existing policies: one case assumes the extension of a selected group of existing public policies—corporate average fuel economy standards, appliance standards, production tax credits, and the elimination of sunset provisions in existing energy policies; the other case assumes only the elimination of sunset provisions. Other discussions include: a look at evolving environmental regulations that affect the power sector; the economics of carbon capture and storage; prospects for shale gas production, including cost uncertainty and its impact on decisions for new power plant builds, fuel use, and emissions; and the basis for world oil price and production trends in *AEO2011*.

The *Market trends* section summarizes the projections for energy markets. The analysis in *AEO2011* focuses primarily on a Reference case, Low and High Economic Growth cases, and Low and High Oil Price cases. Results from a number of other alternative cases also are presented, illustrating uncertainties associated with the Reference case projections for energy demand, supply, and prices. Complete tables for the five primary cases are provided in Appendixes A through C. Major results from many of the alternative cases are provided in Appendix D. Complete tables for all the alternative cases are available on EIA's website in a table browser at www.eia.gov/oiaf/aeo/tablebrowser/.

AEO2011 projections are based generally on Federal, State, and local laws and regulations in effect as of the end of January 2011. The potential impacts of pending or proposed legislation, regulations, and standards (and sections of existing legislation that require implementing regulations or funds that have not been appropriated) are not reflected in the projections. In certain situations, however, where it is clear that a law or regulation will take effect shortly after the *AEO* is completed, it may be considered in the projection.

AEO2011 is published in accordance with Section 205c of the U.S. Department of Energy (DOE) Organization Act of 1977 (Public Law 95-91), which requires the EIA Administrator to prepare annual reports on trends and projections for energy use and supply.

Projections by EIA are not statements of what will happen but of what might happen, given the assumptions and methodologies used for any particular scenario. The Reference case projection is a business-as-usual trend estimate, given known technology and technological and demographic trends. EIA explores the impacts of alternative assumptions in other scenarios with different macroeconomic growth rates, world oil prices, and rates of technology progress. The main cases in *AEO2011* generally assume that current laws and regulations are maintained throughout the projections. Thus, the projections provide policy-neutral baselines that can be used to analyze policy initiatives.

While energy markets are complex, energy models are simplified representations of energy production and consumption, regulations, and producer and consumer behavior. Projections are highly dependent on the data, methodologies, model structures, and assumptions used in their development. Behavioral characteristics are indicative of real-world tendencies rather than representations of specific outcomes.

Energy market projections are subject to much uncertainty. Many of the events that shape energy markets are random and cannot be anticipated. In addition, future developments in technologies, demographics, and resources cannot be foreseen with certainty. Many key uncertainties in the *AEO2011* projections are addressed through alternative cases.

EIA has endeavored to make these projections as objective, reliable, and useful as possible; however, they should serve as an adjunct to, not a substitute for, a complete and focused analysis of public policy initiatives.

Updated *Annual Energy Outlook 2011* Reference case (April 2011)

The *AEO2011* Reference case included in the final published report released in April 2011 is updated from the Reference case that was used in the *AEO2011 Early Release Overview* (December 2010). The Reference case was updated to incorporate modeling changes and reflect changes based on recent legislation and regulations that were not available when the *Early Release Overview* was published. Major changes made for the updated Reference include:

- Added a 30-percent investment tax credit for fuel cells, with a 2016 expiration date
- Retired the Oyster Creek nuclear power plant at the end of 2019
- Revised the amount of new wind capacity built in 2012 (7 rather than 10 gigawatts)
- Benchmarked oil production to EIA's January *Short-Term Energy Outlook* (including revision of undiscovered oil drilling schedules)
- Delayed additional deepwater offshore projects
- Forced economic life to be 43 years for coalbed methane play that was deciding on a 16-year life
- Updated carbon-dioxide-enhanced oil recovery
- Updated natural gas reserve reporting
- Updated 2011 cellulosic ethanol subsidy
- Updated ethanol tax credit, biodiesel tax credit, and ethanol tariff through 2011
- Allowed E15 use in 2001-2006 model year light-duty vehicles (in addition to 2007-present)
- Updated battery cost curve
- Updated sales of electric, hybrid electric, microhybrid, and plug-in electric vehicles
- Updated High Technology case assumptions
- Updated historical data for energy-related carbon dioxide emissions and updated carbon dioxide emissions factors for biomass, based on upcoming EIA data reports.

Future analyses using the *AEO2011* Reference case will start from the version released with this complete report.

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Executive summary

The projections in the Energy Information Administration's (EIA) *Annual Energy Outlook 2011 (AEO2011)* focus on the factors that shape the U.S. energy system over the long term. Under the assumption that current laws and regulations remain unchanged throughout the projections, the *AEO2011* Reference case provides the basis for examination and discussion of energy production, consumption, technology, and market trends and the direction they may take in the future. It also serves as a starting point for analysis of potential changes in energy policies. But *AEO2011* is not limited to the Reference case. It also includes 57 sensitivity cases (see Appendix E, Table E1), which explore important areas of uncertainty for markets, technologies, and policies in the U.S. energy economy.

Key results highlighted in *AEO2011* include strong growth in shale gas production, growing use of natural gas and renewables in electric power generation, declining reliance on imported liquid fuels, and projected slow growth in energy-related carbon dioxide (CO_2) emissions even in the absence of new policies designed to mitigate greenhouse gas (GHG) emissions.

AEO2011 also includes in-depth discussions on topics of special interest that may affect the energy outlook. They include: impacts of the continuing renewal and updating of Federal and State laws and regulations; discussion of world oil supply and price trends shaped by changes in demand from countries outside the Organization for Economic Cooperation and Development or in supply available from the Organization of the Petroleum Exporting Countries; an examination of the potential impacts of proposed revisions to Corporate Average Fuel Economy standards for light-duty vehicles and proposed new standards for heavy-duty vehicles; the impact of a series of updates to appliance standard alone or in combination with revised building codes; the potential impact on natural gas and crude oil production of an expanded offshore resource base; prospects for shale gas; the impact of cost uncertainty on construction of new electric power plants; the economics of carbon capture and storage; and the possible impact of regulations on the electric power sector under consideration by the U.S. Environmental Protection Agency (EPA). Some of the highlights from those discussions are mentioned in this Executive Summary. Readers interested in more detailed analyses and discussions should refer to the "Issues in focus" section of this report.

Imports meet a major but declining share of total U.S. energy demand

Real gross domestic product grows by 2.7 percent per year from 2009 to 2035 in the *AEO2011* Reference case, and oil prices grow to about $125 per barrel (2009 dollars) in 2035. In this environment, net imports of energy meet a major, but declining, share of total U.S. energy demand in the Reference case. The need for energy imports is offset by the increased use of biofuels (much of which are produced domestically), demand reductions resulting from the adoption of new vehicle fuel economy standards, and rising energy prices. Rising fuel prices also spur domestic energy production across all fuels—particularly, natural gas from plentiful shale gas resources—and temper the growth of energy imports. The net import share of total U.S. energy consumption in 2035 is 17 percent, compared with 24 percent in 2009. (The share was 29 percent in 2007, but it dropped considerably during the 2008-2009 recession.)

Much of the projected decline in the net import share of energy supply is accounted for by liquids. Although U.S. consumption of liquid fuels continues to grow through 2035 in the Reference case, reliance on petroleum imports as a share of total liquids consumption decreases. Total U.S. consumption of liquid fuels, including both fossil fuels and biofuels, rises from about 18.8 million barrels per day in 2009 to 21.9 million barrels per day in 2035 in the Reference case. The import share, which reached 60 percent in 2005 and 2006 before falling to 51 percent in 2009, falls to 42 percent in 2035 (Figure 1).

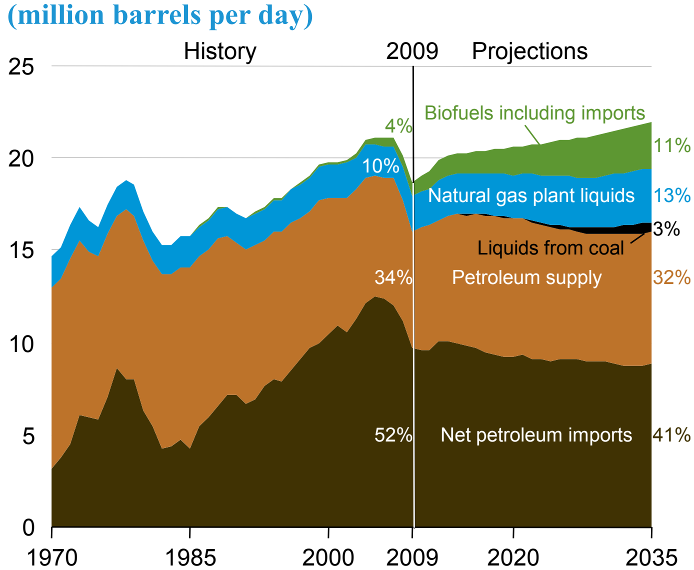
Domestic shale gas resources support increased natural gas production with moderate prices

Shale gas production in the United States grew at an average annual rate of 17 percent between 2000 and 2006. Early success in shale gas production was achieved primarily in the Barnett Shale in Texas. By 2006, the success in the Barnett shale, coupled with high natural gas prices and technological improvements, turned the industry focus to other shale plays. The combination of horizontal drilling and hydraulic fracturing technologies has made it possible to produce shale gas economically, leading to an average annual growth rate of 48 percent over the 2006-2010 period.

Shale gas production continues to increase strongly through 2035 in the *AEO2011* Reference case, growing almost fourfold from 2009 to 2035. While total domestic natural gas production grows from 21.0 trillion cubic feet in 2009 to 26.3 trillion cubic feet in 2035, shale gas production grows to 12.2 trillion cubic feet in 2035, when it makes up 47 percent of total U.S. production—up considerably from the 16-percent share in 2009 (Figure 2).

The estimate for technically recoverable unproved shale gas resources in the Reference case is 827 trillion cubic feet. Although more information has become available as a result of increased drilling activity in developing shale gas plays, estimates of technically recoverable resources and well productivity remain highly uncertain. Estimates of technically

Figure 1. U.S. liquids fuel consumption, 1970-2035 (million barrels per day)



recoverable shale gas are certain to change over time as new information is gained through drilling, production, and technological and managerial development. Over the past decade, as more shale formations have gone into commercial production, the estimate of technically and economically recoverable shale gas resources has skyrocketed. However, the increases in recoverable shale gas resources embody many assumptions that might prove to be incorrect over the long term.

Alternative cases in *AEO2011* examine the potential impacts of variation in the estimated ultimate recovery per shale gas well and the assumed recoverability factor used to estimate how much of the play acreage contains recoverable shale gas. In those cases, overall domestic natural gas production varies from 22.4 trillion cubic feet to 30.1 trillion cubic feet in 2035, compared with 26.3 trillion cubic feet in the Reference case. The Henry Hub spot price for natural gas in 2035 (in 2009 dollars) ranges from $5.35 per thousand cubic feet to $9.26 per thousand cubic feet in the alternative cases, compared with $7.07 per thousand cubic feet in the Reference case.

Despite rapid growth in generation from natural gas and nonhydropower renewable energy sources, coal continues to account for the largest share of electricity generation

Assuming no additional constraints on CO_2 emissions, coal remains the largest source of electricity generation in the *AEO2011* Reference case because of continued reliance on existing coal-fired plants. EIA projects few new central-station coal-fired power plants, however, beyond those already under construction or supported by clean coal incentives. Generation from coal increases by 25 percent from 2009 to 2035, largely as a result of increased use of existing capacity; however, its share of the total generation mix falls from 45 percent to 43 percent as a result of more rapid increases in generation from natural gas and renewables over the same period. The role of natural gas grows due to low natural gas prices and relatively low capital construction costs that make it more attractive than coal. The share of generation from natural gas increases from 23 percent in 2009 to 25 percent in 2035.

Electricity generation from renewable sources grows by 72 percent in the Reference case, raising its share of total generation from 11 percent in 2009 to 14 percent in 2035. Most of the growth in renewable electricity generation in the power sector consists of generation from wind and biomass facilities (Figure 3). The growth in generation from wind plants is driven primarily by State renewable portfolio standard (RPS) requirements and Federal tax credits. Generation from biomass comes from both dedicated biomass plants and co-firing in coal plants. Its growth is driven by State RPS programs, the availability of low-cost feedstocks, and the Federal renewable fuels standard, which results in significant cogeneration of electricity at plants producing biofuels.

Proposed environmental regulations could alter the power generation fuel mix

The EPA is expected to enact several key regulations in the coming decade that will have an impact on the U.S. power sector, particularly the fleet of coal-fired power plants. Because the rules have not yet been finalized, their impacts cannot be fully analyzed, and they are not included in the Reference case. However, *AEO2011* does include several alternative cases that examine the sensitivity of power generation markets to various assumed requirements for environmental retrofits.

The range of coal plant retirements varies considerably across the cases (Table 1), with a low of 9 gigawatts (3 percent of the coal fleet) in the Reference case and a high of 73 gigawatts (over 20 percent of the coal fleet). The higher end of this range is driven by the somewhat extreme assumptions that all plants must have scrubbers to remove sulfur dioxide and selective catalytic reduction to remove nitrogen oxides, that natural gas wellhead prices remain at or below about $5 through 2035, and that environmental

Figure 2. U.S. natural gas production, 1990-2035 (trillion cubic feet per year)

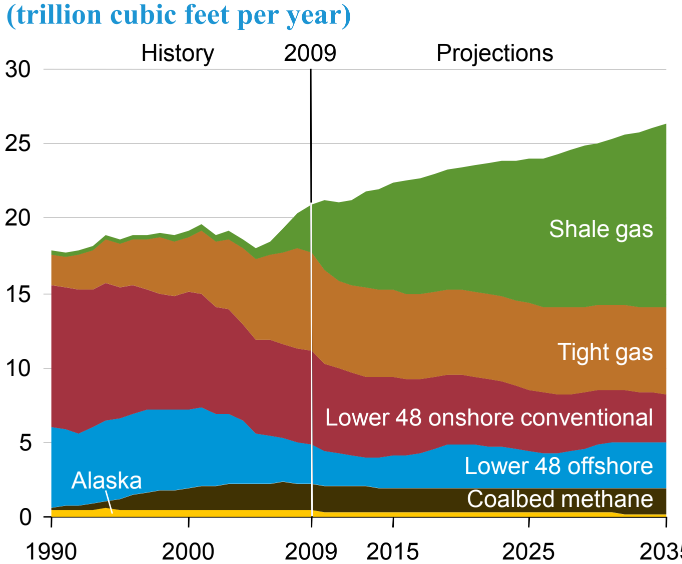
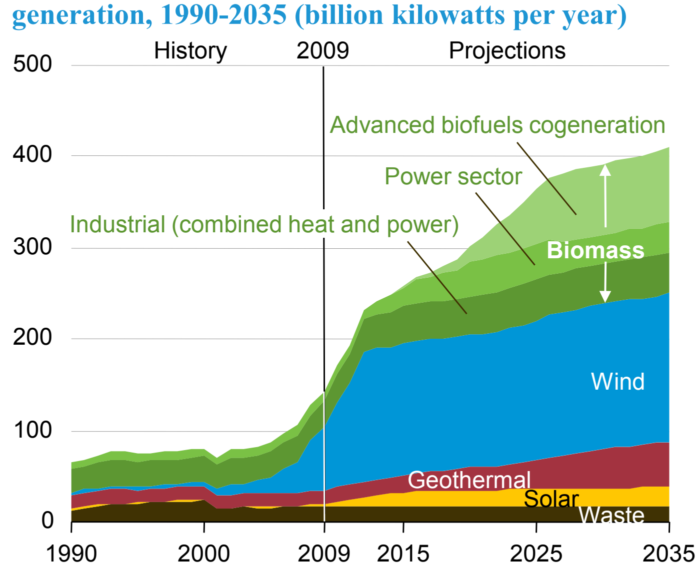


Figure 3. U.S. nonhydropower renewable electricity generation, 1990-2035 (billion kilowatts per year)



retrofit decisions are based on an assumption that retrofits occur only if plant owners can recover their costs within 5 years. The latter quick cost recovery assumption is meant to represent the possibility of future environmental regulation, including for GHGs.

In all these cases, coal continues to account for the largest share of electricity generation through 2035. Many of the coal plants projected to be retired in these cases had relatively low utilization factors and high heat rates historically, and their contribution to overall coal-fired generation was relatively modest.

Electricity generation from natural gas is higher in 2035 in all the environmental regulation sensitivity cases than in the Reference case. The faster growth in electricity generation with natural gas is supported by low natural gas prices and relatively low capital costs for new natural gas plants, which improve the relative economics of gas when regulatory pressure is placed on the existing coal fleet. In the alternative cases, natural gas generation in 2035 varies from 1,323 billion kilowatthours to 1,797 billion kilowatthours, compared with 1,288 billion kilowatthours in the Reference case.

Assuming no changes in policy related to greenhouse gas emissions, carbon dioxide emissions grow slowly and do not return to 2005 levels until 2027

After falling by 3 percent in 2008 and 7 percent in 2009, largely as a result of the economic downturn, energy-related CO_2 emissions grow slowly in the *AEO2011* Reference case due to a combination of modest economic growth, growing use of renewable technologies and fuels, efficiency improvements, slower growth in electricity demand (in part because of the recent recession), and more use of natural gas, which is less carbon-intensive than other fossil fuels. In the Reference case, which assumes no explicit regulations to limit GHG emissions beyond vehicle GHG standards, energy-related CO_2 emissions do not return to 2005 levels (5,996 million metric tons) until 2027, growing by an average of 0.6 percent per year from 2009 to 2027, or a total of 10.6 percent. CO_2 emissions then rise by an additional 5 percent from 2027 to 2035, to 6,311 million metric tons in 2035 (Figure 4).

To put the numbers in perspective, population growth is projected to average 0.9 percent per year, overall economic growth 2.7 percent per year, and growth in energy use 0.7 percent per year over the same period. Although total energy-related CO_2 emissions increase from 5,996 million metric tons in 2005 to 6,311 million metric tons in 2035 in the Reference case, emissions per capita fall by 0.7 percent per year over the same period. Most of the growth in CO_2 emissions in the *AEO2011* Reference case is accounted for by the electric power and transportation sectors.

The projections for CO_2 emissions are sensitive to many factors, including economic growth, policies aimed at stimulating renewable fuel use or low-carbon power sources, and any policies that may be enacted to reduce GHG emissions. In the *AEO2011* Low and High Economic Growth cases, projections for total primary energy consumption in 2035 are 106.4 quadrillion British thermal units (Btu) (6.9 percent below the Reference case) and 122.6 quadrillion Btu (7.4 percent above the Reference case), and projections for energy-related CO_2 emissions in 2035 are 5,864 million metric tons (7.1 percent below the Reference case) and 6,795 million metric tons (7.7 percent above the Reference case), respectively.

Figure 4. U.S. carbon dioxide emissions by sector and fuel, 2005 and 2035 (million metric tons)

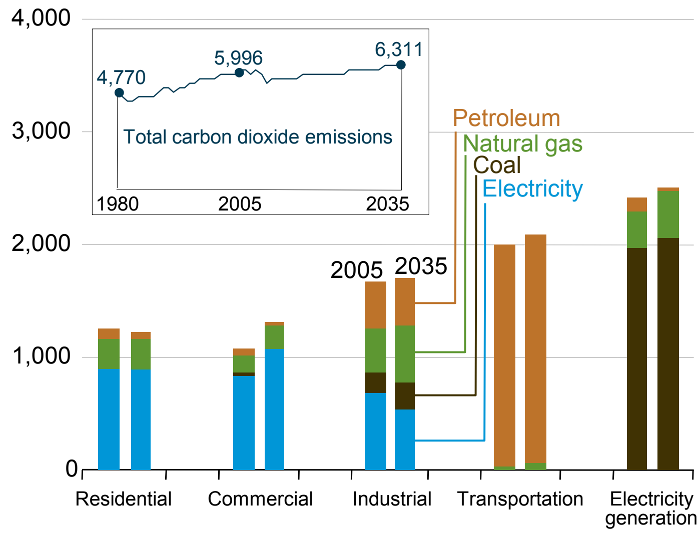


Table 1. Coal-fired plant retirements in alternative cases, 2010-2035

Analysis case	Coal-fired capacity retired (gigawatts)	Average size of plants retired (megawatts)	Average heat rate of plants retired (million Btu per kilowatthour)
Reference	8.8	93.0	12,338
Transport Rule Mercury MACT 20	13.5	91.4	12,053
Transport Rule Mercury MACT 5	17.8	83.3	12,102
Retrofit Required 20	19.2	84.5	12,034
Retrofit Required 5	44.8	91.2	11,579
Low Gas Price	15.6	104	12,098
Low Gas Price Retrofit Required 20	39.5	97.8	11,576
Low Gas Price Retrofit Required 5	72.6	109.6	11,363

Legislation and regulations

Introduction

The *Annual Energy Outlook 2011 (AEO2011)* Reference case generally assumes that current laws and regulations affecting the energy sector remain unchanged throughout the projection (including the implication that laws which include sunset dates do, in fact, become ineffective at the time of those sunset dates). Currently, there are many pieces of legislation and regulation that appear to have some probability of being enacted in the not-too-distant future, and some laws include sunset provisions that may be extended. However, it is difficult to discern the exact forms that the final provisions of pending legislation or regulations will take, and sunset provisions may or may not be extended. Even in situations where existing legislation contains provisions to allow revision of implementing regulations, those provisions may not be exercised consistently. In certain situations, however, where it is clear that a law or regulation will take effect shortly after the *Annual Energy Outlook (AEO)* modeling work is completed, it may be considered in the projection. Sensitivity cases that incorporate alternative assumptions about proposed policies or existing policies subject to periodic updates are also included among the many alternative cases completed as part of the *AEO*. The Federal and State laws and regulations included in *AEO2011* are based on those in effect as of the end of January 2011. In addition, at the request of the Administration and Congress, the U.S. Energy Information Administration (EIA) has regularly examined the potential implications of proposed legislation in Service Reports. Those reports, and others that were completed before 2010, can be found on the EIA website at www.eia.gov/oiaf/service_rpts.htm.

Examples of recently enacted State and Federal legislation incorporated in *AEO2011* include:

- State provisions passed in 2010 in Connecticut [*1*], Maine [*2*], New Jersey [*3*], and New York [*4*] that reduced the maximum allowable sulfur content of heating oil sold, as well as some plans to include mandated percentages of biodiesel content.
- Final regulations promulgated by the California Air Resources Board (CARB) in January 2010 to implement a Low Carbon Fuel Standard (LCFS) [*5*]. The LCFS program aims to reduce the carbon intensity of motor gasoline and diesel fuel sold in California by 10 percent over the years 2012 through 2020 by increasing the volumes of alternative low-carbon fuels being introduced into the marketplace.
- The Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010, enacted in December 2010 [*6*]. This law includes an extension of the Volumetric Ethanol Excise Tax Credit at $0.45 per gallon through 2011, a retroactive extension of the $1.00 per gallon biodiesel excise tax credit through 2011, and an extension of the $0.54 per gallon tariff on imported ethanol through 2011.
- Updates to State renewable portfolio standard (RPS) programs, representing laws and regulations of 30 States and the District of Columbia that require renewable electricity generation.

Examples of recent Federal and State regulations, as well as provisions considered in earlier *AEO*s that have been affected by subsequent court decisions, include the following:

- Approval of a waiver allowing the use of motor gasoline blends containing up to 15 percent ethanol for vehicles of model year (MY) 2001 and newer by the U.S. Environmental Protection Agency (EPA) in January 2011 [*7*].
- Issuance of new guidelines by the EPA in April 2010 regarding the compliance of surface coal mining operations in Appalachia with the provisions of the Clean Water Act, the National Environmental Policy Act, and the environmental justice Executive Order (E.O. 12898) [*8*]. The guidance explains the approach that the EPA will be following in permit reviews and instructs Regional offices to use clear, consistent, and science-based standards in reviewing the permits.

Detailed information on several Federal and State legislative and regulatory developments considered in *AEO2011* is provided below.

1. Updated State air emissions regulations

Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is a program that includes 10 Northeast States that have agreed to curtail and reverse growth in their carbon dioxide (CO_2) emissions. The RGGI program includes all electricity generating units with a capacity of at least 25 megawatts and requires an allowance for each ton of CO_2 emitted [*9*]. The first year of mandatory compliance was in 2009.

Each participating State was provided a CO_2 budget consisting of a history-based baseline with a cushion for emissions growth, so that meeting the cap would be relatively easy initially and become more stringent in subsequent years. The requirements cover 95 percent of CO_2 emissions from the region's electric power sector. Overall, the RGGI States as a whole must maintain covered emissions at or below a level of 188 million tons CO_2 through 2012, after which a mandatory 2.5-percent annual decrease in CO_2 emissions through 2018 reduces the total for covered CO_2 emissions in the RGGI States to 10 percent below the initial calculated budget. Although each State was given its own emissions budget, allowances are auctioned at a uniform price across the entire region.

At the most recent RGGI auction in March 2011, 42 million allowances were offered and sold at a clearing price of $1.89 per ton of CO_2 [*10*], just above the price floor. The previous auction in December 2010 also cleared at the price floor, because total emissions from electricity generators did not grow as anticipated.

RGGI's impact on electricity markets is included in the *AEO2011* Reference case. Its impact on actual emissions, especially in the early years, is minimal because of its relatively modest reduction targets. Also, it is difficult to capture the nuances of initiatives that cover only single States or groups of States that do not correspond to the regions used in the National Energy Modeling System (NEMS). Therefore, EIA estimated generation for the Mid-Atlantic region and capped emissions from those facilities. Pennsylvania's emissions were not restricted, because Pennsylvania is an observing member and is not participating in the cap-and-trade program or subject to any mandatory emission reductions.

California greenhouse gas reduction program

California is moving forward with its plans to cap and then reverse the growth of State greenhouse gas (GHG) emissions. After surviving a challenge on the ballot in November 2010, the mandatory restrictions begin to take effect in January 2012. After the law was passed and signed, a scoping plan was written that outlines the major components of the regulations [*11*]. In all, there are 21 programs in the law that will mitigate GHG emissions through a variety of mechanisms—from landfill methane control to proper tire pressurization programs [*12*]. While *AEO2011* incorporates programs from the law, such as the LCFS and 33-percent RPS—where rules are sufficiently specified to allow modeling in the *AEO*—other programs, such as the carbon cap-and-trade provisions, are not included either because they do not include sufficient specification of implementing regulations or because they include provisions that cannot be modeled in NEMS.

The programs that are expected to generate the highest level of emission reductions are the cap-and-trade system (which is not included in *AEO2011*) and the 33-percent RPS [*13*]. The RPS requires investor-owned electricity providers to meet this mandate by 2020. CARB is in charge of the program, although other agencies still have roles in the implementation. The cap-and-trade program is scheduled to begin its first phase in 2012, covering GHG emissions from electricity (including imports) and large industrial facilities emitting more than 25,000 metric tons CO_2 annually [*14*]. Allowances are given away initially, but it is assumed that a market will develop in which allowances will trade for a price as demand grows and the number of available allowances shrinks. (The number of available allowances is scheduled to decline by 2 percent per year, starting from 165.8 million metric tons in 2012.) In 2015, distributors of fossil fuels will be added to the program, and the cap will increase to 394.5 metric tons. In the subsequent 5-year period, the cap will decrease by 3 percent annually. In addition to CO_2, the six other most common GHGs emitted (methane, nitrous oxide, sulfur hexafluoride, nitrogen trifluoride, hydrofluorocarbons, and perfluorocarbons) will also fall under the program's jurisdiction.

Several issues remain to be resolved, including finalization of the allowance allocation system, implementation of an auction system, and the possibility of a price cap. The exact distribution of the allowance revenue has not been determined nor has the treatment of natural gas as a fuel. This is all information that needs to be defined before the program can be incorporated in the *AEO*. A goal of the program is to link to other State trading programs, although the status of neighboring States' programs is uncertain. A San Francisco superior court judge also recently ruled that CARB did not conduct adequate environmental reviews or thoroughly explore cap-and-trade alternatives for meeting the reduction goal in Assembly Bill (AB) 32. This may also delay the program's implementation [*15*].

2. State renewable energy requirements and goals: Update through 2010

To the extent possible, *AEO2011* incorporates the impacts of State laws requiring the addition of renewable generation or capacity by utilities doing business in the States. Currently, 30 States and the District of Columbia have enforceable RPS or similar laws (Table 2). Under such standards, each State determines its own levels of renewable generation, eligible technologies, and noncompliance penalties. *AEO2011* includes the impacts of all laws in effect in 2010 (with the exception of Hawaii, because NEMS provides electricity market projections for the continental United States only).

In the *AEO2011* Reference case, States generally meet their ultimate RPS targets. RPS compliance in most regions is approximated, because NEMS is not a State-level model, and each State generally represents only a portion of one of the NEMS electricity regions. Compliance costs in each region are tracked, and the projection for total renewable generation is checked for consistency with any State-level cost-control provisions, such as caps on renewable credit prices, limits on State compliance funding, or impacts on consumer electricity prices. In general, EIA has confirmed each State's requirements through original documentation, although the Database of State Incentives for Renewables & Efficiency (DSIRE) also assisted EIA's efforts [*16*].

No States that did not previously have RPS programs have enacted new renewable generation laws over the past year. States that have made significant modifications to existing laws include the following:

California

Through several executive orders, CARB is now charged with implementing a 33-percent RPS by 2020 as part of the carbon-reduction guidelines originally laid out in AB 32 [*17*] (see previous section). This standard is a significant increase from the previous 20-percent version administered by the California Energy Commission and Public Utility Commission. More information can be found in the subsequent section on airborne emission regulations.

Table 2. Renewable portfolio standards in the 30 States with current mandates

State	Program mandate
AZ	Arizona Corporate Commission Decision No. 69127 requires 15 percent of electricity sales to be renewable by 2025, with interim goals increasing annually. A specific percentage of the target must be from distributed generation. Multiple credits may be provided to solar generation and systems manufactured in-State.
CA	As a follow-up from AB 32 and Executive Order S-21-09, the CARB now administers a new RPS that requires 33-percent renewable generation by 2020.
CO	Enacted in March 2010, House Bill (HB) 1001 strengthens the State's existing RPS program by requiring 20 percent of electricity generated by investor-owned utilities in 2015 to be renewable, increasing to 30 percent by 2020. There is also a distributed generation requirement. In-State generation receives a 25-percent credit premium.
CT	Public Act 07-242 mandates a 27-percent renewable sales requirement by 2020, including a 4-percent requirement for sales from higher efficiency or combined heat and power systems. Of the overall total, 3 percent may be met by waste-to-energy and conventional biomass facilities.
DE	Senate Substitute 1 amended Senate Bill 119 to extend the increasing RPS targets to 2025; 25 percent of generation is now required to come from renewable sources in 2025. There is a separate requirement for solar generation (3.5 percent of the total in 2025) and penalty payments for compliance failure. Offshore wind receives 3.5 times the standard credit amount.
HI	HB 1464 sets the renewable mandate at 40 percent by 2030. All existing renewable facilities are eligible to meet the target, which has two interim milestones.
IL	Public Act 095-0481 created an agency responsible for overseeing the mandate of 25 percent renewable sales by 2025, with escalating annual targets. In addtion, 75 percent of the required sales must be generated from wind and 6 percent from solar. The plan also includes a cap on incremental costs resulting from the penetration of renewable generation. In 2009, the rule was modified to cover sales outside a utility's home territory.
IA	In 1983, an RPS mandating 105 megawatts of renewable energy capacity was adopted.
KS	In 2009, HB 2369 established a requirement that 20 percent of installed capacity must use renewable resources by 2020.
ME	In 2007, Public Law 403 was added to the State's RPS requirements. The law requires a 10-percent increase from the 2006 level of renewable capacity by 2017, and that level must be maintained in subsequent years. The years leading up to 2017 also have new capacity milestones. Generation from eligible community-owned facilities receives a 10-percent credit premium.
MD	In April 2008, HB 375 revised the preceding RPS to include a target of 20 percent renewable generation by 2022, including a 2-percent solar target. HB 375 also raised penalty payments for "Tier 1" compliance shortfalls to 4 cents per kilowatthour. Senate Bill 277, while preserving 2022 target of 2 percent solar, made the interim solar requirements and penalty payments slightly less stringent.
MA	The State RPS has a goal of a 15-percent renewable share of total sales by 2020 and includes necessary payments for compliance shortfalls. Eligible biomass is restricted to low-carbon life cycle emission sources. A Solar Carve-Out Program was also added, which seeks to establish 400 megawatts (DC) of solar generating capacity.
MI	Public Act 295 established an RPS that will require 10 percent renewable generation by 2015. Bonus credits are given to solar energy.
MN	Senate Bill 4 created a 30-percent renewable requirement by 2020 for Xcel, the State's largest supplier, and a 25-percent requirement by 2025 for other suppliers. The 30-percent requirement for Xcel consists of 24 percent that must be from wind, 1 percent that can be from wind or solar, and 5 percent that can be from other resources.
MO	In November 2008, Missouri voters approved Proposition C, which mandates a 2-percent renewable energy requirement in 2011, increasing incrementally to 15 percent of generation in 2021. Bonus credits are given to renewable generation within the State.
MT	HB 681, approved in April 2008, expanded the State RPS provisions to all suppliers. Initially the law covered only public utilities. A 15-percent share of sales must be renewable by 2015. The State operates a renewable energy credit market.
NV	The State has an escalating renewable target, established in 1997 and revised in 2005 and again in 2009 by Senate Bill 358. The most recent requirement mandates a 25-percent renewable generation share of sales by 2025. Up to one-fourth of the 25-percent share may be met through efficiency measures. There is also a minimum requirement for PV systems, which receive bonus credits.
NH	HB 873, passed in May 2007, legislated that 23.8 percent of electricity sales must be met by renewables in 2025. Compliance penalties vary by generation type.
NJ	In 2006, the State RPS was revised to increase renewable energy targets. Renewable generation is to provide 22.5 percent of sales by 2021, with interim targets. AB 3520 requires 5,316 gigawatthours of solar generation by 2026. SB 2036 has a specific offshore wind target of 1,100 megawatts of capacity.

(continued on page 9)

Table 2. Renewable portfolio standards in the 30 States with current mandates (continued)

State	Program mandate
NM	Senate Bill 418, passed in March 2007, directs investor-owned utilities to derive 20 percent of their sales from renewable generation by 2020. The renewable portfolio must consist of diversified technologies, with wind and solar each accounting for 20 percent of the target. There is a separate standard of 10 percent by 2020 for cooperatives.
NY	The Public Service Commission issued updated RPS rules in January of 2010, expanding the program to a 29-percent requirement by 2015. There is also a separate end-use standard. The program is administered and funded by the State.
NC	In 2007, Senate Bill 3 created an RPS of 12.5 percent by 2021 for investor-owned utilities. There is also a 10-percent requirement by 2018 for cooperatives and municipals. Through 2018, 25 percent of the target may be met through efficiency standards, increasing to 40 percent in later years.
OH	Senate Bill 221, passed in May 2008, requires 25 percent of electricity sales to be produced from alternative energy resources by 2025, including low-carbon and renewable technologies. One-half of the target must come from renewable sources. Municipals and cooperatives are exempt.
OR	Senate Bill 838, signed into law in June 2007, required renewable targets of 25 percent by 2025 for large utilities and 5 to 10 percent by 2025 for smaller utilities. Renewable electricity on line after 1995 is considered eligible.
PA	The Alternative Energy Portfolio Standard, signed into law in November 2004, has an 18-percent requirement by 2020. Most of the qualifying generation must be renewable, but there is also a provision that allows waste coal resources to receive credits.
RI	The Renewable Energy Standard was signed into law in 2004. The program requires that 16 percent of total sales be renewable by 2019. The interim program targets escalate more rapidly in later years. If the target is not met, a generator must pay an alternative compliance penalty. State utilities must also procure 90 megawatts of new renewable capacity, including 3 megawatts of solar, by 2014.
TX	Senate Bill 20, passed in August 2005, strengthened the State RPS by mandating 5,880 megawatts of renewable capacity by 2015. There is also a target of 500 megawatts of renewable capacity other than wind.
WA	In November 2006, Washington voters approved Initiative 937, which specifies that 15 percent of sales from the State's largest generators must come from renewable sources by 2020. There is an administrative penalty of 5 cents per kilowatthour for noncompliance. Generation from any facility that came on line after 1999 is eligible.
WV	HB 103, passed in June 2009, established a requirement that 25 percent of sales must come from alternative energy resources by 2025. Alternative energy was defined to include various renewables, along with several different fossil energy technologies.
WI	Senate Bill 459, passed in March 2006, strengthened the State RPS with a requirement that, by 2015, each utility must generate 10 percent of its electricity from renewable resources, up from the previous requirement of 2.2 percent in 2011. The renewable share of total generation must be at least 6 percentage points above the average renewable share from 2001 to 2003.

Colorado

The State strengthened its existing RPS by requiring that 30 percent of sales be generated from renewable sources by 2020 [*18*]. Investor-owned qualifying utilities must also provide appropriate incentives so that renewable distributed generation makes up 3 percent of total sales [*19*].

Delaware

Although Delaware's RPS structure remains largely unchanged, Senate Substitute No. 1 for Senate Bill 119 extended the targets by an additional 5 years, to 2025. In 2025, 25 percent of sales must be from renewable sources. The solar provisions also are extended, and 3.5 percent of sales must come from electricity generated by solar photovoltaic cells [*20*].

Massachusetts

After temporarily suspending biomass eligibility on the basis of a study of life-cycle carbon emissions from biomass feedstocks, the Commonwealth changed its RPS to clarify and restrict the sources of biomass that will be eligible to meet its standard [*21*]. Although the changes attempt to prevent excess CO_2 emissions from biomass generation, there still is much uncertainty about the true carbon footprints of various biomass feedstocks, as well as the future of eligible materials. Also, a Solar Carve-Out Program was added to the State's RPS, requiring additional installations to bring total installed photovoltaic capacity to 400 megawatts [*22*].

New Jersey

The State enacted two pieces of legislation affecting its RPS. AB 3520 [*23*] changed and extended its solar target to require a fixed amount of renewable generation rather than a percentage of renewable capacity: 5,316 gigawatthours of generation will be required in 2026. Senate Bill 2036 [*24*] established an offshore wind target of 1,100 megawatts. However, considerable regulatory uncertainties remain to be resolved.

New York

In January 2010, the New York Public Service Commission issued new orders expanding the State-funded RPS program [*25*]. The main-tier program seeks to establish 29 percent renewable generation by 2015, including existing capacity that already meets more than two-thirds of the new mandate. The program will be funded through a limited State fund of $2 billion. Moreover, a supplemental customer-sited tier will increase installations of end-use solar, wind, and anaerobic digester capacity.

3. Updates on liquid fuels taxes and tax credits

Excise taxes on highway fuels

The handling of Federal highway fuel taxes in *AEO2011* is unchanged from *AEO2010*. Gasoline is taxed at 18.4 cents per gallon, diesel fuel is taxed at 24.4 cents per gallon, and jet fuel for use in commercial aviation is taxed at 4.4 cents per gallon, as specified in the 2005 Transportation Equity Act [*26*]. The taxes are not adjusted for inflation and remain at the same nominal values through 2035. Although the highway fuel taxes expire in 2011 under current law, their assumed extension is consistent with Federal budgeting procedures which dictate that excise taxes dedicated to a trust fund, if expiring, are assumed to be extended at current rates [*27*].

Federal fuel taxes are the primary source of funding for the Highway Trust Fund, which is used to maintain the interstate highway system as well as mass transit systems. Recent vehicle efficiency improvements and lower consumer demand have led to shortfalls in the Trust Fund's revenues over the past few years.

State fuel taxes are calculated and allocated by Census Region, based on a volume-weighted average of diesel, gasoline, and jet fuel sales. State fuel taxes in *AEO2011* are updated to their most recent values (as of June 2010) [*28*].

Tax credits and tariffs for biofuels

In December 2010, the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010 became law [*29*]. The law includes an extension through 2011 of the $0.45 per gallon Volumetric Ethanol Excise Tax Credit, which was previously set to expire at the end of 2010 as specified in the Food, Conservation, and Energy Act of 2008 [*30*]. The cellulosic biofuels [*31*] production tax credit, also specified in the Food, Conservation, and Energy Act of 2008, remains set to expire in January 2013. The credit is $1.01 per gallon, but if applied to cellulosic ethanol it is reduced by the amount of the excise tax credit available to ethanol blends (assumed to be $0.45 per gallon through 2011).

In addition, the law includes a retroactive extension (through 2011) of the $1.00 per gallon biodiesel excise tax credit, which had been set to expire in December 2009. The credit applies to biodiesel made from recycled vegetable oils or animals fats and to renewable diesel. The tax package also includes an extension through 2011 of the $0.54 per gallon tariff on imported ethanol, which had been set to expire at the end of 2010. Both extensions are included in the *AEO2011* Reference case.

4. California Low Carbon Fuel Standard

California's LCFS will be administered by CARB [*32*]. In general, the regulated parties under the LCFS legislation are fuel producers or importers who sell motor gasoline or diesel fuel in California. The legislation is designed to reduce the carbon intensity of motor gasoline and diesel fuels sold in California by 10 percent between 2012 and 2020 through the increased sale of alternative low-carbon fuels. Each low-carbon fuel has its own carbon intensity, based on life-cycle analyses conducted under the guidance of CARB for a number of approved fuel pathways. The carbon intensities are calculated on an energy-equivalent basis, measured in grams of CO_2-equivalent emissions per megajoule.

The *AEO2011* Reference case incorporates the California LCFS, using CARB's mandated carbon intensities and approved fuel pathways [*33*]. Although NEMS is not a State-level model, CARB-mandated gasoline and diesel are modeled separately from other gasoline and diesel sold in the Pacific Census Division 9 (which also includes Washington, Oregon, Alaska, and Hawaii). In cases where data for California are not available, information from Census Division 9 is used as a proxy. Because CARB has not yet officially quantified penalties for LCFS noncompliance, the Reference case incorporates a monetary penalty estimated to encourage compliance, based on relevant provisions in the California Health and Safety Code [*34*].

Carbon intensities provide a measure of complete well-to-wheels or life-cycle emissions of each fuel pathway, including indirect land-use change (ILUC) penalties where applicable [*35*]. The ILUC penalty is used to account for potential changes in land use as the production of biofuels increases. Because the science behind the ILUC penalty is relatively new and still controversial, potential revisions and updates are expected as the LCFS evolves. For example, *AEO2011* assumes that corn ethanol is treated as having 20 percent lower GHG emissions than gasoline.

The fuel pathways used in EIA's analysis include existing technologies—such as Midwestern corn ethanol, imported sugarcane ethanol, and soy-based biodiesel—as well as a number of "next-generation" technologies, including cellulosic ethanol and biomass-to-liquid (BTL) fuels. Other provisions in the LCFS legislation also allow nonregulated parties, such as electricity and hydrogen producers, to contribute. With the exception of efforts to streamline the development and installation of home charging stations, there does not appear to be any significant effort at present to promote plug-in vehicles or to enhance public charging stations and other infrastructure.

The LCFS results in the transportation into California of additional renewable fuels produced in other regions or countries. To meet the LCFS gasoline mandate, consumption of motor fuel containing up to 85 percent ethanol (E85) in Census Division 9 increases to more than 2.4 billion gallons in 2020, allowing a larger share of ethanol consumption to contribute to lowering the gasoline carbon intensity. For the diesel mandate, every gallon of CARB diesel contains 20 percent biodiesel (the maximum generally recommended by original equipment manufacturers) by 2017.

The largest source of compliant fuel is sugarcane ethanol, imported primarily from Brazil, and biodiesel. Imported sugarcane ethanol has a much lower carbon intensity than domestically produced corn ethanol, primarily as a result of production methods that use fewer fossil fuel inputs. It is assumed that, in the last years of the LCFS program, such next-generation technologies as cellulosic ethanol and BTL will begin to reach the market and make a larger contribution toward meeting the LCFS. The same can be said for LCFS-compliant diesel, which requires the blending of more costly biomass-based diesel fuels.

In the later years of the LCFS, gasoline blends with ethanol content greater than E10, such as E85, will be needed for the gasoline mandate to be met. Even if ethanol with the lowest carbon footprint is used in E10 blends, it will not lower the carbon intensity of gasoline sufficiently for the LCFS to be met. Consequently, the amount of E85 available in California is a key factor in determining the mix of fuels with low carbon pathways, such as sugarcane ethanol and cellulosic ethanol, that can be used in meeting the gasoline mandate. For the diesel mandate, a blend of 20 percent biodiesel is already common today, and with the addition of such next-generation technologies as BTL fuels that are potentially "drop-in" fuels usable in existing distribution channels, the mandate can be met without new infrastructure.

5. Representing impacts of the U.S. EPA's interim permit review guidelines for surface coal mining operations

In April 2010, the EPA issued a set of new guidelines to several of its regional offices for monitoring the compliance of surface coal mining operations in Appalachia with the provisions of the Clean Water Act (CWA), the National Environmental Policy Act, and the environmental justice Executive Order (E.O. 12898) [*36*]. The stated purpose of the guidance was to explain more fully the approach that the EPA will be following in permit reviews and to provide additional assurance that its regional offices use clear, consistent, and science-based standards in reviewing the permits. Although the new guidelines went into effect immediately, they were subjected to review both by the public and by the EPA's Science Advisory Board, with a set of final guidelines to be issued in the spring of 2011.

Issuance of the new EPA guidelines is related primarily to the ongoing controversy over use of the mountaintop removal method at a number of surface coal mining operations in Central Appalachia—primarily in southern West Virginia and eastern Kentucky. Although the guidelines propose a more rigorous review for all new surface coal mines in Appalachia, the EPA indicates that the practice of valley fills, primarily associated with the mountaintop removal method, is the aspect of Appalachian coal mining that will be most scrutinized. In particular, the EPA points to new scientific evidence that dissolved solids in drainage from existing valley fills in Central Appalachia are adversely affecting downstream aquatic systems.

Although the proposed use of valley fills at mining sites will not necessarily preclude the issuance of permits for surface mines under Sections 402 and 404 of the CWA, the EPA guidelines recommend that all practicable efforts be made to minimize their use. Section 402 of the CWA pertains to the issuance of National Pollution Discharge Elimination System permits. Section 404 relates to the issuance of permits for the discharge of dredge or fill material into the waters of the United States, including wetlands. Issuance of Section 404 permits comes under the authority of the U.S. Army Corps of Engineers but is subject to EPA oversight.

Two recent actions by the EPA related to its review of Section 404 permits for proposed mountaintop mining operations in West Virginia indicate the Agency's heightened concern with regard to valley fills. In January 2010, the EPA announced its approval for the issuance of a Section 404 permit for Patriot Coal's proposed Hobet 45 mountaintop mining operation. The EPA indicated that the company was able to eliminate the need for any valley fills and, as a result, reduce the estimated adverse downstream impact by 50 percent.

In contrast, in January 2011, the EPA issued a final determination effectively denying a Section 404 permit for Arch Coal Company's Spruce No. 1 mountaintop mining operation, which would have resulted in the burial of 6.6 miles of headwater streams under the spoil of four separate valley fills [*37*]. Although a Section 404 permit for the mine was approved by the U.S. Army Corps of Engineers in January 2007, the EPA indicated that additional information had been obtained since then about its earlier concerns related to the project. The EPA indicated that its action to deny four of the six valley fills proposed for the Spruce No. 1 mine would protect not only wildlife in the parts of streams directly affected by the proposed mining operation but also the aquatic wildlife communities downstream from the project site. As was the case with the Hobet 45 mine, the EPA requested that Arch Coal submit possible corrective actions to the Spruce No. 1 mine plan to mitigate environmental impacts. Primarily on the basis of economic considerations, Arch Coal declined to offer additional changes to the proposed plan for the mine.

In *AEO2011*, the impact of the EPA's April 2010 guidelines for surface coal mining operations is represented by downward adjustments to the coal mining productivity assumptions for Central Appalachian surface mines (Figure 5), resulting in slightly higher estimated production costs for the region and mine type. The assumed productivity levels for Central Appalachian surface mines are roughly 15 to 20 percent lower than those that would have been used for a case without the EPA's new permit review guidelines. The revised productivity levels are based on the assumption that large surface mining operations will decline gradually toward the productivity levels for smaller surface mines in the region as a result of the more restrictive guidelines for overburden management at large mountaintop mining operations. No adjustments were made to the productivity assumptions for other Appalachian supply regions in response to the new EPA permit review guidelines, because few if any surface mining operations in other regions employ the mountaintop removal method.

6. EPA approval of E15 waiver

In October 2010, the EPA approved a waiver for the use of motor gasoline blends containing up to 15 percent ethanol (E15) in MY 2007 and newer vehicles—an increase over the 10 percent ethanol limit (E10) set in 1978 [*38*]. In January 2011, the EPA extended the waiver to vehicles manufactured in years 2001-2006 [*39*]. That change was incorporated in the modeling for *AEO2011*.

Although the EPA's January 2011 ruling will allow the use of E15 blend in approximately 60 percent of the current vehicle fleet, there are issues that may limit its widespread adoption:

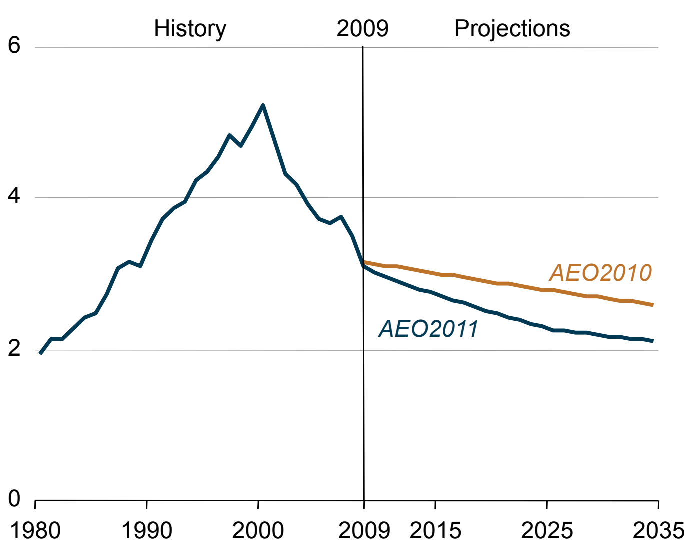
- Retailers must justify the significant costs of upgrading pumps and storage tanks while weighing the prospects for increased liability and uncertain consumer acceptance. Because the majority of U.S. service stations are "pay at the pump," there is concern about potential liability for engine damage resulting from consumer misfueling in motor vehicles not approved for E15 use, as well as in small engine applications. In addition, much of the retail outlet infrastructure for blends containing more than 10 percent ethanol lacks Underwriter Laboratory certification, creating concerns about the costs of any equipment malfunctions.
- In addition to liability issues, infrastructure costs in the form of blender pumps and additional storage tanks could deter retailers from choosing to offer a higher ethanol blend. Most service stations use two storage tanks, one containing a regular E10 blend and the other a premium blend. Adding a higher E15 blend could force service station owners either to add an additional tank and modified pumps or to stop offering E10 gasoline blends or profitable premium-grade fuels.
- Retailers may be unwilling to commit to E15 in the short term, because consumer acceptance is uncertain. Warning labels about possible engine damage could dampen consumer demand, despite educational efforts.

To examine the potential impacts of high and low penetration of E15 fuel in retail markets, two sensitivity cases were compared with the *AEO2011* Reference case. In the High E15 case, ethanol blending above 10 percent occurs earlier in the projection and increases more rapidly than in the Reference case. The High E15 case also assumes that any State which currently has laws or regulations prohibiting ethanol blends above 10 percent or oxygenate content in excess of 3.5 percent will remove those restrictions by 2015. As a result, ethanol use for gasoline blending increases to 18.1 billion gallons in 2015, compared with 15.8 billion gallons in the Reference case, and to 21.2 billion gallons in 2020, compared with 17.8 billion gallons in the Reference case.

Most of the additional ethanol needed to meet increased demand in the High E15 case is corn ethanol produced domestically,with cellulosic ethanol and imported ethanol beginning to make larger contributions after 2020. Ethanol blending increases to 14.5 percent of the motor gasoline pool in 2020—compared with 12.4 percent in the Reference case—and to 14.8 percent in 2035.

In the Low E15 case, the results are similar to those in the Reference case, and many of the infrastructure and regulatory barriers reflected in the Reference case govern the dynamics in the Low E15 case. Ethanol blending in the Low E15 case never rises above 11.5 percent of the motor gasoline pool and is 11.4 percent in 2035. Total ethanol supply in 2020 is almost 2 billion gallons less than in the Reference case, but with E85 consumption increasing at a faster rate after 2020, it reaches levels similar to those in the Reference case. In 2035, E85 use in the Low E15 case totals about 12 billion gallons, or 2 billion gallons more than in the Reference case. In both cases, total ethanol supply in 2035 is approximately 28 billion gallons.

Figure 5. Surface coal mining productivity in Central Appalachia, 1980-2035 (short tons per miner per hour)



Rapid increases in E85 consumption in the Reference, High E15, and Low E15 cases indicate the importance for ethanol producers of E85 availability after the motor gasoline blending pool has been saturated, even with an increase to a 15-percent limit for ethanol blends. Growth in E85 consumption is affected by the level of demand for ethanol in gasoline blends, particularly in the High E15 case. Because most of the growth in ethanol use for blending occurs in the near term in the High E15 case, growth in E85 use begins later (in 2024) than in the Reference and Low E15 cases (2016).

While more ethanol blended into gasoline reduces its energy content and often the miles per gallon of the vehicle using it, *AEO2011* assumes that only E85 will be priced at a discount for its lower energy content. E10 and E15 are assumed to compete for demand on price alone. Nevertheless, the ability to switch out volumes of E85 with E15 can be expected to affect gasoline pricing. When E15 penetration is high, gasoline prices are lower, because more of the less expensive blend stock (ethanol) is used. In addition, there is less need to encourage E85 demand by subsidizing infrastructure cost and E85 prices with higher gasoline prices. With low penetration the opposite is true: gasoline prices are higher, because more cost recovery is needed for E85 marketing and infrastructure, and less ethanol is available for blending.

7. Mandates for low-sulfur heating oil in the Northeast

During 2010, Connecticut [*40*], Maine [*41*], New Jersey [*42*], and New York [*43*] passed legislation to reduce the maximum allowable sulfur content of heating oil sold in their markets. Pennsylvania proposed a similar law, but it was not approved. Connecticut and Maine will begin regulating maximum sulfur content by mid-2011, with Connecticut reducing the maximum to 50 parts per million (ppm) and Maine reducing the maximum to 15 ppm. The Connecticut law includes a second reduction to 15 ppm in 2014. Connecticut and Maine also put in place requirements for 2-percent biodiesel content in heating oil, starting in mid-2011. The New Jersey legislation reduces the maximum sulfur content to 500 ppm in 2014 and includes a second reduction to 15 ppm in 2016. New York reduced the maximum sulfur content to 15 ppm starting in 2012. The new laws in each of the four States are included in *AEO2011*.

On February 1, 2011, the U.S. Department of Energy also announced plans to convert the inventory of almost 2 million barrels in the Northeast Heating Oil Reserve to cleaner burning ultra-low-sulfur distillate. The first phase of this transition was the sale of the 2 million barrels of heating oil in February 2011. The receipts from those sales will be used to purchase ultra-low-sulfur heating oil to refill the reserve before the 2011-2012 heating oil season begins.

Endnotes for legislation and regulations

Links current as of April 2011

1. Connecticut State Senate, Bill 382, "An Act Requiring Biodiesel Blended Heating Oil and Lowering the Sulfur Content of Heating Oil Sold in the State," website www.cga.ct.gov/2010/TOB/S/2010SB-00382-R00-SB.htm.
2. Maine State Legislature, "An Act To Establish Biofuel and Ultra-low Sulfur Requirements for Number 2 Home Heating Oil," website www.mainelegislature.org/legis/bills/bills_124th/billtexts/HP116001.asp.
3. New Jersey State Department of Environmental Protection, Amendment N.J.A.C. 7:27-9.2, "Sulfur in Fuels," website www.nj.gov/dep/rules/adoptions/adopt_100920a.pdf.
4. New York State Senate, Bill S1145C, "S1145C-2009: Requires a Reduction in Sulfur Emissions for All Heating Oil Used in Non-Attainment Areas," website http://open.nysenate.gov/legislation/bill/S1145C-2009#.
5. California Air Resources Board, LCFS Final Regulation Order, "Low Carbon Fuel Standard," website www.arb.ca.gov/regact/2009/lcfs09/finalfro.pdf.
6. 111th Congress, Public Law 312, "Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010," Sections 701, 704, and 708, website www.gpo.gov/fdsys/pkg/PLAW-111publ312/html/PLAW-111publ312.htm.
7. U.S. Environmental Protection Agency, "E15 (A Blend of Gasoline and Ethanol)," website www.epa.gov/otaq/regs/fuels/additive/e15.
8. U.S. Environmental Protection Agency, "April 1, 2010 Memorandum: Improving EPA Review of Appalachian Surface Coal Mining Operations Under the Clean Water Act, National Environmental Policy Act, and the Environmental Justice Executive Order," website http://water.epa.gov/lawsregs/guidance/wetlands/mining.cfm#memo20100401.
9. Regional Greenhouse Gas Initiative, "Fact Sheet: The Regional Greenhouse Gas Initiative (RGGI)," website www.rggi.org/docs/RGGI_Fact_Sheet.pdf.
10. Regional Greenhouse Gas Initiative, "Auction Results," website www.rggi.org/market/co2_auctions/results.
11. California Air Resources Board, Climate Change Scoping Plan: A Framework for Change, (Sacramento, CA: December 2008), website www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.
12. California Air Resources Board, Climate Change Scoping Plan: A Framework for Change, (Sacramento, CA: December 2008), website www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.
13. On April 12, 2011, California Governor Jerry Brown signed into law a 33-percent RPS that replaces the previous Executive Order. The new law can be viewed at http://leginfo.ca.gov/pub/11-12/bill/sen/sb_0001-0050/sbx1_2_bill_20110412_chaptered.pdf.
14. State of California Air Resources Board, "California Cap-and-Trade Program Resolution 10-42" (December 26, 2010), website www.arb.ca.gov/cc/capandtrade/capandtrade/draft%20resolution.pdf.
15. W. Buchanan, "Calif. Cap-Trade Plan Dealt Blow by S.F. Judge,"San Francisco Chronicle (San Francisco, CA: February 4, 2011), website http://articles.sfgate.com/2011-02-04/news/27100791_1_air-board-ab32-emissions-plan.
16. More information about DSIRE can be found at website www.dsireusa.org/about.
17. State of California, Air Resources Board, Resolution 10-23 (September 23, 2010), website www.arb.ca.gov/regact/2010/res2010/res1071.pdf.
18. State of Colorado, 67th General Assembly, House Bill 10-1001 (March 2010), website www.leg.state.co.us/CLICS/CLICS2010A/csl.nsf/BillFoldersAll?OpenFrameSet.
19. Colorado Department of Regulatory Agencies, Public Utilities Commission, "Rules Regulating Electric Utilities," website www.dsireusa.org/documents/Incentives/CO24R.pdf.
20. State of Delaware, 145th General Assembly, Senate Bill #119, Senate Substitute No. 1 (June 18, 2010), website www.legis.delaware.gov/LIS/lis145.nsf/vwLegislation/SB+119/$file/legis.html?open.
21. Commonwealth of Massachusetts, Executive Office of Energy and Environmental Affairs, "Renewable Portfolio Standard – Biomass Policy Regulatory Process," website www.mass.gov/?pageID=eoeeaterminal&L=4&L0=Home&L1=Energy%2C+Utilities+%26+Clean+Technologies&L2=Renewable+Energy&L3=Biomass&sid=Eoeea&b=terminalcontent&f=doer_renewables_biomass_policy-reg-process&csid=Eoeea.
22. Commonwealth of Massachusetts, Executive Office of Energy and Environmental Affairs, "Solar Carve-out Regulation Finalized," website www.mass.gov/?pageID=eoeeaterminal&L=5&L0=Home&L1=Energy%2C+Utilities+%26+Clean+Technologies&L2=Renewable+Energy&L3=Solar&L4=RPS+Solar+Carve-Out&sid=Eoeea&b=terminalcontent&f=doer_renewables_solar_ongoing-public-rulemaking&csid=Eoeea.
23. State of New Jersey , Assembly Bill 3520, "The Solar Energy Advancement and Fair Competition Act" (January 12, 2010), website www.njleg.state.nj.us/2008/Bills/A4000/3520_R3.PDF.

24. State of New Jersey , Senate Bill 2036, "Offshore Wind Economic Development Act" (June 21, 2010), website www.njleg.state.nj.us/2010/Bills/S2500/2036_R2.PDF.

25. New York State Public Service Commission, "Retail Renewable Portfolio Standard: Case 03-E-0188," website www3.dps.state.ny.us/W/PSCWeb.nsf/All/1008ED2F934294AE85257687006F38BD?OpenDocument.

26. U.S. Department of Transportation, Federal Highway Administration, "SAFETEA-LU: Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users" (July 29, 2005), website www.fhwa.dot.gov/safetealu/.

27. U.S. House of Representatives, Office of the Law Revision Counsel, 2 USC Chapter 20, "Emergency Powers To Eliminate Budget Deficits," Subchapter 1, Section 907 , "The Baseline," website http://uscode.house.gov/download/pls/02C20.txt.

28. Defense Energy Support Center, "Compilation of United States Fuel Taxes, Inspection Fees, and Environmental Taxes and Fees," Edition 2010-10 (June 5, 2010), website www.desc.dla.mil/dcm/files/tax%20compilation%202010-10.doc.

29. 111th Congress, Public Law 312, "Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010," Sections 701, 704, and 708, website www.gpo.gov/fdsys/pkg/PLAW-111publ312/html/PLAW-111publ312.htm.

30. 110th Congress, Public Law 110-234, "Food, Conservation, and Energy Act of 2008," Section 15331, website http://frwebgate.Access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_public_laws&docid=f:publ246.110.pdf.

31. The cellulosic biofuels represented in NEMS are cellulosic ethanol, BLT diesel, and BTL naphtha.

32. California Air Resources Board, "Final Regulation Order: Subarticle 7. Low Carbon Fuel Standard," website www.arb.ca.gov/regact/2009/lcfs09/finalfro.pdf.

33. California Air Resources Board, "Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline" and "Carbon Intensity Lookup Table for Diesel and Fuels that Substitute for Diesel," website www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf.

34. "2009 California Health and Safety Code, Section 43025-43031.5, Chapter 1.5, Penalties for Violation of Fuel Regulations," website http://law.justia.com/codes/california/2009/hsc/43025-43031.5.html.

35. ILUC penalties apply to biofuels produced from harvested biomass, which currently include corn ethanol, sugarcane ethanol, and soy-based biodiesel.

36. U.S. Environmental Protection Agency, "April 1, 2010 Memorandum: Improving EPA Review of Appalachian Surface Coal Mining Operations Under the Clean Water Act, National Environmental Policy Act, and the Environmental Justice Executive Order," website http://water.epa.gov/lawsregs/guidance/wetlands/mining.cfm#memo20100401.

37. U.S. Environmental Protection Agency, "Clean Water Act Section 404(c): 'Veto Authority': Spruce No. 1 Surface Mine, Final Determination - January 2011 (Logan County, WV)," website http://water.epa.gov/lawsregs/guidance/cwa/dredgdis/spruce.cfm.

38. U.S. Environmental Protection Agency, "Partial Grant and Partial Denial of Clean Air Act Waiver Application Submitted by Growth Energy To Increase the Allowable Ethanol Content of Gasoline to 15 Percent; Decision of the Administrator; Notice," Federal Register, Vol. 75, No. 213 (Washington, DC: November 4, 2010), website www.regulations.gov/search/Regs/contentStreamer?objectId=0900006480b80cca&disposition=attachment&contentType=pdf.

39. U.S. Environmental Protection Agency, "Partial Grant of Clean Air Act Waiver Application Submitted by Growth Energy To Increase the Allowable Ethanol Content of Gasoline to 15 Percent; Decision of the Administrator," Federal Register, Vol. 76, No. 17 (Washington, DC: January 26, 2011), website www.regulations.gov/search/Regs/contentStreamer?objectId=0900006480b80cca&disposition=attachment&contentType=pdf.

40. State of Connecticut, General Assembly, Raised Bill No. 382, February Session 2010, "An Act Requiring Biodiesel Blended Heating Oil and Lowering the Sulfur Content of Heating Oil Sold in the State," website www.cga.ct.gov/2010/TOB/S/2010SB-00382-R00-SB.htm.

41. Maine State Legislature, "An Act To Establish Biofuel and Ultra-low Sulfur Requirements for Number 2 Home Heating Oil," website www.mainelegislature.org/legis/bills/bills_124th/billtexts/HP116001.asp.

42. New Jersey State Department of Environmental Protection, Amendment N.J.A.C. 7:27-9.2, "Sulfur in Fuels," website www.nj.gov/dep/rules/adoptions/adopt_100920a.pdf.

43. New York State Senate, Bill S1145C, "S1145C-2009: Requires a Reduction in Sulfur Emissions for All Heating Oil Used in Non-Attainment Areas," website http://open.nysenate.gov/legislation/bill/S1145C-2009#.

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Issues in focus

Introduction

The "Issues in focus" section of the *Annual Energy Outlook (AEO)* provides an in-depth discussion on topics of special interest, including significant changes in assumptions and recent developments in technologies for energy production and consumption. Detailed quantitative results are available in Appendix D. The first topic updates a discussion included in the *Annual Energy Outlook 2010 (AEO2010)* that compared the results of two cases with different assumptions about the future course of existing energy policies. One case assumes the elimination of sunset provisions in existing energy policies; that is, the policies are assumed not to sunset as they would under current law. The other case assumes the extension of a selected group of existing policies—corporate average fuel economy (CAFE) standards, appliance standards, and production tax credits (PTCs)—in addition to the elimination of sunset provisions.

Other topics include (2) a discussion of projected trends in world oil supply and prices based on assumed changes in demand from countries outside the Organization for Economic Cooperation and Development (OECD) or in the availability of oil supply from the Organization of the Petroleum Exporting Countries (OPEC); (3) an examination of the potential impacts of proposed revisions to CAFE standards for light-duty vehicles (LDVs); (4) potential impacts of proposed CAFE standards for heavy-duty trucks; (5) potential impacts of a series of updates to efficiency standards for residential and commercial appliances, alone or in combination with revised building codes; (6) an analysis of potential impacts on natural gas and crude oil production of expanded drilling in U.S. offshore fields; (7) prospects for shale gas; (8) the impacts of cost uncertainty on the construction of new electric power plants; (9) the economics of carbon capture and storage; and (10) the impacts of proposed U.S. Environmental Protection Agency (EPA) regulations in the electric power sector.

The topics explored in this section represent current and emerging issues in energy markets; but many of the topics discussed in *AEO*s published in recent years also remain relevant today. Table 3 provides a list of titles from the 2010, 2009, and 2008 *AEO*s that are likely to be of interest to today's readers—excluding topics that are updated in *AEO2011*. The articles listed in Table 3 can be found on the U.S. Energy Information Administration's (EIA's) website at www.eia.gov/analysis/reports.cfm?t=128.

1. No Sunset and Extended Policies cases

Background

The *Annual Energy Outlook 2011 (AEO2011)* Reference case is best described as a "current laws and regulations" case, because it generally assumes that existing laws and current regulations will remain unchanged throughout the projection period, unless the legislation establishing them sets a sunset date or specifies how they will change. The Reference case often serves as a starting point for the analysis of proposed legislative or regulatory changes. While the definition of the Reference case is relatively straightforward, there may be considerable interest in a variety of alternative cases that reflect the updating or extension of current laws and regulations. In that regard, areas of particular interest include:

- Laws or regulations that have a history of being extended beyond their legislated sunset dates. Examples include the various tax credits for renewable fuels and technologies, which have been extended with or without modifications several times since their initial implementation.
- Laws or regulations that call for the periodic updating of initial specifications. Examples include appliance efficiency standards issued by the U.S. Department of Energy (DOE) and CAFE and greenhouse gas (GHG) emissions standards for vehicles issued by National Highway Traffic Safety Administration (NHTSA) and the EPA.
- Laws or regulations that allow or require the appropriate regulatory agency to issue new or revised regulations under certain conditions. Examples include the numerous provisions of the Clean Air Act (CAA) that require the EPA to issue or revise regulations if it finds that an environmental quality target is not being met.

Table 3. Key analyses of interest from *Issues in focus* in recent *AEO*s

AEO2010	*AEO2009*	*AEO2008*
Energy intensity trends in *AEO2010*	Economics of plug-in hybrid electric vehicles	Impacts of uncertainty in energy project costs
Natural gas as a fuel for heavy trucks: issues and incentives	Impact of limitations on access to oil and natural gas resources in the Federal Outer Continental Shelf	Limited Electricity Generation Supply and Limited Natural Gas Supply cases
Factors affecting the relationship between crude oil and natural gas prices	Expectations for oil shale production	Trends in heating and cooling degree-days: Implications for energy demand
U.S. nuclear power plants: continued life or replacement after 60?	Bringing Alaska North Slope natural gas to market	Liquefied natural gas: Global challenges
Accounting for carbon dioxide emissions from biomass energy combustion	Tax credits and renewable generation	
	Greenhouse gas concerns and power sector planning	

To provide some insight into the sensitivity of results to different characterizations of baseline policies, two alternative cases are discussed in this section. No attempt is made to cover the full range of possible uncertainties in these areas, and readers should not view the cases discussed as EIA projections of how laws or regulations might or should be changed.

Analysis cases

The two cases prepared—the No Sunset case and Extended Policies case—incorporate all the assumptions from the *AEO2011* Reference case, except as identified below. Changes from the Reference case assumptions in these cases include the following.

No Sunset case

- Extension of tax credits for renewable energy sources in the utility, industrial, and buildings sectors and for energy-efficient equipment in the buildings sector, including:
  - The PTC of 2.1 cents per kilowatthour or the 30-percent investment tax credit (ITC) available for wind, geothermal, biomass, hydroelectric, and landfill gas resources, currently set to expire at the end of 2012 for wind and 2013 for the other eligible resources, are assumed to be extended indefinitely.
  - For solar power investment, a 30-percent ITC that is scheduled to revert to a 10-percent credit in 2016 is, instead, assumed to be extended indefinitely at 30 percent.
  - In the buildings sector, tax credits for the purchase of energy-efficient equipment, including PV in new houses, are assumed to be extended indefinitely, as opposed to ending in 2010 or 2016 as prescribed by current law. The business ITCs for commercial-sector generation technologies and geothermal heat pumps are assumed to be extended indefinitely, as opposed to expiring in 2016; and the business ITC for solar systems is assumed to remain at 30 percent instead of reverting to 10 percent.
  - In the industrial sector, the ITC for combined heat and power (CHP) that ends in 2016 in the *AEO2011* Reference case is assumed to be extended through 2035.
- Extension through 2035 of the $0.45 per gallon blender's tax credit for ethanol (set to expire at the end of 2011).
- Extension through 2035 of the $1.00 per gallon biodiesel excise tax credit (set to expire at the end of 2011).
- Extension through 2035 of the $0.54 per gallon tariff on imported ethanol (set to expire at the end of 2011).
- Extension through 2035 of the PTC for cellulosic biofuels of up to $1.01 per gallon (set to expire at the end of 2012).

Extended Policies case

With the exception of the blender's and other biofuel tax credits, the Extended Policies case adopts the same assumptions as in the No Sunset case, plus the following:

- Federal equipment efficiency standards are updated at particular intervals consistent with the provisions in the existing law, with the levels based on ENERGY STAR specifications, or Federal Energy Management Program (FEMP) purchasing guidelines for Federal agencies. Standards are also introduced for products that currently are not subject to Federal efficiency standards.
- Updated Federal residential and commercial building energy codes reach 30-percent improvement in 2020 relative to the 2006 International Energy Conservation Code (IECC) in the residential sector and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Building Energy Code 90.1-2004 in the commercial sector. Two subsequent rounds in 2023 and 2026 each add an assumed 5-percent incremental improvement to building energy codes.

  The equipment standards and building codes assumed for the Extended Policies case are meant to illustrate the potential effects of these polices on energy consumption for buildings. No cost-benefit analysis or evaluation of impacts on consumer welfare was completed in developing the assumptions. Likewise, no technical feasibility analysis was conducted, although standards were not allowed to exceed "maximum technologically feasible" levels described in DOE's technical support documents.
- The Extended Policies case modifies the Reference case by assuming a 3-percent annual increase in fuel economy standards for new LDVs from model year (MY) 2017 through MY 2025, with subsequent CAFE standards held constant. CAFE standards for LDVs increase from 34.1 miles per gallon (mpg) in MY 2016 to 46.0 mpg in MY 2025.

  The *AEO2011* Reference case and Extended Policies case include both the attribute-based CAFE standards for LDVs for MY 2011 and the joint attribute-based CAFE and vehicle GHG emissions standards for MY 2012 to MY 2016. However, the Reference case assumes that LDV CAFE standards increase to 35 miles per gallon by MY 2020, as called for in the Energy Independence and Security Act of 2007 (EISA2007). CAFE standards are then held constant in subsequent model years, although the fuel economy of new LDVs continues to rise modestly over time.
- The extensions of the blender's and all biofuels excise tax credits and import tariffs through 2035 adopted in the No Sunset case are not included in the Extended Policies case. The renewable fuels standard (RFS) enacted in EISA2007 is an alternative instrument for stimulating demand for biofuels. It already is represented in the *AEO2010* Reference case, and it tends to be the binding driver on biofuels rather than the tax credits.

- In the industrial sector, CHP tax credits are extended to cover all system sizes rather than applying only to systems under 50 megawatts, and the maximum credit (cap) is increased from $15,000 to $25,000 per system. These extensions are consistent with previously proposed or pending legislation.

Analysis results

The changes made to Reference case assumptions in the No Sunset and Extended Policies cases generally lead to lower estimates for overall energy consumption, increased use of renewable fuels, particularly for electricity generation, and reduced energy-related carbon dioxide (CO_2) emissions. Because the Extended Policies case includes most of the assumptions in the No Sunset case but adds others, the impacts in the Extended Policies case tend to be greater than those in the No Sunset case. Although these cases show lower energy prices—because the tax credits and end-use efficiency standards lead to lower energy demand and reduce the cost of renewable fuels—consumers spend more on appliances that are more efficient in order to comply with the tighter appliance standards, and the Government receives lower tax revenues as consumers and businesses take advantage of the tax credits.

Energy consumption

Total energy consumption in the No Sunset case is close to the level in the Reference case (Figure 6). Improvements in energy efficiency lead to slightly reduced consumption in this case, despite somewhat lower energy prices.

Total energy consumption in the Extended Policies case, which assumes the issuance of more stringent efficiency standards for end-use equipment and LDVs in the future, is lower than in the Reference case. In 2035, total energy consumption in the Extended Policies case is nearly 7 percent below the projection in the Reference case. As an example of individual end uses, the assumed future standard for residential electric water heating, which requires installation of heat pumps starting in 2021, has the potential to reduce their electricity use by 50 percent from the Reference case level in 2035. Overall, delivered energy use in the buildings sector in 2035 is 8.5 percent lower in the Extended Policies case than in the Reference case.

Transportation energy consumption

The Extended Policies case modifies the Reference case by assuming a 3-percent annual increase in the stringency of CAFE standards for MY 2017 to MY 2025, with subsequent standards held constant. The LDV CAFE standards in the Extended Policies case increase from 34.1 mpg in 2016 to 46.0 mpg in 2025, as compared with 35.6 mpg in the Reference case. Sales of unconventional vehicles (including those that use diesel, alternative fuels, and/or hybrid electric systems) play a substantial role in meeting the higher fuel economy standards, growing to around 70 percent of new LDV sales in 2035, compared with about 40 percent in the Reference case.

As a result of more stringent CAFE standards, LDV energy consumption declines in the Extended Policies case, from 16.1 quadrillion British thermal units (Btu) (8.6 million barrels per day) in 2009 to 14.8 quadrillion Btu (8.3 million barrels per day) in 2025 and 14.4 quadrillion Btu (8.1 million barrels per day) in 2035—representing a 10-percent reduction from the Reference case in 2025 and a 19-percent reduction in 2035 (Figure 7). Liquid fuel consumption in the transportation sector continues to grow in the Extended Policies case, from 13.6 million barrels per day in 2009 to 14.1 million in 2025 and 14.2 million in 2035, but at a slower rate than in the Reference case. Cumulative consumption of liquid fuel for transportation between 2017 and 2035 drops by 6.5 billion barrels, or 6 percent, in comparison with the Reference case.

Figure 6. Total energy consumption in three cases, 2005-2035 (quadrillion Btu)

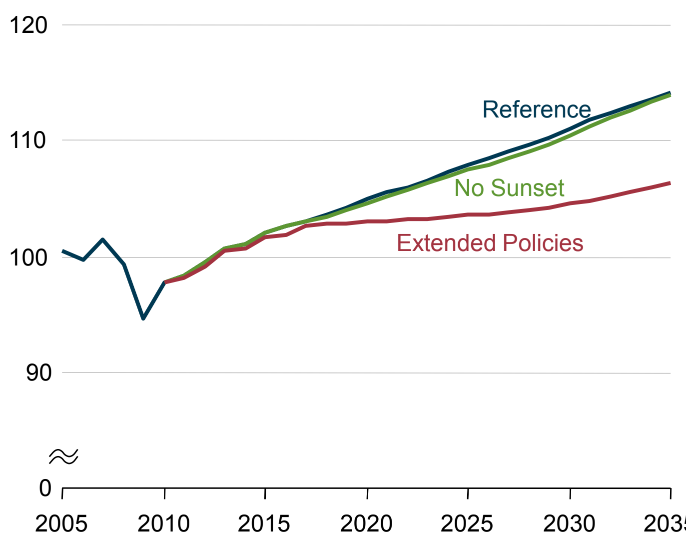
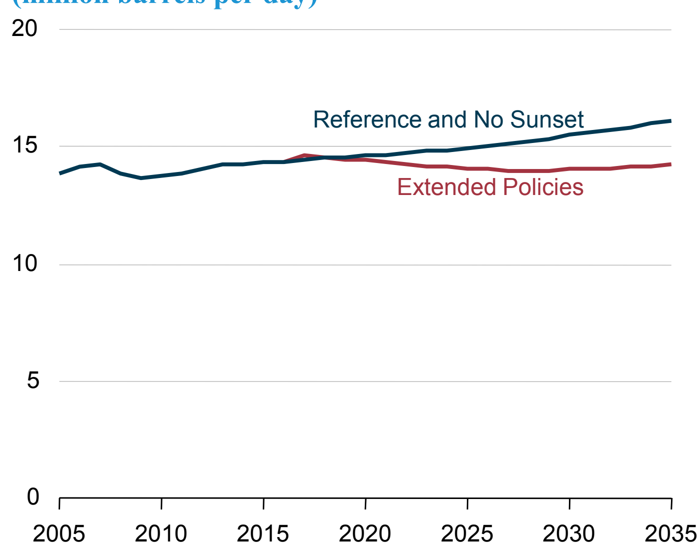


Figure 7. Total liquid fuels consumption for transportation in three cases, 2005-2035 (million barrels per day)



Renewable electricity generation

The extension of tax credits for renewables through 2035 would, over the long run, lead to more rapid growth in renewable generation than projected in the Reference case. When the renewable tax credits are extended without extending energy efficiency standards, as is assumed in the No Sunset case, there is a significant increase in renewable generation in 2035 relative to the Reference case projection (Figure 8). Extending both renewable tax credits and energy efficiency standards results in more modest growth in renewable generation, because renewable generation in the near term is a significant source of new generation to meet load growth, and enhanced energy efficiency standards tend to reduce overall electricity consumption and the need for new generation resources.

In the Reference case, growth in renewable generation accounts for 26 percent of total generation growth from 2009 to 2035. In the No Sunset and Extended Policies cases, growth in renewable generation accounts for 36 to 38 percent of total generation growth. In 2035, the share of total electricity generation accounted for by renewables is 14 percent in the Reference case, as compared with 16 percent in the No Sunset case and the Extended Policies case.

In all three cases, the most rapid growth in renewable capacity occurs in the near term. After that, the growth slows through 2020 before picking up again. Before 2015, ample supplies of renewable energy in relatively favorable resource areas (such as windy lands or accessible geothermal sites), combined with the Federal incentives, make renewable generation competitive with conventional sources. With slow growth in electricity demand and the addition of capacity stimulated by renewable incentives before 2015, little new capacity is needed between 2015 and 2020. In addition, in some regions, attractive low-cost renewable resources already have been exploited, leaving only less favorable sites that may require significant investment in transmission as well as other additional infrastructure costs. Starting around 2020, significant new sources of renewable generation also appear on the market as a result of cogeneration at biorefineries built primarily to produce renewable liquid fuels to meet the Federal RFS, where combustion of waste products to produce electricity is an economically attractive option.

After 2020, renewable generation in the No Sunset and Extended Policies cases increases more rapidly than in the Reference case, and as a result generation from nuclear and fossil fuels is reduced from the levels in the Reference case (Figure 9). Natural gas represents the largest source of displaced generation. In 2035, electricity generation from natural gas is 8 percent lower in the No Sunset case and 16 percent lower in the Extended Policies case than in the Reference case.

Energy-related CO_2 emissions

In the No Sunset and Extended Policies cases, lower overall energy demand leads to lower levels of energy-related CO_2 emissions than in the Reference case. The Extended Policies case shows much larger emissions reductions than the No Sunset and Reference cases, in part, due to the inclusion of a tighter CAFE policy for transportation. From 2012 to 2035, energy-related CO_2 emissions are reduced by a cumulative total of 5.2 billion metric tons (a 3.7-percent reduction over the period) in the Extended Policies case from the Reference case projection, as compared with 0.7 billion metric tons (a 0.5-percent reduction over the period) in the No Sunset case (Figure 10). The increase in fuel economy assumed for new LDVs in the Extended Policies case leads to nearly one-half the total reduction in CO_2 emissions in the Reference case projection by 2035. The balance of the reduction in CO_2 emissions is due to greater efficiency improvement in appliances and increased penetration of renewable of electricity generation.

Figure 8. Renewable electricity generation in three cases, 2005-2035 (billion kilowatthours)

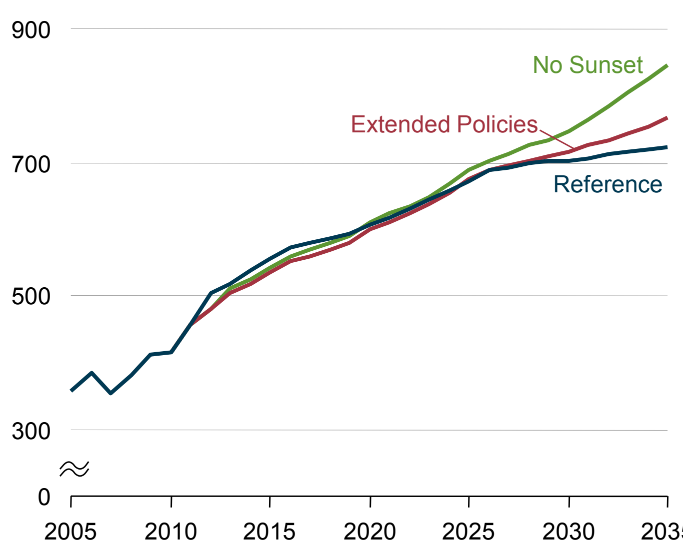
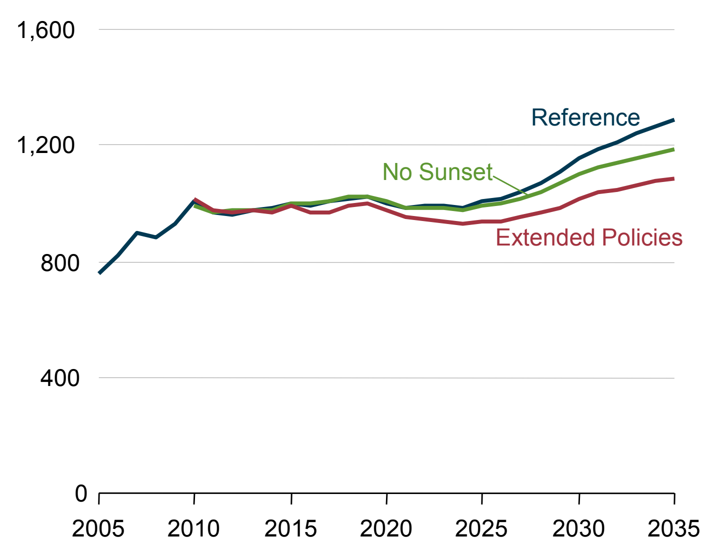


Figure 9. Electricity generation from natural gas in three cases, 2005-2035 (billion kilowatthours)



The majority of the emissions reductions in the No Sunset case are the result of increases in electricity generation from renewable fuels. By convention, emissions associated with the combustion of biomass for electricity generation are not counted, because they are assumed to be balanced by carbon uptake when the feedstock is grown. A small reduction in transportation sector emissions in the No Sunset case is counterbalanced by an increase in emissions from refineries during the production of synthetic fuels that receive tax credits. Relatively small incremental reductions in emissions are attributable to renewables in the Extended Policies case, mainly because electricity demand is lower than in the Reference case, reducing the consumption of all fuels used for generation, including biomass.

In the residential sector, in both the No Sunset and Extended Policies cases, water heating, space cooling, and space heating together account for most of the emissions reductions from Reference case levels. In the commercial sector, only the Extended Policies case sees substantial emission reductions in those categories.

Energy prices and tax credit payments

With lower levels of overall energy use and more consumption of renewable fuels in the No Sunset and Extended Policies cases, energy prices are lower than in the Reference case. In 2035, natural gas wellhead prices are $0.21 per thousand cubic feet (3 percent) and $0.60 per thousand cubic feet (9 percent) lower in the No Sunset and Extended Policies cases, respectively, than in the Reference case (Figure 11), and electricity prices are 2 percent and 6 percent lower than in the Reference case (Figure 12).

The reductions in energy consumption and CO_2 emissions in the Extended Policies case require additional equipment costs to consumers and revenue reductions for the U.S. Government. From 2011 to 2035, residential and commercial consumers spend an additional $11 billion per year (in real 2009 dollars) on average for newly purchased end-use equipment, distributed generation systems, and residential building shell improvements in the Extended Policies case than in the Reference case. On the other hand, they save an average of $29 billion per year on their energy bills.

Tax credits paid to consumers in the buildings sector in the Extended Policies case average $14 billion (real 2009 dollars) more per year than in the Reference case. In comparison, revenue reductions as a result of tax credits in the buildings sector average $1 billion more per year over the same period than in the Reference case. However, 60 percent of the revenue reductions in the Reference case occur by 2016 when most of the tax credits are scheduled to expire.

The largest response to Federal PTC incentives for new renewable generation is seen in the No Sunset case, with extension of the PTC resulting in annual average reductions in Government tax revenues of approximately $730 million over the 2011 to 2035 period, as compared with $230

Figure 10. Energy-related carbon dioxide emissions in three cases, 2005-2035 (million metric tons)

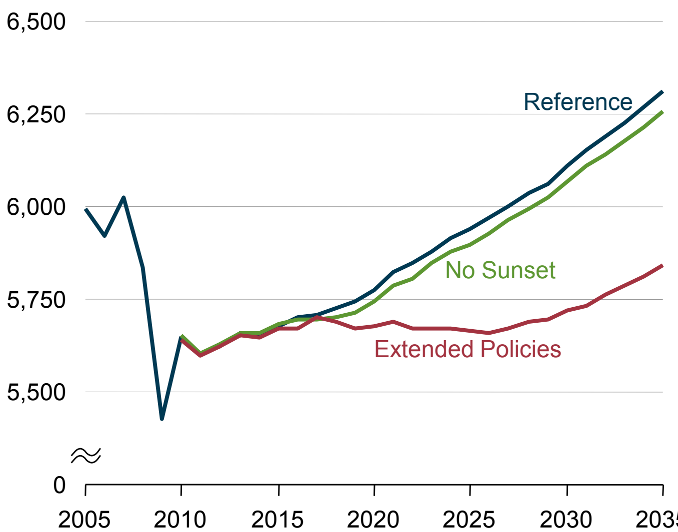


Figure 11. Natural gas wellhead prices in three cases, 2005-2035 (2009 dollars per thousand cubic feet)

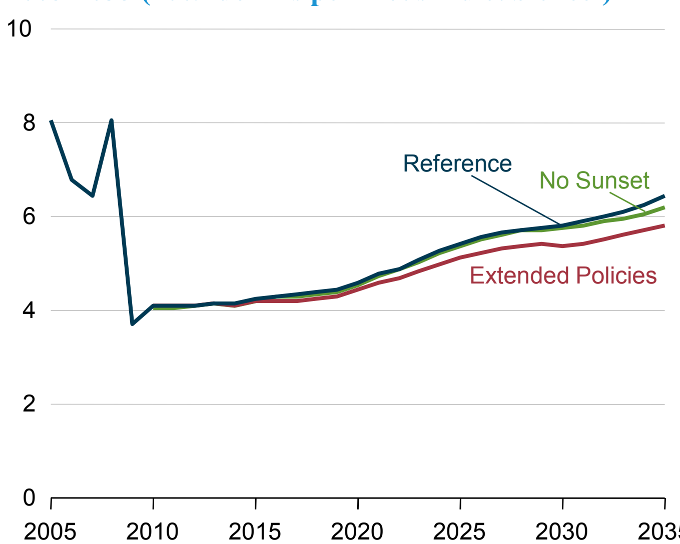
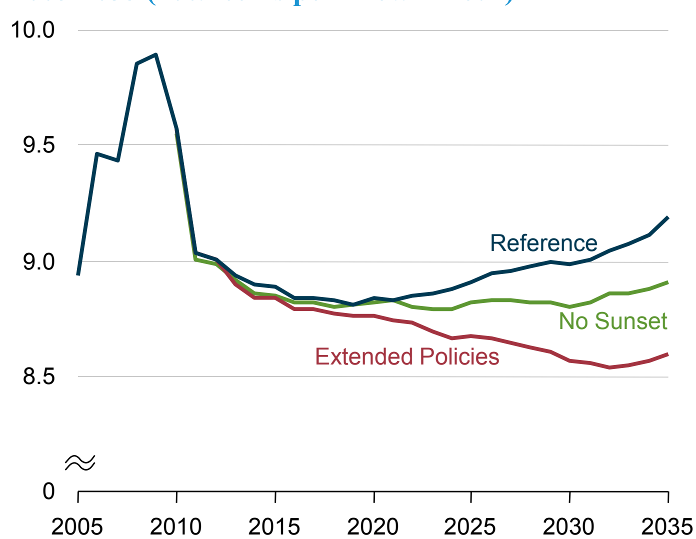


Figure 12. Average electricity prices in three cases, 2005-2035 (2009 cents per kilowatthour)



million per year in the Reference case. Additional reductions in Government tax revenue in the No Sunset case result from extensions of both the ethanol and biodiesel blenders tax credits and the cellulosic biofuels PTC, with annual average tax revenue reductions over the period from 2011 to 2035 of $3.1 billion per year (2009 dollars) in comparison with the Reference case.

2. World oil price and production trends in *AEO2011*

The world oil price is represented in *AEO2011* as the price of light, low-sulfur crude oil delivered at Cushing, Oklahoma. Projections of future supply and demand are made for "liquids." The term "liquids" refers to conventional petroleum liquids, such as conventional crude oil, natural gas plant liquids, and refinery gain, in addition to unconventional liquids, such as biofuels, bitumen, coal-to-liquids (CTL), coal- and biomass-to-liquids, gas-to-liquids (GTL), extra-heavy oils, and oil shale (derived from kerogen).

World oil prices are influenced by a number of factors, some of which have mainly short-term impacts. Others, such as expectations about world oil demand and OPEC production decisions, affect prices in the longer term. Supply and demand in the world oil market are balanced through responses to price movements, and the factors underlying expectations for supply and demand are both numerous and complex. The key factors determining long-term expectations for oil supply, demand, and prices can be summarized in four broad categories: the economics of non-OPEC conventional liquids supply; OPEC investment and production decisions; the economics of unconventional liquids supply; and world demand for liquids.

In 2010, the "prompt month contract" for crude oil (the contract for the nearest month's trading) remained relatively steady from January to November, at a monthly average between $74 and $84 per barrel (2009 dollars), before increasing to just over $89 per barrel in December [*44*].

Long-term prospects

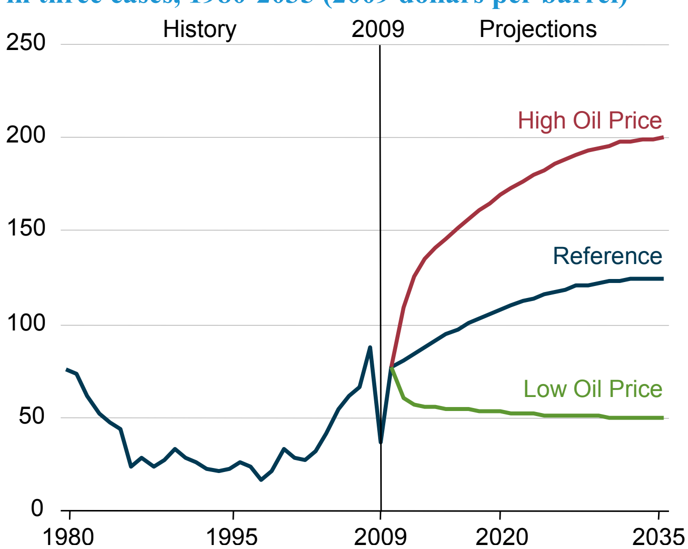
In past *AEO*s, High Oil Price and Low Oil Price cases have been used to explore the potential impacts of changes in world liquids supply on world (and U.S.) oil markets as a result of either OPEC production decisions or changes in economic access to non-OPEC resources. In *AEO2011*, the High Oil Price and Low Oil Price cases have been expanded to incorporate alternative assumptions about liquids supply, economic developments, and liquids demand as key price determinants. The assumed price paths in the *AEO2011* High and Low Oil Price cases bracket a broad range of possible future world oil price paths, with prices in 2035 (in real 2009 dollars) at $200 per barrel in the High Oil Price case and $50 per barrel in the Low Oil Price case, as compared with $125 in the Reference case (Figure 13). This is by no means the full range of possible future oil price paths.

Reference case

The global oil market projections in the *AEO2011* Reference case are based on the assumption that current practices, politics, and levels of access will continue in the near to mid-term. The Reference case assumes that continued robust economic growth in the non-OECD nations, including China, India, and Brazil, will more than offset relatively tepid growth projected for many OECD nations. In the Reference case, non-OECD liquids consumption is about 25 million barrels per day higher in 2035 than it was in 2009, but OECD consumption grows by less than 3 million barrels per day over the same period. Total liquids consumption grows to 103 million barrels per day by 2030 and 111 million barrels per day by 2035.

The *AEO2011* Reference case assumes that limitations on economic access to resources in many areas restrain the growth of non-OPEC conventional liquids production over the projection period and that OPEC production meets a relatively constant share of about 40 percent of total world liquids supply. With those constraining factors, satisfying the growing world demand for liquids in coming decades requires production from higher cost resources, particularly for non-OPEC producers with technically challenging supply projects. In the Reference case, the increased cost of non-OPEC supplies and a constant OPEC market share combine to support average increases in real world oil prices of about 5.2 percent per year from 2009 to 2020 and 1.0 percent from 2020 to 2035. In 2035, the average real price of crude oil in the Reference case is $125 per barrel in 2009 dollars.

Figure 13. Average annual world oil prices in three cases, 1980-2035 (2009 dollars per barrel)



Increases in non-OPEC production in the Reference case come primarily from high-cost conventional projects in areas with inconsistent fiscal or political regimes and from increasingly expensive unconventional liquids projects that are made economical by rising oil prices and advances in production technology (Figure 14). Oil sands production in Canada and biofuels production mostly from the United States and Brazil are the most important components of the world's unconventional resources, accounting for nearly 70 percent of the projected incremental supply between 2009 and 2035 in the Reference case.

Low Oil Price cases

In earlier *AEO*s, the Low Oil Price case assumed that significantly improved access to resources and the willingness of OPEC members to increase their market share would result in low prices and ample supplies, leading to strong increases in demand over the long term. For *AEO2011*, the Low Oil Price case has been changed to one in which relatively low demand for liquids, combined with greater economic access to and production of conventional resources, results in sustained low oil prices. In particular, the new Low Oil Price case focuses on demand in non-OECD countries, where uncertainty about future growth is much higher than in the OECD nations. The *AEO2011* Low Oil Price case assumes that world oil prices fall steadily after 2011 to about $50 per barrel in 2030 and stabilize at that level through 2035, and that relatively low gross domestic product (GDP) growth in the non-OECD countries, compared to the Reference case, keeps their liquids demand at relatively low levels. Average annual GDP growth in the non-OECD nations is assumed to be 1.5 percentage points lower than in the Reference case, or about 3.6 percent on average. The result is that non-OECD demand for liquids in 2035 is 15 million barrels per day lower than would have been projected in previous *AEO*s, as represented in the *AEO2011* Traditional Low Oil Price case. Total world liquids consumption rises to only 108 million barrels per day in 2035 in the *AEO2011* Low Oil Price case.

In both the Low Oil Price case and the Traditional Low Oil Price case, low prices limit the development of relatively expensive unconventional supplies. Thus, the volumes of unconventional production supplied are the same in the two cases (Figure 15). Similarly, there is only a modest difference between the volumes of non-OPEC conventional liquids supplies in the two cases. In contrast, OPEC conventional liquids supplies, which increase by about 28 million barrels per day in the Traditional Low Oil Price case, increase by only about 15 million barrels per day in the Low Oil Price case.

High Oil Price cases

In the *AEO2011* High Oil Price case, high demand for liquids, combined with more constrained supply availability, results in a sharp, continued increase in world oil prices. As in the Low Oil Price case, GDP growth is used as a proxy for liquids demand growth in the non-OECD nations. Annual GDP growth in non-OECD nations is assumed to be 1.0 percentage points higher in the High Oil Price case than in the Reference case, or 5.7 percent on average. Coupled with more constrained supply, oil prices increase to $200 per barrel in 2035 as a consequence. Despite the higher prices, however, total world liquids consumption grows to 115 million barrels per day in the High Oil Price case, or 4 million barrels per day higher than in the Reference case. In contrast, in the Traditional High Oil Price case, only world liquids supply strategies are assumed to result in higher oil prices and tight supplies, which constrain increases in demand over the long term.

In both the High Oil Price case and the Traditional High Oil Price case, high prices and restrictions on the production of lower cost conventional liquids encourage the development of relatively expensive unconventional supplies. The outlook is similar in the two cases, with about 20 million barrels per day of unconventional resources brought to market in 2035. Non-OPEC liquids supplies are slightly higher in the High Oil Price case than in the Traditional High Oil Price case, but the largest difference between the two cases is in conventional OPEC supplies. The High Oil Price case assumes that OPEC will increase production to maximize revenues, because demand in non-OECD nations is not dampened by high prices. In this case, OPEC conventional liquids supplies increase by almost 8 million barrels per day from 2009 to 2035, as compared with a decline of 2 million barrels per day in the Traditional High Oil Price case.

Figure 14. Total liquids production by source in the Reference case, 2000-2035 (million barrels per day)

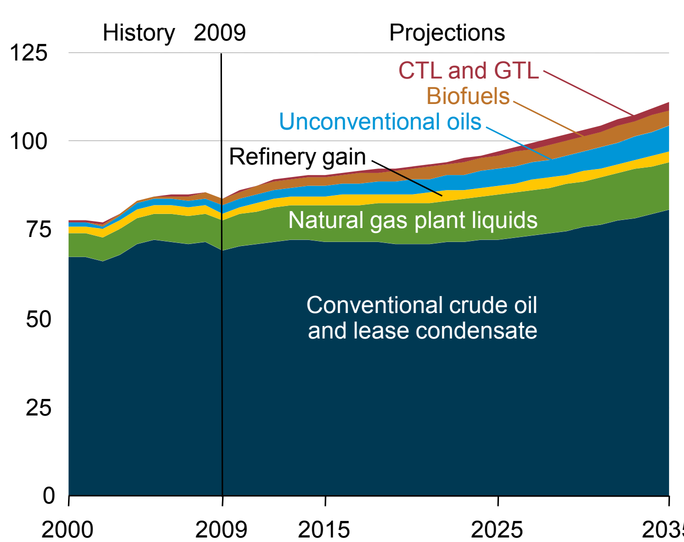
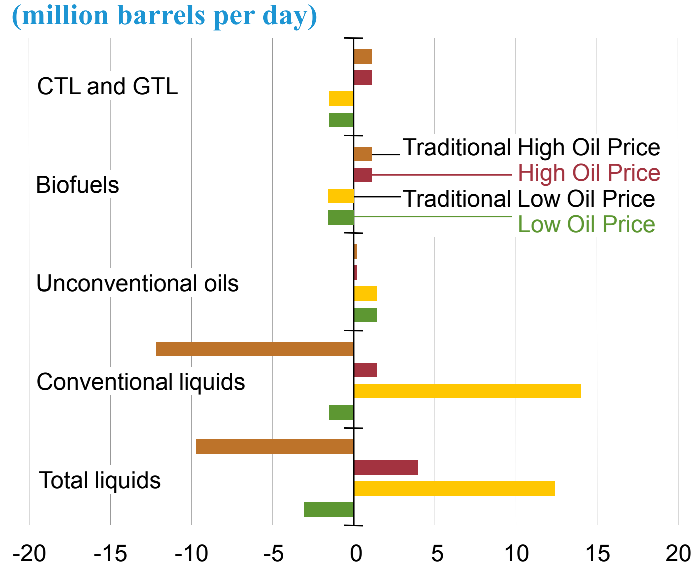


Figure 15. Differences from Reference case liquids production in four Oil Price cases, 2035 (million barrels per day)



3. Increasing light-duty vehicle greenhouse gas and fuel economy standards for model years 2017 to 2025

EPA Notice of Intent to conduct a joint rulemaking

In September 2010, the EPA and NHTSA issued a Notice of Intent to issue a proposed rule that will set GHG emissions and fuel economy standards for LDVs for MY 2017 through MY 2025 [*45*]. The LDV standards cover both passenger cars and light trucks. The notice provides an initial GHG emissions assessment for several potential levels of stringency, representing decreases of 3, 4, 5, and 6 percent per year in GHG emissions and corresponding increases in mpg equivalent fuel efficiency levels from the MY 2016 fleetwide average of 250 grams per mile. For each level of stringency, four technological pathways were analyzed, corresponding to different penetration mixes of advanced gasoline technologies, vehicle mass reductions, and advanced hybrid electric, plug-in hybrid electric, and plug-in electric vehicles.

The four technological pathways were not meant as requirements but were used to show that the potential levels of stringency examined by the EPA and NHTSA are technically feasible. Although the notice provided an initial evaluation of a potential range of increases in stringency, it recognized that much more technological and economic analysis would be needed before a specific standard could be released. The EPA and NHTSA expect to release a proposed rulemaking in September 2011 and to issue a final rulemaking by July 2012.

Sensitivity cases

Two sensitivity cases were used to analyze the impacts of more stringent GHG emissions and fuel economy standards on LDVs in MY 2017 through MY 2025. Fuel economy and GHG emissions standards for MY 2011 through MY 2016 have been promulgated already as final rulemakings, and are already represented in the Reference case; they were, therefore, not modified in these sensitivity cases.

The *CAFE 3% Growth (CAFE3) case* is a modified Reference case that assumes a 3-percent annual increase in fuel economy standards for MY 2017 through MY 2025 LDVs, starting from the levels for MY 2016 LDVs, with the subsequent post-MY 2025 standards held constant. In 2025, the combined LDV fuel economy standard, at 46.1 mpg, is 29 percent higher than the standard assumed in the *AEO2011* Reference case. The *CAFE 6% Growth (CAFE6) case* assumes a 6-percent annual increase in fuel economy standards for new LDVs from MY 2016 levels for MY 2017 through MY 2025, with the subsequent standards held constant. In 2025, the LDV fuel economy standard, at 59.3 mpg, is 66 percent higher than the standard assumed in the Reference case (Figure 16). For new passenger cars, the fuel economy standard in 2025 is 40.4 mpg in the Reference case, 53.5 mpg in the CAFE3 case, and 75.4 mpg in the CAFE6 case. For new light-duty trucks, the fuel economy standard in 2025 is 29.7 mpg in the Reference case, 38.1 mpg in the CAFE3 case, and 45.5 mpg in the CAFE6 case.

The standards enacted for MY 2011 through 2016 are attribute-based, using vehicle footprint, and allow credits for alternative technologies and fuels to be applied toward compliance. The Notice of Intent for MY 2017 through 2025 does not address the type of attribute standard that would be employed or the structure of credits allowed toward compliance. The sensitivity cases examined here assume a continuation of the current footprint-based attribute standards, as well as credit banking.

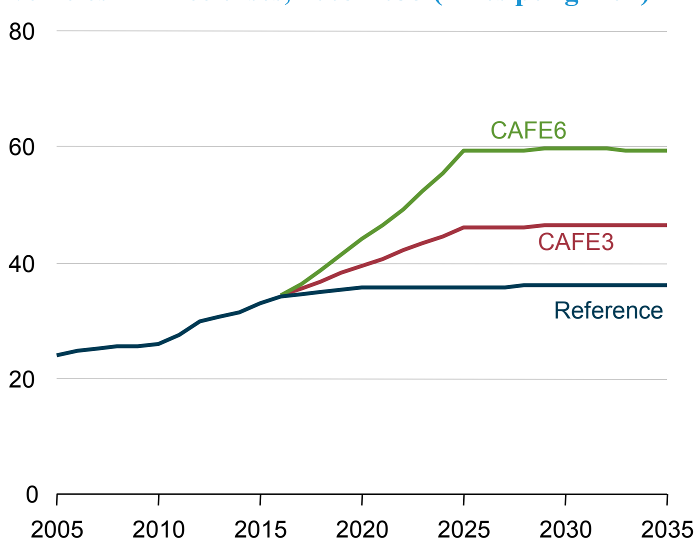
Results

In view of the substantial rate of fuel economy improvement required, compliance with the more stringent CAFE standards cases would require a rapid increase in sales of unconventional vehicles (those that use diesel, alternative fuels, and/or hybrid electric systems) and significant improvement in the fuel economy of conventional vehicles that continue to rely solely on gasoline spark-ignited engines for motive power (Table 4). Such rapid changes are likely to challenge the financial, engineering, and production capabilities of the automotive industry. In addition, increased costs for vehicles that employ technologies unfamiliar to consumers could result in lower new vehicle sales relative to the Reference case.

Although this analysis does not address those potential issues, it does project the levels of market penetration by unconventional vehicles and advanced technologies that would be needed for compliance with the more stringent standards, and it estimates the costs of compliance given Reference case assumptions for technology efficiency improvement and cost. The resulting impacts on new LDV sales, stocks, energy demand, and CO_2 emissions are discussed below.

Sales of unconventional vehicles, which will be critical to achieving the required fuel economy improvements, are projected to grow to 70 percent of total new LDV sales in 2025

Figure 16. Combined CAFE standards for light-duty vehicles in three cases, 2005-2035 (miles per gallon)



in the CAFE3 case and nearly 90 percent in the CAFE6 case, as compared with 40 percent in the Reference case. In the CAFE3 case, the largest increases in new sales market shares are among hybrid electric, diesel, and micro hybrid systems in conventional gasoline vehicles (Figure 17), all of which are more fuel efficient than their conventional gasoline counterparts. The increase in hybrid and diesel vehicle sales displaces sales of both conventional gasoline and flex-fuel vehicles. The more stringent standards in the CAFE6 case cause an even greater reduction in conventional gasoline and flex-fuel vehicle sales, significantly expanding the market adoption of plug-in hybrid and all-electric vehicles, which are more fuel efficient than their unconventional counterparts, and even greater sales share for hybrid electric and diesel vehicles.

While declining as a share of total new vehicle sales, sales of conventional gasoline vehicles without micro hybrid systems still account for a significant percentage (30 percent) of new vehicles in the CAFE3 case and a less, but still important share (11 percent) in the CAFE6 case. Conventional gasoline vehicle fuel economy increases in both cases through the introduction of new fuel-efficient technologies and improved vehicle designs. In order to meet the increased fuel economy requirements, conventional vehicle subsystems (engine, transmission, aerodynamics, vehicle weight, and horsepower) would have to be modified to ensure compliance. Included in conventional gasoline vehicle technologies but counted separately in the discussion above are micro hybrid systems, which are present in 36 percent of conventional gasoline vehicles in the CAFE3 case and 58 percent in the CAFE6 case in 2025, compared with 12 percent in the Reference case.

The market adoption of unconventional vehicles and inclusion of additional technologies that improve the fuel economy of conventional gasoline vehicles results in higher average prices for new LDVs compared to the Reference case. As a result, while vehicle operating costs would fall (see below), consumers would need to purchase more expensive vehicles (Figure 18). A distribution of vehicle sales by price in 2010, derived from Ward's Automotive data [*46*], shows that 31 percent of the new vehicles purchased by consumers were within a price range of $10,000 to $25,000, 49 percent within $25,000 to $35,000, and 19 percent at prices above $35,000. In the CAFE3 case, the distribution in 2025 shifts to 15 percent within $10,000 to $25,000, 61 percent within $25,000 to $35,000, and 24 percent above $35,000 (all 2009 dollars). The sales distribution in 2025 shifts even more in the CAFE6 case, with 9 percent within $10,000 to $25,000, 56 percent within $25,000 to $35,000, and 35 percent above $35,000 (all 2009 dollars).

The cases estimate a demand response for new vehicle sales as a result of changes in average new vehicle price by employing a price elasticity of demand of -1. While this measure attempts to quantify the potential impact of the increase in vehicle price on sales, it is not intended to be inclusive of all the potential factors that could affect new vehicle purchase decisions made by consumers. As a result of higher vehicle prices, total new LDV sales in 2025 are 8 percent lower in the CAFE3 case and 14 percent lower in the CAFE6 case than in the Reference case.

As vehicle attributes change to meet more stringent CAFE standards, such as decreased average vehicle horsepower and weight, some consumers switch from passenger cars to light-duty trucks, which in the CAFE3 case have average fuel economies in 2025 comparable to those for passenger cars in 2016. The share of total new LDV sales made up by light-duty trucks is 40 percent in the CAFE3 case and 41 percent in the CAFE6 case in 2025, up from 38 percent in the Reference case, but still far lower than their share (more than 50 percent) in 2005. Note, however, that consumer incentives to switch from cars to light trucks are sensitive to the assumed relative stringency of cars versus light truck CAFE.

Although the CAFE sensitivity cases allow for fluctuation in new LDV sales and switching between purchases of passenger cars and light-duty trucks, additional impacts on fuel demand would be associated with the continued use of existing vehicle stocks. As consumers defer new vehicle purchases, the utilization of older, less fuel-efficient vehicles increases relative to the Reference case.

Table 4. Unconventional light-duty vehicle types

Unconventional vehicle type	Description
Micro hybrid	Vehicles with gasoline engines, larger batteries, and electrically powered auxiliary systems that allow the engine to be turned off when the vehicle is coasting or idle and then quickly restarted. Regenerative braking recharges the batteries but does not provide power to the wheels for traction.
Hybrid electric (gasoline or diesel)	Vehicles that combine internal combustion and electric propulsion but have limited all-electric range and batteries that cannot be recharged using grid power.
Diesel	Vehicles that use diesel fuel in a compression-ignition internal combustion engine.
Plug-in hybrid electric (10- and 40-mile all-electric range)	Vehicles that use battery power to drive for some distance, until a minimum level of battery power is reached, at which point they operate on a mixture of battery and internal combustion power. Plug-in hybrids also can be engineered to run in a "blended mode," where an onboard computer determines the most efficient use of battery and internal combustion power. The batteries can be recharged from the grid by plugging a power cord into an electrical outlet.
Plug-in electric (100- and 200-mile range)	Vehicles that operate by electric propulsion from batteries that are recharged either from the grid exclusively or through regenerative breaking.
Flex-fuel	Vehicles that run on gasoline or any gasoline-ethanol blend up to 85 percent ethanol.

The demand for mobility and the stock of vehicles available in the Reference case are maintained over the projection period in the CAFE cases, but the two CAFE cases assume longer vehicle survival rates and more intensive use of older vehicles.

The United States currently has a total LDV stock of around 230 million vehicles. That number grows to over 300 million vehicles by 2035 in the Reference and CAFE cases. Although the introduction of more stringent fuel economy standards in the CAFE cases stimulates sales of more fuel-efficient new vehicles, it takes time for the new vehicles to penetrate the vehicle fleet in significant numbers to affect the average of fuel economy of the entire LDV stock. In the CAFE cases, the trend is even slower, as a result of reduced scrappage and increased travel of older vehicles. Consequently, the average on-road fuel economy of the LDV stock, which represents the fuel economy realized by all vehicles in use, increases from 22.4 mpg in 2016 to 28.6 mpg in 2025 in the CAFE3 case and 30.2 mpg in the CAFE6 case, as compared with 25.7 mpg in the Reference case. In 2035, the average on-road fuel economy of the LDV stock increases to 34.0 mpg in the CAFE3 case and 39.4 mpg in the CAFE6 case, 22 percent and 41 percent higher, respectively, than the Reference case average of 27.9 mpg (Figure 19).

In the two CAFE cases, more stringent fuel economy standards lead to reductions in total delivered energy consumption, including all fuels. Fuel bills fall by a similar amount. Total cumulative delivered energy consumption by LDVs from 2017 to 2035 is 10 percent lower in the CAFE3 case than in the Reference case and 13 percent lower in the CAFE6 case. In 2025, total delivered energy consumption by LDVs is 19 percent lower in the CAFE3 case and 27 percent lower in the CAFE6 case than in the Reference case. Total liquids fuel consumption in 2035 is 1.9 million barrels per day lower in the CAFE3 case and 2.8 million barrels per day lower in the CAFE6 case than in the Reference case (Figure 20). Reductions in total delivered energy consumption and liquids fuel

Figure 17. Model year 2025 light-duty vehicle market shares by technology type in three cases (percent of total sales)

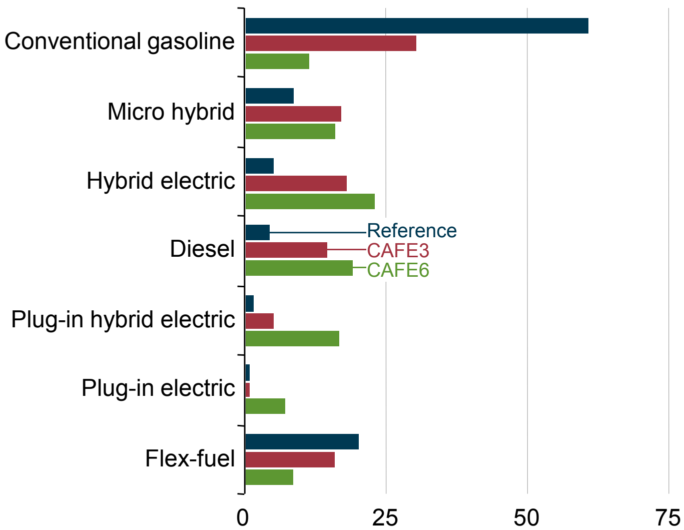


Figure 18. Distribution of new light-duty vehicle sales by vehicle price (2009 dollars) in 2025 in the CAFE3 and CAFE6 cases (percent of total sales compared to 2010)

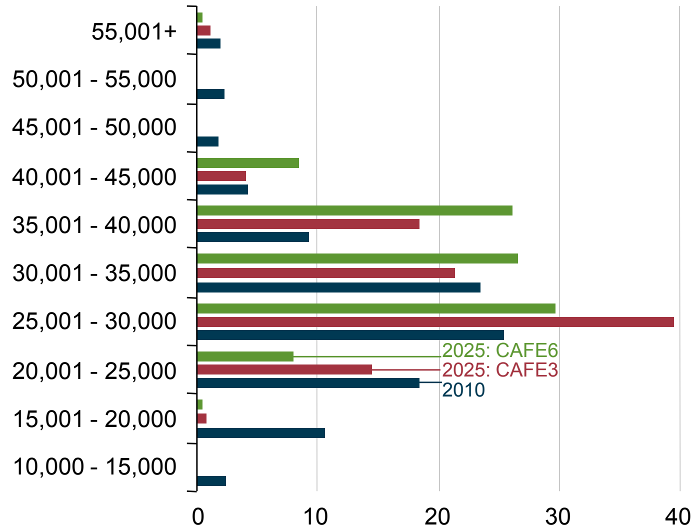


Figure 19. On-road fuel economy of the light-duty vehicle stock in three cases, 2005-2035 (miles per gallon)

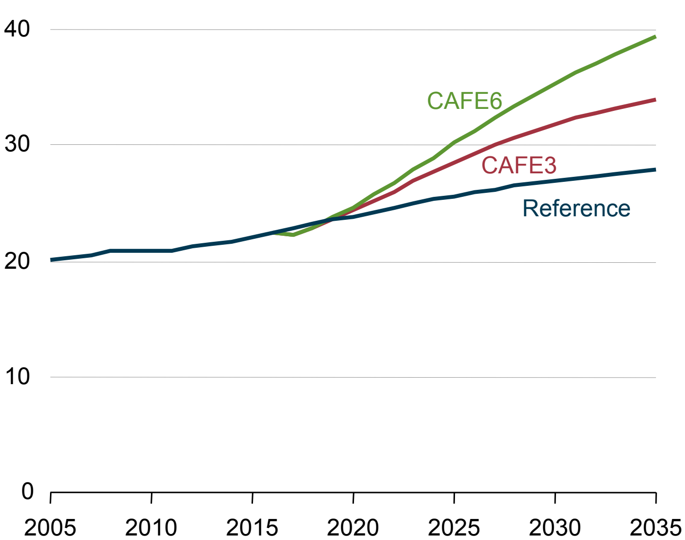
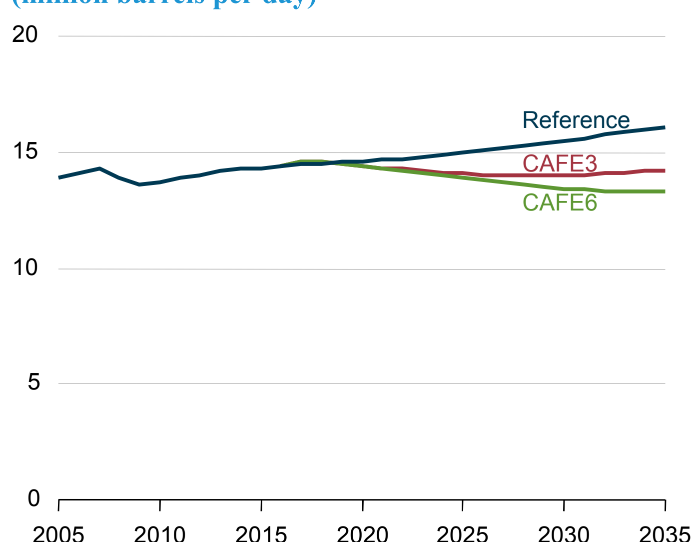


Figure 20. Total liquid fuels consumption by light-duty vehicles in three cases, 2005-2035 (million barrels per day)



consumption are more pronounced later in the projection period, when a greater percentage of the total vehicle stock consists of vehicles with higher fuel economy.

The declines in total LDV energy demand in the CAFE cases lead to large reductions in motor gasoline consumption—from 98 percent of total LDV energy use in 2016 to 84 percent in 2025 and 77 percent in 2035 in the CAFE3 case, as compared with 91 percent in 2025 and 89 percent in 2035 in the Reference case. The more stringent fuel economy standards called for in the CAFE6 case lead to even greater reductions in motor gasoline consumption, to 83 percent of total LDV energy use in 2025 and 69 percent in 2035.

Despite the overall decline in energy consumption by LDVs, the changing composition of the fleet by vehicle fuel type leads to increased consumption of some fuels. Lower demand for motor gasoline reduces the amount of ethanol that can be blended into the motor gasoline pool as either E10 or E15. As a consequence, more fuel containing up to 85 percent ethanol (E85) is sold to meet the RFS. E85 accounts for 11 percent of total LDV energy use in 2035 in the CAFE3 case and 14 percent in the CAFE6 case, compared with 7 percent in the Reference case. Diesel fuel consumption increases to 11 percent and 15 percent of total LDV energy use in 2035 in the CAFE3 and CAFE6 cases, respectively, compared with 4 percent in the Reference case. Electricity use by LDVs remains less than 1 percent of total LDV energy use in both the Reference and CAFE3 cases but reaches 3 percent of the total in the CAFE6 case, where sales of plug-in vehicles and all-electric vehicles expand.

Reductions in LDV delivered energy consumption lead to lower GHG emissions from the transportation sector. Cumulative CO_2 emissions from transportation over the period from 2009 through 2035 are 2.2 billion metric tons lower in the CAFE3 case and 2.6 billion metric tons lower in the CAFE6 case than in the Reference case, reductions of 6 percent and 7 percent, respectively. CO_2 emissions decline from 1,927 million metric tons in 2016 to 1,826 million metric tons in 2025 in the CAFE3 case and to 1,815 million metric tons in the CAFE6 case, as compared with 1,940 million metric tons in the Reference case. In 2035, CO_2 emissions from transportation fuel use total 1,859 million metric tons in the CAFE3 case and 1,788 million metric tons in the CAFE6 case, compared with 2,080 million metric tons in the Reference case (Figure 21).

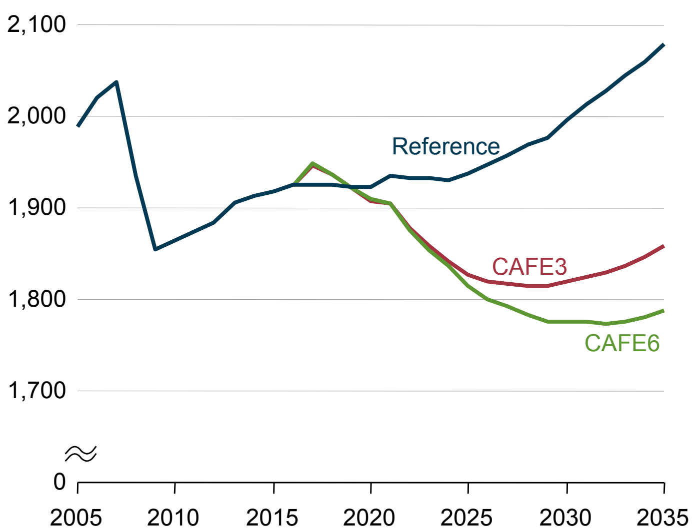
CO_2 emissions from the electric power and refinery sectors also are affected by increased electricity use for plug-in vehicles. Cumulative emissions from the electric power sector over the period from 2017 to 2035 are 118 million metric tons higher in the CAFE3 case and 416 million metric tons higher in the CAFE6 case than in the Reference case—increases that are equal to 0.3 percent and 0.9 percent of total CO_2 emissions from electricity generation, respectively, over the same period. More stringent fuel economy standards reduce motor gasoline demand by more than they increase demand for diesel and E85 fuels. As a result, cumulative CO_2 emissions from refineries between 2017 and 2035 decline by 359 million metric tons in the CAFE3 case and 471 million metric tons in the CAFE6 case from the Reference case level—declines of 8.8 percent and 11.6 percent, respectively.

Issues

Setting LDV fuel economy standards 6 to 14 years into the future is a difficult undertaking, given the uncertainties associated with technology availability and cost, consumer acceptance and willingness to pay for unfamiliar technology, and fuel prices. The availability and cost of advanced vehicle technologies are critical in determining the ability of manufacturers to meet more stringent standards, but there is a high degree of uncertainty regarding the cost and availability of key technologies so far into the future.

For example, battery technologies used in plug-in vehicles are important in meeting more stringent standards in the CAFE3 case and are critical to compliance in the CAFE6 case. The future cost and performance of battery technologies in 2025 cannot be known with confidence. If there are limited breakthroughs in the cost, safety, or life of batteries, then the ability to meet, for example, the levels of stringency called for in the CAFE6 case, which will very likely necessitate plug-in vehicles, will be extremely challenging. On the other hand, a breakthrough in battery technology or another known technology, or the introduction of a new unforeseen technology, could dramatically lessen the burden on manufacturers of meeting more stringent CAFE standards in terms of both cost and availability.

Figure 21. Total transportation carbon dioxide emissions (million metric tons carbon dioxide equivalent)



When manufacturers bring an advanced vehicle technology to market, consumers must be willing to buy it. There is a high level of uncertainty about consumer willingness to pay significantly higher prices for more fuel-efficient vehicles. In recent history, consumers have tended to value upgrades in performance, vehicle size, and other attributes at the expense of fuel economy.

For example, assuming an annual vehicle use of 14,000 miles per year, a fuel price of $4 per gallon, and no discount rate, a consumer would save 117 gallons of fuel worth $467 each year by driving a vehicle with a fuel economy of 40 mpg instead of 30 mpg. However, purchasing a vehicle that gets 70 mpg instead of 60 mpg would save only 33 gallons, worth $133 (Figure 22). This is important, because the cost of adding technology to an already fuel-efficient vehicle tends to get increasingly expensive (for example, changing a conventional gasoline vehicle to a plug-in hybrid electric vehicle). As manufacturers strive to improve fuel economy, the least costly technologies that reduce fuel consumption will be incorporated first. Employing additional technology to increase fuel economy further will require the use of more expensive technologies.

Consumer willingness to pay for improved fuel economy changes dramatically with different potential fuel prices, which are highly uncertain. If the price of fuel in 14 years is significantly higher than today's prices, a cost-conscious consumer may be willing to pay much more for a vehicle with higher fuel economy, perhaps even without increases in CAFE and GHG standards. Conversely, if fuel prices in the future are relatively low, it may be difficult to convince consumers to pay for fuel economy improvements if the savings from improving fuel economy have only a small impact on their annual fuel expenditures. The willingness of consumers to purchase vehicles with higher fuel economy could also affect both new vehicle sales and scrappage rates.

4. Fuel consumption and greenhouse gas emissions standards for heavy-duty vehicles

The proposed rulemaking

The EPA and NHTSA in November 2010 jointly issued a proposed rulemaking that would, for the first time, establish greenhouse gas emissions and fuel consumption standards for heavy-duty vehicles (HDVs) [*47*].The proposed standards separately address three discrete vehicle categories: combination tractors, heavy-duty pickup trucks and vans, and vocational vehicles (Table 5). The final regulations are scheduled to be issued by July 2011.

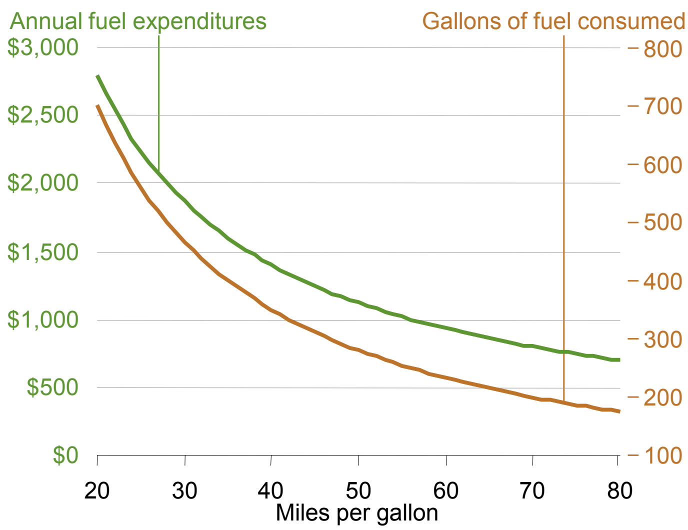
For combination tractors, standards are proposed by cab type, roof type, and engine type. For heavy-duty pickups and vans, the proposed standards are categorized by diesel or gasoline engine and are set as total vehicle gallons per 100 miles, or grams per mile, based on a vehicle's "work factor"—a weighted average of payload and towing capacity. For vocational vehicles, the standards are proposed for different chassis types, according to gross vehicle weight rating (GVWR) and engine type. Standards for combination tractor cabs and vocational vehicles are set as gallons per 1,000 ton-miles or grams per ton-mile, and engine standards are set as gallons per 100 brake horsepower-hours [*48*] or grams per horsepower-hour.

Heavy-duty vehicle fuel economy standards

AEO2011 includes a sensitivity case that analyzes the estimated impacts of the proposed fuel consumption and GHG emissions standards for heavy-duty trucks. However, because of data and modeling limitations, impacts of the standards for specific truck types or engines could not be represented. Instead, the *HDV Fuel Economy Standards case* approximates the proposed fuel consumption and GHG emissions standards by increasing the on-road fuel economy of new heavy-duty trucks by approximately 8.5 percent in MY 2017 from MY 2010 levels.

The increase in on-road fuel economy for heavy-duty trucks in MY 2017 in the sensitivity case is based on estimates developed from the U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey (VIUS) [*49*] and from Ward's Auto [*50*], which together provide data on vehicle body type, tractor cab type, and engine type by GVWR classification. The estimated vehicle distributions were combined with the EPA and NHTSA estimates of reductions in fuel consumption in MY 2017 for combination tractors and vocational vehicles and in MY 2018 for heavy-duty pickups and vans, compared to a MY 2010 baseline [*51*].

Figure 22. Total annual fuel consumption (gallons) for consumers driving 14,000 miles per year and annual fuel expenditures at a $4.00 per gallon fuel price (2009 dollars)



Using data from VIUS and Ward's Automotive, fuel consumption reductions provided by EPA and NHTSA were combined and aggregated into the reported categorization of heavy-duty trucks used in *AEO2011*: medium heavy-duty trucks (includes Class 3 through Class 6 trucks with GVWR 10,001 to 26,000 pounds) and heavy heavy-duty trucks (Class 7 and Class 8 trucks with GVWR greater than 26,001 pounds), regardless of vehicle body or engine type. This weighting and aggregation showed an approximately 10 percent reduction in fuel consumption for both categories of heavy-duty trucks in MY 2017 from MY 2010 levels, relative to a simulated fuel economy estimate. The reduction in fuel consumption was modeled as an increase in on-road new vehicle fuel economy to account for the potential variation of simulation-tested fuel economy from expected on-road performance. Increases in fuel economy begin in MY 2014, the first year that GHG emissions standards are binding (Figure 23).

Between MY 2014 and MY 2017, the new heavy-duty truck standards lead to the adoption of technologies to improve fuel economy that otherwise would not have been purchased.

For new medium heavy-duty trucks, average on-road fuel economy increases from 7.9 mpg (gasoline) in 2013 (the year before imposition of binding GHG emission standards) to 8.5 mpg in 2017—a 7.8-percent increase from the *AEO2011* Reference case projection. On-road fuel economy for heavy heavy-duty trucks increases from 5.7 mpg in 2013 to 6.2 mpg in 2017, a 9.6-percent increase from the Reference case. After 2017 the standards are held constant, but owner-operators have the option of purchasing additional fuel-efficient technology according to their economic choice based on the net present value of fuel savings compared with the incremental cost of the technology. In 2035, the on-road fuel economy of new medium and heavy heavy-duty trucks reaches 8.4 and 6.4 mpg, respectively, as compared with 7.8 and 6.4 mpg in the Reference case.

Results

In the HDV Fuel Economy Standards case, new medium and heavy heavy-duty trucks with higher on-road fuel economy gradually penetrate the market. Progress is limited, however, due to the slow turnover in the stock of heavy trucks, which have a median lifetime of 29 years. Between 2014 and 2035, new heavy-duty truck sales per year are equal to about 6 percent of the total heavy-duty truck stock, ranging between about 600,000 and 900,000 new heavy-duty trucks sales per year out of a total stock that grows from 10 million in 2014 to 17 million in 2035. As new heavy-duty trucks are added to the total stock and older trucks with lower fuel economy are removed from service, the average on-road fuel economy for the total stock of medium and heavy heavy-duty trucks increases in the HDV Fuel Economy Standards case (Figure 24).

For medium heavy-duty trucks average on-road fuel economy increases from 7.9 median mpg in 2013 to 8.0 mpg in 2017 and 8.4 mpg in 2035, as compared with 7.9 mpg and 7.8 mpg, respectively, in the Reference case. For heavy heavy-duty trucks, on-road fuel economy increases from 5.7 mpg in 2013 to 5.9 mpg in 2017 and 6.3 mpg in 2035, as compared with 5.7 mpg and 6.2 mpg, respectively, in the Reference case.

The higher on-road fuel economy of the heavy-duty truck stock reduces total delivered energy consumption in the Fuel Economy Standards case. Total cumulative delivered energy consumption by heavy-duty trucks from 2014 to 2035 is 3 percent lower in the Fuel Economy Standards case than in the Reference case. The difference amounts to a cumulative reduction of slightly less than 1 percent of total delivered transportation energy consumption from 2014 to 2035. Total delivered energy consumption is 0.6 percent lower in 2017, the first year of complete implementation, and 0.5 percent lower in 2035 in the Fuel Economy Standards case than in the Reference case. Total liquids fuel consumption in 2035 is about 75 thousand barrels per day lower in the Fuel Economy Standards case than in the Reference case (Figure 25). However, heavy-duty truck total delivered energy and liquids fuel consumption climbs in both cases, as travel demand increases with growth in industrial output.

Cumulative CO_2 emissions from 2014 to 2035 are lower by 276 million metric tons (about 3 percent) in the HDV Fuel Economy Standards case than in the Reference case, representing a reduction of less than 1 percent in total CO_2 emissions from the transportation sector (Figure 26).

Issues

The HDV Fuel Economy Standards case approximates the proposed rulemaking by aggregating vehicle body type data from the 2002 VIUS. (The survey has not been updated since 2002.) There may be significant differences between the heavy-duty truck market today and the market a decade ago. Further, there are data uncertainties associated with the 2002 VIUS, but the data were used because VIUS is the only source of information on vehicle body type. Also, little if any information is available on other metrics used in the proposed standards.

Numerous limitations in the available data on the types and numbers of heavy trucks sold according to the vehicle classifications specified in the proposed standards make it difficult to estimate the energy impacts that could be expected as heavy-duty trucks begin to comply with the new standards. Without better and more complete data, it is difficult to analyze the composition of the heavy-duty truck market at the level of diversity included in the proposed standards, or the efficiency and fuel economy metrics associated with each classification in the standards. In addition, the lack of data makes it difficult to define an accurate baseline from which to gauge improvement.

Table 5. Vehicle categories for the HDV standards

Vehicle category	Description	Truck classes covered
Combination tractors	Semi trucks that typically pull trailers.	Class 7 and Class 8 (GVWR 26,001 pounds and above)
Heavy-duty pickups and vans	Pickup trucks and vans, such as 3/4-ton or 1-ton pickups used on construction sites or 12- to 15-person passenger vans.	Class 2b and Class 3 (GVWR 8,501 to 14,000 pounds)
Vocational vehicles	Includes a wide range of truck configurations, such as delivery, refuse, utility, dump, cement, school bus, ambulance, and tow trucks. For purposes of the rulemaking, vocational vehicles are defined as all heavy-duty trucks that are not combination tractors or heavy-duty pickups or vans.	Class 2b through Class 8 (GVWR 8,501 pounds and above)

Another issue is how compliance will be measured, and how well compliance testing procedures will replicate the average real-world performance of combination tractors, heavy-duty pickups and vans, and vocational vehicles. For combination tractors, which tend to spend a majority of their operation under steady conditions, such as highway driving, engine manufacturers must demonstrate compliance by using the steady-state Supplemental Engine Test [*52*]. Tractor manufacturers will then be required to install certified engines, with tractor compliance measured by an input-based truck simulation model, the Greenhouse Gas Emissions Model (GEM). GEM uses fixed input values, such as payload and trailer weights. Compliance will vary with the GEM inputs for aerodynamics, weight, tires, and idle reduction and speed limiter technologies.

Compliance for heavy-duty pickups and vans will be determined by a vehicle test procedure similar to the national program for LDVs, using the highway fuel economy test and the Federal test procedure for city driving, weighted 45 percent and 55 percent, respectively. Heavy-duty pickups and vans are assumed to be loaded to one-half of their payload capacity.

Vocational vehicles also use the GEM simulation model to demonstrate chassis compliance, using fixed curb and payload weights for each vehicle category, with tires being the only manufacturer-specific technology that can be input into the model. The proposed rulemaking weights the test drive-cycle as 37 percent at 65 miles per hour cruise, 21 percent at 55 miles per hour cruise, and 42 percent in transient performance, which broadly covers urban conditions. Chassis manufacturers will be allowed to install only certified CO_2 and fuel consumption compliant engines based on the transient Heavy-Duty Federal Test Procedure.

As validation, GEM results for fuel consumption and CO_2 emissions were compared with three SmartWay certified tractors in a chassis testing procedure. The GEM results were within 4 percent of the chassis testing results. Although the testing

Figure 23. On-road fuel economy of new medium and heavy heavy-duty vehicles in two cases, 2005-2035 (miles per gallon gasoline equivalent)

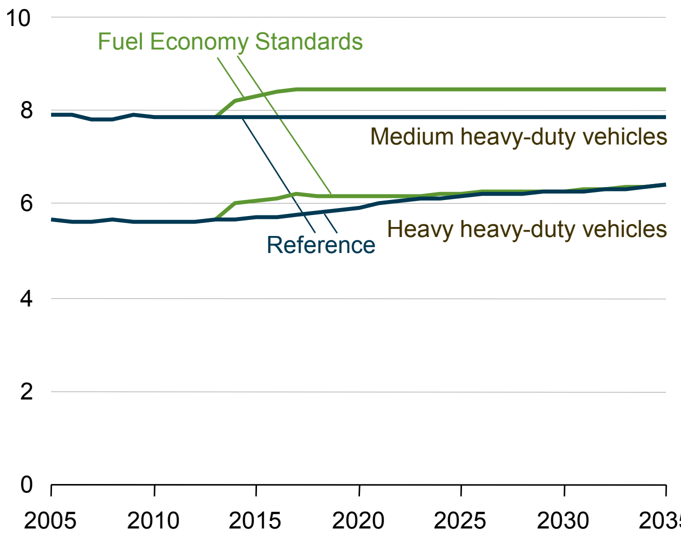


Figure 24. Average on-road fuel economy of medium and heavy heavy-duty vehicles in two cases, 2005-2035 (miles per gallon gasoline equivalent)

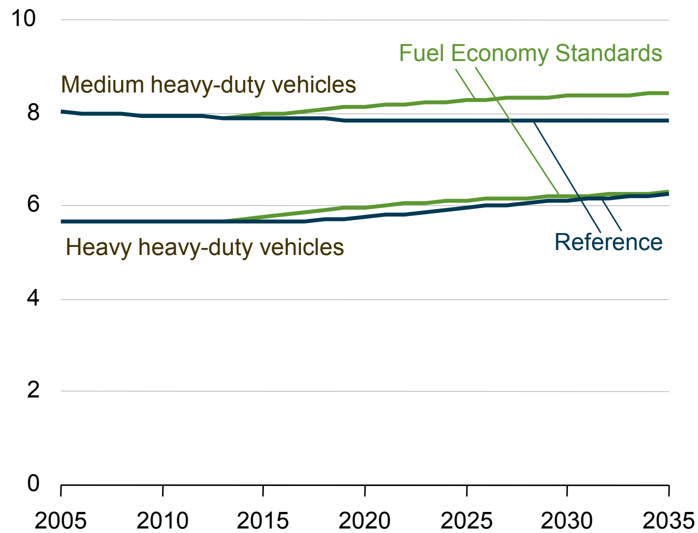


Figure 25. Total liquid fuels consumed by the transportation sector in two cases, 2005-2035 (million barrels per day)

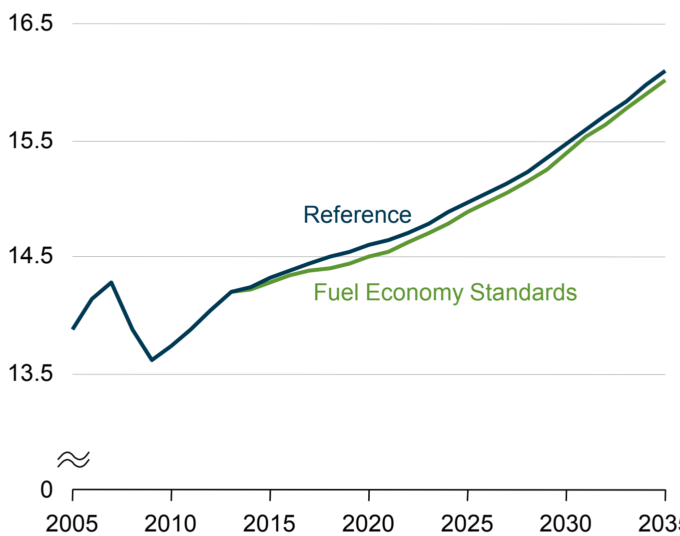
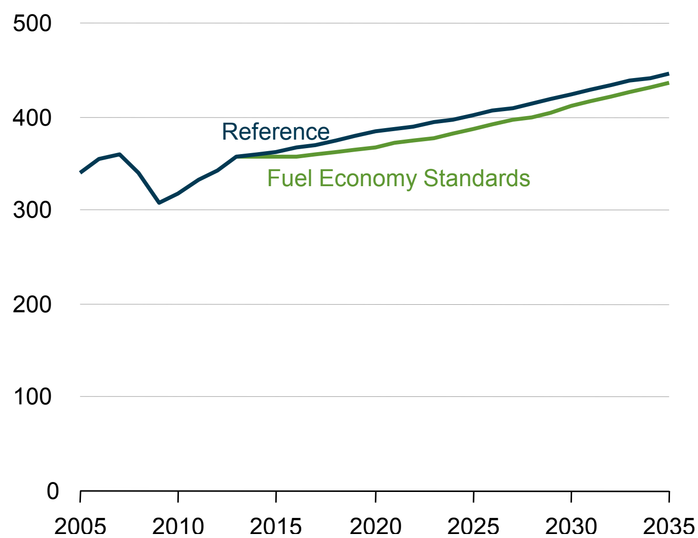


Figure 26. CO_2 emissions from heavy-duty vehicles in two cases, 2005-2035 (million metric tons)



mechanisms may accurately reflect real-world conditions, they may either underestimate or overestimate average fuel consumption and CO_2 emissions by vehicle category. Ultimately, fuel savings will be realized from the new standards; but given data limitations it is difficult to say with certainty the extent to which they will occur.

5. Potential efficiency improvements in alternative cases for appliance standards and building codes

In 2009, the residential and commercial buildings sectors used 19.6 quadrillion Btu of delivered energy, or 21 percent of total U.S. energy consumption. The residential sector accounted for 57 percent of that energy use and the commercial sector 43 percent. In the *AEO2011* Reference case, delivered energy for buildings increases by 16 percent, to 22.8 quadrillion Btu in 2035, which is moderate relative to the rate of increase in the number of buildings and their occupants. Accordingly, energy use in the buildings sector on a per-capita basis declines in the projection. The decline of buildings energy use per capita in past years is attributable in part to improvements in the efficiencies of appliances and building shells, and efficiency improvements continue to play a key role in projections of buildings energy consumption.

Three alternative cases in *AEO2011* illustrate the impacts of appliance standards and building codes on energy delivered to the residential and commercial sectors (Figure 27). The Expanded Standards case assumes multiple rounds of updates to appliance standards for most end uses. The Expanded Standards and Codes case includes the same updates to standards and adds several rounds of updates to national building codes. These cases differ from the Extended Policies case, in that they do not include the tax credit extensions assumed in the No Sunset case. The 2010 Technology case assumes that future equipment purchases are limited to the options available in 2010, and that the 2010 building codes remain unchanged through 2035. The 2010 Technology case includes all current Federal standards, but unlike the Reference case it does not include future efficiency levels established by equipment manufacturers and efficiency advocates through consensus agreements.

Without the benefits of technology improvement, buildings energy use in the 2010 Technology case grows to more than 24 quadrillion Btu in 2035, compared to under 23 quadrillion Btu in the Reference case. In the Expanded Standards and Codes case, energy delivered to the buildings sectors does not exceed 21 quadrillion Btu throughout the projection period.

Background

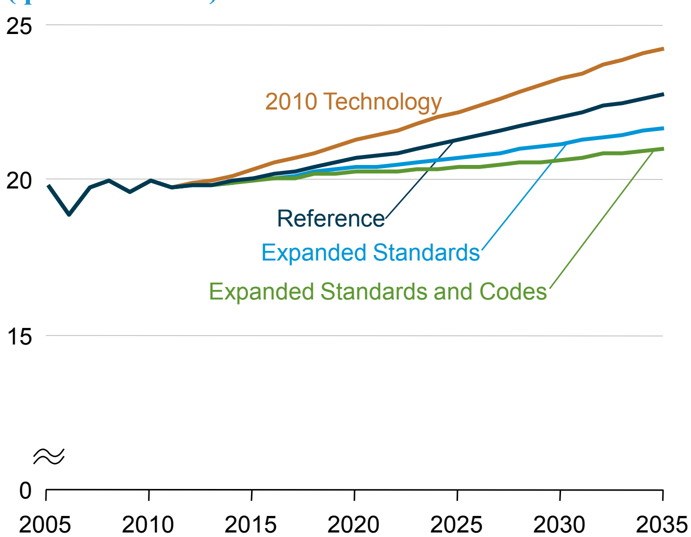
Governments at both the State and Federal levels have used appliance standards and building codes to mandate minimum levels of efficiency in commercially available products and in new construction. California first established standards for selected appliances in the mid-1970s, and the Federal Government followed in 1987 with the National Appliance Energy Conservation Act. Currently, most major end-use devices are covered by Federal standards, and some States have added standards for such products as televisions, audio and video equipment, swimming pool pumps, commercial holding cabinets for hot food, and bottle-type water dispensers.

There are no Federal building codes; rather, codes are set at the State level. For residential buildings, most State codes are some version of the IECC. Commercial building codes are more likely to be based on specifications developed jointly by the American National Standards Institute, the ASHRAE, and the Illuminating Engineering Society of North America. In addition, the States have sole responsibility for compliance monitoring and enforcement of the codes, and efforts vary significantly across States.

Although both contribute to efficiency improvements and reduced energy consumption, building codes and appliance standards achieve those goals in different ways. Appliance standards set efficiency levels and require new equipment to provide a given level of service output (e.g., heat, light, or refrigeration) with a reduced level of energy input.

Building codes can reduce energy mainly for heating and cooling equipment by increasing insulation and decreasing air infiltration. Better insulation impedes heat transfer, and better infiltration control reduces air transfer between outdoor elements and indoor conditioned space. Those measures make the work done by heating and cooling equipment more effective, essentially by creating a more robust barrier between outdoor and indoor spaces.

Figure 27. Residential and commercial delivered energy consumption in four cases, 2005-2035 (quadrillion Btu)



Appliance standards

DOE's thresholds for setting Federal standards include average energy use in excess of 150 kilowatthours (or Btu equivalent) per household for any 12-month period; aggregate household energy use in excess of 4.2 billion kilowatthours (14.3 trillion Btu); and technological feasibility of substantial efficiency improvement for the product. For example, a typical refrigerator under the 2001 DOE standard can use up to 510 kilowatthours per year, and residential refrigeration in aggregate consumed

367 trillion Btu in 2009. Once a product is covered by DOE, the States must seek waivers from Federal preemption in order to implement their own standards.

Assumptions for future efficiency standards in the Extended Policies case and the Expanded Standards case are based on ENERGY STAR specifications or, for some products in the commercial sector, FEMP guidelines. The first round of standards in the Expanded Standards case assumes ENERGY STAR levels, but the improvements assumed for subsequent rounds are only 50 percent of those assumed for the first round (7.5 percent in the case of dehumidifiers). This approach is taken because, for example, an ENERGY STAR dehumidifier uses 15 percent less energy than required by the most recent standard, but it may be unreasonable to assume that future standards for dehumidifiers (or any other equipment) will always be able to achieve improvements of the same magnitude. In addition, the assumed future standards do exceed the "maximum technologically feasible" levels described in technical support documents for DOE's rulemaking.

Future efficiency levels for several products, in addition to standards already promulgated by DOE, are included in the *AEO2011* Reference case. Efficiency advocates and equipment manufacturers have developed consensus agreements on regional standards for electric heat pumps, central air conditioners, and furnaces, and national standards for refrigerators, freezers, clothes washers, clothes dryers, dishwashers, and room air conditioners. In those cases, efficiency levels in additional rounds of standards are limited to one-half the ENERGY STAR improvement increment.

The ENERGY STAR program provides an annual summary of market penetration by qualified products [*53*]. For some product categories with high levels of market penetration, ENERGY STAR specifications are updated more frequently, to encourage greater efficiency. Consequently, ENERGY STAR levels may be the most up-to-date and consistent set of efficiency levels that are plausible for future standards.

The Expanded Standards case includes updated standards for currently covered products as well as new standards for products not yet covered. Updated standards for covered products are introduced according to DOE's rulemaking schedule, which typically staggers rulemakings and revisits standard levels every 6 years. Standards for products not previously covered are assumed to be added to the schedule, with the last standard being introduced in 2019. For most end uses, only one additional round of standards is applied. Exceptions in the residential sector include boilers, geothermal heat pumps, and dehumidifiers, with two rounds of standards. Two additional rounds of standards are also assumed for geothermal heat pumps in the commercial sector.

By law, the DOE rulemaking process requires that efficiency improvements be imposed at neutral cost to consumers. Extensive cost-benefit analysis in the process involves thorough engineering and market analyses of potential impacts on consumers and is subject to scrutiny and input from equipment manufacturers, efficiency advocates, and other stakeholders. The sensitivity cases described here focus on the aggregate energy impacts of additional standards and codes, but do not address the impacts on consumer welfare. Future efficiency levels are based solely on estimations of improvements for currently available products.

Building codes

Residential and commercial building energy codes [*54*] are currently applied at the State level with no consistent schedule for adoption, compliance, or enforcement. Current residential building codes vary widely: some States comply with 2009 IECC or better, while others have codes that predate the 1998 MEC / IECC or have no mandatory codes at all. On the commercial side, the most stringent States have adopted ASHRAE 90.1-2007 or better, while the least stringent States either have no mandatory code or have codes that precede ASHRAE 90.1-1999. The Energy Policy Act of 1992 required certification of building energy code updates from all States, so that residential codes would meet or exceed the (now obsolete) Council of American Building Officials' 1992 Model Energy Code, and commercial codes would meet or exceed ASHRAE 90.1-1989. As of 2010, a State-level scorecard from efficiency advocates identified 12 States that still do not have mandatory energy codes for either residential or commercial buildings [*55*].

The American Recovery and Reinvestment Act of 2009 (ARRA) provides State Energy Program (SEP) funding, contingent on the updating of a State's building codes to ASHRAE 90.1-2007 and the IECC that was most recent when ARRA was passed in 2009, and on the State's providing a plan to achieve at least 90-percent compliance within 8 years. All 50 States applied for and received SEP funds with those conditions. The Reference case assumes that States comply with ARRA. The Expanded Standards and Codes case adds three rounds of building codes, the first of which mandates a 15-percent improvement over IECC 2009 in the residential sector and a 30-percent improvement over ASHRAE 90.1-2004 in the commercial sector by 2020. Two subsequent rounds in 2023 and 2026 each add an assumed 5-percent incremental improvement.

Results for the residential sector

Because many of the products targeted by the appliance standards program are used in the residential sector, about 60 percent of the additional buildings sector efficiency gains in the Expanded Standards and Codes case are realized there. Figure 28 shows cumulative energy savings relative to the 2010 Technology case in three cases for various groups of residential end uses.

The Reference case includes technology improvement in every end use. Also, two consensus agreements among equipment manufacturers and efficiency advocates provide additional significant reductions in consumption. In 2009, a consensus agreement recommended regional standards for some heating and cooling equipment as an alternative to the national standards of the past. In 2010, a consensus agreement recommended standards for refrigerators, freezers, room air conditioners, clothes washers, clothes dryers, and dishwashers. Those consensus agreements are included in the Reference case as *de facto* standards, and they contribute to the cumulative reduction in delivered energy use of 13.4 quadrillion Btu in the Reference case relative to the 2010 Technology case.

The Expanded Standards case shows significant improvement in miscellaneous energy loads, mostly as the result of an assumed standard for standby power in 2014. Standards for televisions and computer monitors are introduced in 2016, as recent improvements in display technology have offered room for energy savings. Products such as home audio equipment and DVD players that have been subject to State standards are assumed to be covered at the Federal level, further contributing to energy savings. Similarly, energy use for personal computers and related equipment, such as printers, modems, and routers, also are affected by the standards for standby power and assumed new DOE rulemakings for peripheral devices. Ultimately, the energy consumption associated with televisions, set-top boxes, personal computers, and related equipment is reduced by 1.8 quadrillion Btu in 2035 in the Expanded Standards case.

Electric water heating, with an assumed standard mandating heat pump water heaters in 2021, is reduced by 2.0 quadrillion Btu in 2035 in the Expanded Standards case relative to the Reference case. Electricity use for large kitchen appliances (refrigeration and cooking) display relatively little improvement in the Expanded Standards case. Refrigeration already is subject to stringent standards in the Reference case, whereas cooking equipment has less room for technological improvement. A lighting standard is assumed to be set in 2026, establishing an efficacy level for general-service bulbs at the level of compact fluorescent lamps; however, that level is not much higher than the standard that already has been promulgated and will go into effect in 2014. Energy use for laundry and dishwashing equipment shows little direct improvement in the Expanded Standards case, because standards for those products are more likely to limit water use than energy use.

The building codes in the Expanded Standards and Codes case provide an additional 2.9 quadrillion Btu of savings for space heating and cooling relative to those in the Expanded Standards case. Space heating accounts for most of the savings. In addition, some features of new building codes could focus on thermal improvements, such as reducing air infiltration or increasing the solar heat gain coefficients of windows, which may be beneficial in winter months but slightly detrimental in summer months.

Results for the commercial sector

Buildings in the commercial sector are less homogeneous than those in the residential sector, in terms of both form and function. The wider range of commercial equipment makes standard-setting more difficult, and although many products have been subject to Federal efficiency standards, FEMP guidelines, and ENERGY STAR specifications, coverage is not as comprehensive as in the residential sector. Figure 29 shows cumulative energy savings relative to the 2010 Technology case in three cases for various groups of commercial end uses.

Like the residential sector, commercial buildings with residential-size equipment were affected by the 2009 consensus agreement for heating and cooling products, which is included in the Reference case. This contributes to a cumulative reduction in delivered energy use for commercial heating, ventilation, and air conditioning of 1.5 quadrillion Btu (2 percent) in the Reference case relative to the 2010 Technology case. Office-related computer equipment sees significant energy savings, primarily because laptops gain market share from desktop computers.

In the Expanded Standards case, office equipment again accounts for a large share of the efficiency gains, because desktop computers and their monitors, laptops, copiers, fax machines, printers, and multi-function devices are assumed to be subject to

Figure 28. Residential delivered energy savings in three cases, 2010-2035 (cumulative differences from the 2010 Technology case, quadrillion Btu)

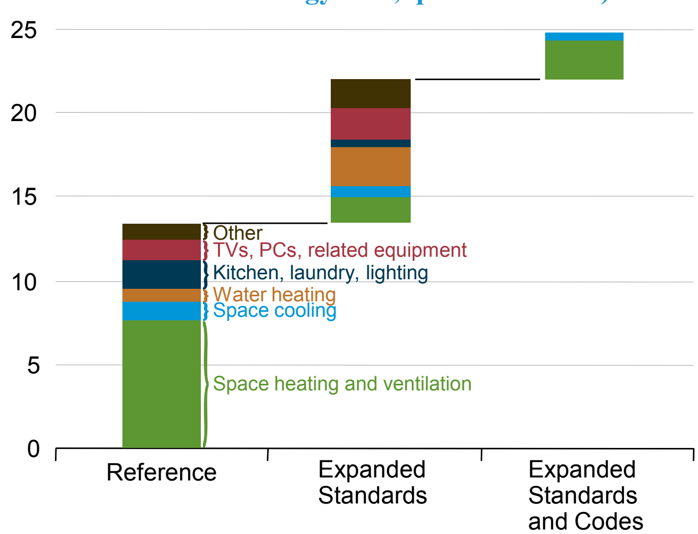
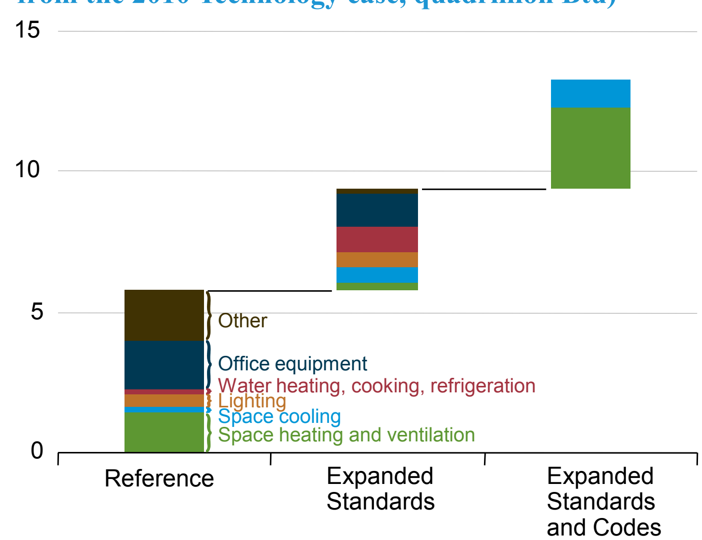


Figure 29. Commercial delivered energy savings in three cases, 2010-2035 (cumulative differences from the 2010 Technology case, quadrillion Btu)



efficiency standards, ultimately saving 1.2 quadrillion Btu over the projection period. Lighting in the commercial sector is subject to a tighter standard in 2017, saving 0.6 quadrillion Btu in total through 2035. In addition, an assumed 2021 standard requiring the use of heat pump water heaters leads to a 29-percent reduction in electricity consumption for water heating in 2035.

Building codes in the Expanded Standards and Codes case have nearly as much impact as the assumed standards in the Expanded Standards case, because the assumed building codes are much more stringent than those in the Reference case. Ultimately, the new codes provide almost 3 quadrillion Btu of savings in energy consumption for space heating savings and about 1 quadrillion Btu of savings for space cooling, beyond the reductions attributable to equipment standards.

Summary

In comparison with a case that restricts future equipment to what was available in 2010, the alternative cases described here show the potential for energy savings from the technological improvement and the application of appliance standards and building codes. In the Reference case, assumed technology improvement in general, and consensus agreements on efficiency improvements for some end uses in particular, save 13.4 quadrillion Btu of residential delivered energy—equivalent to 4.4 percent of total residential energy use—from 2010 to 2035. In the commercial sector, 5.6 quadrillion Btu of energy—equivalent to 2.2 percent of total commercial delivered energy—is saved from 2010 to 2035. Assumed appliance standards in the Expanded Standards case provide additional cumulative energy savings from 2010 to 2035 of 2.8 percent and 1.4 percent in the residential and commercial sectors, respectively. On top of those savings, the tighter building codes assumed in the Expanded Standards and Codes case provide additional cumulative reductions in energy use of 1.0 percent and 1.6 percent in the residential and commercial sectors, respectively. Ultimately, in the Reference case, 19.0 quadrillion Btu of delivered energy consumption is avoided over 25 years relative to projected consumption in the 2010 Technology case. That total is roughly equivalent to the energy that the buildings sectors consumed in 2006. The Expanded Standards and Codes case goes beyond the Reference case to save an additional 19.0 quadrillion Btu of delivered energy from 2010 to 2035.

6. Potential of offshore crude oil and natural gas resources

The 2010 Macondo oil well accident in the Gulf of Mexico heightened awareness of the risks associated with exploration and development of offshore crude oil and natural gas resources, particularly in deep water. In addition, there is significant uncertainty about the offshore resources available in the Gulf of Mexico and Alaska offshore areas. Despite the risks and uncertainties, however, offshore crude oil and natural gas production is expected to remain an important component of U.S. supply through 2035.

In 2009, offshore production accounted for 1.79 million barrels per day or 33 percent of the 5.36 million barrels per day of total U.S. crude oil production and 2.70 trillion cubic feet or 13 percent of the 20.96 trillion cubic feet of U.S. natural gas production. In the *AEO2011* Reference case, offshore production accounts for roughly 32 percent of total domestic crude oil production and 11 percent of total domestic natural gas production over next 25 years.

Analysis cases

Three sensitivity cases were used to evaluate the impacts of key assumptions related to the availability of offshore crude oil and natural gas resources and the costs of exploring and developing them. Specific assumptions in the three cases are discussed below.

High OCS Resource case

Resource estimates for most of the U.S. outer continental shelf (OCS) are uncertain, particularly for resources in undeveloped regions where there has been little or no exploration and development activity, and modern seismic survey data are lacking. In several recent studies prepared for the DOE [*56*] and the National Association of Regulatory Utility Commissioners [*57*], technically recoverable resources in undeveloped areas of the OCS have been estimated at 2 to 5 times the latest (2006) estimates from the U.S. Department of the Interior's Bureau of Ocean Energy Management.

The *AEO2011* High OCS Resource case assumes a technically recoverable undiscovered crude oil resource base in the Atlantic, Pacific, and Alaska OCS and in areas of the eastern and central Gulf of Mexico (which are currently under a statutory drilling moratorium) that is triple the size of the resource base assumed in the Reference case (Table 6), resulting in a total OCS level of technically recoverable resources of 144.0 billion barrels of crude oil, as compared with 69.3 billion barrels in the Reference case. For natural gas, the High OCS Resource case triples the technically recoverable undiscovered resources in some areas, with the exception of the Alaska OCS. Projected natural gas production from the Alaska OCS is not sensitive to the level of technically undiscovered resources, because natural gas prices are not high enough to support investment in a pipeline to bring natural gas from the North Slope area to market.

Reduced OCS Access case

The Reduced OCS Access case assumes leases in the Pacific, Atlantic, Eastern Gulf of Mexico, and Alaska OCS regions are not available until after 2035, as detailed in Table 7.

High OCS Cost case

The High OCS Cost case assumes that costs for exploration and development of offshore oil and natural gas resources are 30 percent higher than those in the Reference case. The higher cost assumption is not intended to be an estimate of the impact of any new regulatory or safety requirements, but is simply used to illustrate the potential impacts of higher costs on the production of OCS crude oil and natural gas resources.

Analysis results

In the High OCS Resource case, the assumed increase in technically recoverable OCS resources in undeveloped areas impacts crude oil and natural gas production through 2035, primarily because of the long lead times required for resource development in the offshore, regardless of the size of the resources discovered. In most areas, depending on location and water depth, a period of 3 to 10 years for exploration, infrastructure development, and developmental drilling is required from lease acquisition to first production. Because the assumed availability of leases in the Pacific, Atlantic, Eastern Gulf of Mexico, and Alaska is the same in the Reference and High OCS Resource cases, crude oil and natural gas production is not affected by the high resource assumption until 2025 and after.

In 2035, offshore crude oil production in the High OCS Resource case is 51 percent higher, at 3.25 million barrels per day, than the Reference case production level of 2.15 million barrels per day (Figure 30). The majority of the increase (65 percent) is from the Alaska OCS, based on the assumed discovery and development of a large field with 2 billion barrels of recoverable crude oil resources. As a result, total domestic crude oil production in 2035 is 1.05 million barrels per day (18 percent) higher in the High OCS Resource case than in the Reference case. Cumulative total domestic crude oil production from 2010 to 2035 in the High OCS Resource case is only 5 percent higher than in the Reference case.

Changes in domestic oil production tend to have only a modest impact on crude oil and petroleum product prices, because any change in domestic oil production is diluted in the world oil market. In 2009, the United States produced 5.36 million barrels per day of crude oil and lease condensate, or 7 percent of the world total of 72.26 million barrels per day. Unlike crude oil supply and prices, domestic natural gas supply and prices are determined largely by supply and demand for natural gas in the North American market, where the development and production of shale gas in the Lower 48 States is largely responsible for current and foreseeable future market conditions.

Natural gas production in U.S. offshore areas in 2035 is 0.7 trillion cubic feet higher in the High OCS Resource case than in the Reference case, putting some downward pressure on natural gas prices (Figure 31). In 2035, the Henry Hub spot price is about 3 percent lower in the High OCS Resource case than in the Reference case. However, the lower price results in only a small increase in natural gas consumption, 0.2 trillion cubic feet. Thus, the increase in OCS natural gas production is offset by a decrease of 0.5 trillion cubic feet in production from onshore domestic supply sources.

In the Reduced OCS Access case, removing the Pacific, Atlantic, Eastern Gulf of Mexico, and Alaska OCS from future leasing consideration lowers projected domestic production of both crude oil and natural gas. The impact on domestic crude oil production starts after 2026 as a result of the lead time between leasing and production and the economics of projects in undeveloped areas. In 2035, offshore crude oil production in the Reduced OCS Access case, at 1.78 million barrels per day, is 17 percent or 0.17 million barrels per day lower than in the Reference case, resulting in a 6 percent decrease in total domestic crude oil production.

Offshore natural gas production in 2035 is 5 percent lower in the Reduced OCS Access case than in the Reference case (2.92 trillion cubic feet compared with 3.05 trillion cubic feet), resulting in a decrease in total U.S. natural gas production of less than 1 percent. Cumulatively, total domestic crude oil and natural gas production from 2010 to 2035 is less than 1 percent lower in the Reduced OCS Access case than in the Reference case.

In the High OCS Cost case, exploration and development costs for crude oil and natural gas resources in all U.S. offshore regions are 30 percent higher than in the Reference case, resulting in lower levels of offshore crude oil and natural gas production throughout the projection period. The largest difference in production levels between the two cases occurs in 2015, when total U.S. offshore crude oil production is 112,000 barrels per day (6 percent) lower and offshore natural gas production is 0.2 trillion cubic feet (9 percent) lower than in the Reference case.

The higher exploration and production costs in the High OCS cost case change the economics of oil and gas development projects and reduce the number of wells drilled annually in offshore areas. Because of the higher costs, exploration and development of some offshore resources occur later, when prices are higher. In 2035, lower 48 offshore crude oil production is 2 percent lower, and lower 48 offshore natural gas production is 3 percent lower, in the High OCS Cost case than in the Reference case. Impacts on crude oil and natural gas

Table 6. Technically recoverable undiscovered U.S. offshore oil and natural gas resources assumed in two cases

	Crude oil (billion barrels)		Natural gas (trillion cubic feet)	
	Reference	High OCS Resource	Reference	High OCS Resource
Developing Gulf of Mexico	32.0	32.0	173.7	173.7
Undeveloped Gulf of Mexico	3.7	11.0	21.5	64.4
Mid- and South Atlantic	1.4	4.1	12.4	37.1
Southern Pacific	5.7	17.1	10.1	30.4
Alaska	26.6	79.8	132.1	132.1
Total undiscovered	**69.3**	**144.0**	**349.8**	**437.7**

prices and consumption are small. In Alaska, however, the increase in costs deters the development of additional offshore resources that are economically viable in the Reference case.

7. Prospects for shale gas

Production of natural gas from large underground shale formations (shale gas) in the United States grew by an average of 17 percent per year from 2000 to 2006. Early successes in shale gas production occurred primarily in the Barnett Shale of north central Texas. By 2006, successful shale gas operations in the Barnett shale, improvements in shale gas recovery technologies, and attractive natural gas prices encouraged the industry to accelerate its development activity in other shale plays. The combination of two technologies—horizontal drilling and hydraulic fracturing—made it possible to produce shale gas economically, and from 2006 to 2010 U.S. shale gas production grew by an average of 48 percent per year. Further increases in shale gas production are expected, with total production growing by almost threefold from 2009 to 2035 in the *AEO2011* Reference case. However, there is a high degree of uncertainty around the projection, starting with the estimated size of the technically recoverable shale gas resource.

Estimates of technically recoverable shale gas are certain to change over time as new information is gained through drilling and production, and through development of shale gas recovery technology. Over the past decade, as more shale formations have been explored and used for commercial production, estimates of technically and economically recoverable shale gas resources have skyrocketed. However, the estimates embody many assumptions that might prove to be untrue in the long term.

In the *AEO2011* Reference case, estimates of shale gas resources are based in part on an assumption that production rates achieved to date in a limited portion of a formation are representative of future production rates across the entire formation—even though experience to date has shown that production rates from neighboring shale gas wells can vary by as much as a factor of 3. Moreover, across a single shale formation, there are significant variations in depth, thickness, porosity, carbon content, pore pressure, clay content, thermal maturity, and water content, and as a result production rates for different wells in the same formation can vary by as much as a factor of 10.

There is also considerable uncertainty about the ultimate size of the technically and economically recoverable shale gas resource base in the onshore lower 48 States and about the amount of gas that can be recovered per well, on average, over the full extent of a shale formation. Uncertainties associated with shale gas formations include, but are not limited to, the following:

- Most shale gas wells are only a few years old, and their long-term productivity is untested. Consequently, reliable data on long-term production profiles and ultimate gas recovery rates for shale gas wells are lacking.
- In emerging shale formations, gas production has been confined largely to "sweet spots" that have the highest known production rates for the formation. When the production rates for the sweet spot are used to infer the productive potential of an entire formation, its resource potential may be overestimated.
- Many shale formations (particularly, the Marcellus shale) are so large that only a portion of the formation has been extensively production tested.
- Technical advances can lead to more productive and less costly well drilling and completion.

Table 7. First year of available offshore leasing in two cases

	Reference	Reduced OCS Access
Eastern Gulf of Mexico	2022	After 2035
North Atlantic	After 2035	After 2035
Mid- and South Atlantic	2018	After 2035
Northern and Central Pacific	After 2035	After 2035
Southern Pacific	2023	After 2035
Alaska	2010	After 2035

Figure 30. Offshore crude oil production in four cases, 2009-2035 (million barrels per day)

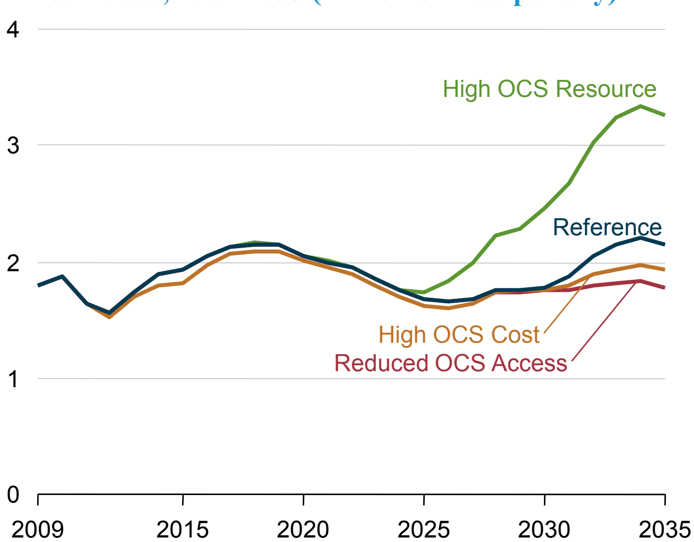
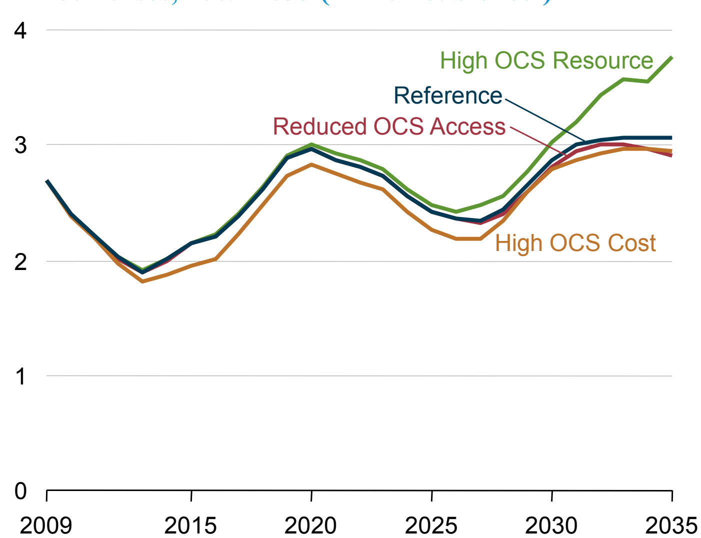


Figure 31. Offshore natural gas production in four cases, 2009-2035 (trillion cubic feet)



- Currently untested shale formations, such as thin seam formations, or untested portions of existing formations, could prove to be highly productive.

Although public estimates of onshore lower 48 shale gas resources, as reported by private institutions, have grown over the past decade as more shale gas plays have been production tested, it is not known what shale formations were included in the estimates or what methodology and data were used to derive them. For example, an estimate relying only on publicly reported costs and performance profiles for shale gas wells would tend to overestimate the size of the economic resource base, because public information is skewed toward high-production and high-profit wells. Given the lack of information about how private institutions have derived their resource estimates, this analysis considers a set of alternative resource estimates that are intended to provide a plausible but not definitive range of potential shale gas resources.

Analysis cases

Two key determinants of the estimated technically recoverable shale gas resource base are (1) estimated ultimate recovery (EUR) per well and (2) an assumed recovery factor that is used to estimate how much of the acreage of shale gas plays contains recoverable natural gas. Four *AEO2011* cases examine the impacts of higher and lower estimates of total recoverable shale gas resources on natural gas prices and production. The four cases are not intended to represent a confidence interval for the resource base, but rather to illustrate how different resource assumptions affect projections of domestic production, prices, and consumption.

High resource cases

Two high shale resource cases were created by increasing two different assumptions underlying the resource estimate. The estimated unproved technically recoverable resource base (excluding 20.1 trillion cubic feet of inferred reserves) is the same in both high shale resource cases and is 50 percent higher than in the Reference case (1,230 trillion cubic feet in the two high shale resource cases, compared with 827 trillion cubic feet in the Reference case).

- In the *High Shale EUR case*, the EUR per shale gas well is assumed to be 50 percent higher than in the Reference case. The higher estimate could result from, for example, better placement of the horizontal lateral within the formation; better completion techniques that allow more of the pore space and absorbed gas to reach the well bore; and/or determination that well recompletions are both productive and economic.
- In the *High Shale Recovery case*, 50 percent more natural gas is assumed to be recovered from each shale formation. The EUR per well is unchanged from the Reference case, and so 50 percent more wells are needed to recover the gas contained in each shale play. Higher recovery could result if a larger portion of each shale formation than originally estimated proves to be productive and economic, and/or if the drilling of more wells, more horizontal laterals, or both closer to each other proves to be productive and economic.

Low shale resource cases

Two low shale resource cases were created by adjusting the same factors described above for the high shale resources cases, but in the opposite direction. The estimated unproved technically recoverable shale gas resources is 423 trillion cubic feet in both of the low shale resource cases, 50 percent lower than the 827 trillion cubic feet level in the Reference case.

- In the *Low Shale EUR case*, the EUR per shale gas well is assumed to be 50 percent lower than in the Reference case. The lower estimate could result, for example, from faster rates of decline in gas production than expected in the Reference case, and/or considerably lower ultimate recovery rates than expected for wells in areas where shale formations have not yet been tested.
- In the *Low Shale Recovery case*, 50 percent less natural gas is recovered from each shale gas play, because, for example, a large number of formations are less productive and less economic than currently anticipated. The EUR per well is unchanged from the Reference case, but the number of wells required to recover the resource is 50 percent lower, because there is 50 percent less natural gas in each shale gas play that can be recovered economically.

The 50-percent variations in the shale gas cases approximate the range of shale gas resource estimates reported by the U.S. Geological Survey for 20 shale gas assessment units in 5 petroleum basins, using the Survey's 95 percent and 5 percent probability resource volumes as indicative of the degree of uncertainty in shale gas resource estimates.

As discussed below, in the High Shale EUR and High Shale Recovery cases, natural gas prices are lower than in the Reference case; however, the energy models used for the *AEO2011* projections do not allow for liquefied natural gas (LNG) exports from domestic facilities. Consequently, net natural gas exports in the Reference, High Shale EUR, and High Shale Recovery cases could be greater if domestic LNG export terminals were represented in the models.

Analysis results

The four shale gas cases illustrate the uncertainties that surround shale gas resources, which could have significant implications for future natural gas prices, production, and consumption (Table 8). They also illustrate that the type of uncertainty involved (EUR or recovery) also bears on the question of how prices, production, and consumption could unfold as uncertainties about the U.S. shale gas resource base are resolved over time.

The largest variations from the Reference case are in the High and Low Shale EUR cases, where lower and higher costs per unit of shale gas production have the effect of increasing and decreasing total production from U.S. shale gas wells. In the Low Shale EUR case, the Henry Hub natural gas price in 2035 is $2.19 per million Btu or 31 percent higher than the Reference case price of $7.07 per million Btu (2009 dollars). Conversely, in the High Shale EUR case, the Henry Hub price in 2035 is $1.72 per million Btu or 24 percent lower than in the Reference case.

In 2035, shale gas production is more than three times as high in the High Shale EUR case as in the Low Shale EUR case, at 17.1 trillion cubic feet and 5.5 trillion cubic feet, respectively, as compared with 12.2 trillion cubic feet in the Reference case. The High and Low Shale EUR cases show the largest variation in shale gas production, as well as the greatest variation in natural gas prices. The High and Low Shale Recovery cases show less variation in production and natural gas prices. In the Low Shale Recovery case, shale gas production totals 8.2 trillion cubic feet in 2035, as compared with 15.1 trillion cubic feet in the High Shale Recovery case. Even in the Low Shale EUR case, however, with the lowest production projections, overall growth in U.S. natural gas production is still primarily the result of an increase in shale gas production from the 2009 level of 3.3 trillion cubic feet.

Price impacts in the High and Low Shale Recovery cases are less pronounced, because the cost per unit of production from each shale formation is the same as in the Reference case. Instead, the recoverable shale gas volume associated with each formation is varied, leading to a corresponding change in the level of drilling required to recover the gas. In the Low Shale Recovery case, the Henry Hub natural gas price in 2035 is $1.10 per million Btu or 16 percent higher than in the Reference case. In the High Shale Recovery case, the Henry Hub price is $1.04 per million Btu or 15 percent lower than in the Reference case. As discussed below, other types of domestic natural gas production and imports are affected by, and reflected in, changes in natural gas prices across the shale gas analysis cases.

In the Low Shale EUR and Low Shale Recovery cases, with higher natural gas prices, total U.S. natural gas consumption in 2035 is 2.4 trillion cubic feet and 1.2 trillion cubic feet lower, respectively, than the Reference case projection of 26.6 trillion cubic feet. Conversely, in the High Shale EUR and High Shale Recovery cases, with lower natural gas prices, total U.S. natural gas consumption in 2035 is 3.1 trillion cubic feet and 1.7 trillion cubic feet higher, respectively, than the Reference case projection.

Natural gas consumption in the specific end-use sectors varies similarly with changes in natural gas prices: higher prices result in less consumption, and lower prices result in more consumption. The electric power sector shows the greatest sensitivity to changes in natural gas prices. In the Low Shale EUR and Low Shale Recovery cases, natural gas use for electric power generation in 2035 is 6.4 trillion cubic feet and 7.1 trillion cubic feet, respectively, compared with 7.9 trillion cubic feet in the Reference case in 2035. In the High Shale EUR and High Shale Recovery cases, total natural gas use for electricity generation in 2035 is 9.6 trillion cubic feet and 8.9 trillion cubic feet, respectively (higher than in the Reference case).

Natural gas consumption in the electric power sector is more responsive to price changes than in the other sectors, because much of the electric power sector's fuel consumption is determined by the dispatching of existing generation units based on the operating cost of each unit, which in turn is determined largely by the costs of competing fuels, such as coal and

Table 8. Natural gas prices, production, imports, and consumption in five cases, 2035

Projection	Low Shale EUR	Low Shale Recovery	Reference	High Shale Recovery	High Shale EUR
Henry Hub spot natural gas prices (2009 dollars per million Btu)	**9.26**	**8.17**	**7.07**	**6.03**	**5.35**
Total U.S. natural gas production (trillion cubic feet)	**22.4**	**24.6**	**26.3**	**28.5**	**30.1**
Onshore lower 48	17.2	19.6	23.1	25.5	27.2
Shale gas	5.5	8.2	12.2	15.1	17.1
Other gas	11.7	11.4	10.8	10.4	10.1
Offshore lower 48	3.5	3.2	3.1	2.8	2.7
Alaska	1.8	1.8	0.2	0.2	0.2
Total net U.S. natural gas imports (trillion cubic feet)	**1.7**	**0.7**	**0.2**	**-0.3**	**-0.5**
Total U.S. natural gas consumption (trillion cubic feet)	**24.1**	**25.4**	**26.6**	**28.3**	**29.6**
Electric power	6.4	7.1	7.9	8.9	9.6
Residential	4.6	4.7	4.8	4.9	4.9
Commercial	3.6	3.7	3.8	3.9	4.1
Industrial	7.5	7.8	8.0	8.4	8.7
Other	2.0	2.1	2.1	2.2	2.3

natural gas. Natural gas use in the end-use consumption sectors is generally less responsive to variations in fuel prices, because opportunities to switch to other fuels typically arise only when a new facility is built, or when an existing facility's equipment is retired or replaced.

Other sources of natural gas supply also respond to changes in shale gas production and natural gas prices across the shale gas analysis cases. Higher shale gas production tends to imply lower production of other natural gas. For example, other onshore lower 48 natural gas production in 2035 varies by 1.6 trillion cubic feet, and offshore lower 48 natural gas production varies by 0.8 trillion cubic feet, between the High and Low Shale EUR cases.

The volume of Alaska natural gas production is determined largely by the presence or absence of an Alaska natural gas pipeline to transport gas into Alberta, Canada, where the gas would be transshipped to the lower 48 States. Whether and when an Alaska gas pipeline is built depends on whether lower 48 natural gas prices are sufficiently high to allow recovery of the pipeline's capital and operating expenses while also providing a sufficient natural gas price at the North Slope wellhead. In the Low Shale EUR and Low Shale Recovery cases, an Alaska gas pipeline begins operation in 2026 and in 2030, respectively, delivering 3.8 billion cubic feet per day into the lower 48 natural gas market.

Just as natural gas prices determine the levels of domestic gas production and consumption, they also determine the level of net natural gas imports, with higher gas prices resulting in higher net natural gas imports. The High Shale EUR and High Shale Recovery cases are particularly noteworthy, because projected natural gas prices in those cases are sufficiently low to cause increases in Mexico's imports of U.S. natural gas that, in 2035, make the United States a net exporter of natural gas, with net exports totaling about 0.5 and 0.3 trillion cubic feet, respectively. U.S. net exports could be even greater if domestic LNG export terminals were developed, but this is not represented in the *AEO* models in the High Shale EUR and High Shale Recovery cases. Under the higher prices associated with the Low Shale EUR and Low Shale Recovery cases, the United States is a net importer of natural gas in 2035, with net imports totaling 1.7 and 0.7 trillion cubic feet year (7 percent and 3 percent of consumption), respectively.

8. Cost uncertainties for new electric power plants

Capital costs are a key consideration in decisions about the type of new generating plant or capacity addition that will be built to meet future demand for electricity. Capital costs for new power plants include materials, skilled labor, and generating equipment. For *AEO2011*, EIA commissioned a study of the cost components for different utility-scale electric power technologies, with the goal of presenting costs for different plant types in a common set of cost categories to facilitate comparison of capital costs. A major change from previous years in assumptions for the cost study included a significant increase in the assumed costs for coal and nuclear power projects [*58*].

There is, however, a great deal of uncertainty about future capital costs for all generating technologies. The completion of initial projects could yield experience that enables costs for future projects to be reduced, through a "learning by doing" process. A slow economic recovery could soften demand for the materials and labor used in building new power plants, which also could lower construction costs. Conversely, a failure to "learn" increases in the costs of labor and key commodities, or an uncertain outlook for the economy in general could increase the costs of future projects.

Because some plant types—coal, nuclear, and most renewables—are more capital-intensive than others (in particular, natural gas), the mix of future capacity installations and consequently the fuels used for power generation depends on both the relative and absolute level of capital costs. If construction costs increase proportionately for plants of all types, leaving relative costs unchanged, natural-gas-fired capacity will be more economical than the more capital-intensive coal and nuclear technologies. Over the longer term, higher construction costs could lead to higher electricity prices, which could slow the growth of electricity consumption.

Case descriptions

Several alternative cases assuming different trends in capital costs for power plant construction were used to examine the implications of different cost paths for new power plant construction. Because there is a correlation between rising power plant construction costs and rising commodity prices, construction costs in *AEO2011* are tied to a producer price index for metals and metal products.

The nominal index is converted to a real annual cost factor, using 2013 as the base year. The resulting cost factor for the Reference case remains nearly flat in the early years of the projection, then declines through the end of the projection, so that the construction cost factors in 2035 are nearly 20 percent lower than in 2011. As a result, future capital costs are lower even before technology learning adjustments are applied. The cost factor remains constant across all technology types.

In the *Frozen Plant Capital Cost case*, base overnight construction costs for all new electricity generating technologies are assumed to remain constant at 2015 levels, when the cost factor peaks in the Reference case. Cost decreases can still occur as a result of technology learning, but overall decreases are slower than in the Reference case. In 2035, capital costs for each technology are roughly 25 percent higher in the Frozen Plant Capital Cost case than in the Reference case.

In the *Decreasing Plant Capital Cost case*, base overnight construction costs for each generating technology in 2010 is 20 percent lower than in the Reference case in 2010, and they decline more rapidly in the projection. In 2035, capital costs for all technologies are about 40 percent lower in the Decreasing Plant Capital Cost case than in the Reference case.

Other alternative cost cases focus on specific technologies to examine the effects of cost reductions that could occur more rapidly for a given technology (for example, as a result of research and development funding or international learning experience).

In the *Low Nuclear Cost case*, capital and operating costs for new nuclear capacity are 20 percent lower than in the Reference case in 2010, and they fall to 40 percent lower in 2035.

In the *Low Fossil Technology Cost case*, capital and operating costs for each new fossil-fired generating technology is 20 percent lower than in the Reference case in 2010, and they fall to 40 percent lower in 2035.

Capacity additions

Overall capacity requirements and the mix of generating types change across the cases. In the Reference case, 223 gigawatts of new generating capacity are added from 2010 to 2035, as compared with 216 gigawatts in the Frozen Capital Cost case and 272 gigawatts in the Decreasing Plant Capital Cost case, where higher and lower electricity prices, respectively, lead to changes in total electricity demand. In addition, slightly more existing capacity is retired in the Decreasing Plant Capital Cost case, because new capacity is less expensive, and some older plants are retired and replaced with new capacity.

In all the cost cases, the majority of new capacity is natural-gas-fired (Figure 32). In the Frozen Plant Capital Cost case, builds of all types drop slightly from the level in the Reference case, but the mix of new generating capacity is similar to that in the Reference case. In the Decreasing Plant Capital Cost case, more new capacity of all types is built than in the Reference case, with nuclear and renewables both capturing slightly higher shares of total capacity builds. The increase in renewable capacity builds the Decreasing Plant Capital Cost case consists primarily of wind capacity.

In the cases that focus on specific technologies, the mix of capacity builds changes to favor those with declining costs. In the Low Fossil Technology Cost case, all coal- and natural-gas fired capacity is less expensive to build than in the Reference case, but the costs for nuclear and renewable capacity are the same as those in the Reference case. As a result, more coal and natural gas capacity is built, and less renewable capacity. Similarly, in the Low Nuclear Cost case, total additions of new nuclear capacity increase to 25 gigawatts, from 6 gigawatts in the Reference case. The new nuclear capacity primarily displaces natural-gas-fired capacity.

Electricity generation and prices

The alternative capital cost cases have smaller impacts on the overall mix of generation by fuel type, because capital cost assumptions do not affect the operation of existing capacity. Coal maintains the largest share of total generation in 2035 in all the cases, varying only from 42 percent to 44 percent across all the cases (Figure 33). The renewable share of generation in 2035 also remains fairly constant at 14 percent to 15 percent in all the cases, because the requirements of different State and regional RPS programs still must be met. In the Decreasing Plant Capital Cost case, generation from biomass co-firing is lower than in the Reference case, and wind generation provides more of the renewable requirement, because generating costs for new technologies, including wind, are lower than the costs for biomass co-firing. The nuclear share of total generation in 2035 is between 17 and 18 percent in all but one of the cases, increasing to 20 percent in the Low Nuclear Cost case. Natural-gas-fired

Figure 32. Additions to U.S. generating capacity by fuel type in five cases, 2009-2035 (gigawatts)

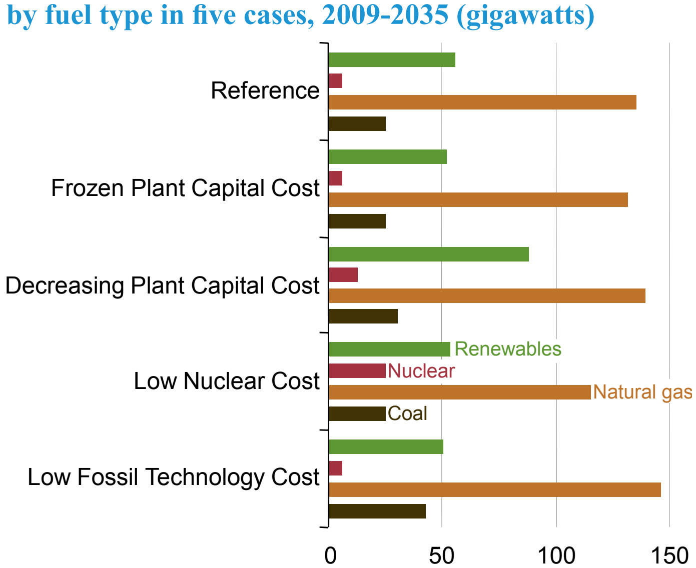
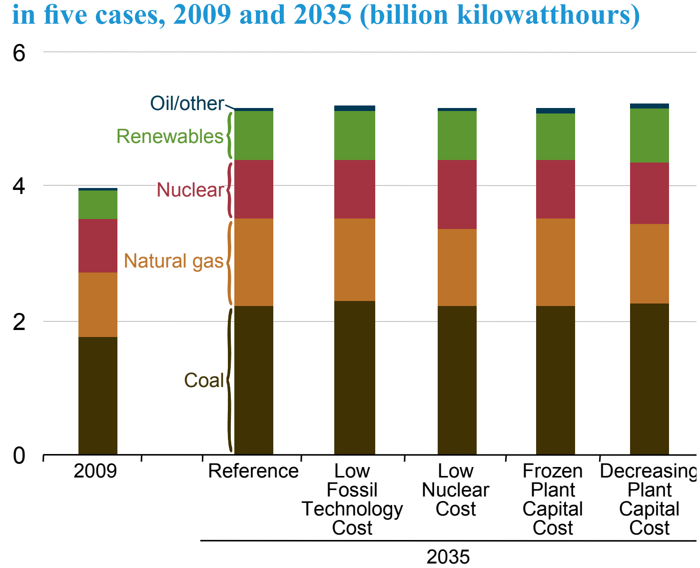


Figure 33. U.S. electricity generation by fuel in five cases, 2009 and 2035 (billion kilowatthours)



generation, typically the marginal generating choice, drops in the Decreasing Plant Capital Cost case, where new capacity of all types is cheaper than in the Reference case.

Electricity prices in 2035 are 1 percent higher in the Frozen Plant Capital Cost case than in the Reference case, because construction costs are higher. In the Decreasing Plant Capital Cost case, electricity prices in 2035 are 4 percent lower than in the Reference case. In the Lower Nuclear Cost and Low Fossil Technology Cost cases, where only those two technologies are affected, price changes are smaller than those in the cases where all technologies were adjusted (Figure 34).

9. Carbon capture and storage: Economics and issues

Background

Carbon capture and storage (CCS) is a process in which CO_2 is separated from emission streams and injected into geologic formations, avoiding its release into the atmosphere. Typically, the captured CO_2 is transported by pipeline from the emissions source to a suitable storage site.

Capturing and storing CO_2 from power plants and industrial processes adds significant capital and operating costs. In some cases, captured CO_2 may have considerable value—for example, it may be sold to oil producers for use in CO_2-enhanced oil recovery (EOR). In some mature oil fields, producers can recover significantly more of the oil in place by injecting CO_2 into a well. CO_2-EOR has been used in the United States for more than 30 years, providing experience in transporting and injecting CO_2 as well as increasing petroleum production [*59*]. However, broad deployment of CCS technology would require additional incentives to be economical, beyond the value added from CO_2-EOR. At present, CCS activity is limited to a few large-scale tests around the world, largely funded by governments.

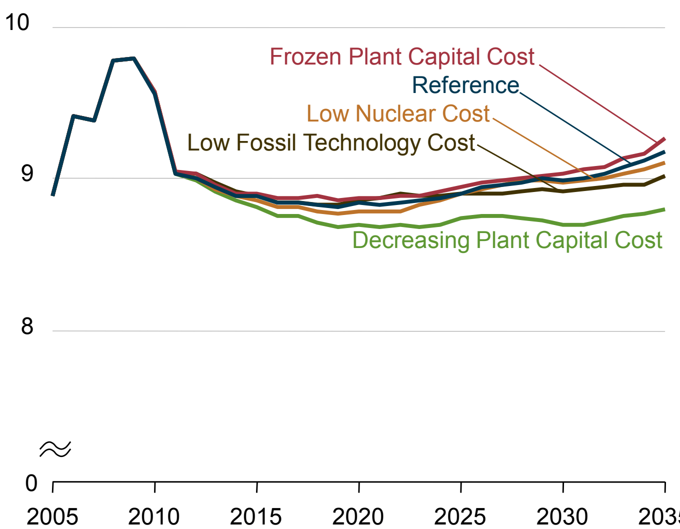
Wide-scale adoption of CCS could allow for continued widespread use of fossil fuels in a low-carbon energy system. Significant barriers to the technology remain, however, such as the cost of building and operating capture-ready industrial facilities, the feasibility of permanently storing CO_2 underground, and the difficulty of constructing significant infrastructure to transport CO_2 to injection sites. Such challenges would have to be overcome in order to enable widespread deployment of CCS. The preponderance of expected costs for CCS deployment are for capturing and compressing the CO_2. However, uncertainty in the cost of permanent storage is also significant.

Current research on CCS is focused on lowering the cost of carbon capture and validating the feasibility of permanent CO_2 storage. The primary goal of the research is to make CCS viable for fossil fuel power plants, which are the largest potential source of CO_2 for CCS and present the most difficult technical hurdles in making CCS economically feasible. A few industrial processes, such as ethanol and ammonia production, yield emissions that are nearly pure CO_2, mitigating the technical challenge and energy intensity of CO_2 capture.

In 2009, CO_2-EOR operators injected nearly 50 million metric tons of CO_2 into operating domestic oil wells, most of which was obtained from natural sources. However, the limited supply of natural CO_2 has provided enough incentive for a few facilities to capture anthropogenic CO_2. This activity has also financed the construction of several pipelines to transport CO_2 to oil fields. There is potential for more early adopters of CCS to continue receiving payments from CO_2-EOR operators, but the quantity of CO_2 that potentially could be used for EOR is small in comparison with the 2.2 billion metric tons emitted in the U.S. power sector in 2009.

Table 9 lists the five commercial-scale CCS projects now in operation worldwide, according to the International Energy Agency. All the projects shown in Table 9 are being monitored over the long term, to ensure that the stored CO_2 does not leak. This is why the Rangely Weber and Weyburn-Midale projects are counted as CCS demonstrations even though they are primarily EOR projects [*60*].

Figure 34. U.S. electricity prices in five cases, 2005-2035 (2009 cents per kilowatthour)



Carbon capture

In order for CO_2 to be transported and stored, it must be isolated from emissions sources and compressed to a supercritical state [*61*]. For fossil fuel power plants, this is the most expensive component of CCS, because the flue gases of existing coal-fired power plants contain only 12 to 14 percent CO_2, and those from existing natural-gas-fired power plants contain only 3 to 4 percent CO_2 [*62*]. Existing technologies for capturing the CO_2 from dilute flue gases are energy-intensive, and consequently their operating costs are high. The National Energy Technology Laboratory is supporting research focused on the development of technologies that can lower the cost of capture, either by developing techniques to lower the cost of purifying dilute CO_2 streams or by increasing the purity of CO_2 in the flue gases of fossil fuel power plants. The goal of the research is to develop and eventually commercialize carbon capture technologies that can be used routinely by power plant operators while adding less than 10 percent to consumers' electricity costs [*63*].

CO_2 emissions from fossil-fuel power plants can be captured through pre-combustion, post-combustion, or oxy-combustion processes. In the near term, the most likely approach for capturing CO_2 from existing coal-fired power plants is to retrofit them with post-combustion capture systems, in which flue gas is treated with a solvent (usually, an amine or chilled ammonia) to separate CO_2 from the flue gas before it is released to the atmosphere. Not all existing fossil fuel power plants can be retrofitted for CCS, however, given the costs, space requirements, and need for access to cooling water, all of which can contribute to making a project infeasible.

CCS technology may be more easily integrated as part of a new fossil-fuel plant, where cost and efficiency savings could be realized by including CCS in the initial design. New coal-fired plants with CCS can be built with post-combustion capture systems, similar to retrofits, or with pre-combustion capture systems that gasify the coal and capture CO_2 from the newly formed syngas before combustion. Retrofitting natural-gas-fired combined-cycle plants with post-combustion technology is also a possibility, as are new natural gas power plants with pre-combustion capture. Carbon capture technologies currently are in the early stages of development, and it is unclear which may be developed on a commercial scale.

CO_2 pipelines

Once captured, CO_2 must be transported to a suitable site for sequestration or EOR. The most cost-effective method is to move CO_2, compressed to a supercritical state, by pipeline. The technology for building pipelines to transport gases over long distances is mature, based on experience with natural gas pipelines, as well as more than 3,000 miles of CO_2 pipelines currently in use to supply CO_2-EOR fields. Large-scale adoption of CCS is likely to require significant construction of new pipelines. Interstate CO_2 pipelines (unlike natural gas pipelines) are not regulated by the Federal Energy Regulatory Commission, and the lack of national eminent domain authority to ease construction [*64*] represents a possible impediment to the development of a national pipeline network.

Geologic sequestration and CO_2-EOR

Several types of geologic formation have been identified as being suitable for permanent carbon sequestration. Key requirements for a formation that can be used for CO_2 storage include being able to store CO_2 cost-effectively, prevent leakage of injected CO_2, and avoiding interference with other valuable geologic formations, such as freshwater aquifers. The largest contributors to the costs of sequestration are the drilling, operating, and monitoring of wells. Cost-effective storage depends largely on the ability of a field to store the CO_2 densely so as to limit the number of injection wells required. Permanent storage capabilities depend on the presence of an impermeable cap rock and lack of faults or uncapped well bores to the surface. Depleted oil and gas fields, deep saline aquifers, and unmineable coal seams all meet these criteria, and all have been identified as good candidates for sequestration. Basalt formations and offshore sediments may also prove to be feasible in the future [*65*].

In the United States, many specific formations have been identified as suitable for sequestration; however, their potential costs and capacities are uncertain. With the exception of depleted oil and gas fields, the geology of sequestration opportunities is not well characterized, and the behavior of injected supercritical CO_2 is not completely understood. It has been estimated that the cost of injection in a saline aquifer can vary by a factor of 3 within a single formation, depending on the geology of the aquifer. Furthermore, injection costs can vary between reservoirs by orders of magnitude [*66*]. Current research is focused on characterizing the geology of sequestration sites and developing methods to estimate capacities and the feasibility of permanently storing CO_2 in specific formations accurately.

Until now, U.S. experience with injecting CO_2 underground has largely been limited to CO_2-EOR. Natural sources of CO_2 comprise a majority of current supply, but some anthropogenic CO_2, largely from natural gas processing plants, is captured and used for CO_2-EOR [*67*]. As long as CO_2 is a valuable commodity, CO_2-EOR operators will maximize oil production to the extent possible and attempt to recover as much injected CO_2 as they can, but there will be little interest in permanent storage. However, CO_2-EOR has helped to establish a market for captured CO_2 and has provided a better understanding of the technical issues involved in injecting CO_2.

Table 9. Commercial-scale CCS projects operating in 2010

Project name	Country	CO_2 source	Quantity injected (million metric tons per year)	Start year
Sleipner	Norway	Natural gas processing	1.0	1996
In Salah	Algeria	Natural gas processing	1.0	2004
Snohvit	Norway	Natural gas processing	0.7	2008
Rangely Weber	United States	Natural gas processing	1.0	1986
Weyburn-Midale	United States/Canada	Coal gasification plant	3.2	2000

Analysis results

Reference case

Without a cost for emitting CO_2 or government support for CCS, there is no reason to add CCS capabilities to facilities other than when oil producers are willing to pay the entire capital and operating costs of capturing and transporting CO_2 for EOR. In the Reference case oil producers are assumed to purchase CO_2 from emitters in several industries at a price that gives emitters sufficient economic incentive to capture their emissions. Interregional CO_2 pipelines may be constructed if oil prices and EOR opportunities make them economical. Pipeline construction is delayed, however, by the time required to get permits and construct such large projects.

In the Reference case, CO_2-EOR plays an increasing role in U.S. petroleum production. Early in the projection period, most CO_2 is obtained from natural sources (Figure 35). As demand for CO_2 increases beyond the capacity of natural sources, industrial emitters with relatively pure streams of CO_2 begin to capture and sell the CO_2 to EOR operators. No anthropogenic CO_2 is captured from power plants beyond the 2 gigawatts of advanced coal with sequestration that is assumed to be supported by Federal incentives, because the cost is too high for oil producers to implicitly fund the construction of a CCS-capable power plant. CO_2-EOR supports more than 1.1 million barrels per day of domestic oil production in 2035 in the Reference case, nearly 4 times the CO_2-EOR production level in 2009. CO_2-EOR provides 19 percent of total U.S. crude oil production in 2035.

Oil prices represent a key uncertainty for future CO_2-EOR projects, because they are the most significant factor in determining the economic feasibility of projects. Other major uncertainties are the amount of CO_2 available to oil producers and the CO_2 emissions cost required to give emitters enough incentive to capture it. In 2035, more than 125 million metric tons CO_2 per year is captured from anthropogenic sources outside the power sector—equivalent to more than 10 percent of the 1,147 million metric tons of direct CO_2 emissions from the industrial sector in 2035. Because not all industrial emissions are sufficiently pure to be captured cheaply, the Reference case results for CO_2-EOR imply that a large proportion of all CO_2 emissions from ethanol fermentation, CTL and BTL plants, hydrogen production in refineries, ammonia plants, and natural gas processing plants will be captured for sale.

GHG Price Economywide case

An additional case, which includes a CO_2 price, illustrates the potential role for CCS in mitigating U.S. CO_2 emissions. In the GHG Price Economywide case, the CO_2 price (in 2009 dollars) rises from $25 per ton in 2013 to $77 per ton in 2035, encouraging the deployment of CCS technology in the power sector. Due to lower capital costs and relatively low natural gas prices, natural gas combined-cycle plants with sequestration are cheaper to build than advanced coal plants with sequestration (Figure 36), although a significant number of existing coal-fired power plants are retrofitted for CCS after 2030. Additional carbon capture capability is constructed for CTL and BTL plants in the refining sector. Commercial-scale CTL and BTL plants with CCS provide a relatively inexpensive source of CO_2 that can be used for EOR.

One factor that could limit future CO_2-EOR activity is the availability of CO_2. In the GHG Price Economywide case, emitters have an economic incentive to capture and store CO_2, given the cost of emitting CO_2 into the atmosphere. In this case, oil producers can purchase CO_2 captured from power plants, with the price to oil producers decreasing as the amount of CO_2 captured increases due to the higher CO_2 supply.

Figure 35. CO_2 injection volumes in the Reference case, 2005-2035 (million metric tons per year)

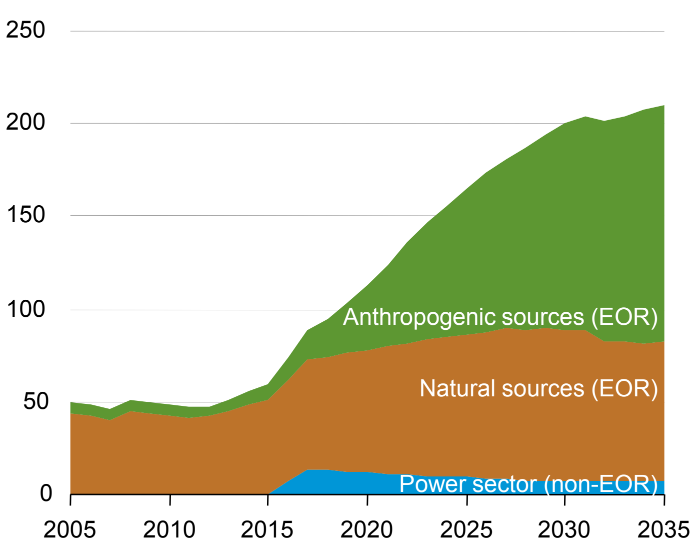
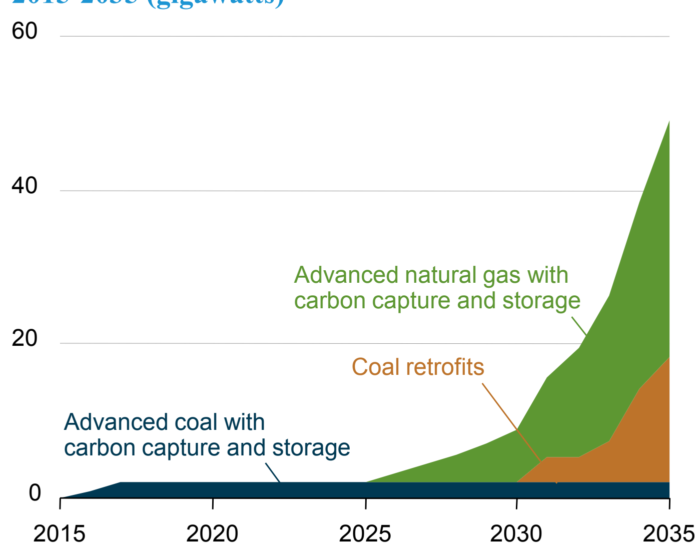


Figure 36. CCS capacity additions in the U.S. electric power sector in the GHG Price Economywide case, 2015-2035 (gigawatts)



Oil producers cannot use all the CO_2 that is captured in the electricity and refining sectors in the GHG Price Economywide case, especially in the later years of the projection period. As a result, significant quantities of CO_2 are sequestered in non-EOR geologic fields (Figure 37). However, despite the low-cost sources of CO_2 for oil producers that come on line after 2015 in the GHG Price Economywide case, there is only a relatively small increase (127,000 barrels per day) in domestic petroleum production, primarily because of the relatively late timing of CCS installations in the power sector and a limit to the number of oil fields suitable for CO_2-EOR that are not already developed in the Reference case.

An alternative viewpoint on the effect that a U.S. carbon mitigation policy could have on CO_2-EOR production is provided in a recent report by Advanced Resources International (ARI) [*68*], which suggests that as much as 3.6 million barrels per day of incremental oil production could have been stimulated if the American Clean Energy and Security Act had passed in 2009. That analysis is not fully comparable with the *AEO2011* projections, however, because the ARI projection was based in part on an earlier version of the National Energy Modeling System that did not fully incorporate a comprehensive framework for developing EOR fields, pipeline infrastructure, and deployment of the technology.

Other sensitivity cases

Two sensitivity cases illustrate the uncertainties in the Reference case projections for CO_2-EOR production. The Low EOR case assumes that the amount of inexpensive, anthropogenic CO_2 that can be accessed by oil producers is lower than in the Reference case. The Low EOR/GHG Price Economywide case adds the GHG Price Economywide case assumptions to those of the Low EOR case.

Figure 38 shows projected CO_2-EOR volumes in the Reference case, GHG Price Economywide case, Low EOR case, and Low EOR/GHG Price Economywide case. The Low EOR case and the Low EOR/GHG Price Economywide case show a stronger response of CO_2-EOR to the increase in availability of CO_2 from carbon capture as a result of the assumed carbon policy. In the Low EOR case, there is significant unsatisfied demand for CO_2 at fields that are suitable for EOR. The GHG price provides a means for that demand to be satisfied.

10. Power sector environmental regulations on the horizon

The EPA is expected to enact several key regulations in the coming decade—pertaining to air emissions, solid waste, and cooling water intake—that will affect the U.S. electric power sector, particularly the fleet of coal-fired power plants. In order to comply with those new regulations, existing coal-fired plants may need extensive environmental control retrofits if they are to remain in operation [*69*]. Because the final makeup of the expected rules is uncertain, *AEO2011* includes alternative cases that assume different variations of possible retrofit requirements. They should be viewed as sensitivity cases, rather than projections of what is likely to happen.

Background on rules

Transport Rule

The Transport Rule, proposed by the EPA in July 2010 [*70*], is designed to reduce emissions of sulfur dioxide (SO_2) and nitrous oxide (NO_x) from electric power plants in the eastern half of the United States. The purpose of the rule is to assist States in complying with the National Ambient Air Quality Standards (NAAQS) for fine particulate matter ($PM_{2.5}$) and ground-level ozone [*71*]. The EPA determined that a major reason many States were not meeting the NAAQS for $PM_{2.5}$ and ozone was emissions from

Figure 37. CO_2 injection volumes in the GHG Price Economywide case, 2005-2035 (million metric tons per year)

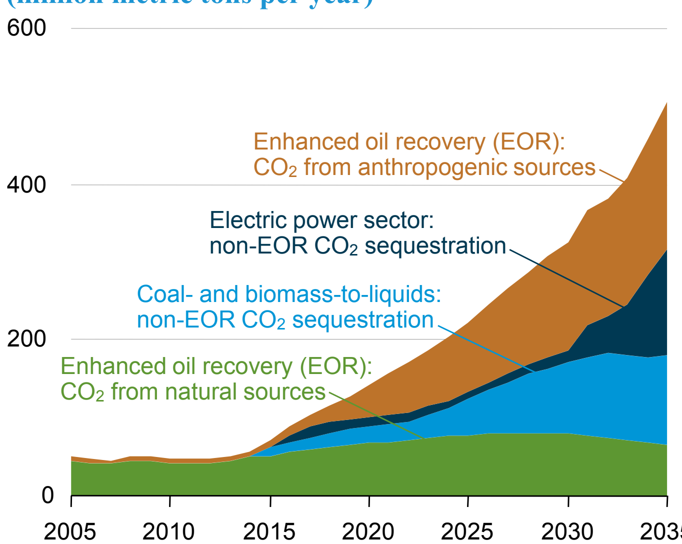
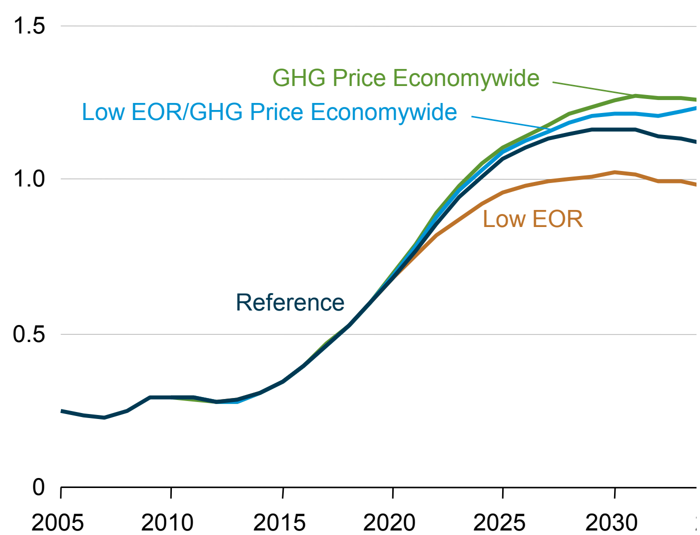


Figure 38. CO_2-EOR oil production in four cases, 2005-2035 (million barrels per day)



power plants in upwind States. Accordingly, the Transport Rule establishes State-level emissions caps designed to limit the effects of power plant emissions on the air quality of neighboring States.

The Transport Rule was developed to address legal flaws in the EPA's Clean Air Interstate Rule (CAIR), which was vacated by the U.S. District Court of Appeals in 2008 [*72*]. First proposed in 2005, CAIR would have established an interstate cap-and-trade system for SO_2 and NO_x emissions in 28 eastern States, designed to meet the same goals as the Transport Rule. The court ruled that CAIR could not be implemented under the Clean Air Act, concluding that a broad regional cap-and-trade system would not guarantee improved air quality in specific local regions, as required by CAA. The court temporarily reinstated CAIR in December 2008, but it ordered the EPA to revise the rule to address the flaws cited. The EPA included limits on interstate trading in the newly proposed Transport Rule specifically for that purpose.

In June 2010, the EPA proposed three versions of the Transport Rule. The EPA's preferred option would cap emissions in each participating State, allow for a limited amount of emissions trading between States, and permit unlimited intrastate trading. A second alternative would prohibit any interstate trading but allow intrastate trading. A third option would disallow all emissions trading. The EPA is expected to announce a final rule in the spring of 2011.

In designing the Transport Rule, the EPA determined that 28 States have SO_2 emissions levels high enough to contribute significantly to $PM_{2.5}$ nonattainment in downwind States, and that 26 States have NO_x emissions levels high enough to contribute to ozone nonattainment. The Transport Rule would require each of those States to reduce emissions to a defined cap by 2012. An additional 15 States would be required to reduce SO_2 emissions further by 2014 (Table 10).

In addition, the EPA is considering lowering the NAAQS for annual ozone concentrations from the current limit of 75 parts per billion. If it does, additional reductions in NO_x emissions from power plants probably will be required beyond the sensitivity case evaluated here. The EPA has hinted that this would be done by increasing the stringency of the Transport Rule for NO_x at some point in the future.

There are several possible strategies for reducing SO_2 emissions from coal-fired power plants: plant owners can use lower sulfur coal in their boilers, retire plants without emissions controls, or install emissions control equipment—primarily, flue gas desulfurization (FGD) scrubbers. There are two key types of FGD scrubbers, wet and dry. Wet scrubbers remove SO_2 from post-combustion flue gas by using a wet alkaline solution, typically containing limestone. Dry scrubbers send the flue gas through a semi-dry alkaline sorbent that removes the SO_2 [*73*]. *AEO2011* assumes that all future SO_2 control systems will consist of wet FGD scrubbers.

For NO_x there are two basic emissions reduction technologies: combustion and post-combustion. Combustion technologies adjust the combustion reaction so that less NO_x is produced. Post-combustion technologies remove NO_x from the exhaust after it is produced. The choice of control technology is based on plant-specific characteristics, such as unit capacity, boiler configuration, and coal type. Combustion retrofits generally are accomplished by modifying existing boilers so that less NO_x is produced in the combustion process—usually a less costly option but also less effective at removing emissions than post-combustion controls.

There are two types of post combustion NO_x controls: selective catalytic converters (SCRs) and selective noncatalytic converters (SNCRs). Both technologies use a reagent (typically ammonia or urea) to react with the flue gas in order to reduce NO_x to nitrogen and water. In SCRs the reaction occurs in the presence of a catalyst bed; in SNCRs the catalyst bed is not included. The catalyst increases the cost and scale of a retrofit project, but it also increases the efficiency of NO_x removal. SCRs also are more easily scaled up, which makes them a more effective option for larger plants. The most stringent pollution control case in *AEO2011* assumes that all plants not currently using NO_x controls will be required to install SCRs.

Utility boiler MACT

In March 2011, the EPA proposed rules to regulate emissions of mercury, other metals, and acid gases from power plants. The rules are intended to enforce Section 112 of the Clean Air Act's limits on emissions of hazardous air pollutants (HAPs) from electric power plants. The rule requires that all power plants larger than 25 megawatts capacity install the MACT needed to reduce emissions of affected pollutants to levels that match the performance of top-performing plants of the same type. Hydrogen chloride (HCl) and $PM_{2.5}$ were used as proxies for all acid gases and for metals other than mercury, respectively, because they would tend to be captured by the same control devices. The rule is intended to result in the removal of 91 percent of mercury and HCl from the emissions of coal-fired power plants and the installation of fabric filters at all plants in order to meet the PM limits.

Table 10. Transport Rule emissions targets, 2012 and 2014 (million metric tons)

	Annual SO_2 (28 States)	Annual NO_x (28 States)	Ozone season NO_x (26 States)	Annual SO_2 (15 additional States)
Actual 2005 emissions	8.9	2.7	0.9	--
Actual 2009 emissions	4.6	1.4	0.6	--
2012 emissions targets	3.4	1.3	0.6	--
2014 emissions targets	3.4	1.3	0.6	2.6

Potential regulation of coal combustion residuals

In June 2010, the EPA released a proposal for regulating coal combustion residuals (CCRs) from electric power plants under the Resource Conservation and Recovery Act (RCRA). Two options given by the EPA were to regulate CCRs under Subtitle C of the RCRA, which would classify CCRs as a hazardous waste pollutant, or Subtitle D, which would classify them as a nonhazardous waste pollutant. By defining CCRs as hazardous, Subtitle C would place more stringent regulations on the storage of coal ash, which probably would result in the closure of surface ash impoundments.

Subtitle D would require the EPA to establish a national criterion for permitting CCR disposal but would leave implementation of such a system to the States. Under Subtitle D, the EPA is considering two options for existing surface impoundments, which are referred to as "Subtitle D" and "Subtitle D Prime." The primary difference between the two options is that, under Subtitle D, existing surface impoundments would either have to be retrofitted with composite liners or cease receiving CCRs within 5 years, while under the Subtitle D Prime, existing surface impoundments could continue to operate to the end of their useful lifetimes without the installation of composite liners. RCRA Subtitle C would require active regulation by the EPA. Under Subtitle D, the main vehicle for enforcement would be citizen lawsuits. As of January 2011, the EPA was reviewing comments on the proposed rule, with a final rule expected to be released in 2011.

In complying with the proposed regulations for CCRs, plants could face increased costs for CCR disposal, depending on specific plant characteristics. Plants with on-site coal ash impounds could incur costs for retrofits or replacements. Plants with wet ash handling systems could be required to switch to dry ash handling systems. The Tennessee Valley Authority (TVA) has already announced that it will replace all wet ash handling systems with dry systems across its entire coal-fired fleet (about 17 gigawatts total capacity). TVA estimates that the investment required for the conversion will be between $1.5 billion and $2.0 billion over the next 10 years [*74*]. However, because of uncertainty about the makeup of the final rule and the difficulty of assessing project costs, which are inherently site-specific, the potential CCR regulations are not included in any *AEO2011* cases.

The EPA has been seeking to regulate mercury emissions from power plants since they were first designated a HAP in December 2000. In 2005, the EPA proposed a cap-and-trade system for mercury under the Clean Air Mercury Rule (CAMR). However, regulating with a cap-and-trade policy required that the EPA first remove mercury from the HAPs list. That action was challenged in court by several States and environmental organizations, and as a result the U.S. Court of Appeals for the District of Columbia Circuit vacated CAMR in 2008 [*75*].

Despite the court's ruling, the EPA still is required by the CAA to regulate mercury emissions from power plants. The utility boiler MACT rules are intended to fulfill that obligation. Currently, there are 189 listed HAPs. In developing the MACT standards, the EPA determines the emissions of each of those pollutants from power plant boilers. In its proposed rule, the EPA has designated certain pollutants as "proxy" pollutants, meaning that the regulation of one substance could serve to cover others. The rule is expected to be finalized by November 2011. After it is issued, power plant owners will have until 2015 to comply, although extensions of up to 2 years may be granted.

Mercury emissions from power plants can be reduced by fabric filters and activated carbon injection (ACI) systems, which work by injecting powdered carbon into flue gases to bind the mercury and then using particulate control equipment, such as fabric filters, to remove it. Mercury can also be removed by equipment designed to reduce other pollutants, such as FGD scrubbers. FGD scrubbers are especially effective in reducing mercury from bituminous coal emissions, due to its particular chemical makeup. ACI systems may be necessary to remove mercury from subbituminous and lignite coal emissions. In the sensitivity cases discussed here, all coal-fired plants are required to reduce mercury emissions by 90 percent.

Acid gas can be removed through the use of FGD scrubbers or direct sorbent injection (DSI). DSI has lower capital costs than FGD scrubbers, but the technology has not yet been widely deployed in the power sector. In its regulatory impact analysis of the Air Toxics Rule, the EPA assumes significant deployment of DSI [*76*]. Because of DSI's relatively low capital costs, the EPA sees it as an attractive, low-cost way for smaller coal plants with lower utilization factors to comply with the rule and continue operating. Other analyses are not as optimistic on the prospect of DSI. For example, a study by the Edison Electric Institute on the impacts of several proposed EPA rules for the power sector shows DSI being installed on only 9 gigawatts of capacity to comply with the utility boiler MACT [*77*]. In order to represent a more stringent case, *AEO2011* assumes that FGDs will be needed for compliance with the rule.

Retrofit or retire?

Several key economic factors can influence owners' decisions as to whether older power plants should be retrofitted or retired. The stringency of regulations, compliance costs, remaining life of a plant, fuel prices, and expectations regarding electricity demand and prices all may be considered. Plant owners must determine whether expected future revenues from their plants over their remaining lives will be sufficient to recover the investment in new equipment needed to comply with environmental regulations. Key variables in the determination are the costs of retrofit equipment and future electricity prices.

Because natural gas often is the marginal fuel for electricity generation, low natural gas prices make it more likely that older coal-fired plants will be retired. Low natural gas prices reduce the overall cost of generating electricity, eventually leading to reduced revenues from coal-fired plants. The updated estimates of capital costs for coal and nuclear power plants in *AEO2011* are 25 to 37 percent higher than those used in *AEO2010*, whereas capital costs for natural gas combined-cycle plants are essentially unchanged

Potential regulation of cooling water intakes

Section 316(b) of the Clean Water Act (CWA) requires facilities with cooling water intake structures to use the best technology available (BTA) to mitigate the environmental impacts of the systems—specifically, damage to aquatic wildlife. In 2004, the EPA originally proposed regulation of existing power plants under Section 316(b), which is intended to apply to all facilities that remove at least 50 million gallons of water per day from the environment and use at least 25 percent of the water for cooling. A typical 500-megawatt plant with once-through cooling uses approximately 500 million gallons of cooling water per day. However, determining BTA as it applies to the CWA has been the subject of extensive legal delays, culminating in a Supreme Court case, which has delayed implementation of the rule [*78*]. Because of the Court's ruling, the EPA is able to consider both the costs and benefits in the design of its final rule. The EPA issued proposed standards for comment on March 28, 2011.

In a once-through system, intake structures withdraw water for use in a thermal power plant's cooling system. Once used, the water is discharged back into the body of water at a higher temperature. Both the water intake and thermal discharge can cause significant damage to local fish populations. In a closed-cycle cooling system, heat from the power plant is removed through evaporation in a nearby cooling tower. Closed-cycle systems require significantly less water intake than once-through systems, mitigating much of the environmental damage associated with the cooling system.

The determination of BTA for cooling water in power plants could have a substantial effect on the entire power sector. New York State and California already have issued rules that essentially require all plants in their States to have closed-loop cooling systems. If the same standard were implemented nationwide, extensive retrofits would be required. The Electric Power Research Institute (EPRI) has estimated that 312 gigawatts of capacity currently in operation (252 gigawatts of fossil fuel capacity and 60 gigawatts of nuclear capacity) would be affected by such a rule. In some cases it may not be possible to install a closed-loop cooling system, and such a requirement could, therefore, cause some plants to be retired.

Closed-loop cooling is considered the most stringent form of compliance with Section 316(b) of the CWA. Other methods of reducing fish mortality, such as wedge wires, variable speed pumps, and traveling water screens, may not be as effective as cooling towers, but they can be installed at much lower cost. In view of that uncertainty, the *AEO2011* cases do not include compliance with Section 316(b).

from *AEO2010*. In addition, projected natural gas prices in the *AEO2011* Reference case are lower than those in *AEO2010*, reducing the levelized costs of generation for new natural gas power plants. Consequently, new combined-cycle plants are an attractive alternative for replacing capacity lost as a result of coal-fired plant retirements.

Uncertainty about future GHG regulations continues to loom in power sector investment decisions. Despite a lack of Congressional action, many utilities include a CO_2 emissions price in their long-term investment decisions [*79*]. A carbon price would increase the cost of generation for all fossil fuel plants, but the largest impact would be on coal-fired generation. Thus, plant owners could be reluctant to retrofit existing coal plants, given the possibility that GHG regulations might be enacted in the near future. This uncertainty may influence the expectations of plant owners about the economic lives of particular facilities.

In the Reference case and most of the alternative cases for *AEO2011*, existing power plants are assumed to continue operating for at least 20 years, allowing the costs of environmental retrofits to be recovered over a 20-year period. In addition, *AEO2011* includes two cases described below, which assume that investors will implement retrofits only if their costs can be recovered over a 5-year period, given their concern that future laws or regulations aimed at limiting GHG emissions present a significant risk to the long-term operation of the affected units.

Analysis cases

Transport Rule Mercury MACT 20 case

The Transport Rule Mercury MACT 20 case assumes that the Transport Rule will be enacted in 2014, placing limits on SO_2 and NO_x emissions. It also assumes a 90-percent MACT for mercury starting in 2015. This case assumes a 20-year capital recovery period for financing FGD scrubbers and SCRs.

Transport Rule Mercury MACT 5 case

This case is identical to the Transport Rule Mercury MACT 20 case, except that it assumes a 5-year capital recovery period for financing FGD scrubbers and SCRs.

Retrofit Required 20 case

The Retrofit Required 20 case assumes more stringent regulation of air emissions from coal-fired plants and utility boilers, requiring the installation of FGD scrubbers and SCRs. It is based on assumptions of more stringent utility boiler MACT requirements and future NO_x emissions limits. Utility boiler MACT regulations are scheduled to be effective in 2015, but this case assumes a lag of several years to account for possible delays in implementation.

Retrofit Required 5 case

This case is identical to the Retrofit Required 20 case, except that it assumes a 5-year capital recovery period for financing FGD scrubbers and SCRs.

Low Gas Price Retrofit Required 20 case

This case is similar to the Transport Rule Mercury MACT 20 case but uses more optimistic assumptions about future volumes of shale gas production, which leads to lower natural gas prices. The domestic shale gas resource assumption in this case comes from the *AEO2011* High Shale EUR case (Figure 39).

Low Gas Price Retrofit Required 5 case

This case is identical to the Low Gas Price Retrofit Required 20 case, except that it assumes a 5-year capital recovery period for financing FGD scrubbers and SCRs.

GHG Price Economywide case

The GHG Price Economywide case assumes a price on CO_2 emissions that rises from $25 per ton (2009 dollars) in 2013 to $77 per ton in 2035. It does not include any specific provisions of the proposed Kerry-Lieberman and Waxman-Markey bills [*80*], such as offsets, bonus allowances, targeted allowance allocations, or increased efficiency mandates. None of the EPA rules described above is included in the GHG Price Economywide case.

Results

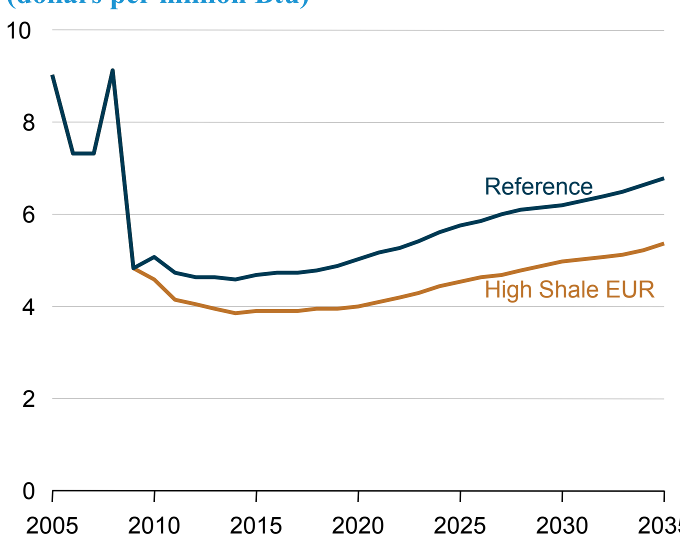
Coal-fired plant retirements

Retirements of coal-fired power plants in the different analysis cases vary with the assumed stringency of environmental rules, the assumed cost recovery period for retrofit investments, natural gas price levels, and assumptions regarding future GHG regulations. Of the 316 gigawatts of coal-fired capacity currently in operation in the United States, 117 gigawatts has no FGD scrubbers installed or currently under construction [*81*]. Lacking some of the controls necessary to comply with potential future regulations, those coal plants may be candidates for retirement if the regulations are enacted. Generally, the poorest performing plants, with the highest heat rates and lowest utilization rates, are the first that might be retired. Table 11 shows the amount of capacity retired along with the retired plants average heat rates and capacity factors in each case.

Projected retirements of coal-fired capacity are higher in each of the analysis cases shown in Table 11 than in the Reference case. Because the emissions reduction requirements in CAIR and the Transport Rule are similar, increased retirements in the Transport Rule Mercury MACT 20 and MACT 5 cases can be attributed to restrictions on allowance trading and to the Mercury MACT. In the Retrofit Required 20 and Retrofit Required 5 cases, explicit mandates are assumed to require the installation of FGDs and SCRs, so that retirement decisions are based on the costs of retrofits. In the Retrofit Required 20 case, most coal-fired plants continue operating beyond 2020. In the Retrofit Required 5 case, with only 5 years to recover the costs of installing retrofits, the amount of coal-fired capacity retired is more than double the amount retired in the Retrofit Required 20 case.

Lower natural gas prices in the Low Gas Price Retrofit Required 20 and Low Gas Price Retrofit Required 5 cases lead to comparatively more retirements of coal-fired capacity—39.5 and 72.6 gigawatts, respectively. Lower natural gas prices reduce the price of electricity in general, lowering power plant revenues. For natural-gas-fired plants, revenue reductions are largely offset by lower fuel costs. For coal-fired plants, assuming that coal prices do not change, there is no offset for the revenue declines, and retrofit projects become uneconomical in some instances. The GHG Price Economywide case assumes a price on CO_2 emissions, which renders many existing coal-fired plants uneconomical. As a result, retirements of coal-fired capacity total 135 gigawatts by 2035.

Figure 39. Natural gas prices in the Reference and High Ultimate Shale Recovery cases, 2005-2035 (dollars per million Btu)



Retrofit equipment installations

In the Retrofit Required 20 and Retrofit Required 5 cases, power plants are required to install FGD scrubbers and SCRs in order to continue operating after 2020, based on the assumption that stringent controls will be required by the EPA for compliance with clean air rules. The combined cost of the two retrofits could range from $500 to $1,000 per kilowatt of capacity, depending on plant size and characteristics [*82*]. More retrofits occur in the Retrofit Required 20 case than in the Retrofit Required 5 case, because the economics of retrofit projects improve with the longer capital recovery period.

The Transport Rule Mercury MACT 20 and Transport Rule Mercury MACT 5 cases mandate emissions reductions, but they do not require the installation of any particular control equipment. Therefore, while there are more retrofit projects in these cases than in the Reference case, there are not nearly as many as in the Retrofit Required 20 and 5 cases, because there are other options for compliance with the rule, such as using more low-sulfur coal and dispatching uncontrolled plants less often—options that are not available in the Retrofit Required 20 and 5 cases. In the Low Gas Price Retrofit Required 20 and 5 cases, lower prices for natural gas lead to lower overall electricity prices and lower plant revenues. There are fewer retrofits in the Low Gas Price cases, because lower revenues make it less likely that plant owners will be able to recover their investments in the equipment.

In the GHG Price Economywide case, 16 gigawatts of existing coal-fired capacity is retrofitted with CCS equipment. CCS is still unproven on a commercial scale, but *AEO2011* assumes that the technology will be available as a carbon mitigation option if a sufficient CO_2 price is in place.

Generation by fuel

Despite the decline in coal-fired capacity in all the analysis cases above, coal remains the largest single source of generation through 2035 in all but one of the cases (Figure 40). Even with more stringent emission caps, once a coal plant has been retrofitted it becomes more economical to run, because SO_2 and NO_x emission allowance costs are no longer incurred. Many of the coal plants that are retired have low utilization factors and high heat rates, and their contribution to overall coal generation is relatively small. In the Retrofit Required 20 and 5 cases, coal-fired generation increases in 2020, as plants that overcome the regulatory hurdle and install retrofits are run more frequently. In the Retrofit Required 20 case, coal-fired generation in 2035 is higher than in the Transport Rule Mercury MACT 20 and 5 cases, as the retrofitted plants are heavily utilized. Other than in the GHG Price Economywide case, electricity generation from coal is lowest in the Low Gas Price Retrofit Required 20 and 5 cases, where low natural gas prices stimulate construction of new natural gas plants to replace retired coal capacity, and existing gas-fired capacity is dispatched more frequently, displacing additional coal-fired generation. In the Low Gas Price Retrofit Required 20 and 5 cases, generation from coal in 2035 is 10 percent and 19 percent below the Reference case level, respectively. In the Low Gas Price Retrofit Required 5 case, the natural gas and coal shares of total generation in 2035 are the same, at 34 percent.

Natural-gas-fired electricity generation in 2035 is higher in all the cases (although it is lower in some earlier years) than in the Reference case. Rapid growth in gas-fired generation is supported by low natural gas prices and relatively low capital costs for new natural gas plants, which improve the relative economics of natural gas when regulatory pressure is placed on the existing coal fleet. Natural gas emits virtually no SO_2 and less NO_x than does coal, making it a more attractive fuel for environmental compliance.

In the Transport Rule Mercury MACT 20 and 5 cases, generation from natural gas grows steadily throughout the projection. In the early years, gas-fired generation is slightly higher than in the Reference case, because fuel switching is used as an option to comply with the flexible requirements of the Transport Rule. In the Retrofit Required 20 case, electricity generation from natural gas increases more slowly, and it is 4 percent lower than the Reference case level in 2025, when retrofitted coal plants no longer incur costs for SO_2 and NO_x emissions allowances (Figure 41). In the Low Gas Price Retrofit Required 20 and 5 cases, utilization of existing combined-cycle natural gas plants is higher throughout the projections, resulting in more gas-fired generation. In all the cases, increases in natural-gas-fired generation after 2025 result predominantly from the construction of new combined-cycle plants to meet growing demand for electricity and replace retired coal capacity.

In the GHG Price Economywide case, coal-fired generation declines steadily throughout the projection. In 2035, generation from coal is approximately 54 percent below the 2009 level, and 11 percent of the electricity generated from coal comes from either new or retrofitted coal plants with CCS. Generation from natural gas increases by more than 90 percent from 2009 to 2035 in the GHG Price Economywide case. Natural gas is a more attractive fuel for complying with a GHG price, because when it is used

Table 11. Coal-fired plant retirements in nine cases, 2010-2035

Analysis case	Coal-fired capacity retired (gigawatts)	Average size of coal-fired plants retired (megawatts)	Average heat rate of coal-fired plants retired (million Btu per kilowatthour)
Reference	8.8	93.0	12,338
Transport Rule Mercury MACT 20	13.5	91.4	12,053
Transport Rule Mercury MACT 5	17.8	83.3	12,102
Retrofit Required 20	19.2	84.5	12,034
Retrofit Required 5	44.8	91.2	11,579
Low Gas Price	15.6	104.0	12,098
Low Gas Price Retrofit Required 20	39.5	97.8	11,576
Low Gas Price Retrofit Required 5	72.6	109.6	11,363
GHG Price Economywide	135.2	157.0	11,454

in an efficient combined-cycle plant, it emits approximately 60 percent less CO_2 per kilowatthour of generation than coal burned in a typical existing plant. Toward the end of the projection, new natural gas plants with CCS are also built in the GHG Price Economywide case, and in 2035 13 percent of gas-fired electricity generation is from plants with CCS.

Generation from nuclear power is the same as in the *AEO2011* Reference case in all cases, with the exception of the GHG Price Economywide and Low Gas Price Retrofit Required 20 cases. In the GHG Price Economywide case, generation from nuclear capacity increases as a result of additional capacity builds. In the Low Gas Price Retrofit Required 20 case, 2.9 gigawatts of nuclear capacity is retired because electricity prices are low. Generation from renewables remains relatively unchanged from the Reference case level through 2035 in all cases.

Fuel use

High levels of electricity generation from natural gas generally mean more natural gas consumption. In all cases examined here, natural gas use in 2035 is higher than in the Reference case (Figure 42). The largest increase in natural gas consumption occurs in the Low Gas Price Retrofit Required 20 and 5 cases, where natural gas consumption in 2035 is 23 percent and 36 percent higher, respectively, than in the Reference case, as well as in the GHG Price Economywide case, where natural gas consumption is 30 percent higher in 2035.

Capacity additions

The retirement of significant amounts of coal-fired capacity, combined with growth in electricity demand, necessitates the construction of additional generation capacity. Natural gas plants with lower generating costs make up the majority of new capacity in all cases, with the largest amount of new natural gas capacity constructed in the Low Gas Price Retrofit Required 20 and 5 cases. Most of the new coal-fired plants that are built have already been announced and are in either planning or construction stages. All new nuclear plants are built as a result of public policies (such as PTCs and the loan guarantee programs). A small amount of new coal-fired capacity is built in the last few years of the Reference case projection, because natural gas prices rise. Renewable capacity additions are similar to the Reference case in all cases.

In the GHG Price Economywide case there is significantly more new capacity construction than in any of the other cases, as coal-fired plants are retired and need to be replaced with low CO_2-emitting technologies (Figure 43). This includes 29 gigawatts of new nuclear capacity added through 2035. In the cases without a CO_2 emissions price, new nuclear power plants are built beyond those explicitly helped by the loan guarantee program. However, a price on CO_2 emissions raises the cost of electricity sufficiently for nuclear power (which releases no CO_2) to become an economically viable option without additional subsidies. Additions of renewable

Figure 40. Electricity generation by fuel in nine cases, 2009 and 2035 (trillion kilowatthours)

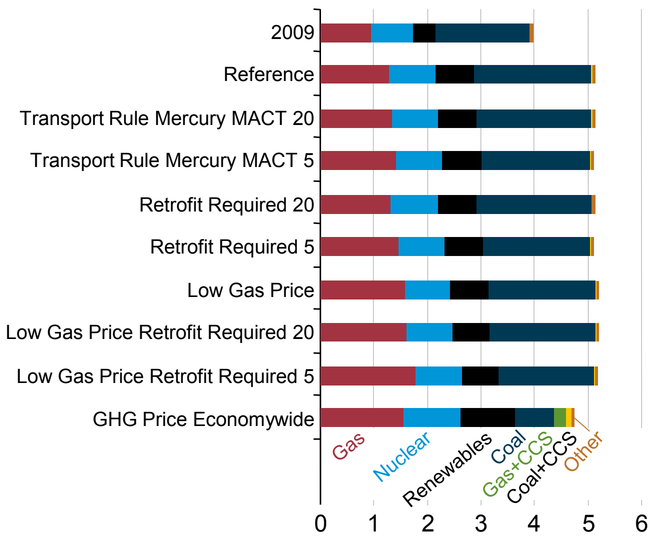


Figure 41. Electricity generation by fuel in nine cases, 2009 and 2025 (trillion kilowatthours)

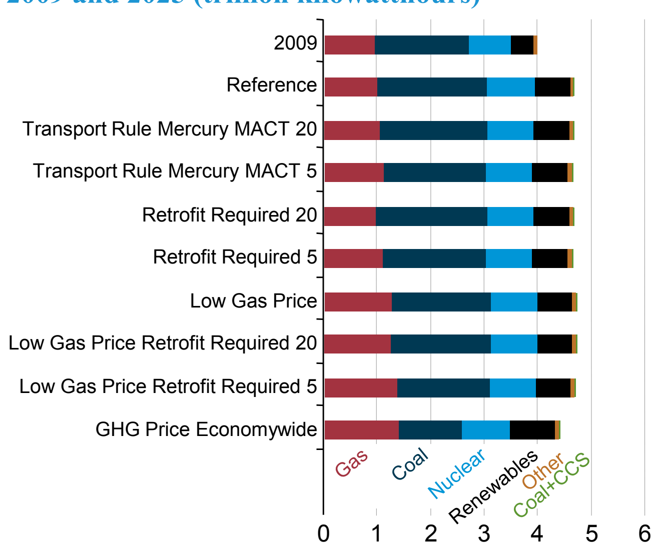
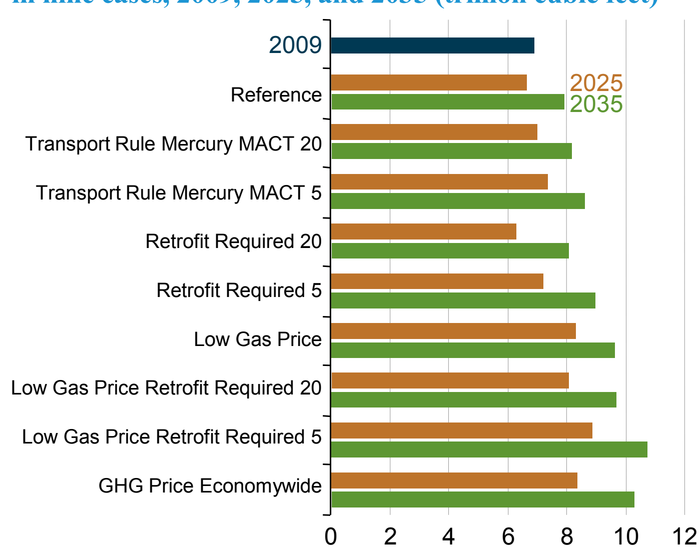


Figure 42. Natural gas consumption in the power sector in nine cases, 2009, 2025, and 2035 (trillion cubic feet)



capacity, also a low-CO_2 source of electricity, are 36 percent higher in the GHG Price Economywide case than in the Reference case in 2035.

Emissions

Emissions of SO_2 decline from Reference case levels in all cases, with more dramatic declines in the Retrofit Required 20 and 5 cases. With the Transport Rule in force, SO_2 emissions decline to levels slightly below the Reference case level. The Reference case already includes CAIR, which remains in effect until the Transport Rule takes effect. CAIR features a flexible trading system and allowance banking, resulting in slightly higher annual emissions toward the end of the projection and more variability in year-to-year emissions levels. Trading is more limited with the Transport Rule because of restrictions on the banking of allowances, which levels out emissions over the projection. NO_x emissions are slightly higher with the Transport Rule than in the Reference case, because fewer NO_x control retrofits are built as a result of the higher NO_x allowance prices under CAIR than under the Transport Rule. There are significant reductions in SO_2 and NO_x emissions in the four Retrofit Required cases, where all coal-fired plants that continue to operate through 2020 are required to be equipped with FGD and SCR. The Retrofit Required 20 and 5 cases are assumed to be implemented nationwide, whereas the Transport Rule Mercury MACT 20 and 5 cases apply only to the targeted States. Except for the Low Gas Price and GHG Price Economywide cases, all cases assume a 90-percent mercury MACT, which reduces mercury emissions significantly from Reference case levels after 2015.

CO_2 emissions from the electric power sector in 2035 are lower in all cases than in the Reference case because of the shift from coal-fired to natural-gas-fired generation, but with electricity demand increasing throughout the projection period they are higher than the 2009 level except in the GHG Price Economywide case (Figure 44). Coal-fired plants that are not retired are used heavily, and natural gas plants still emit CO_2 albeit at a significantly lower rate per kilowatthour than coal plants. In the GHG Price Economywide case, significantly more coal-fired capacity is retired than in the other cases, and more nuclear and renewable capacity, as well as coal and natural gas capacity equipped with CCS, is deployed.

Electricity prices

Electricity prices in 2035 are less than 2 percent above the Reference case level in the Transport Rule Mercury MACT 20, Retrofit Required 20, and Retrofit Required 5 cases. The increase is relatively modest because several low-cost alternatives for complying with the regulations are available. When lower natural gas prices are assumed, the real price of electricity price declines relative to the Reference case price, as lower natural gas prices are reflected in electricity prices. In the GHG Policy case, which assumes that the cost of CO_2 emissions allowances is passed through directly to customers, average electricity prices in 2035 are 38 percent higher than in the Reference case. However, the GHG Price Economywide case does not include any of the consumer rebates from the Waxman-Markey and Kerry-Lieberman bills, which have the effect of significantly lowering electric prices.

Reliability

The possible retirement of significant amounts of coal-fired generating capacity has raised concerns about reliability of the electric power grid. For example, the North American Electric Reliability Council has warned that EPA regulation of emissions from the power sector is a threat to reliability standards. Specific plants may be important to the reliability of a specific region, and if they are shut down before replacement capacity has been constructed, local reliability shortfalls could ensue. However, several safeguards exist to prevent such problems. Merchant plant owners must obtain permission from grid operators before retiring capacity [83],

Figure 43. Cumulative capacity additions in the Reference and GHG Price Economywide cases, 2010-2035 (gigawatts)

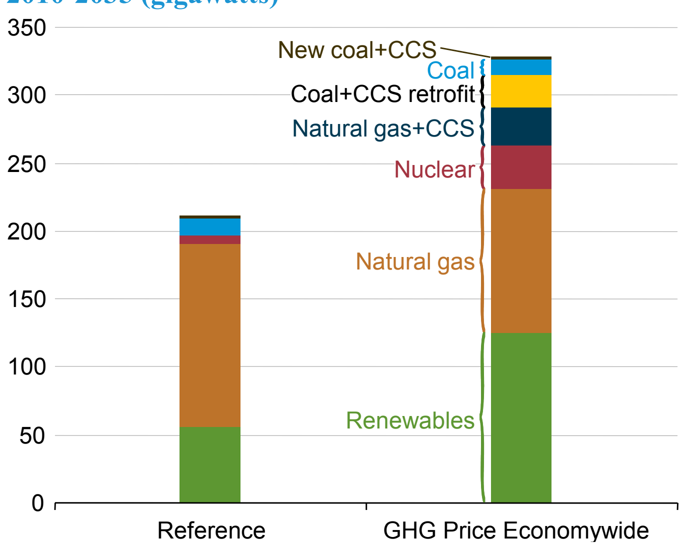
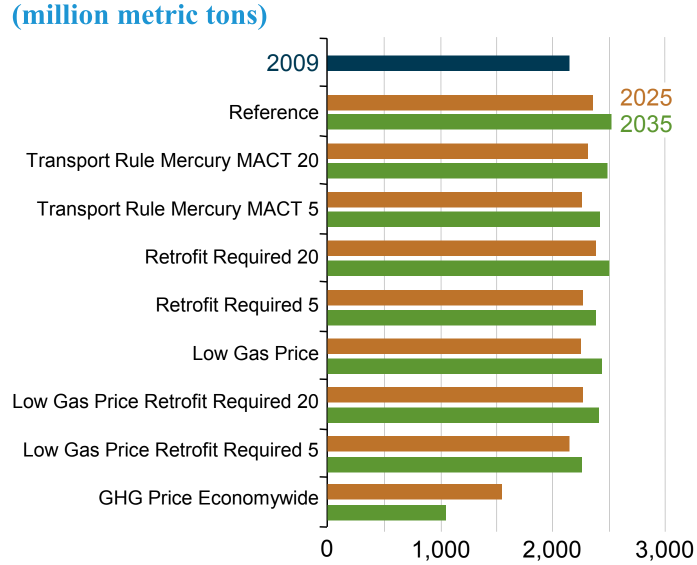


Figure 44. Carbon dioxide emissions from the electric power sector in nine cases, 2009, 2025, and 2035 (million metric tons)



and regulated utilities must demonstrate to their public utility commissions that their fleets meet the reliability standards included in their integrated resource plans.

On a national level, electric reliability shortfalls resulting from the retirement of coal plants can be mitigated both by increasing the utilization of other existing plants and by constructing new capacity. From 2000 to 2009, about 190 gigawatts of natural-gas-fired capacity was added in the U.S. electric power sector. In the *AEO2011* Reference case another 135 gigawatts of natural-gas-fired capacity is added from 2010 to 2035, and in the Low Gas Price case 154 gigawatts of new natural-gas-fired capacity is added. Most of the new capacity is built after 2020 in both cases.

Endnotes for issues in focus

Links current as of April 2011

44. U.S. Energy Information Administration, *Short-Term Energy Outlook* (January 11, 2011), "Table 2. U.S. Energy Prices," website www.eia.doe.gov/emeu/steo/pub/archives/jan11_base.xls#'2tab'!A1.

45. U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards," *Federal Register*, Vol. 75, No. 197 (October 13, 2010), pp. 62739-62750, website http://edocket.access.gpo.gov/2010/2010-25444.htm.

46. Data from Ward's Auto, website www.wardsauto.com (subscription site).

47. U.S. Environmental Protection Agency, "Heavy-Duty Regulations," website www.epa.gov/oms/climate/regulations.htm#1-2; and U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," *Federal Register*, Vol. 75, No. 229 (November 30, 2010), pp. 74451-74456, website http://edocket.access.gpo.gov/2010/2010-28120.htm. For purposes of the proposed rulemaking, heavy-duty vehicles are those with a GVWR of at least 8,501 pounds, except those Class 2b vehicles of 8,501 to 10,000 pounds that are currently covered under LDV fuel economy and GHG emissions standards.

48. Brake horsepower-hour is defined as the horsepower per hour of an engine before the loss in power caused by the gearbox, alternator, water pump, or other auxiliary components, usually determined from the force exerted on a friction brake or dynamometer connected to the drive shaft.

49. U.S. Census Bureau, "Vehicle Inventory and Use Survey," website http://www.census.gov/svsd/www/vius/products.html. Note that the survey has been discontinued.

50. Ward's Auto, "U.S. Factory Sales of Diesel Trucks by GVW, 1965-2010," website www.wardsauto.com (subscription site).

51. See U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," *Federal Register*, Vol. 75, No. 229 (November 30, 2010), pp. 74451-74456, website http://edocket.access.gpo.gov/2010/2010-28120.htm.

52. For more information on vehicle compliance measurement and engine, cab, chassis, and vehicle test procedures, see *Federal Register*, Vol. 75, No. 229 (November 30, 2010), pp. 74451-74456, website http://edocket.access.gpo.gov/2010/2010-28120.htm.

53. U.S. Environmental Protection Agency, "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2009 Summary" (2009), website www.energystar.gov/ia/partners/downloads/2009_USD_Summary.pdf.

54. In this article, the term "building code" refers to building energy codes, as opposed to construction or safety codes, such as those from the International Code Council or the International Building Code.

55. American Council for an Energy-Efficient Economy, "The 2010 State Energy Efficiency Scorecard" (October 2010), website www.aceee.org/research-report/e107.

56. Advanced Resources International, *Outer Continental Shelf Moratoria Areas: Impact of Various Assumptions on Oil and Natural Gas Production Potential* (Arlington, VA: January 2009), prepared for the U.S. Department of Energy, Office of Fossil Energy, website http://fossil.energy.gov/programs/oilgas/publications/oilgas_generalpubs/ocs_moratoria_areas_2008analysis.html.

57. J. Ratafia-Brown, R. Irby, and K. Perry, *Analysis of the Social, Economic and Environmental Effects of Maintaining Oil and Gas Exploration and Production Moratoria on and Beneath Federal Lands* (Washington, DC: February 2010), website www.naruc.org/Publications/NARUC_MORATORIA_REPORT_02-17-10.pdf.

58. U.S. Energy Information Administration, *Updated Capital Cost Estimates for Electricity Generation Plants* (Washington, DC: November 2010), website www.eia.gov/oiaf/beck_plantcosts/index.html.

59. National Energy Technology Laboratory, *Carbon Sequestration Atlas of the United States and Canada*, Third Edition (2010), website www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII.

60. International Energy Agency, *Carbon Capture and Storage: Progress and Next Steps* (Paris, France: 2010), website www.iea.org/papers/2010/ccs_g8.pdf.

61. A supercritical state is a phase of matter in which a fluid has some of the properties of both a liquid and a solid. The advantage for transporting and injecting CO_2 in a supercritical state is that the density can be fine-tuned to increase process efficiencies.

62. International Energy Agency, "IEA Energy Technology Essentials: CO_2 Capture and Storage" (Paris, France: December 2006), website www.iea.org/techno/essentials1.pdf.

63. National Energy Technology Laboratory, *DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update* (September 2010), website www.netl.doe.gov/technologies/coalpower/ewr/pubs/CO2%20Capture%20Tech%20Update%20Final.pdf, p. 14, Box 2.

64. U.S. Department of Energy, *Report of the Interagency Task Force on Carbon Capture and Storage* (Washington, DC: August 2010), website www.fe.doe.gov/programs/sequestration/ccs_task_force.html.

65. National Energy Technology Laboratory, *Methodology for Development of Geologic Storage Estimates for Carbon Dioxide* (August 2008), website www.netl.doe.gov/technologies/carbon_seq/refshelf/methodology2008.pdf.

66. J.K. Eccles, L. Pratson, R.G. Newell, and R.B. Jackson, "Physical and Economic Potential of Geological CO_2 Storage in Saline Aquifers," *Environment Science and Technology*, Vol. 43, No. 6 (February 2009), website http://pubs.acs.org/doi/abs/10.1021/es801572e.

67. National Energy Technology Laboratory, *Carbon Dioxide Enhanced Oil Recovery: Untapped Domestic Energy Supply and Long Term Carbon Storage Solution* (March 2010), website www.netl.doe.gov/technologies/oil-gas/publications/EP/CO2_EOR_Primer.pdf.

68. Advanced Resources International, Inc., *U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage: White Paper* (Arlington, VA: March 2010).

69. Four key regulations currently being considered by EPA are the Air Transport Rule, Utility Boiler Maximum Available Control Technology (MACT), the Coal Combustion and Residuals Rule, and the Cooling Water Intake Structure Rule. Each proposal is designed to enforce existing sections of the CAA, RCRA, and CWA.

70. U.S. Environmental Protection Agency, "Proposed Air Pollution Transport Rule" (Washington, DC: July 26, 2010), website www.epa.gov/airquality/transport/pdfs/TRPresentationfinal_7-26_webversion.pdf.

71. U.S. Environmental Protection Agency, "Proposed Air Pollution Transport Rule" (Washington, DC: July 26, 2010), website www.epa.gov/airquality/transport/pdfs/TRPresentationfinal_7-26_webversion.pdf.

72. U.S. Court of Appeals for the District of Columbia Circuit, "State of North Carolina v. Environmental Protection Agency," No. 05-1244 (Washington, DC: December 23, 2008), website www.epa.gov/airmarkets/progsregs/cair/docs/CAIRRemandOrder.pdf.

74. Tennessee Valley Authority, "Coal Combustion Byproducts" (Oak Ridge, TN: July 2010), website www.tva.gov/news/keytopics/coal_combustion_products.htm.

73. If a wet FGD proves prohibitively expensive for smaller coal plants, other retrofit options exist. Alternative SO_2 control technologies, such as DSI, have lower initial capital cost but higher operating costs than FGD's, making them potentially attractive for smaller to medium size coal plants. While some DSI systems are currently operating, the technology is still in early stages of commercialization. Since it is difficult to assess their long term impact on the coal fleet, they are not included in *AEO2011*.

78. U.S. Supreme Court, "Entergy Corp, v. Riverkeeper, Inc., et al," No. 07-588 (Washington, DC: April 1, 2009), website www.supremecourt.gov/opinions/08pdf/07-588.pdf.

75. U.S. Court of Appeals for the District of Columbia Circuit, "State of New Jersey v. Environmental Protection Agency," No. 05-1097 (Washington, DC: February 8, 2008), website www.cadc.uscourts.gov/internet/opinions.nsf/68822E72677ACBCD8525744000470736/$file/05-1097a.pdf.

76. U.S. Environmental Protection Agency, "Power Plant Mercury and Air Toxics Standards" (Washington, DC: March 16, 2011), website www.epa.gov/airquality/powerplanttoxics/pdfs/overviewfactsheet.pdf.

77. Edison Electric Institute, "Potential Impacts of Environmental Regulation on the U.S. Generation Fleet" (Washington, DC: January 2011), website www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2011IRP/EEIModelingReportFinal-28January2011.pdf. DSI is allowed in one of the studies side cases. The side case also assumes that the 316b Cooling Water Intake Rule and the Coal Combustion Residuals Rule are also in effect.

79. Edison Electric Institute, "Potential Impacts of Environmental Regulation on the U.S. Generation Fleet" (Washington, DC: January 2011), website www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2011IRP/EEIModelingReportFinal-28January2011.pdf. DSI is allowed in one of the studies side cases. The side case also assumes that the 316b Cooling Water Intake Rule and the Coal Combustion Residuals Rule are also in effect.

80. U.S. Energy Information Administration, "Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009" (Washington, DC: August 4, 2009), website www.eia.doe.gov/oiaf/servicerpt/hr2454/index.html.

81. U.S. Energy Information Administration, "Number and Capacity of Existing Fossil-Fuel Steam-Electric Generators with Environmental Equipment" (Washington, DC: April 2011), website www.eia.doe.gov/cneaf/electricity/epa/epat3p10.html.

82. U.S. Environmental Protection Agency, "Emission Control Technologies," website www.epa.gov/airmarkt/progsregs/epa-ipm/docs/v410/Chapter5.pdf.

83. For example, PJM Interconnection requires that Exelon keep its Eddystone Generating Plant in Pennsylvania open for an additional 2 years in order to support system reliability. See *Daily Times*, "Exelon Postpones Shutdown of Eddystone Plant" (Delaware County, PA: March 4, 2010), website www.delcotimes.com/articles/2010/03/04/business/doc4b8f2a66906bf935574426.txt?viewmode=fullstory.

Market trends

Projections by the U.S. Energy Information Administration (EIA) are not statements of what will happen but of what might happen, given the assumptions and methodologies used for any particular case. The Reference case projection is a business-as-usual estimate, given known technology, technological, market, and demographic trends. The main cases in the *Annual Energy Outlook 2011 (AEO2011)* generally assume that current laws and regulations are maintained throughout the projections. Thus, the projections provide a baseline starting point that can be used to analyze policy initiatives. EIA explores the impacts of alternative assumptions in other cases with different macroeconomic growth rates, world oil prices, rates of technology progress, and policy changes.

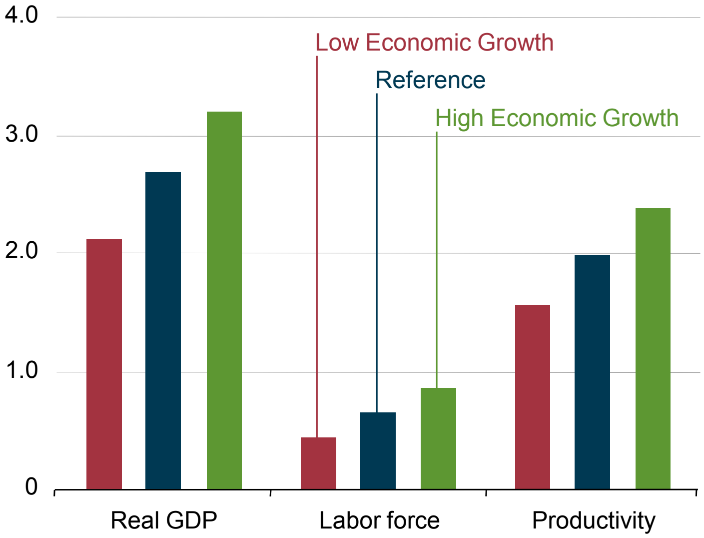
While energy markets are complex, energy models are simplified representations of energy production and consumption, regulations, and producer and consumer behavior. Projections are highly dependent on the data, methodologies, model structures, and assumptions used in their development. Behavioral characteristics are indicative of real-world tendencies rather than representations of specific outcomes.

Energy market projections are subject to much uncertainty. Many of the events that shape energy markets are random and cannot be anticipated. In addition, future developments in technologies, demographics, and resources cannot be foreseen with certainty. Many key uncertainties in the *AEO2011* projections are addressed through alternative cases.

EIA has endeavored to make these projections as objective, reliable, and useful as possible; however, they should serve as an adjunct to, not a substitute for, a complete and focused analysis of public policy initiatives.

Real growth in gross domestic product averages 2.1 to 3.2 percent across cases

Figure 45. Average annual growth rates of real GDP, labor force, and productivity in three cases, 2009-2035 (percent per year)



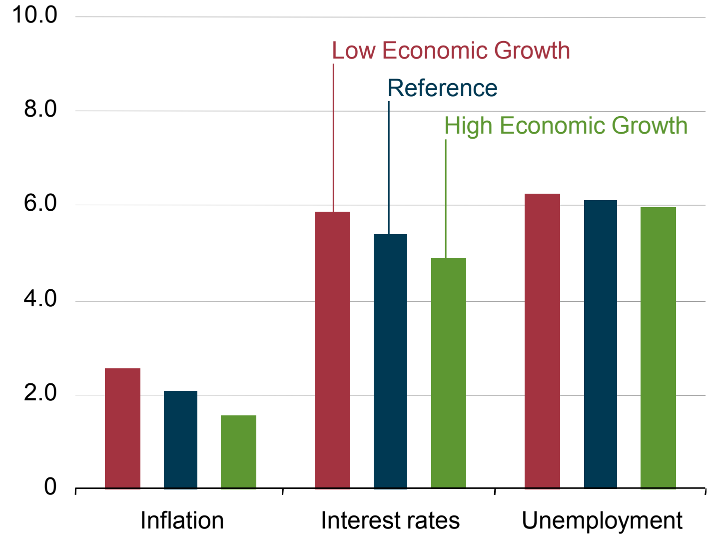
AEO2011 presents three views of economic growth (Figure 45). The rate of growth in real gross domestic product (GDP) depends on assumptions about labor force growth and productivity. In the Reference case, growth in real GDP averages 2.7 percent per year due to a 0.7 percent per year growth in the labor force and a 2.1 percent per year growth in labor productivity.

GDP growth in 2010 partially offsets the decline in 2009, helping GDP to recover to pre-recession levels by 2011. In the *AEO2011* Reference case, economic recovery accelerates in 2012, while employment recovers more slowly. With the percentage losses in employment during the 2007-2009 recession roughly double those of the 1982 recession, the unemployment rate remains elevated for an extended period, returning to its pre-recession 2003 to 2007 average of 5.2 percent by 2022.

The *AEO2011* High and Low Economic Growth cases examine the impacts of alternative assumptions on the economy. The High Economic Growth case includes more rapid expansion of the labor force, nonfarm employment, and productivity, with real GDP growth averaging 3.2 percent per year from 2009 to 2035. With higher productivity gains and employment growth, inflation and interest rates are lower in the High Economic Growth case than in the Reference case. In the Low Economic Growth case, real GDP growth averages 2.1 percent per year from 2009 to 2035, with slower growth rates for the labor force, nonfarm employment, and labor productivity. Consequently, the Low Economic Growth case shows higher inflation and interest rates and slower growth in industrial output.

Inflation, interest rates remain low, unemployment averages about 6 percent

Figure 46. Average annual inflation, interest, and unemployment rates in three cases, 2009-2035 (percent)



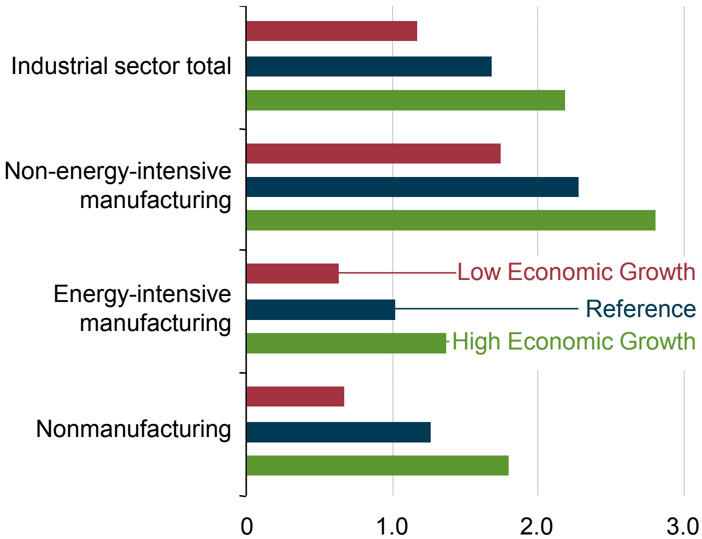
In the *AEO2011* Reference case, annual consumer price inflation averages 2.1 percent from 2009 to 2035, the annual yield on the 10-year Treasury note averages 5.4 percent (nominal), and the unemployment rate averages 6.1 percent (Figure 46). In the High Economic Growth case, population, and labor productivity grow faster than in the Reference case, leading to faster growth in capital stock, labor force, and employment. Potential output growth is faster, and as a result the annual growth rate of real GDP is 0.5 percent higher than in the Reference case. In the Low Economic Growth case, productivity, population, labor force, and capital stock grow more slowly, and real GDP growth is 0.6 percent lower than in the Reference case.

As the economy recovers, real GDP and inflation are expected to grow faster than the average over the past 26 years. By 2020, real GDP and inflation settle into the long-run 26-year average growth rates of 2.7 percent and 2.1 percent, respectively. During the last five years of the projection (2030-2035), real GDP growth slows to 2.5 percent, reflecting slowing growth in population. The Treasury note yield and unemployment rate average 5.8 percent and 5.1 percent, respectively, from 2020 to 2035, with the 10-year Treasury note higher than the 26-year average of 5.4 percent and the unemployment rate lower than the 26-year average of 6.1 percent.

Exports grow more rapidly than imports, as the dollar depreciates and countries in Asia and Latin America with higher economic growth rates develop their domestic markets and pull in more U.S. exports. Export growth supports U.S. employment, leading to lower unemployment rates and an improving trade balance over the projection period.

Output growth for energy-intensive industries slows

Figure 47. Sectoral composition of industrial output growth rates in three cases, 2009-2035 (percent per year)

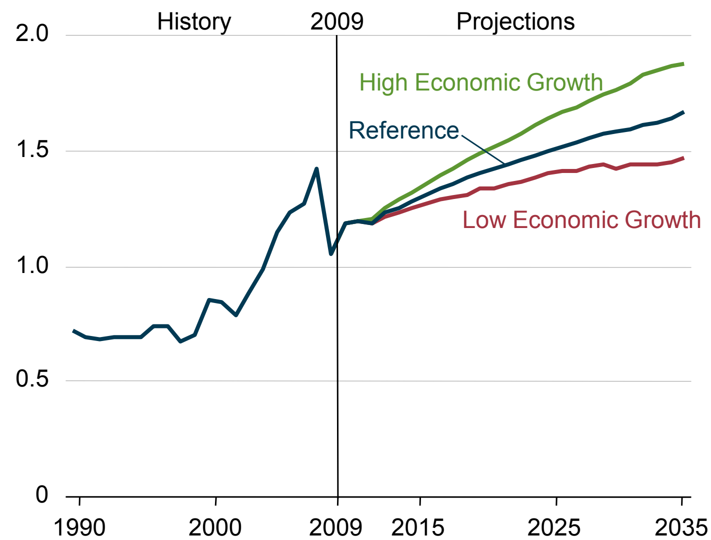


Industrial sector output has grown more slowly than the overall economy in recent decades, as imports have met a growing share of demand for industrial goods, whereas the service sector has grown more rapidly [*84*]. In the *AEO2011* Reference case, real GDP grows at an average annual rate of 2.7 percent from 2009 to 2035, while the industrial sector and its manufacturing component grow by 1.7 percent per year and 1.9 percent per year, respectively (Figure 47). As the economy recovers from the recent recession, growth in U.S. manufacturing output in the Reference case accelerates from 2011 through 2020. After 2020, growth in both GDP and manufacturing output return to rates closer to the historical trend. Increased foreign competition, slow expansion of domestic production capacity, and higher energy prices increase competitive pressure on most manufacturing industries after 2020. These factors weigh particularly heavy on the energy-intensive manufacturing sectors, which taken together grow at a slower rate of about 1.0 percent per year, which reflects projections ranging from a 0.1-percent annual decline for bulk chemicals to a 1.5-percent annual increase for food processing.

A decline in U.S. dollar exchange rates, combined with modest growth in unit labor costs, stimulates U.S. exports, eventually improving the U.S. current account balance. From 2009 to 2035, real exports of goods and services grow at an average annual rate of 6.3 percent, and real imports of goods and services grow by an average of 4.6 percent per year. Strong growth in exports is an important driver for growth projections in the transportation equipment, electronics, and machinery industries.

Energy expenditures rise, but decline relative to gross domestic product

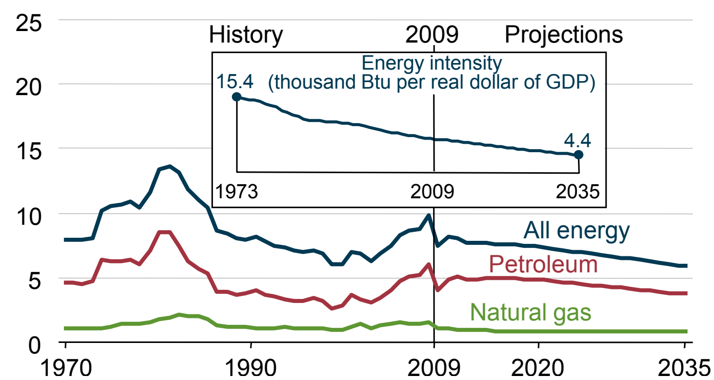
Figure 48. Energy expenditures in the U.S. economy in three cases, 1990-2035 (trillion 2009 dollars)



U.S. energy expenditures totaled $1.1 trillion (2009 dollars) in 2009, lower than the 2007 level of $1.3 trillion. As the economy recovers and energy prices rise, energy expenditures grow to $1.7 trillion in 2035 in the Reference case, $1.9 trillion in the High Growth case, and $1.5 trillion in the Low Growth case (Figure 48). The energy intensity of the economy (thousand British thermal units [Btu] of energy consumed per dollar of real GDP) was 7.4 in 2009. With structural shifts in the economy, improving energy efficiency, and higher real energy prices, U.S. energy intensity falls to 4.4 in 2035.

From 2003 to 2008, rising oil and natural gas prices increased the energy expenditure share of nominal GDP; the 9.8-percent share in 2008 was the highest since 1985. In 2009, the average cost of oil to refiners fell to $54 per barrel [*85*], natural gas prices fell by about half, and the energy expenditure share fell to 7.4 percent. The energy expenditure share declines throughout the projection (Figure 49), reflecting economic growth and declines in energy intensity.

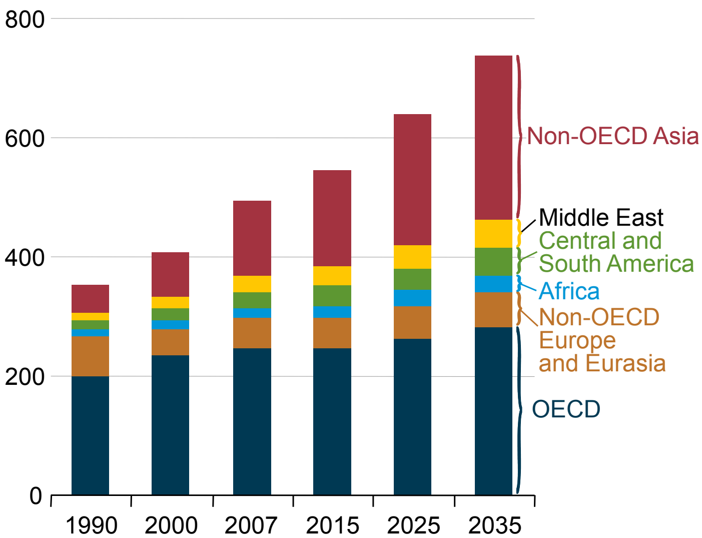
Figure 49. Energy end-use expenditures as a share of gross domestic product, 1970-2035 (nominal expenditures as percent of nominal GDP)



International energy

Non-OECD nations account for 84 percent of growth in world energy use

Figure 50. World energy consumption by region, 1990-2035 (quadrillion Btu)



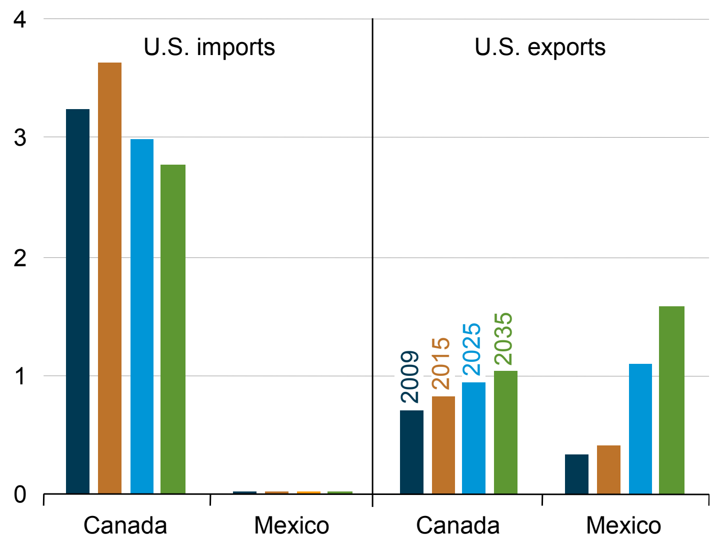
EIA's *International Energy Outlook* shows world marketed energy consumption increasing strongly over the projection period, rising by nearly 50 percent from 2009 through 2035 (Figure 50). Most of the growth occurs in emerging economies outside the Organization for Economic Cooperation and Development (OECD), especially in non-OECD Asia. Total non-OECD energy use increases by 84 percent in the Reference case, compared with a 14-percent increase in the developed OECD nations.

Energy use in non-OECD Asia, led by China and India, shows the most robust growth among the non-OECD regions, rising by 118 percent over the projection period. However, strong growth is also projected for much of the rest of the non-OECD regions: 82 percent growth in the Middle East, 63 percent in Africa, and 63 percent in Central and South America. The slowest growth among the non-OECD regions is projected for non-OECD Europe and Eurasia (including Russia), where substantial gains in energy efficiency are achieved through replacement of inefficient Soviet-era capital equipment.

Worldwide, the use of energy from all sources increases over the projection. Given expectations that oil prices will remain relatively high, petroleum and other liquids are the world's slowest-growing energy sources. High energy prices and concerns about the environmental consequences of greenhouse gas (GHG) emissions lead a number of national governments to provide incentives in support of the development of alternative energy sources, making renewables the world's fastest-growing source of energy in the outlook.

U.S. reliance on imported natural gas falls, and exports rise

Figure 51. North American natural gas trade, 2009-2035 (trillion cubic feet)

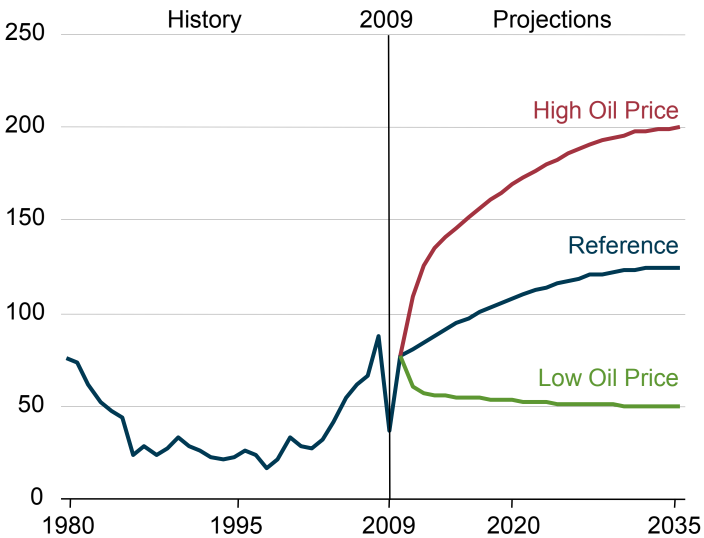


The energy markets of the three North American nations (United States, Canada, and Mexico) are well integrated, with extensive infrastructure that allows cross-border trade between the United States and both Canada and Mexico. The United States, which is by far the region's largest energy consumer, relies on Canada and Mexico for supplies of liquid fuels. Canada and Mexico were the largest suppliers of U.S. liquids imports in 2009, providing 2.5 and 1.2 million barrels per day, respectively. In addition, Canada supplies the United States with substantial natural gas supplies, exporting 3.2 trillion cubic feet to U.S. markets in 2009 (Figure 51).

In the *AEO2011* Reference case, the existing trade relationships between the United States and the two other North American countries continue. In 2035, the United States still imports 2.6 million barrels per day of liquid fuels from Canada and about 1.0 million barrels per day from Mexico. The improving prospects for domestic U.S. natural gas production, however, mean a smaller natural gas import requirement. In 2035, U.S. imports of Canadian natural gas fall to 2.8 trillion cubic feet. On the other hand, U.S. natural gas exports to both Canada and Mexico increase. Canada's imports of U.S. natural gas rise from 0.7 trillion cubic feet in 2009 to 1.0 trillion cubic feet in 2035, and Mexico's imports rise from 0.3 trillion cubic feet in 2009 to 1.6 trillion cubic feet in 2035.

Oil price cases depict uncertainty in world oil markets

Figure 52. Average annual world oil prices in three cases, 1980-2035 (2009 dollars per barrel)



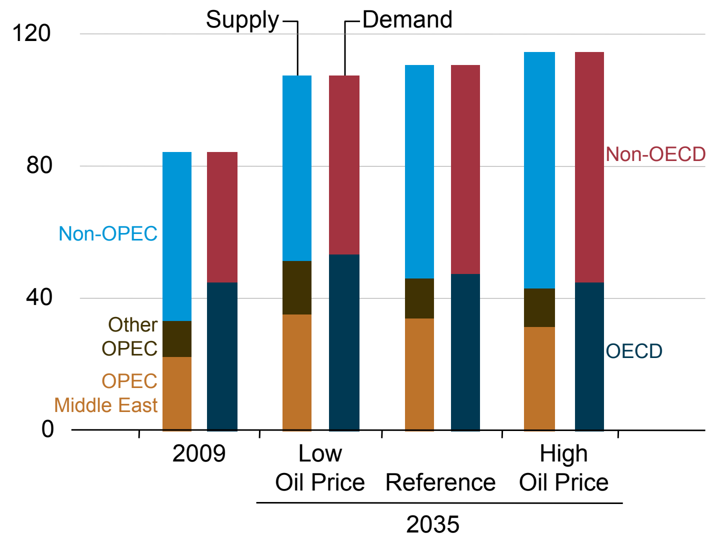
World oil prices in *AEO2011*, defined in terms of the average price of low-sulfur, light crude oil delivered to Cushing, Oklahoma, span a broad range that reflects the inherent volatility and uncertainty of world oil prices (Figure 52). The *AEO2011* price paths are not intended to reflect absolute bounds for future oil prices, but rather to allow analysis of the implications of world oil market conditions that differ from those assumed in the *AEO2011* Reference case. The Reference case assumes a continuation of current trends in terms of economic access to resources outside the Organization of the Petroleum Exporting Countries (OPEC), the OPEC market share of world production, and global economic growth.

The High Oil Price case depicts a world oil market in which total GDP growth in the non-OECD countries is faster than in the Reference case, driving up demand for liquids. On the supply side, conventional production is more restricted by political decisions and limits on economic access to resources (e.g., use of quotas, fiscal regimes, and other approaches that restrict access) compared to the Reference case. Oil production in the major producing countries is reduced (e.g., OPEC share falls to 37 percent), and the consuming countries turn to high-cost unconventional liquids production to satisfy demand.

In the Low Oil Price case, GDP growth in non-OPEC countries is slower than in the Reference case, resulting in lower demand for liquids. Regarding supply, producing countries develop stable fiscal policies and investment regimes directed at encouraging development of their resources. OPEC nations increase production, achieving approximately a 48-percent market share of total liquids production by 2035, up from approximately 40 percent in 2009.

Liquids demand in developing nations is driven by the rate of GDP growth

Figure 53. World liquids supply and demand by region in three cases, 2009 and 2035 (million barrels per day)



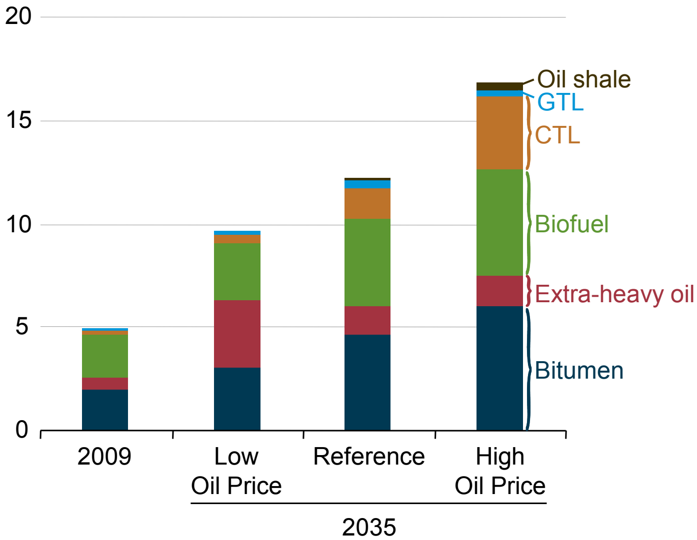
Total use of liquids is similar in the Reference, High Oil Price, and Low Oil Price cases, ranging from 108 to 115 million barrels per day in 2035, respectively. This occurs because the alternative oil price cases reflect a shifting of both supply and demand, with a resulting consumption and production level that is similar. Although total GDP growth in the OECD countries is assumed to be the same in all three cases, non-OECD GDP growth is lower in the Low Oil Price case and higher in the High Oil Price case, changing the shares of global liquids use by OECD and non-OECD countries among the three cases (Figure 53). Thus the cases reflect a future where the impact of income growth as a demand driver of oil prices overwhelms any countervailing impact of oil prices as a driver of growth.

In the Reference case, OECD liquids use grows to 47.9 million barrels per day, while non-OECD liquids use grows to 62.9 million barrels per day, in 2035. In the Low Oil Price case, OECD liquids use in 2035 is higher than in the Reference case, whereas non-OECD use is lower. In the High Oil Price case, OECD use falls to 45.1 million barrels per day in 2035. In contrast, non-OECD use, driven by higher GDP growth, increases to nearly 70 million barrels per day in 2035. Non-OECD Asia and the Middle East account for most of the difference from the Reference case, but liquids use in Central and South America in 2035 is also 1.1 million barrels per day higher than in the Reference case.

Total liquids production is nearly identical in the Reference and High Oil Price cases, with the most significant difference coming from increased unconventional production in the High Oil Price case as some advanced production technologies become economical. In the Low Oil Price case, lower demand and lower prices shutter more expensive conventional liquids projects and reduce unconventional liquids production.

Unconventional liquids gain market share as prices rise

Figure 54. Unconventional resources as a share of total world liquids production in three cases, 2009 and 2035 (percent)



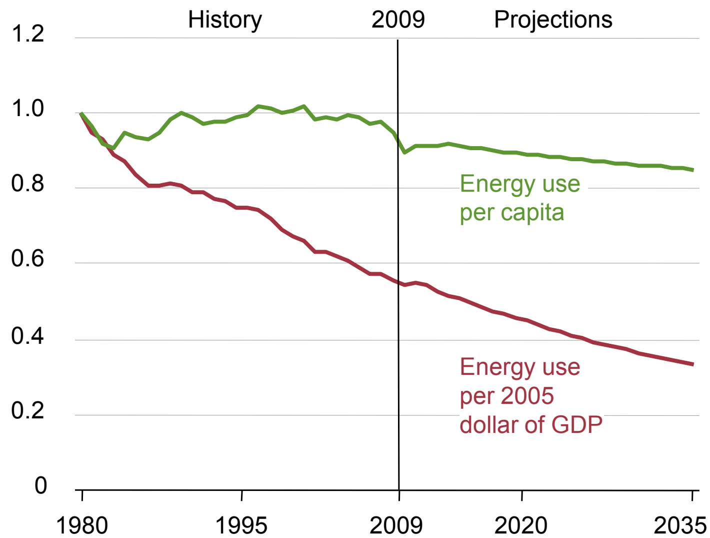
World production of liquid fuels from unconventional resources in 2009 was 4.1 million barrels per day, or about 5 percent of total liquids production. In the *AEO2011* projections, production from unconventional sources grows to about 10.4, 13.5, and 19.4 million barrels per day in 2035 in the Low Oil Price, Reference, and High Oil Price cases, respectively, accounting for about 10, 12, and 17 percent of total world liquids production (Figure 54).

The factors most likely to affect production levels vary for the different types of unconventional liquid. Price is the most important factor for bitumen production from Canadian oil sands, because the fiscal regime and extraction technologies remain relatively constant, regardless of world oil prices. Production of Venezuela's extra-heavy oil depends more on the prevailing investment environment and the assumed government-imposed levels of economic access to resources in the different price cases. In the Low Oil Price case, with more foreign investment in extra-heavy oil, production in 2035 climbs to 3.6 million barrels per day. In the Reference and High Oil Price cases, with growing investment restrictions, extra-heavy oil production is limited to 1.5 million barrels per day and 1.7 million barrels per day, respectively, in 2035.

Production levels for biofuels, coal-to-liquids (CTL), and gas-to-liquids (GTL) are driven largely by the price level and the extent of the need to compensate for restrictions on economic access to conventional liquid resources in other nations. In the Low Oil Price and High Oil Price cases, production from those three sources in 2035 totals 3.6 million barrels per day and 9.0 million barrels per day, respectively.

U.S. average energy use per person and per dollar of GDP declines through 2035

Figure 55. Energy use per capita and per dollar of gross domestic product, 1980-2035 (index, 1980 = 1)

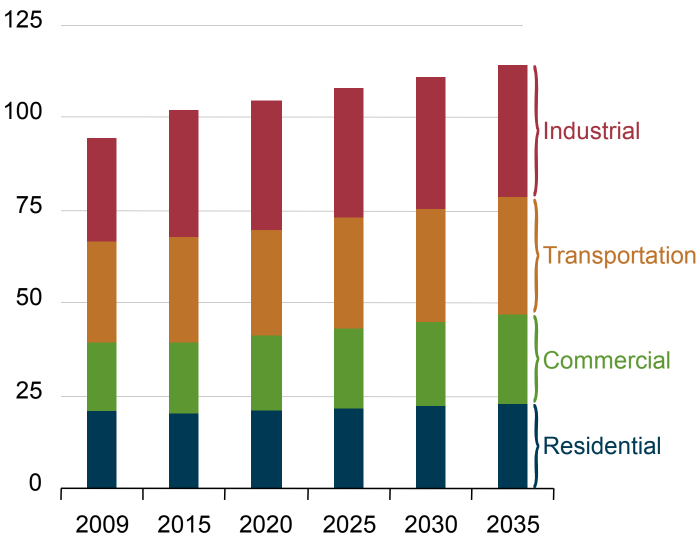


Growth in energy use is linked to population growth through increases in housing, commercial floorspace, transportation, and goods and services. These changes affect not only the level of energy use, but also the mix of fuels used. Energy consumption per capita declined from 337 million Btu in 2007 to 308 million Btu in 2009, the lowest level since 1967. In the *AEO2011* Reference case, energy use per capita increases slightly through 2013, as the economy recovers from the 2008-2009 economic downturn. After 2013, energy use per capita declines by 0.3 percent per year on average, to 293 million Btu in 2035, as higher efficiency standards for vehicles and appliances take effect (Figure 55).

Energy intensity (Btu of energy use per dollar of real GDP) falls as a result of structural changes and efficiency improvements. Since 1990, a growing share of U.S. output has come from less energy-intensive services. In 1990, 68 percent of the total value of output came from services, 8 percent from energy-intensive manufacturing industries, and the balance from non-energy-intensive manufacturing and the nonmanufacturing industries (e.g., agriculture, mining, and construction). In 2009, services accounted for 76 percent of total output and energy-intensive industries only 6 percent. Services continue to play a growing role in the *AEO2011* Reference case, accounting for 79 percent of total output in 2035, with energy-intensive manufacturing accounting for less than 5 percent. In combination with improvements in energy efficiency in all sectors, the shift away from energy-intensive industries pushes overall energy intensity down by an average of 1.9 percent per year from 2009 to 2035.

Industrial and commercial sectors lead growth in primary energy use

Figure 56. Primary energy use by end-use sector, 2009-2035 (quadrillion Btu)



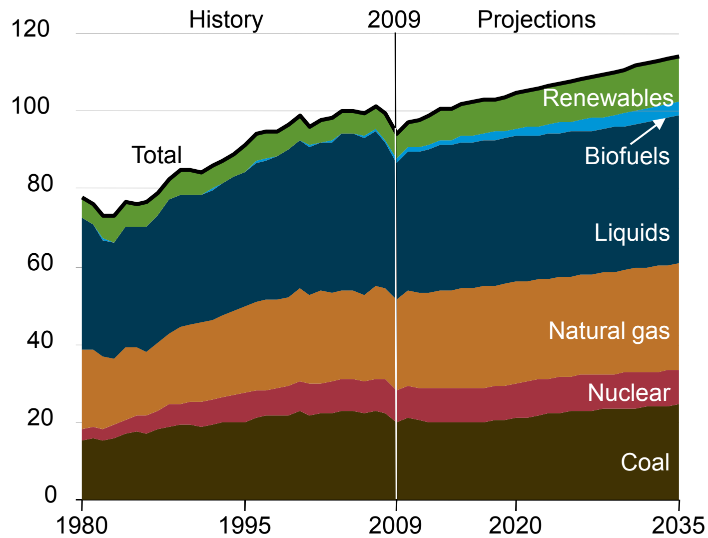
Total primary energy consumption, including fuels used for electricity generation, grows by 0.7 percent per year from 2009 to 2035, to 114.2 quadrillion Btu in 2035 in the *AEO2011* Reference case (Figure 56). The largest increase, 7.2 quadrillion Btu from 2009 to 2035, is in the industrial sector, which was the end-use sector most severely affected by the economic downturn in 2009. When 2008 is used as the base year, the total increase in industrial energy consumption is only about one-half the increase from 2009 to 2035, at 3.3 quadrillion Btu from 2008 to 2035. Factors contributing to the growth in industrial energy consumption include increased use of natural gas for combined heat and power (CHP) generation and increased production of biofuels to meet the renewable fuels standard (RFS) required by EISA2007.

The second-largest increase in total primary energy consumption from 2009 to 2035 (5.8 quadrillion Btu) is in the commercial sector, which currently accounts for the smallest sectoral share of primary energy use. Even as standards for building shells and energy efficiency are being tightened in the commercial sector, the growth rate for commercial energy use, at 1.1 percent per year, is the fastest rate among the end-use sectors, propelled by 1.2-percent average annual projected growth in commercial floorspace.

Primary energy use in the transportation sector grows by 4.7 quadrillion Btu from 2009 to 2035. Light-duty vehicles (LDVs) have accounted for more than 16 percent of total U.S. energy consumption since 2002, and their share declines slightly to 15.5 percent in 2020 as fuel economy standards increase to meet the statutory requirements of EISA2007. Growth in energy consumption by LDVs averages 0.3 percent per year from 2009 to 2035.

Renewable sources lead rise in primary energy consumption

Figure 57. Primary energy use by fuel, 1980-2035 (quadrillion Btu)



Consumption of all fuels increases in the *AEO2011* Reference case, but the aggregate fossil fuel share of total energy use falls from 83 percent in 2009 to 78 percent in 2035 as renewable fuel use grows rapidly (Figure 57). The renewable share of total energy use increases from 8 percent in 2009 to 13 percent in 2035, in response to the Energy Independence and Security Act of 2007 (EISA2007) RFS, availability of Federal tax credits for renewable electricity generation and capacity early in the projection period, and State renewable portfolio standard (RPS) programs.

Consumption of all liquid fuels increases by 0.5 percent per year from 2009 to 2035, with most of the increase accounted for by biofuels. The petroleum share of liquid fuel use declines as consumption of alternative fuels increases and petroleum use is roughly flat. Nearly all use of liquid biofuels occurs in the transportation sector. Biodiesel blended into diesel, motor fuel containing up to 85 percent ethanol (E85), and ethanol blended into motor gasoline account for 54 percent of the growth in liquids fuel consumption from 2009 to 2035.

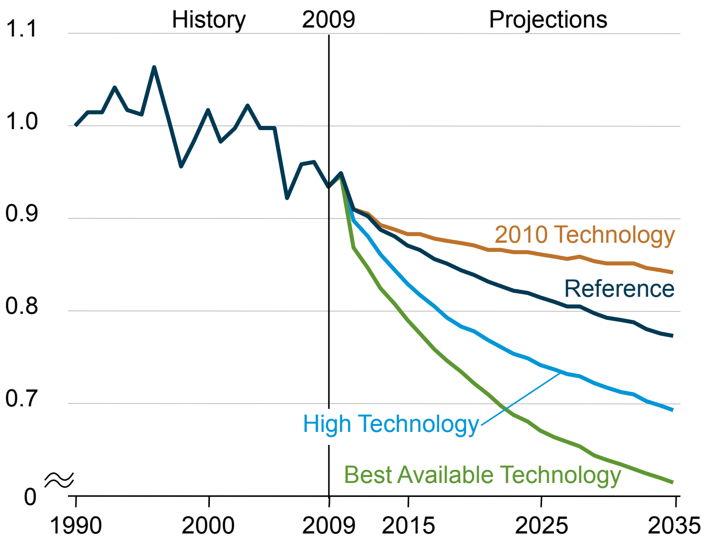
Natural gas consumption grows by about 0.6 percent per year from 2009 to 2035, as the large amount of shale gas resources that can be produced at prices under $7 per thousand cubic feet keeps natural gas prices from 2009 through 2035 below the levels seen from 2005 to 2008.

Coal consumption increases by 0.8 percent per year in the Reference case from 2009 to 2035, or by 0.2 percent per year starting from the 2007 consumption level. Several coal-fired power plants currently under construction, with combined capacity totaling 11.5 gigawatts, come on line by 2012. Nuclear power capacity expands by 9.5 gigawatts, but the nuclear share of primary energy falls from 8.8 percent in 2009 to 8.0 percent in 2035.

Residential sector energy demand

Residential energy use per capita varies with end-use technology assumptions

Figure 58. Residential delivered energy consumption per capita in four cases, 1990-2035 (index, 1990 = 1)



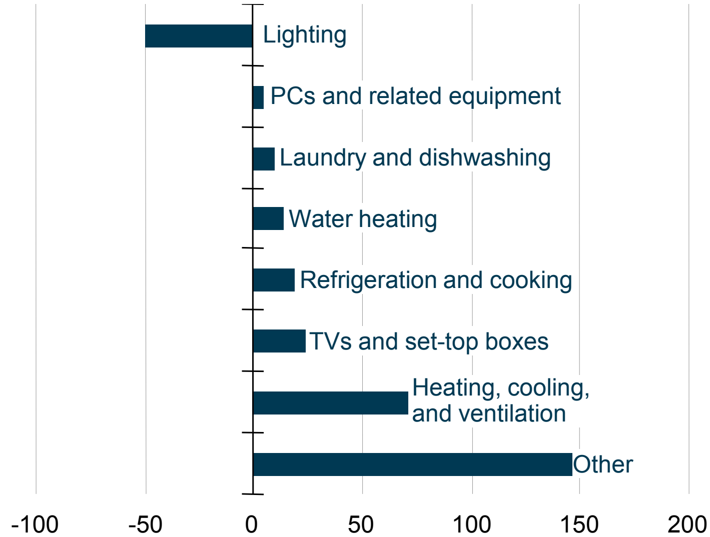
In the *AEO2011* Reference case, residential energy use per capita declines by 17.0 percent from 2009 to 2035 (Figure 58). Delivered energy use stays relatively constant while population grows by 26.7 percent during the period. Growth in the number of homes and in average square footage leads to increased demand for energy services, which is offset in part by efficiency gains in space heating, water heating, and lighting equipment. Population shifts to warmer and drier climates also reduce energy demand for space heating.

Three alternative cases show the potential role of energy-efficient technologies in reducing energy use per capita. The 2010 Technology case assumes no improvement in efficiency for equipment or building shells beyond what is available in 2010. The High Technology case assumes earlier availability, lower cost, higher efficiency, and more energy-efficient consumer purchasing decisions for some advanced equipment. The Best Available Technology case limits purchases of new and replacement appliances to the most efficient available in the year of replacement—regardless of cost—and assumes that new home construction adopts the most energy-efficient components for insulation, windows, and space conditioning equipment.

In the High Technology and Best Available Technology cases, with greater efficiency improvements, household energy use per capita declines by 25.4 percent and 34.1 percent, respectively, from 2009 to 2035. Household energy use per capita falls by 9.6 percent from 2009 to 2035 in the 2010 Technology case, even in the absence of efficiency improvements in commercially available equipment and new building shells, as older equipment is retired and replaced with 2010 vintage equipment.

Electricity use increases despite improved efficiency of electric devices

Figure 59. Change in residential electricity consumption for selected end uses in the Reference case, 2009-2035 (billion kilowatthours)



Electricity use grows 0.7 percent per year, from 42 percent of total residential delivered energy consumption in 2009 to 47 percent in 2035 in the *AEO2011* Reference case. Growing service demand is only partially offset by technological improvements that lead to increased efficiency of electric devices and appliances.

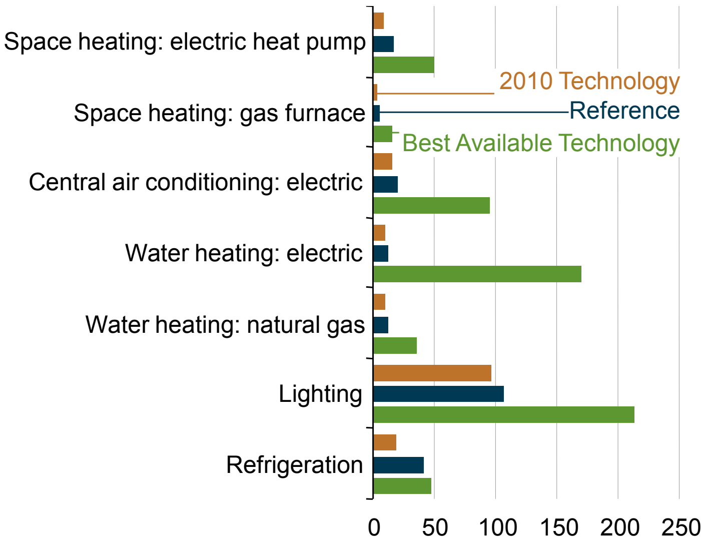
Despite increases in market penetration by ENERGY STAR qualified computers, as well as a general shift from desktop computers to laptops and other portable computing devices, energy use for personal computers (PCs) and related equipment continues to grow slowly, as the number of computers and peripherals per household increases (although at a slower rate than in the past). Contributing to the growth are related electronic devices, such as high-speed internet modems and network routers, which typically lack automatic standby modes and consume full power 24 hours a day.

Increased market penetration is also expected for ENERGY STAR televisions and computer monitors. Flat panel displays capture a growing share of the market and overall stock efficiency improves as light-emitting diodes (LEDs) displace cold cathode fluorescent lamps as a major backlighting technology for liquid crystal displays. Improvements in efficiency are offset to some degree, however, by a trend toward larger screen sizes.

The EISA2007 Federal lighting standards will lead to a decline in energy use for lighting, as low-efficacy incandescent lamps are replaced by compact fluorescent, LED, and high-efficiency incandescent lamps (Figure 59). In 2020, delivered energy use for lighting per household in the Reference case is 33 percent below the 2009 level.

AEO reflects improvement in efficiency standards

Figure 60. Efficiency gains for selected residential equipment in three cases, 2035 (percent change from 2009 installed stock efficiency)



Since their inception in the 1970s, Federal efficiency standards have expanded to cover an extensive range of residential equipment [*86*]. The Reference case captures the continuing effects of the standards, which often are the primary reason for efficiency gains.

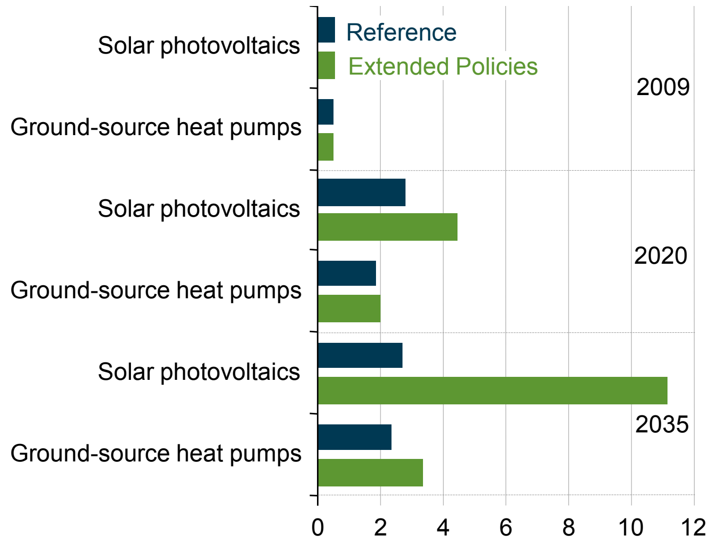
The largest gains in efficiency are expected for lighting, based on EISA2007 standards that require the phased replacement of most incandescent lamps with technologies that by 2020 are roughly three times more efficient than those widely marketed today (Figure 60). Refrigerators and water heaters also have been the subject of recent U.S. Department of Energy rulemakings. Overall, delivered energy use for products covered by the new standards declines by 0.1 percent per year, even as the number of households increase by an average of 1 percent per year.

The Best Available Technology case—which does not consider cost—demonstrates even greater gains in energy efficiency, especially for electric equipment, which has greater potential for improvement. In that case, delivered energy consumption per household declines by 1.7 percent per year from 2009 to 2035, and the total in 2035 is 1.8 quadrillion Btu lower than the 2009 level.

A variety of other products—mostly consumer electronics—are not subject to existing standards, although voluntary programs, such as ENERGY STAR, still lead to some efficiency gains in the *AEO2011* Reference case. Delivered energy use for such products grows faster than the number of households, averaging 1.5 percent per year in the Reference case.

As tax credits expire under current law, gains in residential renewable energy use slow

Figure 61. Residential market saturation by renewable technologies in two cases, 2009, 2020, and 2035 (percent share of single-family homes)



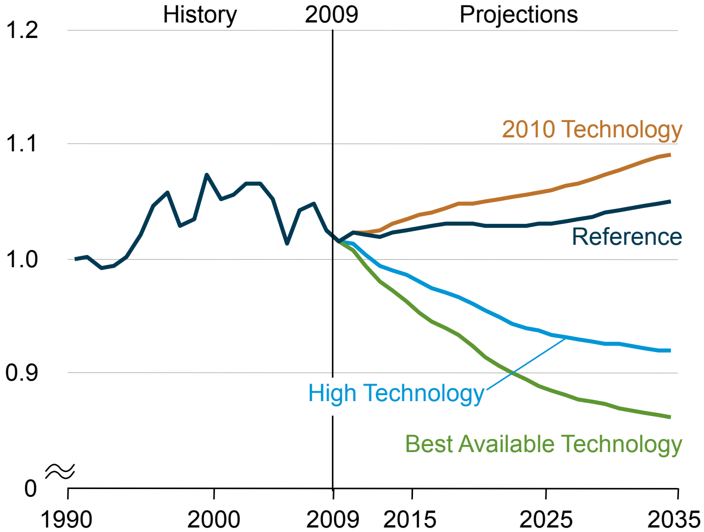
In the residential sector, growth of distributed electricity generation is limited by financial considerations and the interconnection regulations of local electric generators. As technologies improve and policies change, however, the limitations, which vary by State, are assumed to be reduced over time, allowing for faster growth in residential distributed generation (DG).

The current Federal investment tax credit (ITC) for renewable energy installations is available through 2016. When the ITC expires, average growth in solar photovoltaic (PV) capacity in the *AEO2011* Reference case slows from 39 percent per year to less than 1 percent per year. A total of 8.9 gigawatts of photovoltaic capacity is installed by 2035. Likewise, installed wind capacity grows by 48 percent per year from 2009 through 2016, but without the ITC the growth slows to nearly zero percent per year from 2017 to 2035. In the *AEO2011* Extended Policies case, which assumes extension of the ITC through 2035, PV capacity grows by 17 percent per year from 2009 to 2035, and total installed capacity reaches 47.8 gigawatts in 2035.

The number of homes heated by ground-source heat pumps (GSHPs) increases by more than 19 percent per year from 2009 to 2016 in the Reference case, then slows to 3 percent per year after the ITC expires. In 2035, GSHPs account for 2.3 percent of all heating systems installed in single-family homes (Figure 61). In the Extended Policies case, however, sustained tax credits lead to a continued 8.8-percent average annual increase in total installations, from 389,000 units in 2009 to 3,504,000 units in 2035, when GSHPs make up 3.4 percent of all residential heating systems.

End-use efficiency improvements could lower energy consumption per capita

Figure 62. Commercial delivered energy consumption per capita in four cases, 1990-2035 (index, 1990 = 1)



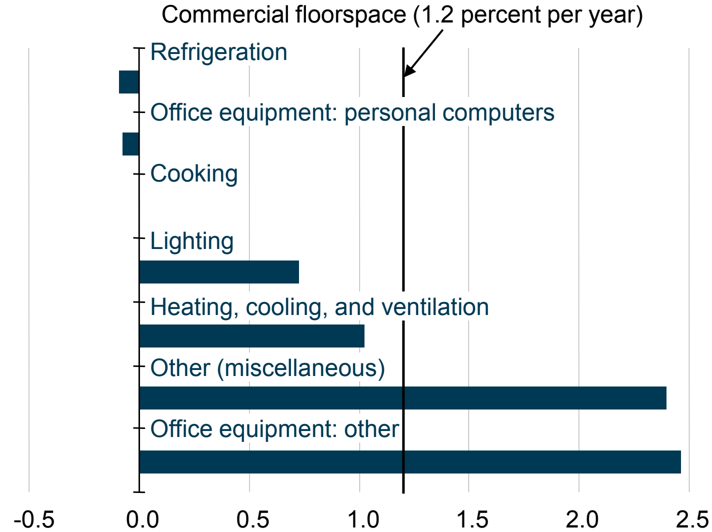
The *AEO2011* Reference case shows minimal change in commercial energy use per capita between 2009 and 2035 (Figure 62). While growth in commercial floorspace (1.2 percent per year) is faster than growth in population (0.9 percent per year), energy use per capita remains relatively steady due to efficiency improvements in equipment and building shells. Efficiency standards and the addition of more efficient technologies account for a large share of the improvement in the efficiency of end-use services, notably in space cooling, refrigeration, and lighting.

Three alternative cases use different assumptions about technology and energy efficiency to examine uncertainty in the projections of commercial energy consumption per capita. The 2010 Technology case limits equipment and building shell technologies to the options available in 2010. The High Technology case assumes lower costs, higher efficiencies for equipment and building shells, and earlier availability of some advanced equipment than in the Reference case, with commercial consumers placing greater importance on the value of future energy savings. The Best Available Technology case limits future equipment choices to the most efficient model for each technology available in the year of replacement and assumes more improvement in the efficiency of building shells for new and existing buildings than in the High Technology case.

Commercial energy consumption per capita in 2035 is 3.9 percent higher in the 2010 Technology case than in the Reference case. In contrast, it is 12.5 percent lower in the High Technology case and 17.9 percent lower in the Best Available Technology case than in the Reference case.

Growth in electricity use dominates the outlook for commercial energy demand

Figure 63. Average annual growth rates for selected electricity end uses in the commercial sector, 2009-2035 (percent per year)



Electricity use increases 1.4 percent per year, from 53 percent of total commercial delivered energy consumption in 2009 to 58 percent in 2035, in the *AEO2011* Reference case. Growth in electricity demand for new electronic equipment more than offsets improvements in equipment and building shell efficiency and growth in CHP.

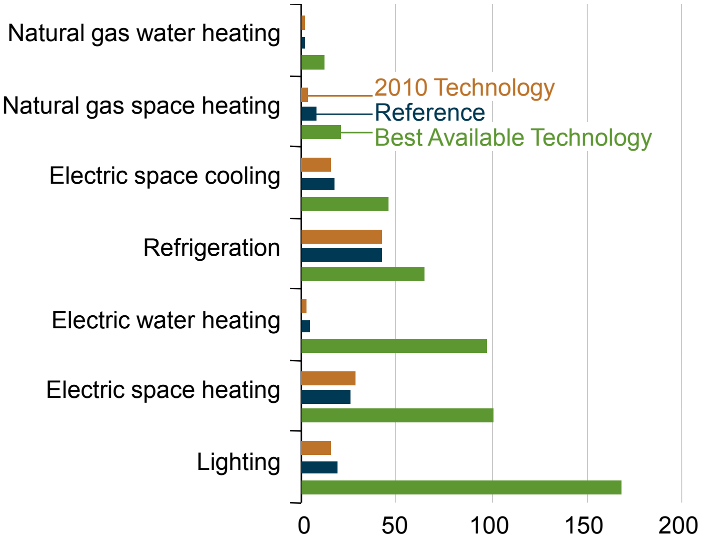
Average annual growth in commercial sector electricity use for PCs and related devices slows between 2009 and 2035, as the market penetration of ENERGY STAR qualified products increases, and laptops gain market share relative to desktop PCs, which use more energy than laptops.

Electricity use for "other" office equipment—including servers and mainframe computers—increases by 2.5 percent per year as demand for high-speed networks and internet connectivity grows, surpassing electricity demand for commercial refrigeration by 2019.

End uses such as space heating and cooling, water heating, and lighting are covered by Federal and State efficiency standards, which have the effect of limiting growth in energy consumption to less than the average of 1.2 percent per year for growth in commercial floorspace (Figure 63). "Other" electric end uses, some of which are not subject to Federal standards, account for much of the growth in commercial electricity consumption. Electricity demand for those other end uses, which include distribution transformers, vertical transport, and medical imaging equipment, increases by an average of 2.4 percent per year and accounts for 39 percent of total commercial electricity consumption in 2035.

Core technologies lead efficiency gains in the commercial sector

Figure 64. Efficiency gains for selected commercial equipment in three cases, 2035 (percent change from 2009 installed stock efficiency)



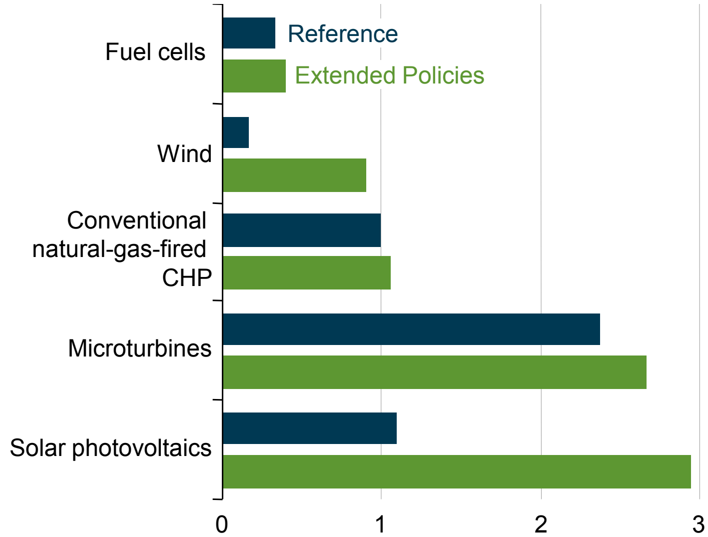
Delivered energy consumption for core space heating, ventilation, air conditioning, water heating, lighting, cooking, and refrigeration uses grows at an average annual rate of 0.6 percent in the *AEO2011* Reference case, compared with 1.2 percent annual growth in commercial floorspace. These core end uses, which frequently have been targets of energy efficiency standards, accounted for just over 60 percent of commercial delivered energy demand in 2009 and are projected to fall to 55 percent of delivered energy in 2035. Energy consumption for the remaining end uses together grows by 1.5 percent per year, led by other electric end uses and by office equipment other than computers.

The percentage gains in efficiency in the Reference case are highest for refrigeration, as a result of provisions in the Energy Policy Act of 2005 (EPACT2005) and EISA2007. Electric space heating shows the next-largest percentage improvement, followed by lighting and cooling (Figure 64).

The Best Available Technology case demonstrates the significant potential for further improvement—especially in electric equipment, led by lighting, space heating, and water heating. In the Best Available Technology case, the share of total commercial delivered energy use accounted for by the core end uses falls to 49 percent in 2035, with significant efficiency gains coming from LED lighting, GSHPs, high-efficiency rooftop heat pumps, centrifugal chillers, and solar water heaters. Those technologies are relatively costly, however, and thus are unlikely to gain wide adoption in commercial applications without improved economics or additional incentives. Additional efficiency improvements could also come from an expansion of standards to include some of the rapidly growing miscellaneous electric applications.

Improved interconnection supports growth in distributed generation

Figure 65. Additions to electricity generation capacity in the commercial sector in two cases, 2009-2035 (gigawatts)



More than 40 States have some form of interconnection standard or guideline that governs the installation of DG capacity and its incorporation into the electricity grid. Current limits on the maximum capacity that can be interconnected are expected to decrease with improvements in technology and the spread of RPS policies and goals over time.

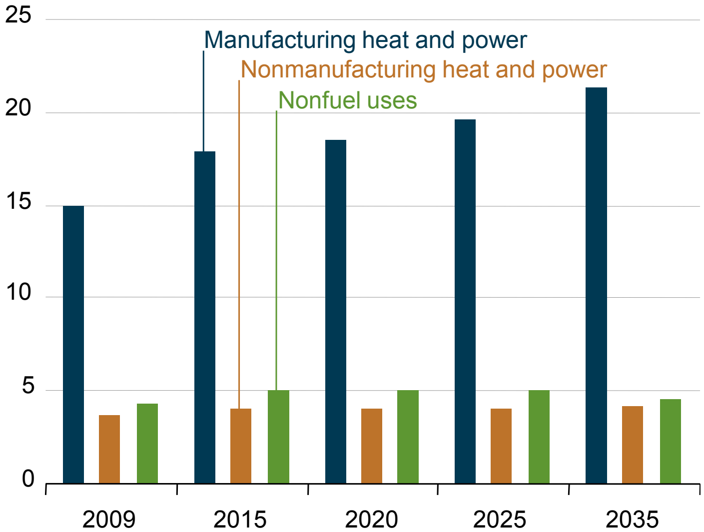
In addition to declining limits on DG interconnection, ITCs for various renewable and nonrenewable DG technologies continue through 2016. With the exception of a permanent 10-percent credit following the expiration of the current 30-percent credit for solar PVs, the *AEO2011* Reference case assumes no ITCs for DG after 2016. The Extended Policies case, on the other hand, assumes that current tax credits continue through 2035.

Total commercial DG capacity in the Reference case increases from 1.9 gigawatts in 2009 to more than 6.8 gigawatts in 2035. In the Extended Policies case, capacity increases to 9.8 gigawatts in 2035. Microturbines show the fastest capacity growth among the DG technologies in the Reference case, averaging 16 percent per year. Commercial sector wind capacity grows by 11 percent per year in the Extended Policies case, more than double the annual growth in the Reference case, as a result of continued tax credits. In 2035, renewable energy accounts for 50 percent of all commercial DG capacity in the Extended Policies case, as compared with less than 35 percent in the Reference case (Figure 65).

Industrial sector energy demand

Heat and power energy consumption increases in manufacturing industries

Figure 66. Industrial delivered energy consumption by application, 2009-2035 (quadrillion Btu)



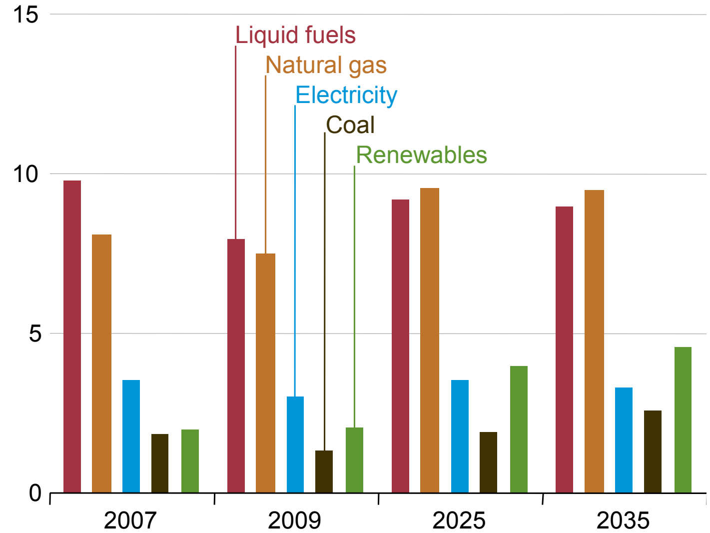
Despite a 54-percent increase in industrial shipments, industrial energy consumption increases by only 19 percent from 2009 to 2035 in the *AEO2011* Reference case. Energy consumption growth is moderated by a shift in the mix of output, as growth in energy-intensive manufacturing output (aluminum, steel, bulk chemicals, paper, and refining) slows and growth in high-value (but less energy-intensive) industries, such as computers and transportation equipment, accelerates.

There is also a relative shift in industrial energy use to manufacturing from nonmanufacturing industries. Manufacturing heat and power as a percentage of total industrial delivered energy consumption grows from 65 percent in 2009 to 71 percent in 2035 (Figure 66). Nonmanufacturing (agriculture, mining, and construction) heat and power energy consumption as a percentage of total energy drops by 2 percent over the projection. The remaining fuel consumption, consisting of nonfuel uses of energy (primarily as feedstocks in chemical manufacturing and asphalt for construction), also declines by about 4 percent.

The rise in manufacturing heat and power consumption in the *AEO2011* Reference case is due primarily to an increase of 1.7 quadrillion Btu in total energy use for production of liquid fuels—both petroleum and nonpetroleum liquids—in the refining industry. From 2009 to 2035, CTL, coal- and biomass-to-liquids (CBTL), and biofuels production accounts for the bulk of the increase, which corresponds to a 48-percent increase in energy consumption for liquid fuels production, although total refinery shipments increase by only 16 percent.

Industrial fuel mix changes as demand increases from low levels in 2009

Figure 67. Industrial energy consumption by fuel, 2007, 2009, 2025 and 2035 (quadrillion Btu)



Demand for all fuels in the industrial sector increases from 2009 levels in the Reference case. As consumption increases, the mix of fuels and their relative shares change slowly, reflecting modest capital spending and limited capability for fuel switching (Figure 67).

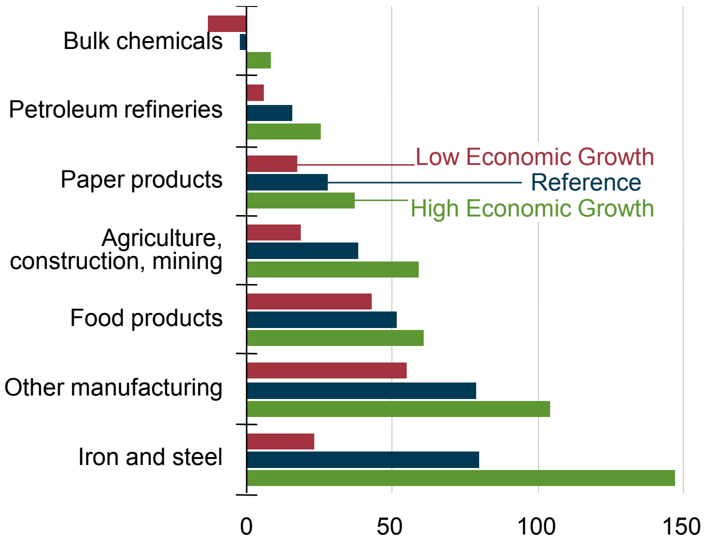
Industrial use of liquid fuels grows by 13 percent from 2009 to 2035, but its share of total liquid fuel consumption declines. Nearly one-half of industrial liquid fuel consumption is for feedstocks in the production of chemicals, and another 20 percent consists of still gas generated and consumed by refineries. Natural gas use in the industrial sector grows by 27 percent from 2009 to 2035, reflecting the recovery in industrial output and relatively low natural gas prices, which spur a large increase in natural gas consumption for CHP generation that offsets a decline in natural gas use for feedstock.

After 2025, increased use of coal for CTL and CBTL production offsets a decline in traditional industrial uses of coal (including steam generation and coke production) as a result of efficiency improvements that reduce the need for process steam. Metallurgical coal use drops, based on an expected decline in smelting and increased use of electric arc furnaces in steel-making.

A decline in the electricity share of industrial energy consumption reflects growth in on-site CHP and efficiency improvements across industries, mostly based on motor efficiency standards. The renewable fuel share expands with growth in lumber, paper, and other industries that consume biomass-based byproducts.

Iron and steel and non-energy-intensive industries show fastest output growth

Figure 68. Cumulative growth in value of shipments by industrial subsector in three cases, 2009-2035 (percent)



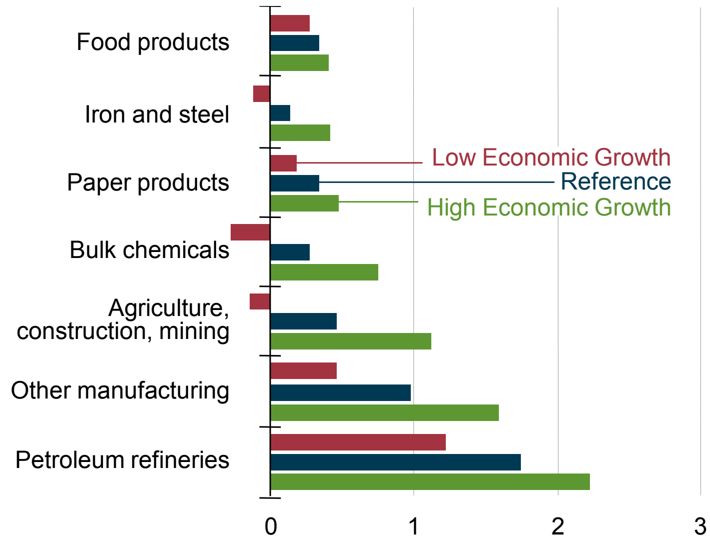
Industrial production recovers from the recent economic downturn and continues to grow over the long term in the *AEO2011* Reference case. The recovery and long-term growth are uneven, however, with the strongest growth in iron and steel and non-energy-intensive manufacturing industries. The remaining industries also recover from the recession, but their production begins to decline after 2025. Over the entire projection, total industrial shipments increase by 54 percent in the Reference case, 35 percent in the Low Economic Growth case, and 75 percent in the High Economic Growth case.

A few energy-intensive manufacturing industries account for the majority of total industrial energy consumption. Ranked by their total energy use, the top five energy-consuming industries—bulk chemicals, refining, paper, steel, and food—accounted for 61 percent of industrial energy consumption and 25 percent of total value of shipments in 2009. With the exception of bulk chemicals, most industries experience overall growth from 2009 to 2035 (Figure 68). Chemical industry output recovers to pre-recession levels by 2015 but then declines by 16 percent from 2015 to 2035.

A rebound in industrial output is being seen already in selected industries, driven by increasing demand based on relative weakness of the U.S. dollar against foreign currencies, which promotes exports of basic commodities [*87*]. Long-term growth in the energy-intensive manufacturing industries is slower, however, as a result of reduced growth in demand for the goods they produce, increased foreign competition, and movement of investment capital to more profitable areas of the economy after the short-term economic rebound from the recession.

Delivered energy use in industry sectors trends upward after recession ends

Figure 69. Change in delivered energy consumption for industrial subsectors in three cases, 2009-2035 (quadrillion Btu)



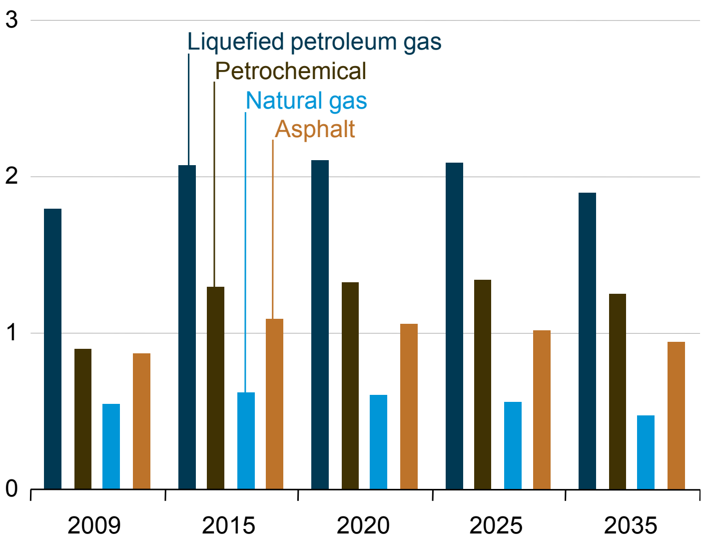
Starting from the low levels of 2009, industrial delivered energy use grows sharply in nearly all the *AEO2011* cases. From 2009 to 2035, industrial energy consumption grows by 7 percent in the Low Economic Growth case, 19 percent in the Reference case, and 31 percent in the High Economic Growth case (Figure 69).

The most significant changes in energy use are in the refining, bulk chemicals, and iron and steel industries. The refining industry (both petroleum and nonpetroleum liquids refineries) shows the strongest growth in the Reference, Low Economic Growth, and High Economic Growth cases. Although total refinery output grows by less than 1 percent per year, the industry's energy use increases modestly in all cases, with continued efforts to remove sulfur from oil inputs, energy-intensive coal liquefaction beginning in 2025, and strong growth in the production of other nonpetroleum liquids. In the Low Economic Growth case, energy use in the bulk chemical industry declines from 2009 to 2035 as its output declines in the face of rising costs for domestic inputs in a globally competitive market. Similarly, energy consumption in the iron and steel industry declines in the Low Economic Growth case as penetration of energy-saving production technologies completely offsets output growth from 2009 to 2035.

Overall energy intensity in the industrial sector declines by 21 percent in the Low Economic Growth case, 23 percent in the Reference case, and 25 percent in the High Economic Growth case. The projections are consistent with the expectation that energy intensity will decline as the economic recovery facilitates investments in more efficient equipment.

Chemical industry use of fuels as feedstocks recovers before declining

Figure 70. Industrial consumption of fuels for use as feedstocks by fuel type, 2009-2035 (quadrillion Btu)



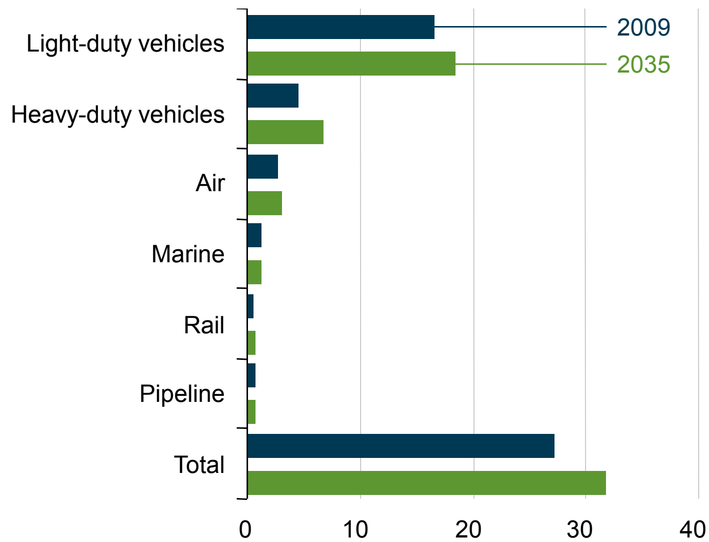
Industrial feedstock consumption includes the use of asphalt and road oil in the construction industry, as well as use of liquid petroleum gas, naphtha, petroleum gas oil, and natural gas as raw materials for the production of various chemicals. The largest share of feedstock energy consumption occurs in the chemical industry, primarily for the production of ethylene and propylene, which are used to make plastics, fertilizers, and a variety of inorganic chemicals.

Industrial energy consumption trends in the *AEO2011* Reference case reflect growth in consumption of all feedstocks after the 2008-2009 economic downturn, followed by a long-term decline as production of basic chemicals falls. Increased use of ethane and propane as alternatives to naphtha and gas oil reflects a recent switch to lighter feedstocks with the rise in crude oil prices relative to natural gas prices. With increasing production of natural gas and natural gas liquids (NGLs), lighter feedstocks become readily available on a continuing basis (Figure 70).

Consumption of all feedstocks is higher in 2035 than in 2009, except for natural gas use, which drops by 14 percent from 2009 to 2035. The use of natural gas as a feedstock falls after 2014, when domestic production of hydrogen, methanol, and ammonia begins a decline that continues through 2035. Ammonia production declines as a result of modest growth in agricultural production and increased foreign competition. Consumption of asphalt and road oil increases through 2016, then declines with slower growth in the construction industry.

Growth in transportation energy use slower than historical trend

Figure 71. Delivered energy consumption for transportation by mode, 2009 and 2035 (quadrillion Btu)



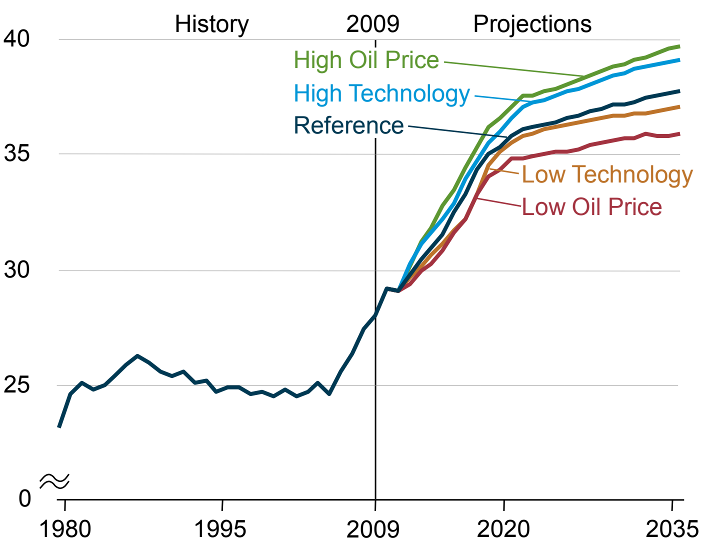
From 2009 to 2035, transportation sector energy consumption grows at an average annual rate of 0.6 percent (from 27.2 quadrillion Btu to 31.8 quadrillion Btu), slower than the 1.2 percent average rate from 1975 to 2009. The slower growth is a result of changing demographics, increased LDV fuel economy, and saturation of personal travel demand.

Energy demand for LDVs increases by 10 percent, or 1.7 quadrillion Btu (1.3 million barrels per day), from 2009 to 2035 (Figure 71). Moderate growth in fuel prices compared with recent history and rising real disposable income combine to increase annual vehicle miles traveled (VMT), although personal travel demand increases at a slower rate than historically. Growth in delivered energy consumption by LDVs is tempered by more stringent standards for vehicle GHG emissions through model year (MY) 2016 and fuel economy through MY 2020. Energy demand for heavy-duty vehicles (including primarily freight trucks but also buses) increases by 48 percent, or 2.2 quadrillion Btu (1.0 million barrels per day), as a result of increased freight travel demand as industrial output grows and the fuel economy of heavy-duty vehicles shows only marginal improvement.

Energy demand for air travel increases by 16 percent, or 0.4 quadrillion Btu (0.2 million barrels per day). Growth in air travel is driven by increases in income and moderate growth in fuel costs, tempered by gains in aircraft fuel efficiency, while growth in air freight movement (caused by export growth) also increases fuel use by aircraft. Energy consumption for marine and rail travel increases as industrial output rises and demand for coal transport grows. Energy use for pipelines stays flat as increasing volumes of natural gas are produced closer to end-use markets.

CAFE and greenhouse gas emissions standards boost vehicle fuel economy

Figure 72. Average fuel economy of new light-duty vehicles in five cases, 1980-2035 (miles per gallon)



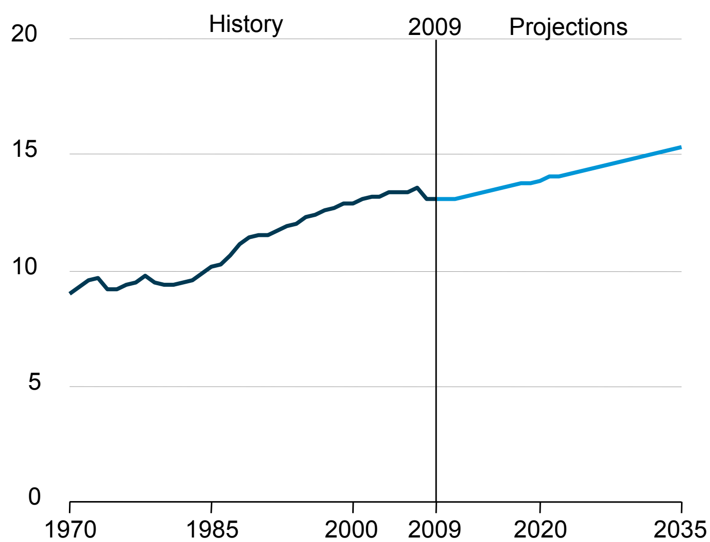
After the introduction of corporate average fuel economy (CAFE) standards in 1978, the fuel economy for all LDVs increased from 19.9 miles per gallon (mpg) in 1978 to 26.2 in 1987. Despite continued technological improvement, fuel economy fell to between 24 and 26 mpg over the next two decades, with sales of light trucks increasing from about 20 percent of new LDV sales in 1980 to 55 percent in 2004 [*88*]. From 2004 to 2008, fuel prices increased, sales of light trucks slowed, and tighter fuel economy standards for light-duty trucks were introduced. As a result, average fuel economy for LDVs rose to 28.0 mpg in 2008.

The National Highway Traffic Safety Administration (NHTSA) introduced new attribute-based CAFE standards for MY 2011 LDVs in 2009, and in 2010 NHTSA and the U.S. Environmental Protection Agency (EPA) jointly announced CAFE and GHG emissions standards for MY 2012 to MY 2016. EISA2007 also requires that LDVs reach an average fuel economy of 35 mpg by MY 2020 [*89*]. In the Reference case, the average fuel economy of new LDVs (including credits for alternative-fuel vehicles and banked credits) rises to 29.8 mpg in 2011, 33.3 mpg in 2016, and 35.8 mpg in 2020 (Figure 72). After 2020, CAFE standards for LDVs remain constant in the Reference case, and LDV fuel economy increases only moderately, to 37.8 mpg in 2035.

In the Reference case, cars represent 65 percent of LDV sales in 2035, compared with 69 percent in the High Oil Price case and 55 percent in the Low Oil Price case. The economics of fuel-saving technologies improve in the High Technology and High Oil Price cases, but the effects on average fuel economy relative to the Reference case are tempered by the fact that CAFE standards already require significant improvement in fuel economy performance and the penetration of advanced technologies.

Travel demand for personal vehicles increases more slowly than in the past

Figure 73. Vehicle miles traveled per licensed driver, 1970-2035 (thousand miles)



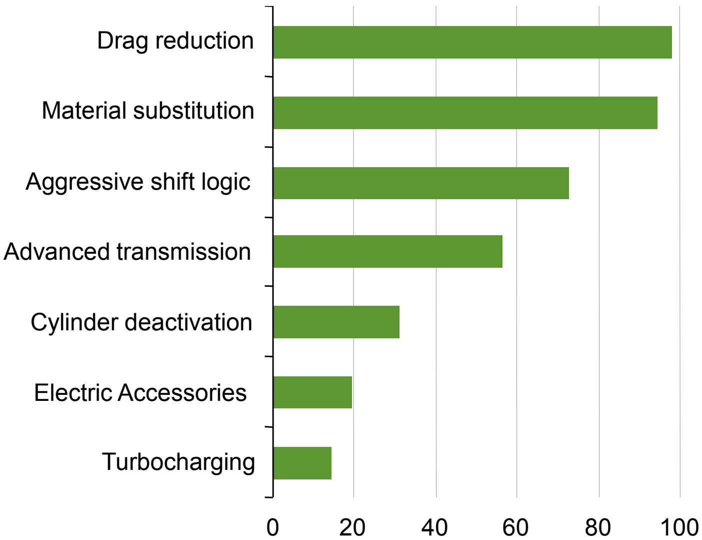
Personal vehicle travel demand, measured as VMT per licensed driver, grew at an average annual rate of 1.1 percent between 1970 to 2007, driven by rising income, a decline in the cost of driving per mile (determined by both fuel economy and fuel price), and demographic changes (such as women fully entering the workforce). Since 2007, VMT per licensed driver has declined slightly because of the sudden spike in the cost of driving per mile followed by the economic downturn. However, VMT per licensed driver begins to grow again in the Reference case, but at a more moderate average annual rate of 0.6 percent, reaching over 15,280 miles in 2035 (Figure 73).

The projected growth in VMT per licensed driver results from a return to rising real disposable personal income, which increases by 90 percent between 2009 and 2035. While motor gasoline prices rise by 60 percent over the period, faster income growth ensures that the impact on travel demand is blunted by a reduction in the percentage of income spent on fuel. In addition, the effect of rising fuel costs is moderated by a 30-percent improvement in new vehicle fuel economy following the implementation of more stringent GHG and CAFE standards for LDVs.

Several demographic forces also play a role in moderating the growth in VMT per licensed driver despite the rise in real disposable income. Although LDV sales increase through 2035, the number of vehicles per licensed driver remains relatively constant (at just over 1). In addition, unemployment remains above pre-recession levels in the Reference case until late in the projection period, further tempering the increase in personal travel demand.

New technologies promise better vehicle fuel efficiency

Figure 74. Market penetration of new technologies for light-duty vehicles, 2035 (percent)



The market adoption of advanced technologies in conventional vehicles facilitates the improvement in fuel economy that is necessary to meet more stringent CAFE standards through MY 2020 and reduce fuel costs thereafter. In the *AEO2011* Reference case, the CAFE compliance of new LDVs rises from 29.1 mpg in 2009 to 35.8 mpg in 2020 and 37.8 mpg in 2035, due in part to greater penetration of unconventionally fueled vehicles and in part to the addition of individual technologies in conventional vehicles (Figure 74).

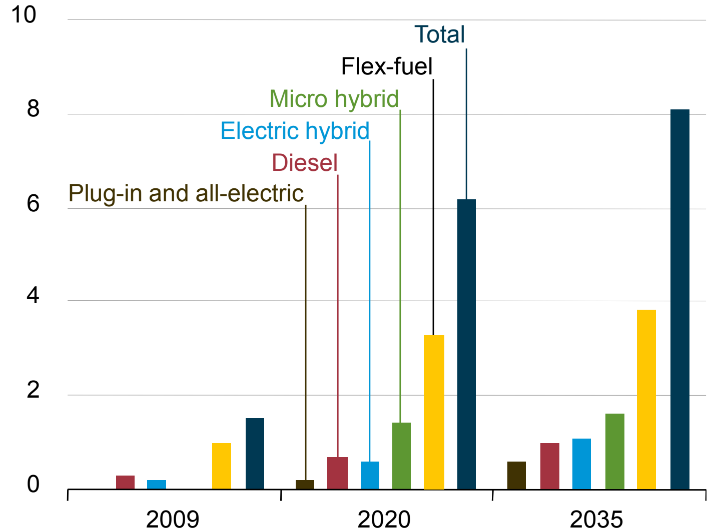
In 2035, advanced drag reduction, which provides fuel economy improvements by reducing vehicle air resistance at higher speeds, is implemented in 98 percent of new LDVs. In addition, with the adoption of light-weight materials through material substitution, the average weights of new cars and light trucks decline by 4.9 percent and 1.5 percent, respectively, from 2009 to 2035, providing additional improvements in fuel economy.

Advanced transmission technologies also improve fuel economy by improving the efficiency of vehicle drive trains. Aggressive shift logic is used in 73 percent of new LDVs in 2035; and other advanced technologies, such as continuously variable, automated manual, and six-speed transmissions, are installed in 56 percent of new conventional vehicles.

Engine technologies that reduce fuel consumption also penetrate the market for new vehicles. Cylinder deactivation and turbocharging reach penetrations of 31 and 14 percent, respectively, in 2035. Electrification of accessories such as pumps and power steering, which also increases fuel economy, is implemented in 19 percent of new LDVs in 2035.

Unconventional vehicle technologies exceed 40 percent of new sales in 2035

Figure 75. Sales of unconventional light-duty vehicles by fuel type, 2009, 2020, and 2035 (million vehicles sold)



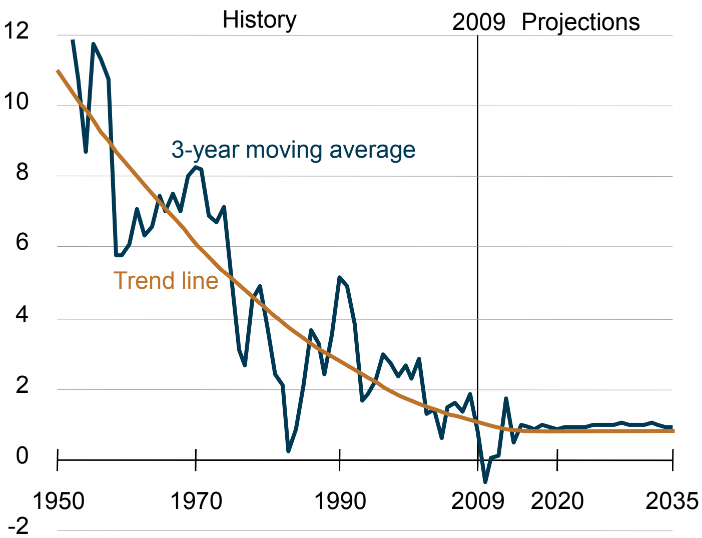
Unconventional vehicles (those that use diesel, alternative fuels, and/or hybrid electric systems) play a significant role in meeting more stringent fuel economy standards and offering fuel savings in the face of relatively higher fuel prices, growing from 15 percent of new vehicle sales in 2009 to 42 percent by 2035 in the *AEO2011* Reference case.

Flex-fuel vehicles (FFVs), which can use blends of ethanol up to 85 percent, represent the largest share of unconventional LDV sales in 2035, at 19 percent of total new vehicle sales and 47 percent of unconventional vehicle sales (Figure 75). Manufacturers selling FFVs currently receive incentives in the form of fuel economy credits earned for CAFE compliance through MY 2016. FFVs also play a critical role in meeting the RFS for biofuels.

Sales of electric and hybrid vehicles that use stored electric energy grow considerably in the Reference case. Micro hybrids, which use start/stop technology to manage engine operation while at idle, account for 8 percent of all conventional gasoline vehicle sales by 2035, the largest share for vehicles that use electric storage. Gasoline-electric and diesel-electric hybrid vehicles account for 5 percent of total LDV sales and 13 percent of unconventional vehicle sales in 2035, and plug-in and all-electric hybrid vehicles account for 3 percent of LDV sales and 8 percent of unconventional vehicle sales. Sales of diesel vehicles also increase, to 5 percent of total LDV sales and 13 percent of unconventional vehicle sales in 2035. Light duty natural gas vehicles account for less than 0.1 percent of new vehicle sales throughout the projection due to their high incremental cost and limited fuel infrastructure.

Residential and commercial sectors dominate electricity demand growth

Figure 76. U.S. electricity demand growth, 1950-2035 (percent, 3-year moving average)



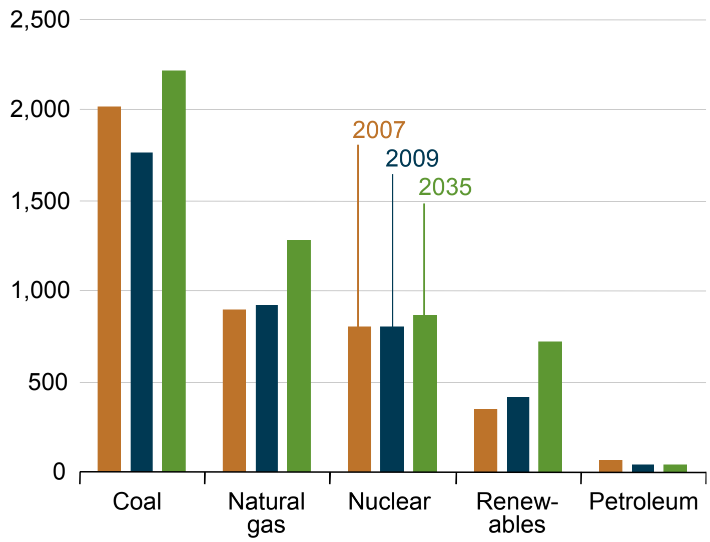
Electricity demand growth has slowed in each decade since the 1950s. After 9.8-percent annual growth in the 1950s, demand (including retail sales and direct use) increased 2.4 percent per year in the 1990s. From 2000 to 2009 (including the 2008-2009 economic downturn) demand grew by 0.5 percent per year. In the Reference case, electricity demand growth rebounds but remains relatively slow, as growing demand for electricity services is offset by efficiency gains from new appliance standards and investments in energy-efficient equipment.

Electricity demand grows by 31 percent in the Reference case (an average of 1.0 percent per year), from 3,745 billion kilowatthours in 2009 to 4,908 billion in 2035 (Figure 76). Residential demand grows by 18 percent over the period, spurred by population growth, rising disposable income, and continued population shifts to warmer regions with greater cooling requirements. Commercial sector electricity demand increases 43 percent, led by the service industries. Industrial electricity demand grows only 9 percent, slowed by increased competition from overseas manufacturers and a shift of U.S. manufacturing toward consumer goods that require less energy to produce.

In the Reference case, average annual electricity prices (2009 dollars) fall 6 percent from 2009 to 2035. Through 2021 prices fall in response to lower coal and natural gas prices, and the phaseout of competitive transition and system upgrade charges included in transmission and distribution costs. After 2021, rising fuel costs more than offset the lower transmission and distribution costs. Economic growth leads to more demand for electricity and the fuels used for generation, raising the prices of both. In the High and Low Economic Growth cases, electricity prices fall by 2 percent and 11 percent, respectively, over the projection period.

Coal-fired plants continue to lead electricity output

Figure 77. Electricity generation by fuel, 2007, 2009, and 2035 (billion kilowatthours)



Assuming no additional constraints on carbon emissions, coal remains the dominant source of electricity generation in the *AEO2011* Reference case (Figure 77). Generation from coal increases by 25 percent from 2009 to 2035, but only 10 percent from pre-recession 2007 levels, largely as a result of increased use of existing capacity. Its share of the total generation mix, however, falls from 45 percent to 43 percent as a result of more rapid increases in generation from natural gas and renewables. Growth in gas-fired generation is supported by low natural gas prices and stable capital costs for new plants. Low natural gas prices make the dispatch of existing plants and construction of new natural-gas-fired plants more competitive.

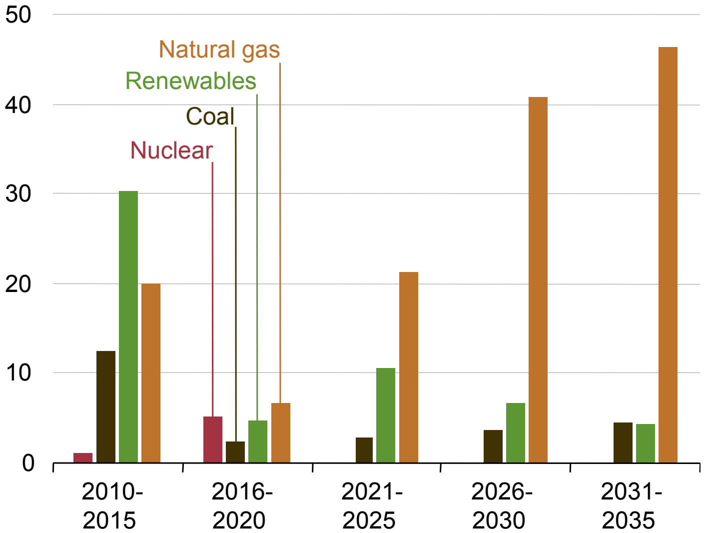
Generation from U.S. nuclear power plants increases by 9 percent from 2009 to 2035, but its share of total generation falls from 20 percent in 2009 to 17 percent in 2035. The Reference case assumes that existing nuclear power plants will continue operating through 2035 (except for retirements already announced); that some plants will be upgraded to higher rated capacities; and that a small number of new nuclear power plants will be built as a result of various incentive programs.

Electricity generation from renewable sources grows by 72 percent in the Reference case, raising its share of total generation from 11 percent in 2009 to 14 percent in 2035. Most of the growth in renewable electricity generation in the power sector consists of generation from wind and biomass facilities. The growth in wind generation is primarily driven by State RPS and Federal tax credits. Generation from biomass comes from both dedicated biomass plants and co-firing in coal plants. Its growth is driven by State RPS, the availability of low-cost feedstocks, and the RFS, which results in significant production of electricity at plants producing biofuels.

Electricity generation

Most new capacity additions use natural gas and renewables

Figure 78. Electricity generation capacity additions by fuel type, 2010-2035 (gigawatts)



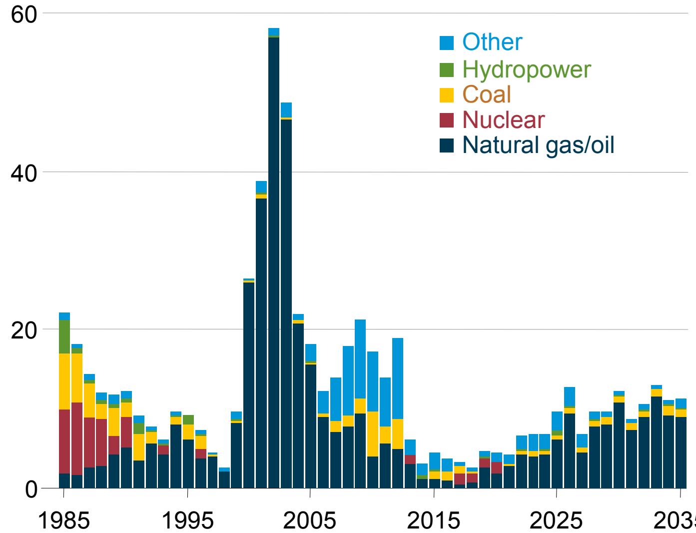
Decisions to add capacity and the choice of fuel depend on a number of factors [*90*]. With growing electricity demand and the retirement of 39 gigawatts of existing capacity, 223 gigawatts of new generating capacity (including end-use combined heat and power) will be needed between 2010 and 2035 (Figure 78).

Natural-gas-fired plants account for 60 percent of capacity additions between 2010 and 2035 in the *AEO2011* Reference case, compared with 25 percent for renewables, 11 percent for coal-fired plants, and 3 percent for nuclear. Escalating construction costs have the largest impact on capital-intensive technologies, including nuclear, coal, and renewables. However, Federal tax incentives, State energy programs, and rising prices for fossil fuels increase the competitiveness of renewable and nuclear capacity. In contrast, uncertainty about future limits on GHG emissions and other possible environmental regulations reduces the competitiveness of coal-fired plants (reflected in the *AEO2011* Reference case by adding 3 percentage points to the cost of capital for new coal-fired capacity).

Capacity additions also are affected by demand growth and by fuel prices, which are uncertain. Total capacity additions from 2010 to 2035 range from 172 gigawatts in the Low Economic Growth case to 290 gigawatts in the High Economic Growth case. With higher natural gas prices, such as in the *AEO2011* Low Shale Estimated Ultimate Recovery (EUR) case, fewer natural-gas-fired plants are added than in the Reference case. In the High Shale EUR case, where delivered natural gas prices are 21 percent lower than in the Reference case by 2035, total gas-fired capacity additions increase to 154 gigawatts between 2009 and 2035 compared to 135 gigawatts in the Reference case. Total capacity additions range from 212 gigawatts in the Low Shale EUR case to 230 gigawatts in the High Shale EUR case.

Annual capacity additions slow significantly after 2012

Figure 79. Additions to electricity generation capacity, 1985-2035 (gigawatts)



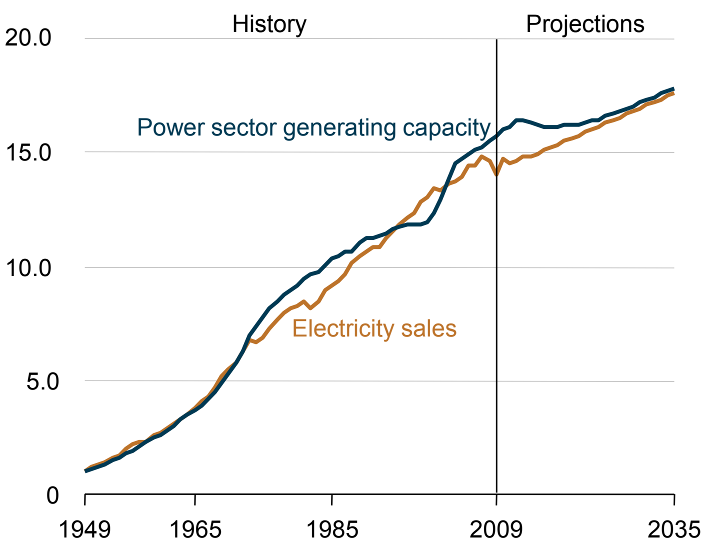
Typically, investments in electricity generation capacity have gone through "boom and bust" cycles, with periods of slower growth followed by strong growth, in response to changing expectations for future electricity demand and fuel prices, as well as changes in the industry, such as restructuring (Figure 79). A construction boom in the early 2000s saw capacity additions averaging 35 gigawatts a year, much higher than had been seen before. More recently, average annual builds have dropped to around 16 gigawatts per year.

In the *AEO2011* Reference case, capacity additions from 2010 to 2035 total 223 gigawatts, including new plants built not only in the power sector but also by end-use generators. Annual additions in 2010, 2011, and 2012 average 17 gigawatts per year, with at least 40 percent of that capacity already under construction. Of those early builds, about 46 percent are renewable capacity built to take advantage of Federal tax incentives and to meet State renewable standards.

Annual builds drop significantly after 2012 and remain below 7 gigawatts per year until 2025. During that period, existing reserves are adequate to meet growth in demand in most regions, given the earlier construction boom and relatively low demand growth following the economic recession. Between 2025 and 2035, average annual builds increase to 11 gigawatts per year, as excess reserves are depleted and total capacity growth is more consistent with demand growth. About 80 percent of the capacity added in the period is natural-gas-fired, due to higher construction costs for other capacity types and uncertain prospects for possible future limitations on GHG emissions.

Growth in generating capacity tracks rising demand for electricity

Figure 80. Electricity sales and power sector generating capacity, 1949-2035 (index, 1949 = 1.0)



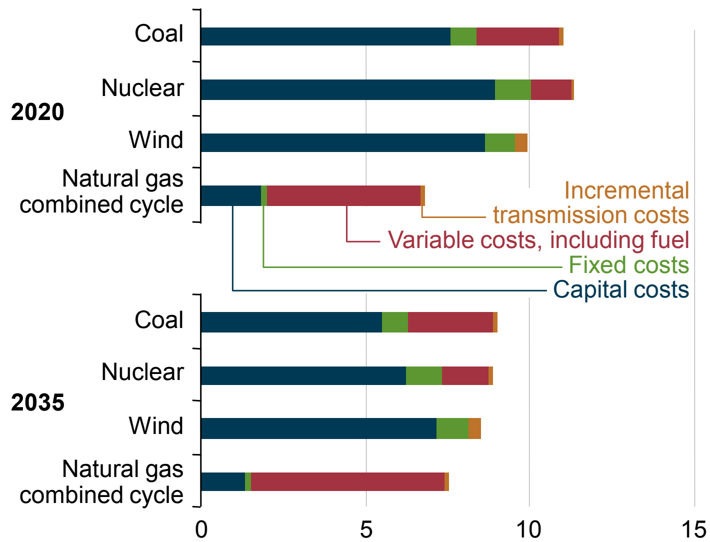
Over the long term, growth in electricity generating capacity and growth in end-use demand for electricity track one another. However, unexpected shifts in demand or dramatic changes affecting capacity investment decisions can cause imbalances for a period of time. Because long-term planning is required for large-scale investments in new capacity, such periods of imbalance can take years to work out.

Figure 80 shows indexes summarizing relative changes in total generating capacity and demand. During the 1950s and 1960s, the capacity and demand indexes tracked very closely. The energy crises of the 1970s and 1980s, together with other factors, slowed electricity demand growth, and capacity growth outpaced demand for more than 10 years afterward, as planned units continued to come on line. Demand and capacity did not align again until the mid-1990s. Then, in the late 1990s, uncertainty about deregulation of the electricity industry caused a downturn in capacity expansion, and another period of imbalance followed, with growth in demand exceeding capacity growth.

In 2000, a boom in construction of new natural-gas-fired plants began, quickly bringing capacity back into balance with demand and, in fact, creating excess capacity. More recently, the economic recession in 2008 and 2009 caused a significant drop in electricity demand. As a result, the lower demand projected for the near term in the *AEO2011* Reference case again results in excess generating capacity. Capacity that is currently under construction is completed in the Reference case, but only a limited amount of additional capacity is built through 2025. In 2025, capacity growth and demand growth are in balance again, and they grow at similar rates through 2035.

Costs and regulatory uncertainties vary across options for new capacity

Figure 81. Levelized electricity costs for new power plants, 2020 and 2035 (2009 cents per kilowatthour)



Technology choices for new generating capacity are based largely on capital, operating, and transmission costs. Coal, nuclear, and renewable plants are capital-intensive (Figure 81), while operating (fuel) expenditures make up most of the costs for gas-fired capacity [*91*]. Capital costs depend on such factors as equipment costs, interest rates, and cost-recovery periods. Fuel costs vary with operating efficiency, fuel price, resource availability, and transportation costs.

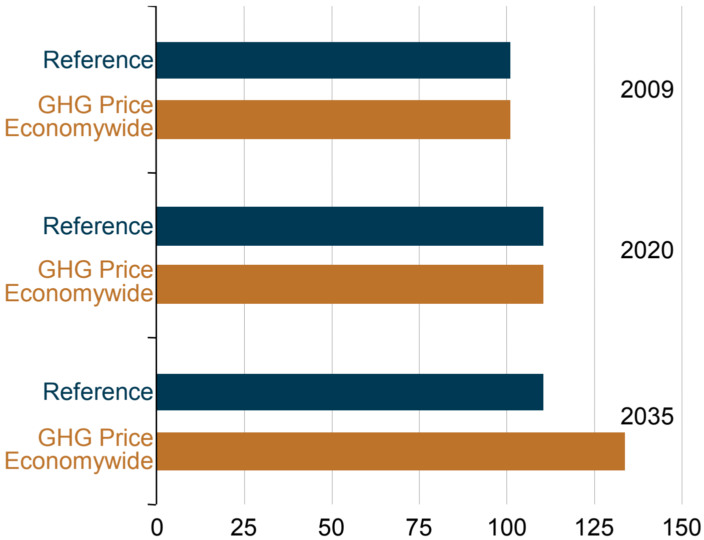
In addition to levelized cost considerations [*92*], some technologies and fuels receive subsidies, such as production tax credits (PTCs) and ITCs. Also, new plants must satisfiy local and Federal emissions standards and must be compatible with the utility's load profile.

Regulatory uncertainty also affects capacity planning. New coal plants may require carbon control and sequestration equipment, resulting in higher material, labor, and operating costs. Alternatively, coal plants without carbon controls could incur higher costs for siting and permitting. Because nuclear and renewable power plants (including wind plants) do not emit greenhouse gases, their costs are not directly affected by regulatory uncertainty in this area.

Capital costs can decline over time as developers gain technology experience. In the Reference case, the capital costs of new technologies are adjusted upward initially, to reflect the optimism inherent in early estimates of project costs, then decline as project developers gain experience. The decline continues at a progressively slower rate as more units are built. Operating efficiencies also are assumed to improve over time, resulting in reduced variable costs unless increases in fuel costs exceed the savings from efficiency gains.

EPACT2005 tax credits stimulate some nuclear builds

Figure 82. Electricity generating capacity at U.S. nuclear power plants in two cases, 2009, 2020, and 2035 (gigawatts)

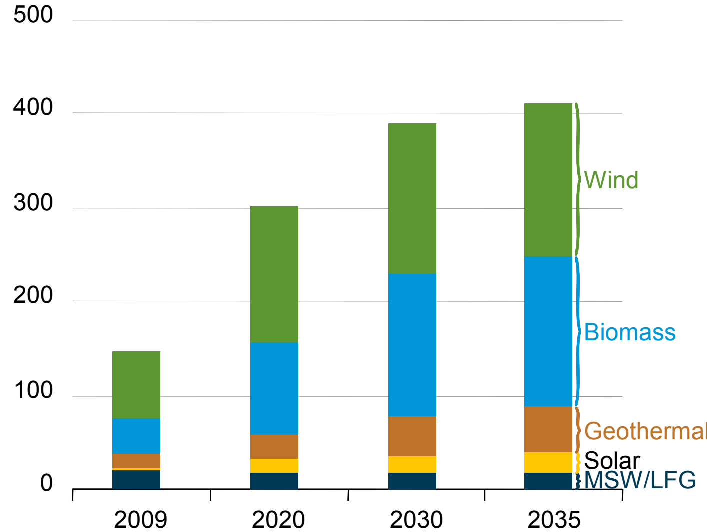


In the *AEO2011* Reference case, nuclear power capacity increases from 101.0 gigawatts in 2009 to 110.5 gigawatts in 2035 (Figure 82), including 3.8 gigawatts of expansion at existing plants and 6.3 gigawatts of new capacity. The new capacity includes completion of a second unit at the Watts Bar site, where construction on a partially completed plant has resumed. Increases in the estimated costs for new nuclear plants make new investments in nuclear power uncertain. Four new nuclear power plants are completed in the Reference case, all of which are brought on line by 2020 to take advantage of Federal financial incentives. High construction costs for nuclear plants, especially relative to natural-gas-fired plants, make other options for new nuclear capacity uneconomical even in the alternative electricity demand and fuel price cases. In the GHG Price Economywide case, which attaches a price to reductions in carbon dioxide, total nuclear capacity additions from 2010 to 2035 increase to 29 gigawatts as a consequence of the higher costs for operating fossil-fueled capacity.

One nuclear unit, Oyster Creek, is expected to be retired at the end of 2019, as announced by Exelon in December 2010. All other existing nuclear units continue to operate through 2035 in the Reference case, which assumes that they will apply for, and receive, operating license renewals, including in some cases a second 20-year extension after they reach 60 years of operation. As discussed in last year's "Issues in focus" section, it will likely be a decade or more before significant insight can be gained regarding what will happen beyond 60 years. With costs for natural-gas-fired generation rising and future regulation of GHG emissions uncertain, the economics of keeping existing nuclear power plants in operation are favorable.

Biomass and wind lead growth in renewable generation

Figure 83. Nonhydropower renewable electricity generation by energy source, 2009-2035 (billion kilowatthours)

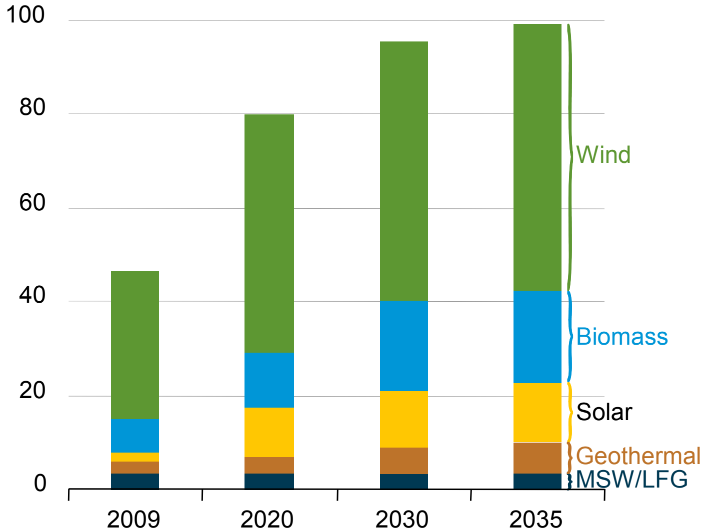


Renewable electricity generation, excluding hydropower, accounts for nearly one-quarter of the growth in electricity generation from 2009 to 2035 in the *AEO2011* Reference case (Figure 83). The increase is supported by RFS, State-level renewable electricity standards, and Federal tax credits. In the Reference case, generation from wind power nearly doubles its share of total generation, while generation from geothermal resources triples as a result of technology advances that make previously marginal sites attractive for development, as well as increasing the resources available at existing geothermal sites.

Renewable electricity generation in the end-use sectors also continues to grow. As a result of the Federal RFS that requires increased use of biofuels, there is an attractive opportunity to use waste heat from biofuel production to generate electricity. Consequently, generation from biomass more than triples from 2009 to 2035, when it accounts for 39 percent of total nonhydroelectric renewable electricity generation. Generation from solar resources increases from 2 percent of nonhydroelectric renewable generation in 2009 to more than 5 percent in 2035, as capital costs, especially for PV technologies in the end-use sectors, decrease over time. End-use solar generation grows from 2.3 billion kilowatthours in 2009 to 16.8 billion kilowatthours in 2035, and additional growth in solar generation comes from utility-scale PV plants, which begin to become competitive in the later years of the projection.

Renewable capacity growth spurred by end-use increases

Figure 84. Nonhydropower renewable electricity generation capacity by source, 2009-2035 (gigawatts)



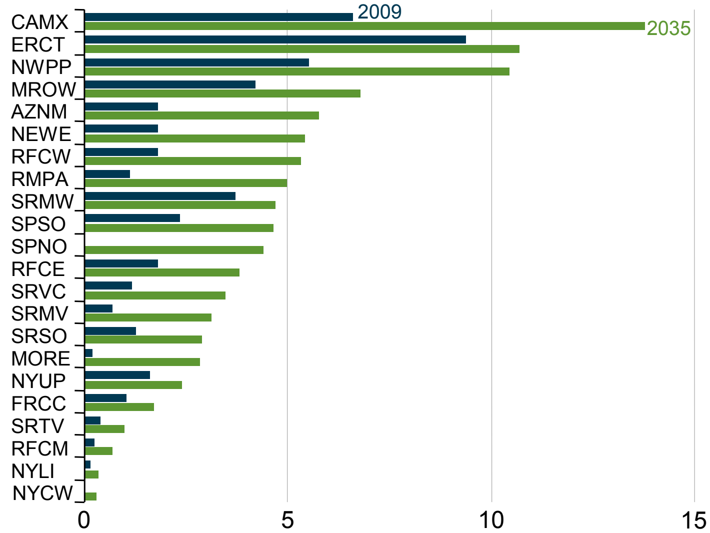
Supported in part by Federal tax credits in the early part of the projection period, the Federal RFS, and State RPS, nonhydropower renewable generating capacity grows at a faster rate than fossil fuel capacity in the *AEO2011* Reference case. Total nonhydropower renewable capacity increases from 47 gigawatts in 2009 to 100 gigawatts in 2035 (Figure 84). The largest increase is in wind-powered generating capacity. Because the Federal PTC expires at the end of 2012, however, 73 percent of the overall increase in wind capacity (18.2 gigawatts) occurs between 2009 and 2012. From 2012 through 2035, only an additional 6.9 gigawatts of wind capacity is added.

Biomass generating capacity grows from 7 gigawatts in 2009 (15 percent of total nonhydropower renewable capacity) to 20.2 gigawatts in 2035 (20 percent). All the growth in biomass capacity occurs in the end-use sectors, mainly at biorefineries, where electricity generation capacity increases as a result of mandates in the Federal RFS that require increased use of biofuels. No growth occurs in dedicated biomass generating capacity, because dedicated open-loop biomass plants remain too expensive to compete successfully with renewable capacity.

Solar generating capacity increases five-fold, with most capacity additions coming in the end-use sectors. The additions are based on a decline in the cost of PV systems over the projection period and the availability of Federal tax credits through 2016. Geothermal capacity also grows as a result of increased site availability, more favorable resource estimates, and lower costs for construction of geothermal facilities.

State portfolio standards increase renewable electricity generation

Figure 85. Regional growth in nonhydroelectric renewable electricity generation capacity, including end-use capacity, 2009-2035 (gigawatts)



Regional growth in renewable generation is based largely on two factors: availability of renewable energy resources and the existence of State RPS programs. After a period of robust RPS enactments in several States, 2010 was a relatively quiet year for RPS expansions. The most prominent change was California's RPS modification, which now requires renewable energy (including hydroelectric plants smaller than 30 megawatts capacity) to make up 33 percent of electricity generation, strengthening the prior 20-percent requirement that was supported by a limited fund.

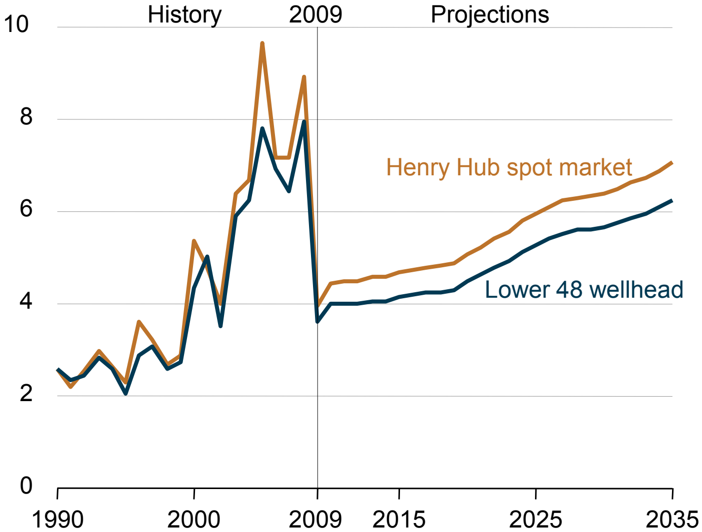
The WECC California region (CAMX), whose area approximates the California State boundaries (for a map of the electricity regions modeled, see Appendix F) has the largest projected nonhydroelectric renewable capacity, at 13.8 gigawatts in 2035 (Figure 85). The vast majority of California's renewable generating plants in 2035 consist of wind and geothermal capacity, each totaling more than 4.5 gigawatts in 2035. The Texas Regional Entity (ERCT) has more wind capacity in 2035 than any other region, at 10.1 gigawatts in 2035, and the second-largest nonhydro renewable capacity overall.

CAMX leads in solar installations, although State RPS programs heavily influence solar growth beyond the Southwest as both the Reliability First Corporation/East (RFCE) and the Reliability First Corporation/West (RFCW) regions have about 1 gigawatt of end-use solar capacity in 2035. Those two regions are not known for a strong solar resource base, and the installations are in response to the ITC in the early years of the projection period and high electricity prices during the later years. Most biomass capacity—confined largely to the end-use sectors—is built at cellulosic ethanol plant sites, most of which are in the Southeast.

Natural gas prices

Price disparity between crude oil and natural gas shifts drilling to liquids-rich shales

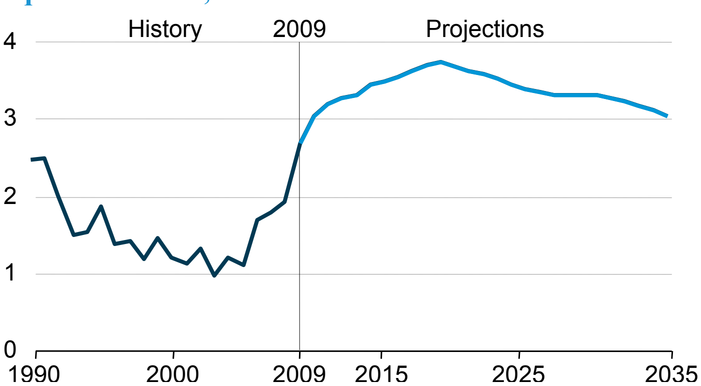
Figure 86. Annual average lower 48 wellhead and Henry Hub spot market prices for natural gas, 1990-2035 (2009 dollars per million Btu)



Unlike crude oil prices, natural gas prices do not return to the higher levels recorded before the 2007-2009 recession (Figure 86). Although some supply factors continue to relate the two markets loosely, the two do not track directly (Figure 87). The large difference between crude oil and natural gas prices results in a shift in drilling toward shale formations with high concentrations of liquids.

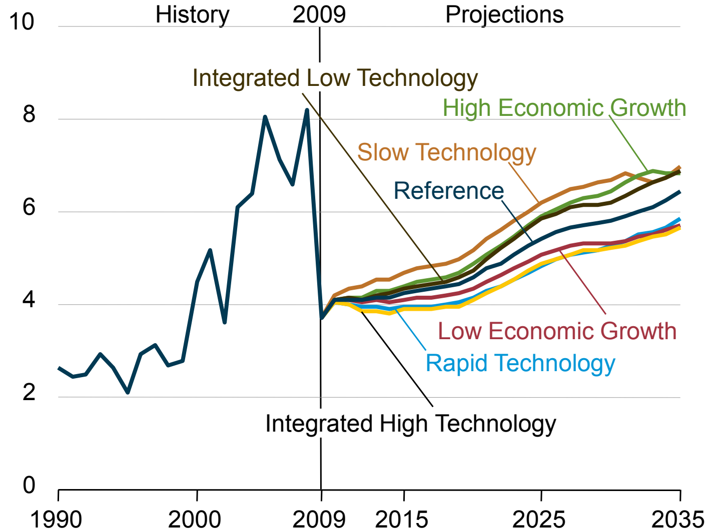
Shale gas continues to have enormous potential. To satisfy consumption levels in the Reference case, the number of lower 48 natural gas wells completed increases by 2.3 percent per year from 2009 to 2035. As a result, the average wellhead price for natural gas increases by an average of 2.1 percent per year, to $6.26 per million Btu in 2035 (2009 dollars). Henry Hub prices increase by 2.3 percent per year, to $7.07 per million Btu in 2035. Nonetheless, the Henry Hub price and average wellhead prices do not pass $5.00 per million Btu until 2020 and 2024, respectively.

Figure 87. Ratio of low-sulfur light crude oil price to Henry Hub natural gas price on an energy equivalent basis, 1990-2035



Natural gas prices vary with economic growth and technology progress

Figure 88. Annual average lower 48 wellhead prices for natural gas in seven cases, 1990-2035 (2009 dollars per thousand cubic feet)



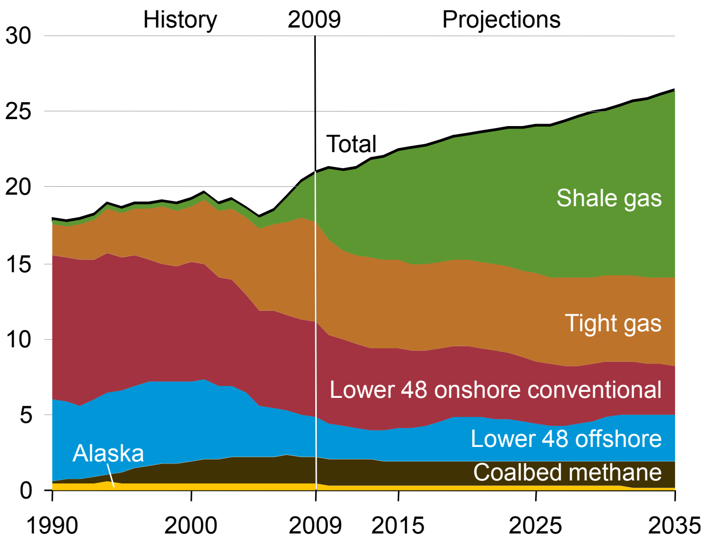
The extent to which natural gas prices in the Rapid and Slow Oil and Gas Technology cases differ from the Reference case depends on assumptions about the rate of improvement in natural gas exploration and production technologies. Technology improvement can reduce drilling and operating costs, expand the economically recoverable resource base, and affect the timing of production increases. It is particularly important to the production of natural gas from shale formations. The Reference case assumes that annual technology improvements follow historical trends. In the Rapid Oil and Gas Technology case, exploration and development costs decline at a faster rate, accelerating growth in production, which puts downward pressure on prices. In the Slow Oil and Gas Technology case, slower respective cost declines lead to higher natural gas prices and lower levels of consumption than in the Reference case (Figure 88).

The same type of impact can be seen from changes in economic growth and demand technologies. In the High Economic Growth and Integrated Low Technology cases, higher levels of demand result in increased production, which puts upward pressure on natural gas prices. In the Low Economic Growth and Integrated High Technology cases, the opposite impact is seen. Lower levels of demand put downward pressure on natural gas prices.

In the High Economic Growth and Slow Oil and Gas Technology cases with faster production growth, prices rise to levels that cause the Alaska pipeline to be completed towards the end of the projection, leading to temporary declines in natural gas prices. In the other cases, natural gas prices remain too low to make the Alaska pipeline economical before 2035.

Shale gas provides largest source of growth in U.S. natural gas supply

Figure 89. Natural gas production by source, 1990-2035 (trillion cubic feet)



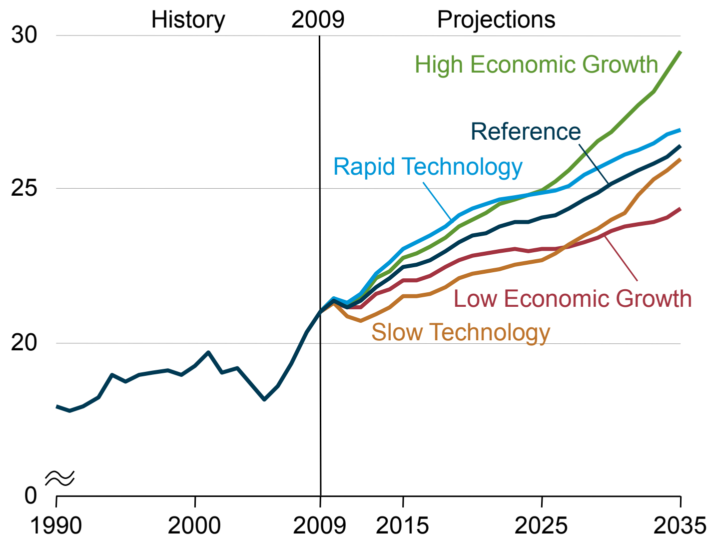
The increase in natural gas production from 2009 to 2035 in the *AEO2011* Reference case results primarily from continued exploration and development of shale gas resources (Figure 89). Shale gas is the largest contributor to production growth, while production from tight sands, coalbed methane deposits, and offshore waters remains stable. Shale gas makes up 47 percent of total U.S. production in 2035, nearly triple its 16-percent share in 2009. The estimate for technically recoverable unproved shale gas resources in the *AEO2011* Reference case is 827 trillion cubic feet. Although more information has become available as a result of increased drilling activity in developing shale gas plays, estimates of technically recoverable resources and well productivity remain highly uncertain. The "Issues in focus" section explores several sensitivity cases that alter the outlook for shale gas resources.

Offshore natural gas production in the Reference case declines initially, reflecting delays in near-term projects in the Gulf of Mexico. According to the latest leasing plan from the Bureau of Ocean Energy Management (BOEM), lease sales in the Mid- and South Atlantic outer continental shelf (OCS) will not occur before 2017. Because the Pacific OCS is considered to have low economic potential, *AEO2011* assumes that leasing in the Pacific will occur only in the southern California offshore and only after 2023.

Production from coalbeds and tight sands does not contribute to total production growth in the Reference case but does remain an important source of natural gas, accounting for 29 to 40 percent of total production from 2009 to 2035.

Economic growth and technology progress affect natural gas supply

Figure 90. Total U.S. natural gas production in five cases, 1990-2035 (trillion cubic feet)



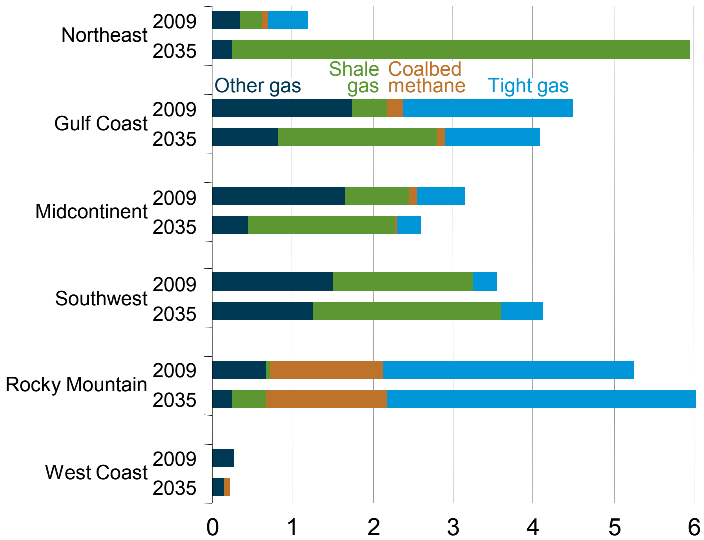
The level of domestic natural gas production is influenced by changes in the rate of economic growth and improvement in exploration and development technologies. The effect of economic growth results from its impact on the level of natural gas consumption. Changes in the rate of technology improvement affect natural gas drilling and production costs, which in turn can affect productive capacity of natural gas wells and change the number of successful wells, resulting in lower or higher production.

From 2009 to 2035, average annual natural gas consumption is 1.1 trillion cubic feet higher in the High Economic Growth case than in the Reference case. Domestic production accounts for 90 percent of this increase, with imports from Canada supplying most of the rest. On average in the High Economic Growth case, 64 percent of the increase in domestic production from 2009 to 2035 comes from shale gas, 15 percent from tight sands, and the remainder from offshore wells, coalbeds, and an Alaska pipeline completed in 2034.

Average annual natural gas production from 2009 to 2035 is 0.7 trillion cubic feet higher and 0.9 trillion cubic feet lower in the Rapid and Slow Technology cases, respectively, than in the Reference case (Figure 90). Shale gas production accounts for most of the difference, increasing by 0.8 trillion cubic feet per year on average from Reference case levels in the High Technology case and decreasing by 0.9 trillion cubic feet per year on average in the Slow Technology case. Higher prices in the Slow Technology case enable the Alaska pipeline to be completed in 2032, displacing more expensive production from tight sands and coalbed methane sources in the Rocky Mountain region, where shale gas is less abundant. Lower production levels in the Slow Technology case result from higher costs, lower resource availability, and, ultimately, reduced consumption in response to higher prices.

Increases in shale gas supply support growth in total natural gas supply production

Figure 91. Lower 48 onshore natural gas production by region, 2009 and 2035 (trillion cubic feet)



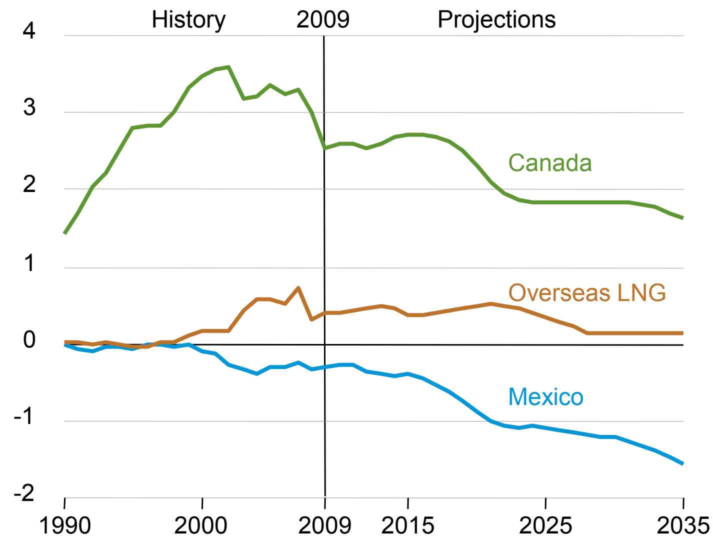
An almost four-fold increase in shale gas production from 2009 to 2035 more than offsets a 26-percent decline in non-shale lower 48 onshore natural gas production in the *AEO2011* Reference case. Significant increases in shale gas production occur in the Northeast and Gulf Coast regions. (See Figure F4 in Appendix F for a map of the regions.) Resource estimates for the Marcellus, Haynesville, and Eagle Ford plays have continued to increase as new information becomes available from exploration and development in those areas.

Dry gas production in the Northeast region increases in the Reference case nearly five-fold from 2009 to 2035 (Figure 91). The majority of the increase comes from the Marcellus shale gas play, which has an estimated technically recoverable resource base of about 400 trillion cubic feet. Because the growth in shale gas production displaces much of the natural gas that currently is supplied to the Northeast from the Gulf Coast and Canada, Gulf Coast gas tends to saturate the Henry Hub market and put downward pressure on natural gas prices.

Even with significant growth in shale gas production, total production in the Gulf Coast and Midcontinent regions falls, reflecting significant declines in sources other than shale formations. In particular, rigs previously used for drilling in tight sands are being moved to shale deposits. In the Southwest, as shale production increases, production from non-shale sources is maintained at a level that allows the region's total production to grow. In the Rocky Mountain region, production increases from tight sands and coalbed methane sources support increases in total production.

U.S. net imports of natural gas decline as domestic production rises

Figure 92. U.S. net imports of natural gas by source, 1990-2035 (trillion cubic feet)



U.S. net imports of natural gas decline in the *AEO2011* Reference case from 11 percent of total supply in 2009 to 1 percent in 2035. The reduction consists primarily of lower imports from Canada and higher net exports to Mexico (Figure 92), as a result of demand growth in both countries that outpace growth in their production.

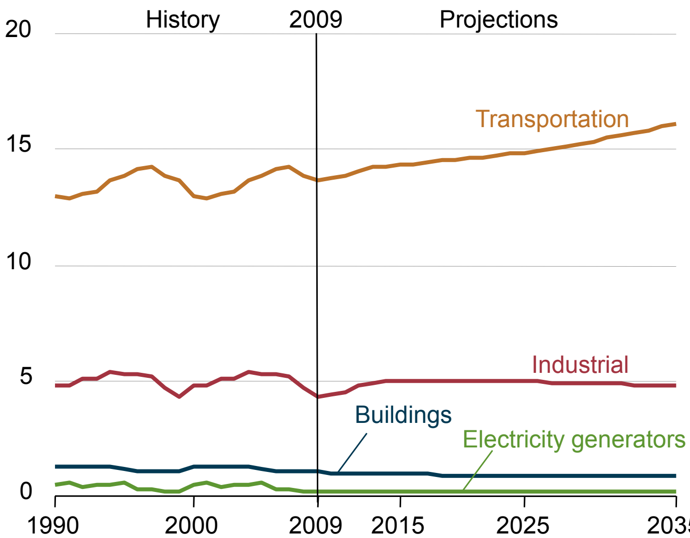
Supplies of natural gas from Canada's conventional sources decline from 2009 to 2035, but those declines are offset by increased production from coalbeds, tight formations, and shale gas deposits, allowing for a relatively constant level of exports to the United States through 2018 before they begin to decline. In addition, net imports to the United States from Canada are offset somewhat by an increase in exports from the United States to eastern Canada.

Mexico's natural gas consumption shows robust growth through 2035, and expected increases in its domestic production are not sufficient to meet demand growth. As a result, Mexico will need to import natural gas to fill the gap. Some of the increased supply to Mexico will be delivered by liquefied natural gas (LNG) tankers, largely to the south of the country, with the remainder coming from the United States.

LNG imports by the United States are minimal in the Reference case and occur largely during periods when world liquefaction capacity exceeds demand. Although U.S. LNG export projects have been proposed, their economic viability remains uncertain in view of the relatively inexpensive sources of natural gas supply available elsewhere in the world. As a result, existing liquefaction capacity in Alaska is the only source for U.S. exports of LNG that is considered in the *AEO2011* Reference case [93].

Transportation uses lead growth in liquid fuels consumption

Figure 93. Liquid fuels consumption by sector, 1990-2035 (million barrels per day)



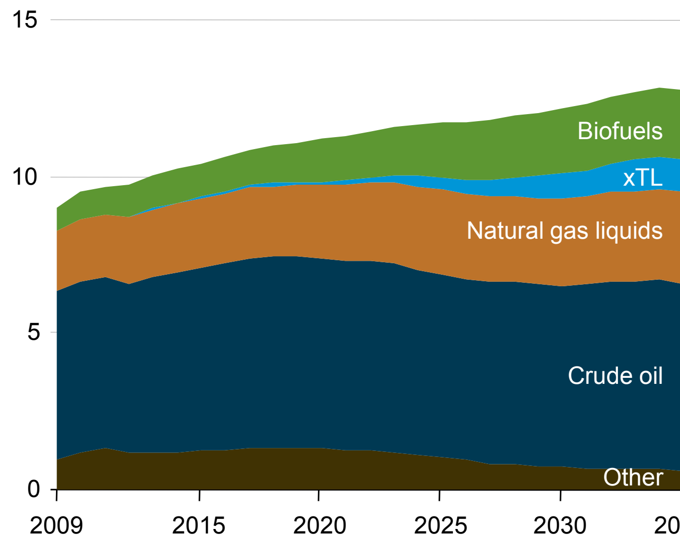
U.S. consumption of liquid fuels—including fuels from petroleum-based sources and, increasingly, those derived from non-petroleum primary fuels such as biomass and natural gas—totals 21.9 million barrels per day in 2035 in the *AEO2011* Reference case, an increase of 2.9 million barrels per day over the 2009 total (Figure 93). In all sectors except transportation, where consumption grows by about 2.5 million barrels per day, liquid fuel consumption remains at about the same level from 2009 to 2035. The transportation sector accounts for 73 percent of total liquid fuels consumption in 2035, up slightly from 71 percent in 2009.

Motor gasoline, ultra-low sulfur diesel, and jet fuel are the primary transportation fuels, supplemented by biofuels such as ethanol and biodiesel. The increase in demand for transportation fuels is met primarily by diesel and biofuels. Motor gasoline consumption increases by approximately 0.3 million barrels per day from 2009 to 2035 in the Reference case, while diesel fuel and E85 consumption increase by 1.3 and 0.8 million barrels per day, respectively, over the period.

Biodiesel and a number of next-generation biofuels account for about 0.6 million barrels per day of the increase in liquid fuels consumption for transportation in 2035. The growth in biofuel use is primarily a result of the RFS mandates in EISA2007, although there is moderate production of corn ethanol beyond that which qualifies for RFS credits. The growth in diesel fuel consumption results from both an expansion of light-duty diesel vehicle sales to meet more stringent CAFE standards and an increase in industrial output that leads to more fuel use by heavy trucks.

Biofuels and natural gas liquids lead growth in total liquids supply

Figure 94. U.S. domestic liquids production by source, 2009-2035 (million barrels per day)



With world oil prices rising in the *AEO2011* Reference case, domestic liquids production grows (Figure 94). From 2009 to 2035, U.S. crude oil production increases by about 600,000 barrels per day.

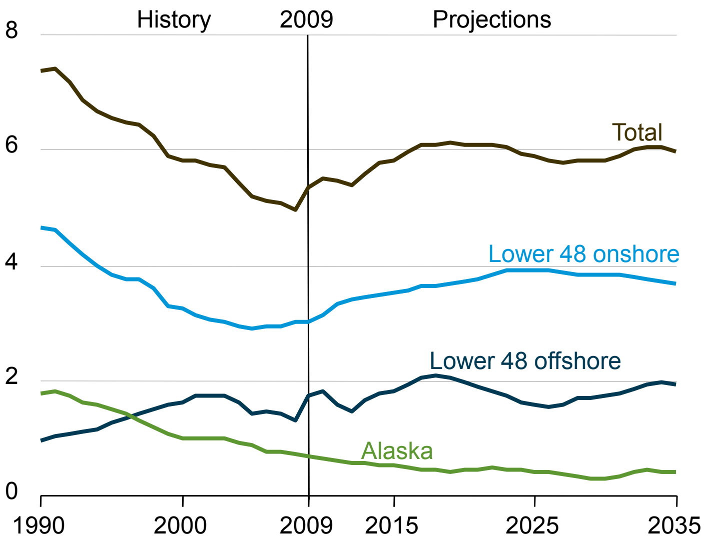
As a result of the EISA2007 RFS, biofuels production increases by almost 1.5 million barrel per day, with ethanol accounting for the largest share of the increase. Ethanol production increases by more than 800,000 barrels per day from 2009 to 2035, displacing approximately 12 percent of gasoline demand in 2035 on an energy-equivalent basis. In the early years of the projection, ethanol is blended with gasoline and consumed as E10 (motor gasoline blends containing up to 10 percent ethanol) or E15 (motor gasoline blends containing up to 15 percent ethanol). By 2035, however, ethanol is consumed in roughly equal shares as E10, E15, and E85.

NGL production increases by 1.0 million barrels per day, to 2.9 million barrels per day in 2035, mainly as a result of strong growth in gas shale production, which tends to have relatively large amounts of liquids associated with it. BTL production increases to 516,000 barrels per day, and CTL production increases to 550,000 barrels per day in 2035.

Much of the increased liquids production comes from oil in shale formations (i.e., produced from kerogen, a solid hydrocarbon), CO_2-enhanced oil recovery (EOR), and next-generation "xTL" production, which includes biomass-to-liquids (BTL), GTL, and CTL.

U.S. crude oil production increases as projected world oil prices rise

Figure 95. Domestic crude oil production by source, 1990-2035 (million barrels per day)



Rising world oil prices, growing shale oil resources (i.e., liquid oil embedded in non-porous shale rock), and increased production using EOR techniques contribute to increased domestic crude oil production from 2009 to 2035 in the *AEO2011* Reference case (Figure 95). The Bakken shale oil formation contributes to growth in crude oil production in the Rocky Mountain Region, and growth in the Gulf Coast region is spurred by the resources in the Eagle Ford and Austin Chalk formations. Some of the decline in oil production in the Southwest region is offset by production coming from the Avalon shale formation.

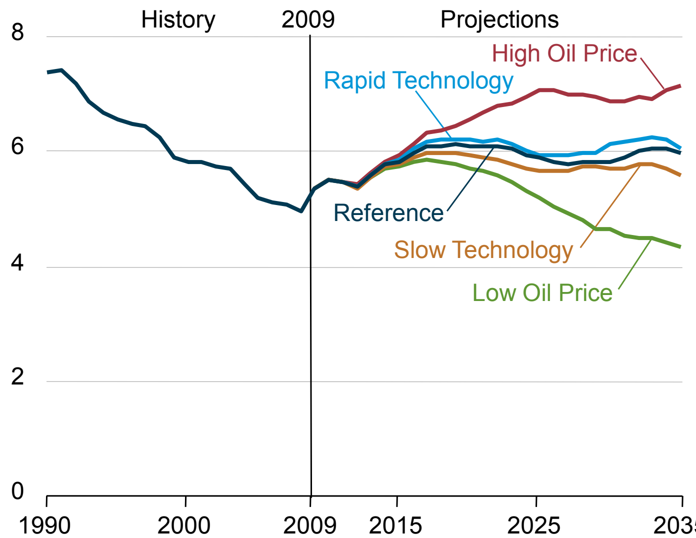
Production with CO_2-EOR increases beginning in 2015 (largely using natural CO_2 sources), continues to grow through 2025 as anthropogenic CO_2 sources increase, and eventually dominates CO_2 production, supporting just over 20 percent of total crude oil production in 2035.

Lower 48 offshore production increases by 13 percent from 2009 to 2035 in the Reference case. According to the recent BOEM leasing plan, lease sales in the Mid- and South-Atlantic OCS will not occur before 2017. In the Pacific OCS, leasing is assumed to occur only off the coast of Southern California and not until after 2023 in the Reference case, because the Pacific OCS is considered to have low potential [*94*].

Oil shale liquid production (i.e., produced from kerogen, a solid hydrocarbon), which comes on line in the Rocky Mountain region in 2029 in the Reference case, accounts for roughly 2 percent of total domestic crude oil production in 2035.

U.S. oil production is more responsive to price changes than to technology gains

Figure 96. Total U.S. crude oil production in five cases, 1990-2035 (million barrels per day)



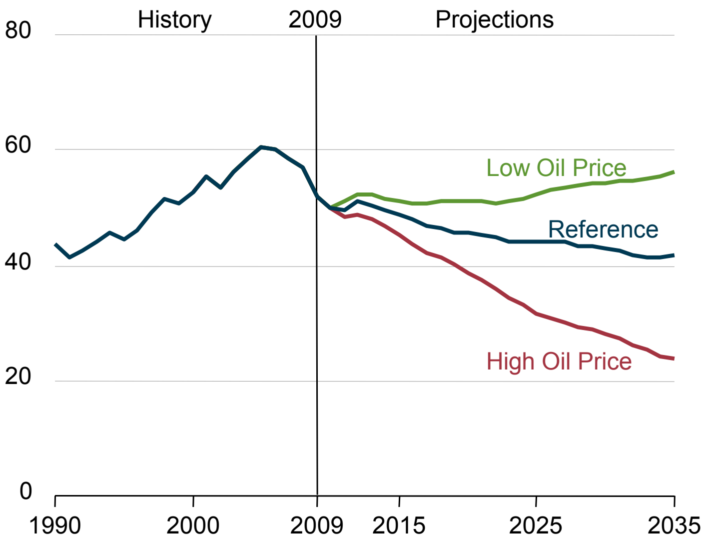
In the *AEO2011* Oil Price and Technology cases, total U.S. crude oil production is more responsive to changes in world oil prices than it is to advances in technology (Figure 96). The most significant difference between the Reference case and the High and Low Oil Price cases is the change in use of CO_2–enhanced EOR in response to the changes in oil price assumptions. From 2015 to 2035, when compared with the Reference case, crude oil production using CO_2 EOR is 17 percent higher on average in the High Oil Price case. In comparison, in the Rapid Technology case, CO_2 EOR technology shows little change, in part because of the limited availability of CO_2 supplies.

Oil production from offshore areas, Alaska, and oil shale deposits also is responsive to changes in world oil prices, because higher or lower prices improve or worsen the economics of those supply sources. For example, production from oil shale in 2035 is nearly threefold higher in the High Oil Price case than in the Reference case, and oil production from offshore drilling is 26 percent higher than in the Reference case.

Advances in horizontal drilling and hydraulic fracturing techniques continue to enhance the development of shale oil formations. Improvements in drilling equipment and monitoring instrumentation are among the key advances that have contributed to the slowdown and subsequent reversal in the decline in U.S. domestic oil production.

Imports of liquid fuels vary with world oil price assumptions

Figure 97. Net import share of U.S. liquid fuels consumption in three cases, 1990-2035 (percent)

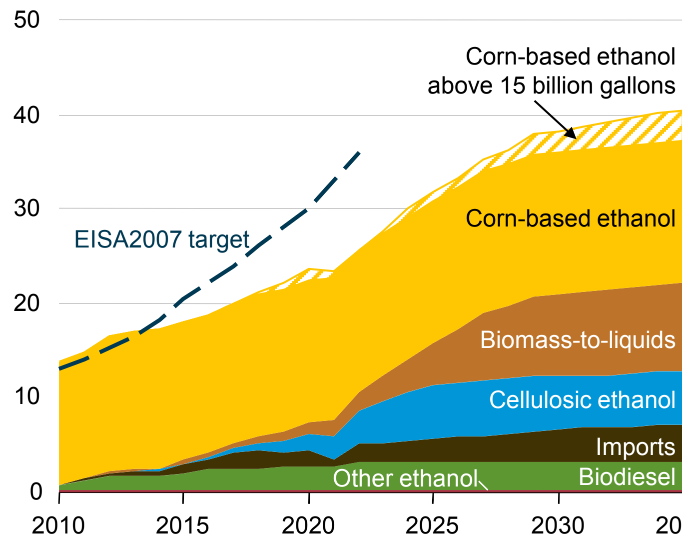


U.S. imports of liquid fuels (including crude oil, petroleum liquids, and liquids derived from nonpetroleum sources), which grew steadily from the mid-1980s to 2005, have been declining since 2005. In the *AEO2011* Reference and High Oil Price cases, imports of liquid fuels continue to decline from 2009 to 2035, although they provide a major part of total U.S. liquids supply over the period. Tighter fuel efficiency standards and higher prices for liquid fuels moderate the growth in liquids demand, even as the combination of higher prices and renewable fuel mandates leads to increased domestic production of both oil and biofuels. Consequently, while consumption of liquid fuels increases steadily in the Reference case from 2009 to 2035, the growth in demand is met by domestic production.

The net import share of U.S. liquid fuels consumption fell from 60 percent in 2005 to 52 percent in 2009. The net import share continues to decline in the Reference case, to 42 percent in 2035 (Figure 97). In the High Oil Price case, the net import share falls to an even lower 24 percent in 2035. Increased penetration of biofuels in the liquids market reduces the need for imports of crude oil and petroleum products in the High Oil Price case. In the Low Oil Price case, the net import share remains flat in the near term, then rises to 56 percent in 2035 as demand increases and imports become cheaper than crude oil produced domestically.

Renewable fuels standard leads to increased production of biofuels

Figure 98. EISA2007 renewable fuels standard, 2010-2035 (billion ethanol equivalent gallons)



The RFS results in a strong increase in renewable fuel production between 2009 to 2022 in the *AEO2011* Reference case (Figure 98). Renewable fuel production, however, does not meet the RFS requirement of 36 billion gallons in 2022 because financial and technological hurdles delay the start of many advanced biofuel projects—particularly, cellulosic biofuel projects.

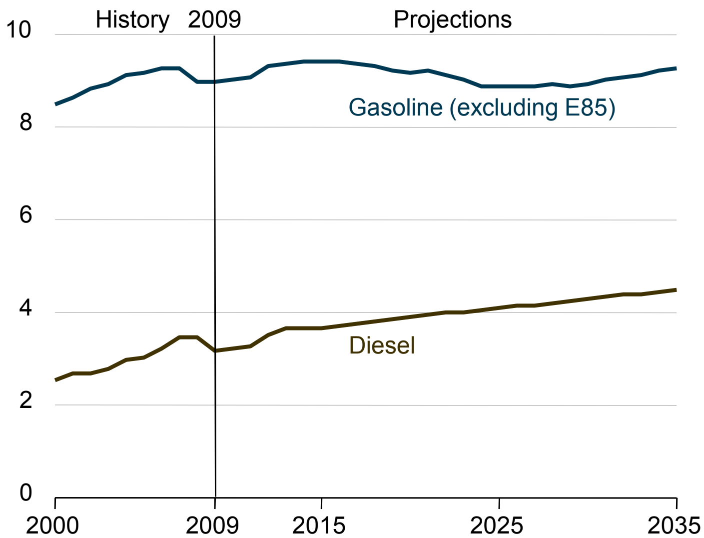
The provisions of the RFS require annual evaluations by the U.S. EPA to determine the status of biofuel production capacity and revise the production mandates for the following year, as needed. The Reference case reflects an EPA reduction in the mandate for cellulosic biofuel production in both 2010 and 2011. Accounting for those modifications and anticipated future changes, only 25.7 billion credits are generated in 2022 in the Reference case, including 15 billion gallons of credits for domestic corn-based ethanol. Corn ethanol consumption grows above the 15 billion gallons that qualifies for the RFS credit to as high as 18 billion gallons by 2035.

The remainder of the biofuel supply in the Reference case consists of cellulosic ethanol, small volumes of next-generation biofuels, and imports of ethanol and biodiesel. In 2022, cellulosic ethanol contributes 3.5 billion gallons of credits towards the RFS mandate, and biodiesel and imported ethanol contribute 2.0 and 2.8 billion gallons of credits, respectively.

The Reference case assumes that the EPA will continue to set RFS targets after 2022, leading to more capacity builds than would have occurred otherwise. The mandate for 36 billion gallons of biofuel is met by 2030, and total biofuel production increases to 37.2 billion ethanol-equivalent gallons in 2035.

Future refinery operations and investments target diesel output

Figure 99. U.S. motor gasoline and diesel fuel consumption, 2000-2035 (million barrels per day)



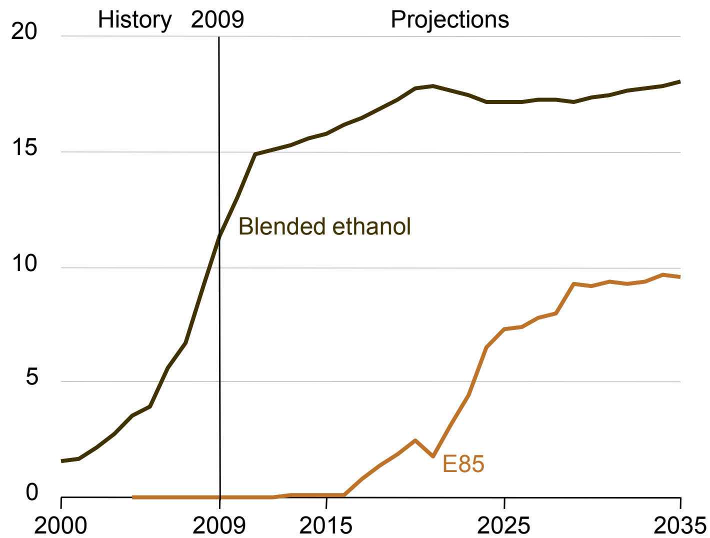
Tighter CAFE standards and increased consumption of ethanol as E85 slow the growth of gasoline consumption in the *AEO2011* Reference case, but diesel consumption increases steadily through 2035 (Figure 99). The resulting increase in diesel output, coupled with a decrease in refinery capacity, causes a shift in the overall slate of refinery outputs.

Although demand for petroleum products declined during the recent economic downturn, new refining capacity that was planned before the downturn comes on line early in the projection, despite lower utilization levels. This new capacity results in the addition of approximately 400,000 barrels per day of new refining distillation capacity by the end of 2012. A portion of the new capacity is configured to process heavier and previously less desirable crudes, capitalizing on their lower costs. The expansions are focused on diesel output for use both domestically and abroad. Given the current economics of refining operations, no additional capacity additions are expected after 2013. As a result, total refining capacity declines gradually after 2013, and more capacity is idled.

Diesel fuel consumption increases by approximately 1.3 million barrels per day from 2009 through 2035 in the Reference case, while motor gasoline consumption increases by 0.3 million barrels per day. The share of total refinery output represented by diesel fuel increases over the projection period.

Higher limit on ethanol blending spurs consumption growth in the near term

Figure 100. U.S. ethanol use in gasoline and E85, 2000-2035 (billion gallons)



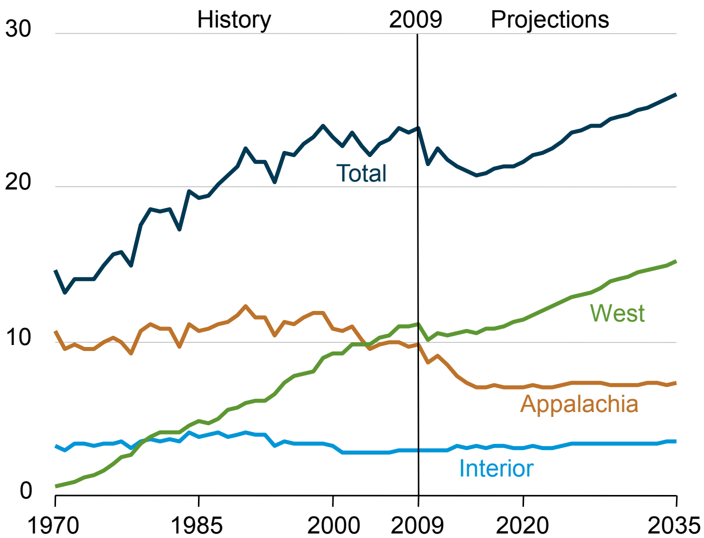
Currently, given the limited retail availability of E85, the primary use of ethanol in the United States is as a blendstock for gasoline. With rapid growth in ethanol capacity and production in recent years, ethanol consumption in 2010 approached the legal gasoline blending limit of 10 percent (E10). Recent EPA actions have increased the blending limit to 15 percent (E15) for vehicles built in 2001 and after. Although the higher blending limit allows ethanol consumption to increase in the near term, a number of issues may constrain its immediate impact.

One of the primary issues expected to slow the widespread adoption of E15 is liability for potential misfueling and infrastructure problems. Retailers will be hesitant to sell E15 if they are not relieved of responsibility for damage to consumer vehicles that may result from misfueling, as well as malfunctions of storage equipment or infrastructure that may be caused by the higher ethanol blend. Consumer acceptance will also play a part; warning labels could deter customers from risking any potential damage from the use of E15.

Given the issues above, ethanol blending in gasoline increases only gradually in the *AEO2011* Reference case (Figure 100), from 13.1 billion gallons in 2010 (about 9 percent of the gasoline pool) to 17.8 billion gallons in 2020 (about 12 percent of the gasoline pool). In 2020, vehicles built in 2001 and after consume E15 primarily, and the remaining growth in ethanol consumption shifts to E85 use, which increases from about 0.8 billion gallons in 2017 to 9.6 billion gallons in 2035.

Early declines in coal production are more than offset by growth after 2014

Figure 101. Coal production by region, 1970-2035 (quadrillion Btu)



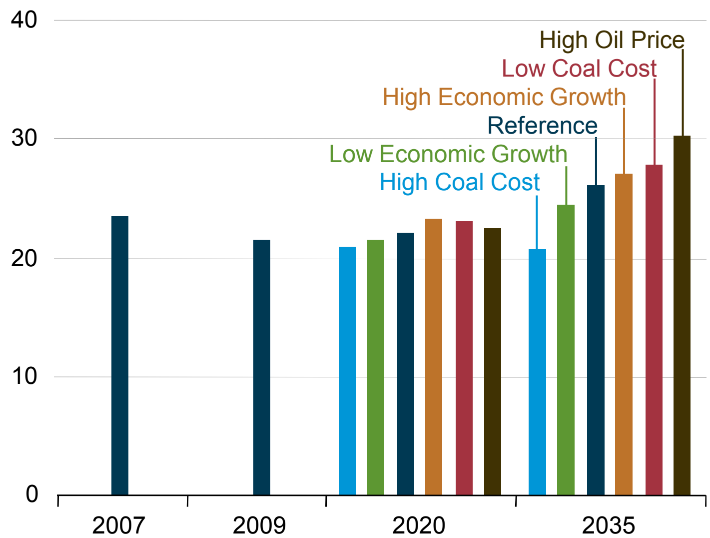
U.S. coal production declined by 2.3 quadrillion Btu in 2009. In the *AEO2011* Reference case, production does not return to its 2008 level until after 2025. Between 2008 and 2014 a potential recovery in coal production is kept in check by continued low natural gas prices and increased generation from renewables and nuclear capacity. After 2014, coal production grows at an average annual rate of 1.1 percent through 2035, with increases in coal use for electricity generation and for the production of synthetic liquids.

Western coal production increases through 2035 (Figure 101) but at a much slower rate than in the past, as demand grows slowly. Low-cost supplies of coal from the West satisfy much of the additional fuel needs at coal-fired power plants east of the Mississippi River and supply most of the coal needed at new CTL and CBTL plants.

Coal production in the Interior region, which has trended slightly downward since the early 1990s, rebounds somewhat in the Reference case, increasing from 2.9 quadrillion Btu in 2009 to 3.5 quadrillion Btu in 2035. Most of the additional production from this region originates from mines tapping into the substantial reserves of mid- and high-sulfur bituminous coal in Illinois, Indiana, and western Kentucky. Appalachian coal production declines substantially from current levels, as coal produced from the extensively mined, higher cost reserves of Central Appalachia is supplanted by lower cost coal from other supply regions. Increasing production in the northern part of the basin, however, does help to moderate the overall production decline in Appalachia.

Long-term outlook for coal production varies considerably across cases

Figure 102. U.S. coal production in six cases, 2007, 2009, 2020, and 2035 (quadrillion Btu)



U.S. coal production varies across the *AEO2011* cases, reflecting different assumptions about the costs of producing and transporting coal, the outlook for economic growth, and the outlook for world oil prices (Figure 102). In addition, although they are not shown in the figure, alternative assumptions about restrictions on GHG emissions could have even larger impacts on coal production over the projection period.

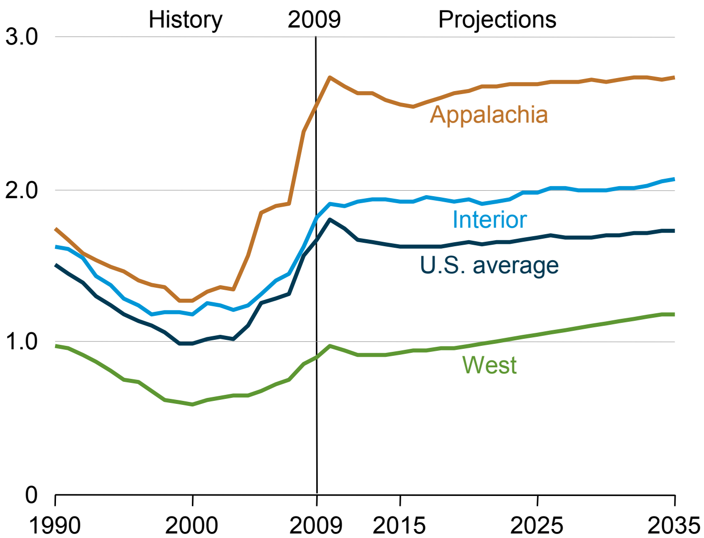
Assumptions about economic growth primarily affect the projections for overall electricity demand, which in turn determine the need for coal-fired generation. In contrast, assumptions about the costs of producing and transporting coal primarily affect the choice of technologies for electricity generation, with coal capturing a larger share of the U.S. electricity market in the Low Coal Cost case and a smaller share in the High Coal Cost case. In the High Oil Price case, higher oil prices stimulate the demand for coal-based synthetic liquids, leading to a substantial expansion of coal use at CTL and CBTL plants. Production of coal-based synthetic liquids totals 1.6 million barrels per day in 2035 in the High Oil Price case, nearly three times the amount in the Reference case.

Coal production in the Reference case increases by 21 percent from 2009 to 2035, whereas the alternative cases show changes ranging from a decrease of 4 percent to an increase of 41 percent. In the earlier years of the projection, from 2009 to 2020, variations in coal production across the cases are smaller, ranging from a decline of 4 percent to an increase of 8 percent, primarily reflecting the smaller changes in overall energy demand over the shorter time frame.

Coal prices

Growth in average minemouth price slows compared to recent history

Figure 103. Average annual minemouth coal prices by region, 1990-2035 (2009 dollars per million Btu)



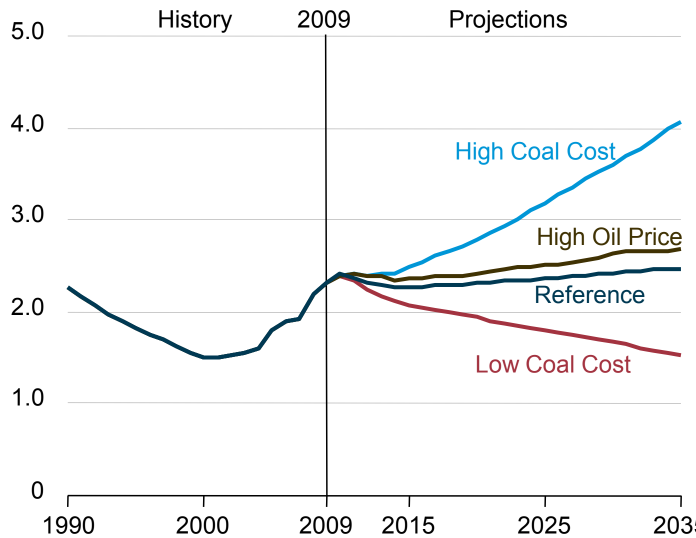
In the Reference case, the average real minemouth price for U.S. coal remains nearly unchanged, declining from $1.67 per million Btu in 2009 to $1.65 in 2020, and then rising to $1.73 in 2035—an increase of 0.2 percent per year over the entire projection period. In contrast, there were sizable increases in coal prices from 2000 to 2009, averaging 6.0 percent per year, and declines from 1990 to 2000 that averaged 4.2 percent per year. The moderation of coal prices in the Reference case results from a variety of factors, including a shift in production from Appalachia to the Interior and Western regions, which have lower costs of production, and a relatively flat outlook for coal mining productivity, which acts to keep mine production costs close to current levels.

In the Western and Interior coal supply regions, slight declines in mining productivity, combined with increased production, result in higher real minemouth prices in the *AEO2011* Reference case, with prices increasing at average annual rates of 1.1 percent in the Western region and 0.5 percent in the Interior region from 2009 to 2035 (Figure 103).

In the Appalachian region, the average real minemouth coal price increases by 0.2 percent per year from 2009 to 2035. The price outlook for Appalachian coal primarily reflects continuing but slower declines in coal mining productivity. Recent increases in the average price of Appalachian coal, from $1.27 per million Btu in 2000 to $2.56 per million Btu in 2009, in part as a result of significant declines in mining productivity over the decade, have substantially reduced the competitiveness of Appalachian coal with coal from other producing regions.

Substantial changes in coal prices would have moderate effects on demand

Figure 104. Average annual delivered coal prices in four cases, 1990-2035 (2009 dollars per million Btu)



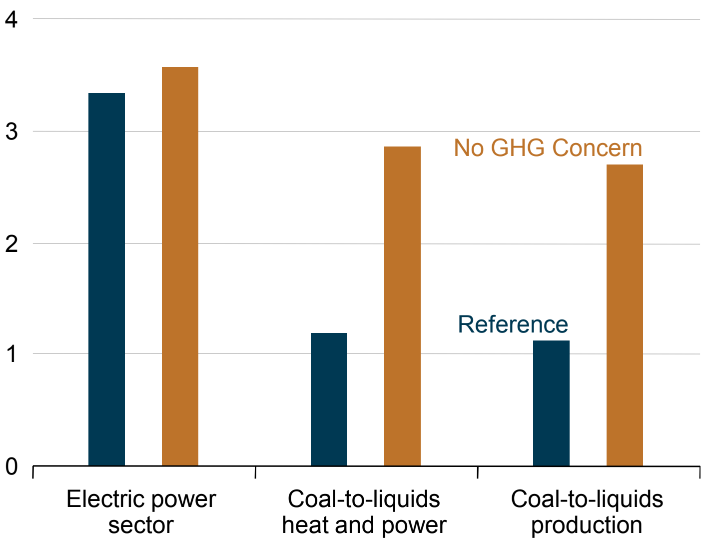
Alternative assumptions for coal mining and transportation costs affect delivered coal prices and demand. Two Coal Cost cases developed for *AEO2011* examine the impacts on U.S. coal markets of alternative assumptions about mining productivity, labor costs, mine equipment costs, and coal transportation rates (Figure 104). Although alternative assumptions about economic growth and world oil prices lead to some variations in the price paths for coal, the differences from the Reference case are relatively small in those cases.

In the High Coal Cost case, the average delivered coal price is $4.08 per million Btu (2009 dollars) in 2035—65 percent higher than in the Reference case, where the average price is $2.47 per million Btu in 2035. Because the higher coal prices result in switching from coal to natural gas and renewables in the electricity sector, U.S. coal consumption in 2035 is 16 percent (3.8 quadrillion Btu) lower in the High Coal Cost case than in the Reference case. In the Low Coal Cost case, delivered coal prices in 2035 average $1.53 per million Btu—38 percent lower than in the Reference case—and total coal consumption is 4 percent (0.9 quadrillion Btu) higher than in the Reference case.

Because the Economic Growth and Oil Price cases use the Reference case assumptions for coal mining and rail transportation costs, they show smaller variations in average delivered coal prices than do the two coal cost cases. Differences in coal price projections in the Economic Growth and Oil Price cases result mainly from higher and lower levels of demand for coal. In the Oil Price cases, higher and lower fuel costs for both coal producers and railroads also contribute to the slight variations in coal prices.

Concerns about GHG legislation affect the long-term outlook for coal

Figure 105. Change in annual U.S. coal consumption by end use in two cases, 2009-2035 (quadrillion Btu)

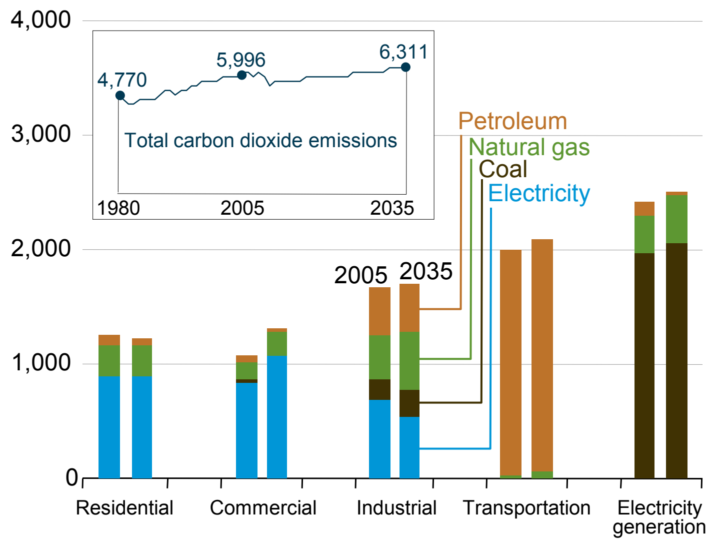


In the Reference case, the cost of capital for investments in GHG-intensive technologies—including conventional coal-fired power plants, CTL plants, CBTL plants, and integrated coal gasification and combined cycle plants without CCS—is increased by 3 percentage points to reflect the behavior of utilities, other energy companies, and regulators concerning the possible enactment of GHG legislation which could mandate that owners purchase allowances, invest in CCS, or invest in other projects to offset their emissions in the future. A No GHG Concern case, in which the additional 3 percentage points for GHG-intensive technologies is removed, is used to evaluate the impact on energy investments.

In the No GHG Concern case, coal use for both electricity generation in the electric power sector and as part of production of coal-based synthetic liquids is 3.5 quadrillion Btu higher than in the Reference case (Figure 105), and 48 gigawatts (including 28 gigawatts at coal-based synthetic liquids plants) of new coal-fired generating capacity is added after 2009, as compared with 26 gigawatts in the Reference case (including about 12 gigawatts currently under construction). Of the 22 gigawatts of additional coal-fired capacity builds in the No GHG Concern case, 16 gigawatts, or 73 percent, are at coal-based synthetic liquids plants and 6 gigawatts are in the electric power sector. As a result, additions of both natural gas and renewable generating capacity are lower in the No GHG Concern case than in the Reference case. The production of coal-based synthetic liquids rises to 1.3 million barrels per day (2.7 quadrillion Btu) in 2035 in the No GHG Concern case, compared with 0.5 million barrels per day (1.1 quadrillion Btu) in the Reference case. Total CO_2 emissions increase to 6,476 million metric tons in 2035 in the No GHG Concern case, about 3 percent higher than in the Reference case and 19 percent higher than in 2009.

Growth of carbon dioxide emissions slows in the projections

Figure 106. U.S. carbon dioxide emissions by sector and fuel, 2005 and 2035 (million metric tons)



On average, energy-related CO_2 emissions in the *AEO2011* Reference case grow slowly, by an average of 0.2 percent per year from 2005 to 2035 as compared with 0.9 percent per year from 1980 to 2005. Reasons for the slower rate of increase include growing use of renewable technologies and fuels, efficiency improvements, slower growth in electricity demand (in part because of the recent recession), and more use of natural gas, which is less carbon-intensive than other fossil fuels. In the Reference case, energy-related CO_2 emissions do not exceed 2005 levels until 2027, and in 2035 they total 6,311 million metric tons or about 5 percent higher than in 2005 (Figure 106).

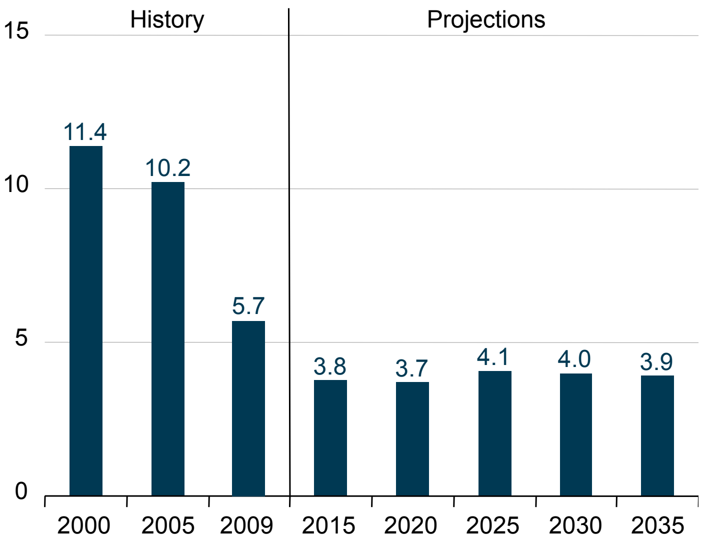
Petroleum remains the largest source of CO_2 emissions over the projection period, but its share falls to 41 percent in 2035 from 44 percent in 2005. Although rising from the relatively low levels of 2009, CO_2 emissions from petroleum, used mainly in the transportation sector, vary little from 2013 to 2025, as improvements in fuel economy and the expanded use of ethanol rise more quickly than travel demand. From 2025 to 2035, with little additional improvement in fuel economy and slower growth in biofuels use, petroleum-related CO_2 emissions increase by an average of 0.6 percent per year.

Emissions from coal, the second largest source of CO_2 emissions, do not reach 2005 levels until 2027. Coal's share of CO_2 emissions remains fairly stable through 2035 because of sustained growth in the CTL industry and some growth in the power sector. From 2009 to 2035, the natural gas share of CO_2 emissions increases relative to its 2005 share, because more natural gas is used to fuel electricity generation and industrial applications.

Emissions from energy use

Sulfur dioxide emissions decrease due to the Clean Air Interstate Rule

Figure 107. Sulfur dioxide emissions from electricity generation, 2000-2035 (million short tons)

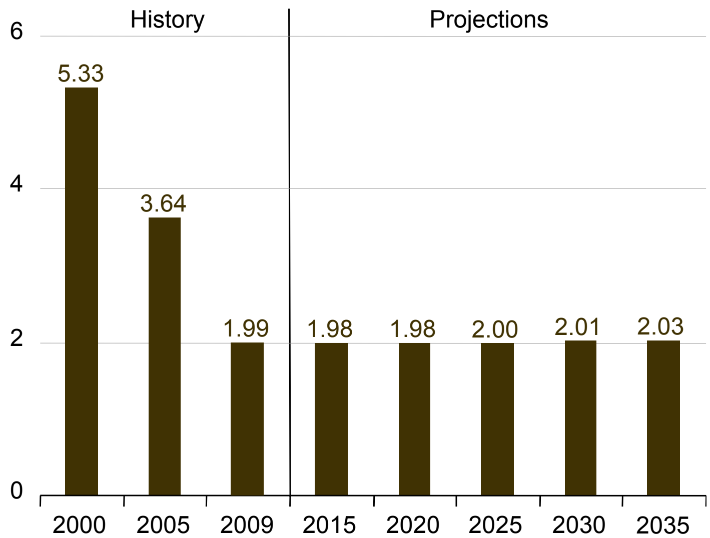


Since the U.S. District Court of Appeals overturned the Clean Air Interstate Rule (CAIR) in July 2008 [*95*], followed by its temporary reinstatement of the rule 6 months later, there has been tremendous uncertainty about regulation of sulfur dioxide (SO_2) emissions from electric power plants. In July 2010, the EPA proposed the Air Transport Rule, which would require emissions reductions similar to those in CAIR, but is designed to address the court's objections to CAIR. Currently, the EPA is reviewing public comments on the Air Transport Rule, and many key details of the regulation have not been determined. Because of the uncertainty about the ultimate makeup of the Air Transport Rule, *AEO2011* assumes that the temporary CAIR rule, which still is the binding rule on SO_2 emissions from power plants, remains in effect through 2035.

In the *AEO2011* Reference case, SO_2 emissions from the U.S. electric power sector fall to between 3.8 and 4.1 million short tons from 2015 to 2035, or an average of about 30 percent below 2009 levels (Figure 107). The reduction occurs as a result of CAIR limits. Emissions fluctuate slightly from year to year after 2020 as a result of allowance banking, which is allowed under CAIR but probably will be more limited under the Air Transport Rule, given its restrictions on allowance trading. In order to meet the emission reduction requirements in CAIR, new flue gas desulfurization (FGD) retrofits are installed on 54 gigawatts of coal capacity from 2009 to 2035, increasing the total amount of generating capacity with FGD equipment installed to approximately 222 gigawatts, or 70 percent of coal-fired generating capacity in the electric power sector, in 2035. In the Reference case, 8.8 gigawatts of coal-fired capacity is retired from 2009 to 2035.

Nitrogen oxide emissions are flat in the Reference case

Figure 108. Nitrogen oxide emissions from electricity generation, 2000-2035 (million short tons)



The Air Transport Rule, released in July 2010, seeks nitrous oxide (NO_x) emissions reductions similar to those in the CAIR. Because key details of the Air Transport Rule have not been finalized, however, it is not included in the *AEO2011* Reference case. A temporary version of CAIR remains binding until the Air Transport Rule can be finalized, and the Reference case assumes that CAIR remains in effect through 2035.

NO_x emissions from electric power plants dropped significantly from 3 million short tons in 2008 to approximately 2 million short tons in 2009, as a result of a reduction in coal-fired electricity generation in 2009. In the Reference case, NO_x emissions stabilize at roughly the 2009 level through 2035 (Figure 108), despite steady increases in coal-fired generation. With a growing number of coal-fired power plants being fitted with NO_x control equipment, NO_x emissions are maintained at the levels needed to meet the CAIR target.

Coal-fired power plants can be retrofitted with any of the three types of NO_x control technologies: selective catalytic converter (SCR), selective noncatalytic converter (SCNR), or low-NO_x burners. The type of retrofit used depends on the specific characteristics of the plant, including the boiler configuration and the type of coal used. From 2009 to 2035, 155 gigawatts of coal-fired capacity is retrofitted with NO_x controls in the Reference case: 61 percent with SCR, 5 percent with SCNR, and 33 percent with low-NO_x burners.

Endnotes for market trends

Links current as of April 2011

84. The industrial sector includes manufacturing, agriculture, construction, and mining. The energy-intensive manufacturing sectors include food, paper, bulk chemicals, petroleum refining, glass, cement, steel, and aluminum.

85. U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC: August 2010), Table 5.21, "Crude Oil Refiner Acquisition Cost, 1968-2009," website www.eia.gov/emeu/aer/txt/stb0521.xls.

86. Products covered include many types of heating and cooling equipment, gas and electric water heaters, refrigerators and freezers, several types of lighting (especially, incandescent lamps and fluorescent ballasts), clothes washers and dryers, dishwashers, ranges and ovens, and swimming pool heaters.

87. Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G.17, "Industrial Production and Capacity Utilization" (Washington, DC: February 2011), website www.federalreserve.gov/releases/g17/Current/#NOTICE.

88. S.C. Davis, S.W. Diegel, and R.G. Boundy, *Transportation Energy Databook: Edition 29*, ORNL-6985 (Oak Ridge, TN: July 2010), Chapter 4, "Light Vehicles and Characteristics."

89. The *AEO2011* Reference case does not include the proposed fuel economy standards for heavy-duty vehicles provided in *Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*, published by the EPA and the NHTSA in April 2010, nor does it include increases in fuel economy standards for LDVs, based on the September 2010 EPA/NHTSA Notice of Upcoming Joint Rulemaking to Establish 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and CAFE Standards, because the notice of intent does not propose any new vehicle standards.

90. The factors that influence decisionmaking on capacity additions include electricity demand growth, the need to replace inefficient plants, the costs and operating efficiencies of different generation options, fuel prices, State RPS programs, and the availability of Federal tax credits for some technologies.

91. Unless otherwise noted, the term "capacity" in the discussion of electricity generation indicates utility, nonutility, and CHP capacity. Costs reflect the average of regional costs.

92. For detailed discussion of levelized costs, see U.S. Energy Administration, "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011," website www.eia.gov/forecasts/aeo/electricity_generation.html.

93. Conoco Phillips has recently announced plans to shut down its Alaska facility, which has been exporting small amounts of LNG to Japan for over 40 years. They have a license to export through 2013. This is Alaska's only export facility.

94. See "Potential of offshore crude oil and natural gas resources" in the "Issues in focus" section of this report.

95. U.S. Court of Appeals for the District of Columbia Circuit, "State of North Carolina v. Environmental Protection Agency," No. 05-1244 (Washington, DC: December 23, 2008), website www.epa.gov/airmarkets/progsregs/cair/docs/CAIRRemandOrder.pdf.

Comparison with other projections

Only IHS Global Insight (IHSGI) produces a comprehensive energy projection with a time horizon similar to that of the *Annual Energy Outlook 2011 (AEO2011)*. Other organizations, however, address one or more aspects of the U.S. energy market. The most recent projection from IHSGI, as well as others that concentrate on economic growth, international oil prices, energy consumption, electricity, natural gas, petroleum, and coal, are compared here with the *AEO2011* Reference case.

1. Economic growth

The range of projected economic growth tends to be wider for the earlier years of the projection period and then narrows in the long run, because the group of concepts—such as population, productivity, and labor force growth—that explain long-run growth trends is smaller than the group of variables that affect projections of short-run growth. From 2009 to 2011, projections for the average annual rate of growth of real gross domestic product (GDP) in the United States range from -0.1 percent to 3.0 percent (Table 12).

In the *AEO2011* Reference case, real GDP grows at a 2.4-percent average annual rate over the 2009-2011 period, lower than projected by the Office of Management and Budget (OMB) and the Interindustry Forecasting Project at the University of Maryland (INFORUM); however, not all of those projections have been updated to take account of the faster pace of economic recovery that became evident late in 2010. The *AEO2011* projection of GDP growth is slightly lower than the projections by IHSGI and higher than projection by the Bureau of Labor Statistics (BLS), although the BLS macroeconomic projections are made only every 2 years. In March 2010, the consensus Blue Chip projection was for 3.0-percent average annual growth in GDP from 2009 to 2011.

The range of GDP growth rates narrows over the period from 2011 to 2015, with projections ranging from 3.0 to 4.0 percent per year. The average annual GDP growth of 3.2 percent in the *AEO2011* Reference case from 2011 to 2015 falls in the middle of the range, with the OMB projecting a stronger recovery from the recession. OMB projects average annual GDP growth of 4.0 percent from 2011 to 2015. INFORUM, IHSGI, and the International Energy Agency (IEA) all project growth rates that are below that in the *AEO2011* Reference case.

There are few public or private projections of GDP growth for the United States that extend to 2035. The *AEO2011* Reference case projects 2.7-percent average annual GDP growth from 2009 to 2035, consistent with trends in labor force and productivity growth. IHSGI projects GDP growth averaging 2.7 percent per year from 2009 to 2035, and INFORUM projects lower GDP growth of 2.5 percent over the same period. INFORUM also projects lower growth in productivity and labor force.

Table 12. Projections of average annual economic growth, 2009-2035

	Average annual percentage growth rates	
Projection	2009-2020	2020-2035
AEO2010 (Reference case)	2.8	2.5
AEO2011 (Reference case)	2.8	2.6
IHSGI (August 2010)	2.8	2.6
OMB (January 2011)[a]	3.2	--
CBO (January 2011)[a]	2.8	--
INFORUM (December 2010)	2.8	2.3
Social Security Administration (May 2010)	2.3	2.1
BLS (December 2009)[a]	2.4	--
IEA (2010)[b]	2.0	2.1
Blue Chip Consensus (March 2010)	2.4	--
ExxonMobil	2.6	2.4
ICF Q4 2010 Integrated Energy Outlook	2.8	2.8

-- = not reported.
[a]CBO and OMB forecasts end in 2021, and growth rates cited are for 2009-2021. BLS forecast ends in 2018. ExxonMobil forecast ends in 2030, and growth rates cited are for 2020-2030.
[b]IEA publishes U.S. growth rates for certain intervals: 2008-2020 growth is 2.0 percent, and 2008-2035 growth rate is 2.1 percent.

2. World oil prices

In the *AEO2011* Reference case, world oil prices rise from \$62 per barrel to approximately \$95 per barrel in 2015 and \$108 per barrel in 2020 (Table 13). From 2020 to 2035, prices increase slowly to \$125 per barrel in 2035. This price trend is slightly lower than the trend shown in the *AEO2010* Reference case.

Table 13. Projections of world oil prices, 2015-2035 (2009 dollars per barrel)

Projection	2015	2020	2025	2030	2035
AEO2011 (Reference case)	94.58	108.10	117.54	123.09	124.94
AEO2010 (Reference case)	94.51	109.30	116.12	124.66	134.47
Deutsche Bank	81.06	91.77	99.75	105.39	109.09
ICF Q4 2010 Integrated Energy Outlook	77.86	77.86	77.86	77.86	77.86
INFORUM	90.97	102.25	108.91	117.02	125.07
IEA (current policy scenario)	94.00	110.00	120.00	130.00	135.00
EVA	87.02	91.97	99.71	110.85	--
IHSGI	90.44	86.15	80.17	82.31	--

-- = not reported.

Market volatility and differing assumptions about the future of the world economy are reflected in the range of price projections for both the short term and the long term; however, most projections show prices rising over the entire course of the projection period although slowing after 2025. The other projections range from $78 per barrel to $95 per barrel in 2015, a span of $17 per barrel; and from $78 per barrel to $135 per barrel in 2035, a span of $57 per barrel. The wide range underscores the uncertainty inherent in the projections. The range of the other projections is encompassed in the range of the *AEO2011* Low and High Oil Price cases, from $55 per barrel to $146 per barrel in 2015 and from $50 per barrel to $200 per barrel in 2035.

World oil price measures are, by and large, comparable across projections. EIA reports the price of imported low-sulfur, light crude oil, approximately the same as the West Texas Intermediate (WTI) price widely cited in the trade press as a proxy for world oil prices. The only series that do not report projections in WTI terms are IEA's *World Energy Outlook 2010*, where prices are expressed as the IEA crude oil import price, and INFORUM, where prices are expressed as the average U.S. refiner acquisition cost of imported crude oil.

3. Total energy consumption

Three of the projections, IHSGI, INFORUM, and ExxonMobil, feature consumption by sector. However, to allow comparison with the IHSGI projection, the *AEO2011* Reference case was adjusted to remove coal-to-liquids (CTL) heat and power, biofuels heat and co-products, and natural gas feedstock use. The ExxonMobil projections do not include electricity consumption in the sectoral consumption breakout. Both the IHSGI and INFORUM projections feature higher total energy consumption than *AEO2011*, while ExxonMobil features lower consumption (Table 14).

Both INFORUM and IHSGI have significantly higher projections of electricity consumption than *AEO2011*, which explains much of the difference in the levels of energy consumption among the three projections: the generation of electricity uses approximately three times the amount of energy from fuel as the amount of useful energy provided to end users. In both the INFORUM and IHSGI projections, the electric power sector consumes 10 quadrillion Btu more energy than projected in *AEO2011*. The greater use of electricity, predominantly for more conventional applications, results in higher electricity prices.

None of the electricity projections includes more than modest penetration of electric vehicles in the transportation sector by 2035 (IHSGI projects almost 300 trillion Btu of electricity consumed in the transportation sector in 2035). The ExxonMobil projection for electricity does not detail electricity consumption, but the amount of energy used to generate electricity is at the 2008 level in 2025 and 2030, with electricity producers aggressively switching to natural gas from coal (the amount of coal used by electricity generators ranks third behind natural gas and nuclear in 2030).

Projected commercial and transportation sector electricity consumption in INFORUM is comparable to that in *AEO2011*, but electricity consumption in the residential and industrial sectors in the INFORUM projection grows to a level more than 50 percent above consumption in 2009, much greater than the increase in *AEO2011* (about 20 percent in the residential sector and 10 percent in the industrial sector). Residential and industrial sector electricity consumption in the IHSGI projection also grows faster than in *AEO2011*, but at a somewhat slower rate than in the INFORUM projection. However, commercial sector electricity consumption grows more rapidly in the IHSGI projection than in both the INFORUM and *AEO2011* projections. *AEO2011* includes the consensus agreement to implement one round of appliance standard updates that holds down residential electricity growth, as well as growth in industrial natural gas usage for combined heat and power, which shifts some industrial energy demand from electricity to natural gas.

Despite the much higher level of electricity consumption in the IHSGI projection, projected total energy consumption is only about 1.2 quadrillion Btu higher than in *AEO2011*. The difference is moderated by lower growth in motor gasoline consumption in the transportation sector in the IHSGI forecast. Motor gasoline consumption in the IHSGI projection in 2035 is almost 3 quads lower than in *AEO2011*, however, the lower level of gasoline consumption is partially offset by about one quad higher diesel fuel consumption. The IHSGI projection includes about 3 million more light-duty truck sales in 2035 (but comparable numbers of light-duty car sales) than *AEO2011*.

INFORUM projects higher prices for motor gasoline than *AEO2011* (more than $1 higher in 2035), with more efficient light-duty vehicles (the vehicle stock average is about 1.8 mpg higher in 2035). However, the total stock of vehicles is larger (due mainly to a stock difference in 2009), and they are driven more miles, leading to a higher level of consumption in the INFORUM forecast than shown in *AEO2011*. The ExxonMobil projection has energy use in each sector level or declining from the level in 2008, which leads to lower overall energy consumption than in the *AEO2011* Reference case.

4. Electricity

Table 15 provides a summary of the results from the *AEO2011* Reference case and compares them with the other projections. Electricity sales increase on average by 1.1 percent per year through 2015 in *AEO2011*, reaching 3,811 billion kilowatthours, which is lower than the other projections. Electricity sales in 2015 range from a low of 3,811 billion kilowatthours in *AEO2011* to a high of 4,500 billion kilowatthours in INFORUM. The IHSGI projection of electricity sales, at 4,119 billion kilowatthours in 2015, also projects higher sales than *AEO2011* for the residential and commercial sectors, while industrial sector sales are slightly less than in *AEO2011*. Both IHSGI and INFORUM project higher sales in 2035 than *AEO2011*. In 2035, IHSGI projects sales of 5,551 billion kilowatthours, INFORUM projects 5,935 billion kilowatthours, and *AEO2011* projects 4,483 billion kilowatthours. Although INFORUM does not provide sales by sector, IHSGI projects higher sales than *AEO2011* for all sectors in 2035.

The average retail electricity price in *AEO2011* falls from 9.8 cents per kilowatthour in 2009 to 8.9 cents per kilowatthour in 2015. IHSGI projects a higher average retail price of 10.4 cents per kilowatthour in 2015, consistent with the higher level of demand in that projection. The average retail electricity price remains relatively flat after 2015 in *AEO2011*, rising to only 9.2 cents per kilowatthour in 2035. In comparison, the average retail electricity price increases to 12.9 cents per kilowatthour in the IHSGI projection, again reflecting the much higher level of electricity sales in that projection.

Although the average retail electricity price in the residential sector falls in *AEO2011* from 11.5 cents per kilowatthour in 2009 to 10.6 cents per kilowatthour in 2025 before rising to 10.8 cents per kilowatthour in 2035, it rises steadily in the Energy Ventures Analysis (EVA) and IHSGI projections, to 18.5 cents per kilowatthour and 13.2 cents per kilowatthour in 2025, respectively. The average residential retail electricity price in the INFORUM projection is similar to those in *AEO2011*. The relative patterns of change in retail electricity prices in the commercial and industrial sectors in the *AEO2011*, EVA, IHSGI, and INFORUM projections are similar to those in the residential sector.

The change in total generation and imports of electricity in 2015 is consistent with sales, ranging from 4,286 billion kilowatthours in *AEO2011* to 4,522 billion kilowatthours in the IHSGI projection. The level of generation continues to increase with the growth

Table 14. Projections of energy consumption by sector, 2009-2035 (quadrillion Btu)

Sector	*AEO2011* Reference	INFORUM	IHSGI	Exxon-Mobil	*AEO2011* Reference	INFORUM	IHSGI	Exxon-Mobil
	2009				2015			
Residential	11.1	11.6	10.6	--	11.0	12.3	11.2	--
Residential excluding electricity	6.5	6.6	6.0	6.0	6.4	6.4	5.9	6.0
Commercial	8.5	8.4	8.4	--	9.0	9.0	9.0	--
Commercial excluding electricity	4.0	3.9	3.8	3.6	4.2	4.0	3.7	3.5
Industrial	21.8	22.3	--	--	26.7	25.1	--	--
Industrial excluding electricity	18.8	19.3	--	19.0	23.2	21.6	--	18.0
Losses[a]	0.7	--	--	--	0.9	--	--	--
Natural gas feedstocks	0.5	--	--	--	0.6	--	--	--
Industrial removing losses and feedstocks	20.6	--	20.0	--	25.2	--	21.4	--
Transportation	27.2	27.0	26.2	27.0	28.5	28.5	27.1	28.0
Electric power	38.3	40.2	39.7	36.0	39.7	45.4	44.6	37.0
Less: electricity demand[b]	12.2	12.6	12.2	--	13.0	14.5	14.1	--
Total primary energy	**94.8**	**96.9**	**--**	**91.0**	**102.0**	**105.9**	**--**	**92.0**
Excluding: losses and feedstocks[a]	**93.6**	--	**92.7**	--	**100.5**	--	**99.2**	--
	2025				2035			
Residential	11.3	13.8	12.1	--	11.7	14.4	12.8	--
Residential excluding electricity	6.3	6.5	5.8	5.0	6.2	6.5	5.7	--
Commercial	9.9	10.0	9.8	--	11.1	11.0	10.8	--
Commercial excluding electricity	4.4	4.2	3.6	3.5	4.6	4.5	3.5	--
Industrial	28.1	28.6	--	--	28.9	30.8	--	--
Industrial excluding electricity	24.6	24.3	--	17.0	25.6	26.0	--	--
Losses[a]	2.3	--	--	--	3.7	--	--	--
Natural gas feedstocks	0.6	--	--	--	0.5	--	--	--
Industrial removing losses and feedstocks	25.2	--	21.9	--	24.7	--	22.3	--
Transportation	29.6	30.2	27.4	27.0	31.8	32.6	28.2	--
Electric power	43.2	54.0	50.4	38.0	46.0	58.4	56.0	--
Less: electricity demand[b]	14.1	17.5	16.6	--	15.3	19.3	18.9	--
Total primary energy	**108.0**	**119.1**	**--**	**92.0**	**114.2**	**128.0**	**--**	**--**
Excluding: losses and feedstocks[a]	**105.1**	--	**105.1**	--	**110.0**	--	**111.2**	--

-- = not reported.
[a]Losses in CTL and biofuel production.
[b]Energy consumption in the sectors includes electricty demand purchases from the electric power sector, which are subtracted to avoid double counting in deriving total primary energy consumption.

Table 15. Comparison of electricity projections, 2015, 2025, and 2035 (billion kilowatthours, except where noted)

Projection	2009	*AEO2011* Reference case	Other projections EVA	IHSGI	ICF	INFORUM
		2015				
Average end-use price (2009 cents per kilowatthour)	9.8	8.9	--	10.4	--	--
Residential	11.5	10.9	13.4	12.0	--	11.5
Commercial	10.1	9.1	12.1	10.9	--	10.1
Industrial	6.8	6.0	8.4	7.1	--	6.8
Total generation plus imports	**4,015**	**4,286**	**4,072**	**4,522**	**4,380**	**--**
Coal	1,772	1,799	1,748	1,905	--	--
Oil	41	43	--	42	--	--
Natural gas[a]	931	1,000	944	1,159	--	--
Nuclear	799	839	850	831	--	--
Hydroelectric/other[b]	437	572	530	586	--	--
Net imports	34	33	--	23	--	--
Electricity sales	3,574	3,811	3,825	4,119	--	4,500
Residential	1,363	1,348	1,489	1,556	--	--
Commercial/other[c]	1,323	1,416	1,419	1,528	--	--
Industrial	882	1,038	917	1,036	--	--
Capability, including CHP (gigawatts)[d]	1,033	1,075	1,061	1,101	1,009	--
Coal	317	322	296	318	297	--
Oil and natural gas	467	469	505	477	423	--
Nuclear	101	106	106	105	105	--
Hydroelectric/other	149	179	155	200	184	--
		2025				
Average end-use price (2009 cents per kilowatthour)	9.8	8.9	--	11.5	--	--
Residential	11.5	10.6	18.5	13.2	--	11.8
Commercial	10.1	9.1	17.1	12.0	--	10.4
Industrial	6.8	6.1	13.0	7.8	--	7.0
Total generation plus imports	**4,015**	**4,704**	**4,144**	**5,282**	**5,060**	**--**
Coal	1,772	2,069	1,603	1,689	--	--
Oil	41	44	--	43	--	--
Natural gas[a]	931	1,003	942	1,756	--	--
Nuclear	799	877	965	1,000	--	--
Hydroelectric/other[b]	437	689	635	794	--	--
Net imports	34	22	--	23	--	--
Electricity sales	3,574	4,142	3,873	4,856	--	5,390
Residential	1,363	1,461	1,595	1,881	--	--
Commercial/other[c]	1,323	1,636	1,615	1,835	--	--
Industrial	882	1,031	664	1,139	--	--
Capability, including CHP (gigawatts)[d]	1,033	1,119	1,065	1,282	1,173	--
Coal	317	326	278	304	261	--
Oil and natural gas	467	489	479	574	579	--
Nuclear	101	111	120	125	108	--
Hydroelectric/other	149	194	188	279	226	--

-- = not reported.
See notes at end of table.

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in sales. In 2035, the total electricity supply from generation plus imports ranges from 5,181 billion kilowatthours in *AEO2011* to 6,025 billion kilowatthours in the IHSGI projection, over 16 percent higher than in *AEO2011*.

AEO2011 projects more coal-fired generation in 2035 than IHSGI—2,218 billion kilowatthours compared with 1,487 billion kilowatthours. The difference in the IHSGI projection, which includes greater electricity demand, is made up by increased generation primarily from natural gas but also from nuclear and hydroelectric/other energy sources. While *AEO2011* shows 1,288 billion kilowatthours of natural-gas-fired generation in 2035, IHSGI shows 2,261 billion kilowatthours. Nuclear generation in 2035 totals 874 billion kilowatthours in *AEO2011*, compared with 1,163 billion kilowatthours in the IHSGI projection, and hydroelectric/other generation in 2035 is 740 billion kilowatthours in *AEO2011*, compared with 1,069 billion kilowatthours in the IHSGI projection.

The mix of generating capability by fuel is relatively similar across the projections in 2015. By 2025, however, the mix of generating capacity begins to change, due to variations in the projected rates of growth in electricity demand and more aggressive retirements of coal capacity in the EVA and ICF International (ICF) projections. Although little coal-fired capacity is retired in the IHSGI projection by 2025, the greater growth in electricity demand is met by a sharp increase in natural gas and hydroelectric/other capacity. Natural-gas- and oil-fired capacity in 2025 totals 574 gigawatts in the IHSGI projection, compared with 489 gigawatts in *AEO2011*. While the ICF projection shows less growth in demand, it shows more retirements of coal capacity by 2025. As a result, ICF shows the highest level of natural-gas- and oil-fired capacity in 2025, at 579 gigawatts.

The faster growth in natural gas and hydroelectric/other capacity continues through 2035 in the IHSGI and ICF projections. Natural-gas- and oil-fired capacity reaches 675 gigawatts and 655 gigawatts in 2035 in the IHSGI and IFC projections, respectively. By comparison, natural-gas- and oil-fired capacity grows to only 572 gigawatts in *AEO2011* in 2035. Hydroelectric/other capacity continues to grow in each of the three projections after 2025, to 384 gigawatts and 297 gigawatts in the IHSGI and ICF projections,

Table 15. Comparison of electricity projections, 2015, 2025, and 2035 (billion kilowatthours, except where noted) (continued)

Projection	2009	*AEO2011* Reference case	Other projections			
			EVA	IHSGI	ICF	INFORUM
		2035				
Average end-use price (2009 cents per kilowatthour)	9.8	9.2	--	12.9	--	--
Residential	11.5	10.8	--	14.8	--	12.6
Commercial	10.1	9.2	--	13.5	--	11.1
Industrial	6.8	6.4	--	8.7	--	7.4
Total generation plus imports	**4,015**	**5,181**	**--**	**6,025**	**5,601**	**--**
Coal	1,772	2,218	--	1,487	--	--
Oil	41	46	--	45	--	--
Natural gas[a]	931	1,288	--	2,261	--	--
Nuclear	799	874	--	1,163	--	--
Hydroelectric/other[b]	437	740	--	1,069	--	--
Net imports	34	14	--	23	--	--
Electricity sales	3,574	4,483	--	5,551	--	5,935
Residential	1,363	1,613	--	2,187	--	--
Commercial/other[c]	1,323	1,886	--	2,139	--	--
Industrial	882	962	--	1,225	--	--
Capability, including CHP (gigawatts)[d]	1,033	1,221	--	1,498	1,346	--
Coal	317	334	--	292	287	--
Oil and natural gas	467	572	--	675	655	--
Nuclear	101	111	--	147	108	--
Hydroelectric/other	149	205	--	384	297	--

-- = not reported.
[a]Includes supplemental gaseous fuels. For EVA, represents total oil and natural gas.
[b]"Other" includes conventional hydroelectric, pumped storage, geothermal, wood, wood waste, municipal waste, other biomass, solar and wind power, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, petroleum coke, and miscellaneous technologies.
[c]"Other" includes sales of electricity to government, railways, and street lighting authorities.
[d]EIA capacity is net summer capability, including CHP plants. IHSGI capacity is nameplate, excluding cogeneration plants.

respectively, compared with 205 gigawatts in *AEO2011*. The IHSGI projection shows the most growth in U.S. nuclear power capacity, to 147 gigawatts in 2035, compared with 111 gigawatts in *AEO2011*. ICF shows 108 gigawatts of nuclear capacity in 2035.

Environmental regulations are an important factor in the selection of technologies for electricity generation. While complete information on the regulations assumed in each of the projection is not available. *AEO2011* includes only current laws and regulations; it does not assume a cap or tax on carbon dioxide (CO_2) emissions. Restrictions on CO_2 emissions could change the mix of technologies used to generate electricity.

5. Natural gas

The variation among published projections of natural gas consumption, production, imports, and prices (Table 16) can be significant. It results from differences in the assumptions that underlie the projections. For example, the natural gas projection in the *AEO2011* Reference case assumes, for the most part, that current laws and regulations will continue through the projection period, whereas other natural gas projections may include anticipated policy developments over the next 25 years. In particular, *AEO2011* does not assume the implementation of regulations limiting CO_2 emissions or other types of emissions beyond those already in effect.

Each of the projections examined here shows an increase in overall natural gas consumption from 2009 to 2035, with the ICF and IHSGI projections having the most significant increases, at 43 percent and 41 percent, respectively. Total natural gas consumption in the INFORUM and ExxonMobil projections remains flat from 2009 to 2015 but grows to a level comparable with those in the *AEO2011*, Deutsche Bank (DB), and EVA projections in 2025. In the later years of all the projections, total natural gas consumption grows despite increasing natural gas prices, with the exception of the DB projection, which shows a decline in consumption from 2025 to 2035. Total natural gas consumption in 2035 in the ICF and IHSGI projections is about 30 percent higher than in the DB projection, which shows the lowest level of total natural gas consumption.

The ICF, ExxonMobil, and IHSGI projections for natural gas consumption by electricity generators are significantly different from the other projections. In 2035, IHGSI is more than double the lowest projection, the *AEO2011* Reference case. *AEO2011*, DB, EVA, and INFORUM show similar projections of natural gas consumption for the electricity generation sector, with annual growth rates of 1 percent across the projection period; the ICF, ExxonMobil, and IHSGI projections show 3-percent annual growth. The slow growth in *AEO2011* reflects slow growth for electricity generation due to the construction of planned coal, renewable, and nuclear capacity builds.

Industrial natural gas consumption varies greatly across the different projections. ICF, INFORUM, EVA, and the *AEO2011* Reference case show growing industrial natural gas consumption throughout the projection period. Industrial natural gas consumption in *AEO2011*, however, increases by 31 percent from 2009 to 2015 and then levels off for the remainder of the projection, whereas in the other projections it grows more steadily. The growth in industrial natural gas consumption in *AEO2011* is attributable to relatively low industrial natural gas prices, a strong increase in natural gas use in combined heat and power plants, and a significant increase in the use of natural gas as a feedstock in the chemical and hydrogen industries. Industrial natural gas consumption remains constant in the ExxonMobil projection throughout the projection period, while industrial natural gas consumption in the IHSGI and DB projections increases initially, then declines from 2015 to 2035. The projections of industrial natural gas consumption in 2035 range from 36 percent above the 2009 level (INFORUM) to 11 percent below the 2009 level (DB).

The basic consumption patterns and levels of natural gas consumption are relatively similar across the residential sector projections, with the exception of DB. (It should be noted that ExxonMobil's projection for residential consumption includes commercial consumption.) Residential sector natural gas consumption in the DB projection increases steadily, growing to 26 percent above the 2009 level in 2035. Three of the six projections (INFORUM, *AEO2011*, and EVA) show relatively similar growth in commercial consumption in the projection period. The projections of commercial natural gas consumption in the ICF, DB and IHSGI projections are initially similar to the other projections, but demand eventually declines, resulting in 2035 projections of commercial natural gas consumption that are below 2009 levels. (INFORUM's 2009 commercial consumption level is 3.68 trillion cubic feet, significantly higher than the others.) The DB projection includes the most significant decline, falling to 23 percent below 2009 levels in 2035.

With the exception of the DB and INFORUM projections for the period after 2025, all the projections show growing domestic natural gas production throughout the projection period, although at different rates. The greatest growth in natural gas production is in the ICF projection, and the lowest is in the INFORUM projection. Natural gas production in the ICF projection exceeds that in the INFORUM projection by 28 percent in 2025. With significant declines in net pipeline imports, ICF and the *AEO2011* Reference case project strong increases in the domestic production share of total natural gas supply. The rest of the projections show domestic natural gas production maintaining a relatively stable share of total natural gas supply, with the exception of the DB projection, where domestic production drops off notably in 2035 with a big increase in LNG imports. In all the other projections, net LNG imports remain well under 1 trillion cubic feet throughout the projection period. Some of the projections show declines in net pipeline imports relative to the 2009 level. The exception is IHSGI, which shows increasing net pipeline imports after 2015, following an initial dip. In comparison with EVA and DB, the *AEO2011* and ICF projections show severe declines in pipeline imports.

Table 16. Comparison of natural gas projections, 2015, 2025, and 2035 (trillion cubic feet, except where noted)

Projection	2009	*AEO2011* Reference case	Other projections: IHSGI	EVA	DB	ICF	ExxonMobil	INFORUM
					2015			
Dry gas production[a]	20.96	22.43	22.70	22.70	21.98	23.75	21.00	21.21
Net imports	**2.64**	**2.69**	**2.19**	**2.60**	**3.01**	**1.68**	**1.60**	**--**
Pipeline	2.23	2.33	1.46	2.20	1.53	1.26	--	--
LNG	0.41	0.36	0.73	0.40	1.48	0.42	--	--
Consumption	**22.71**	**25.11**	**24.89**	**24.70**	**25.17**	**25.30**	**23.00**[b]	**21.20**[c]
Residential	4.75	4.81	4.72	4.90	5.10	5.11	8.00[d]	4.67
Commercial	3.11	3.38	3.05	3.20	3.25	3.20	--	3.86
Industrial[e]	6.14	8.05	6.64	6.90	6.70	6.88	7.00	7.06
Electricity generators[f]	6.89	6.98	8.58	7.60	8.01	7.81	8.00	5.61
Others[g]	1.82	1.90	1.90	2.10	2.11	2.29	0.00[h]	--
Lower 48 wellhead price (2009 dollars per thousand cubic feet)	3.71	4.24	4.74	5.13	4.66	5.29	--	--
End-use prices (2009 dollars per thousand cubic feet)								
Residential	12.20	10.39	11.85	--	--	9.76	--	--
Commercial	9.94	8.60	10.00	--	--	8.77	--	--
Industrial[i]	5.39	5.10	7.18	--	--	6.59	--	--
Electricity generators	4.94	4.79	5.49	--	--	6.27	--	--
					2025			
Dry gas production[a]	20.96	23.98	26.22	24.70	23.48	29.04	24.00	22.67
Net imports	**2.64**	**1.08**	**2.74**	**2.00**	**2.20**	**1.31**	**2.00**	**--**
Pipeline	2.23	0.74	2.01	1.60	1.55	0.68	--	--
LNG	0.41	0.34	0.73	0.40	0.66	0.63	--	--
Consumption	**22.71**	**25.07**	**28.87**	**25.70**	**25.69**	**30.28**	**26.10**[b]	**24.84**[c]
Residential	4.75	4.83	4.62	5.00	5.52	5.20	7.00[d]	4.84
Commercial	3.11	3.56	2.98	3.30	3.25	3.04	--	4.13
Industrial[e]	6.14	8.10	6.47	7.50	6.70	7.21	7.00	7.88
Electricity generators[f]	6.89	6.66	12.64	7.70	8.21	12.18	12.00	7.99
Others[g]	1.82	1.92	2.17	2.20	2.01	2.65	0.10[h]	--
Lower 48 wellhead price (2009 dollars per thousand cubic feet)	3.71	5.43	4.73	6.46	7.15	6.10	--	--
End-use prices (2009 dollars per thousand cubic feet)								
Residential	12.20	12.15	11.59	--	--	10.47	--	--
Commercial	9.94	10.03	9.81	--	--	9.52	--	--
Industrial[i]	5.39	6.33	7.09	--	--	7.35	--	--
Electricity generators	4.94	5.91	5.43	--	--	7.09	--	--

-- = not reported.
See notes at end of table.

(continued on page 99)

Table 16. Comparison of natural gas projections, 2015, 2025, and 2035 (trillion cubic feet, except where noted) (continued)

Projection	2009	*AEO2011* Reference case	IHSGI	EVA	DB	ICF	ExxonMobil	INFORUM
					2035			
Dry gas production[a]	20.96	26.32	28.67	--	21.02	31.92	--	20.59
Net imports	**2.64**	**0.18**	**3.44**	**--**	**3.71**	**0.75**	**--**	**--**
Pipeline	2.23	0.04	2.70	--	1.57	-0.13	--	--
LNG	0.41	0.14	0.75	--	2.14	0.87	--	--
Consumption	**22.71**	**26.55**	**32.06**	**--**	**24.73**	**32.64**	**--**	**27.50**[c]
Residential	4.75	4.78	4.57	--	5.98	5.13	--	4.92
Commercial	3.11	3.82	2.93	--	2.39	2.85	--	4.44
Industrial[e]	6.14	8.02	6.23	--	5.47	7.61	--	8.06
Electricity generators[f]	6.89	7.88	15.94	--	9.07	14.20	--	10.08
Others[g]	1.82	2.07	2.39	--	1.82	2.84	--	--
Lower 48 wellhead price (2009 dollars per thousand cubic feet)	3.71	6.42	4.88	--	8.59	6.52	--	--
End-use prices (2009 dollars per thousand cubic feet)								
Residential	12.20	13.76	11.53	--	--	10.67	--	--
Commercial	9.94	11.28	9.80	--	--	9.78	--	--
Industrial[i]	5.39	7.40	7.13	--	--	7.77	--	--
Electricity generators	4.94	6.97	5.55	--	--	7.47	--	--

-- = not reported.
[a]Does not include supplemental fuels.
[b]Does not include lease, plant, and pipeline fuel.
[c]Does not include lease, plant, and pipeline fuel and fuel consumed in natural gas vehicles.
[d]Natural gas consumed in the residential and commercial sectors.
[e]Includes consumption for industrial combined heat and power (CHP) plants and a small number of industrial electricity-only plants, and natural gas-to-liquids heat/power and production; excludes consumption by nonutility generators.
[f]Includes consumption of energy by electricity-only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes electric utilities, small power producers, and exempt wholesale generators.
[g]Includes lease, plant, and pipeline fuel and fuel consumed in natural gas vehicles.
[h]Fuel consumed in natural gas vehicles.
[i]The 2009 industrial natural gas price for IHSGI is $6.62.

The *AEO2011* Reference case, EVA, and ICF all show similar natural gas production and price levels that increase over time. In contrast, DB projects lower but more stable production levels, with greater price increases; and IHSGI projects stronger growth in natural gas production than *AEO2011*, EVA, and ICF, with lower and more stable prices.

Only three of the projections provide delivered natural gas prices for comparison: the *AEO2011* Reference case, ICF, and IHSGI. However, the ICF and IHSGI price projections are difficult to compare with the *AEO2011* prices because of apparent definitional differences. In the ICF projection, end-use sector prices for the 2009 base year are very different from those in the *AEO2011* and IHSGI projections. Further, the IHSGI industrial delivered natural gas price is difficult to compare. The IHSGI industrial delivered natural gas price in 2009 is $1.23 higher than the 2009 price in *AEO2011* and $1.35 higher than the 2009 price in the ICF projection (all prices in 2009 dollars per thousand cubic feet). The *AEO2011* historical delivered industrial natural gas price is based on the Manufacturing-Industrial Energy Production Survey (rather than EIA's *Natural Gas Monthly*, which represents prices paid to local distribution companies by industrial customers). To put the prices on a more common basis, price margins (the difference between delivered prices and average wellhead prices) can be compared.

For the residential and commercial sectors, each of the projections shows an initial decline in natural gas price margins from 2009 levels. The margins in the *AEO2011* Reference case, however, recover 86 percent of the decline from the 2009 level by 2035, while the ICF and IHSGI margins continue declining throughout the projection period at relatively similar rates. The increase in residential and commercial margins in *AEO2011* is attributable to a significant decline in consumption per customer. From 2015 forward, the projected industrial margins are relatively stable in all three projections, although at significantly different levels. The *AEO2011* and IHSGI natural gas price margins for the electricity sector are similar, with IHSGI showing slightly higher margins; however, those in the ICF projection range from 31 to 106 percent higher than the margins in the other projections from 2015 to 2035.

6. Liquid fuels

In the *AEO2011* Reference case, the U.S. imported refiner's acquisition cost (RAC) for crude oil (in 2009 dollars) increases to $86.83 per barrel in 2015, $107.40 barrel in 2025, and $113.70 per barrel in 2035 (Table 17). Prices are lower in all years in the DB, ICF, and IHSGI projections, ranging from $70 per barrel to $106 per barrel in 2035. In fact, the IHSGI price in 2035 is 9 percent lower than the 2015 price. The ICF price remains steady at $70 per barrel over the entire projection. The prices in the INFORUM projection are slightly higher in 2025 and 2035, reaching $125 per barrel in 2035. Purvin & Gertz (P&G) did not provide a projection of RAC prices.

Domestic crude oil production increases by 11 percent from 2009 to 2035 in the *AEO2011* projection. The INFORUM projection shows production varying within a slightly wider band but remaining at a lower overall level than in *AEO2011*. DB, IHSGI, and P&G all project decreasing domestic crude production. DB's projection for 2035 is 40 percent lower than the *AEO2011* projection, and IHSGI's is 43 percent lower. In the *AEO2011* Reference case, total net imports of crude oil and petroleum products in 2035 are 9 percent lower than in 2009, consistent with projected increases in domestic production of crude oil. IHSGI and INFORUM both project higher total net imports in 2035.

Prices for motor gasoline prices and diesel fuel increase steadily through 2035 in the *AEO2011* projection. INFORUM also projects rising prices but at a faster rate than in *AEO2011*. IHSGI projects decreasing prices. Biofuels supply is listed separately only in the *AEO2011* Reference case and in the P&G projection. In *AEO2011*, biofuels supply increases steadily through 2035 in response to the Renewable Fuels Standard mandate. In the P&G projection, biofuel supply remains steady. Total product demand, including both petroleum products and biofuels, is similar in the *AEO2011* and P&G projections.

7. Coal

The coal projections provided by DB, EVA, ICF, INFORUM, and Wood Mackenzie (WM) present interesting contrasts with the *AEO2011* Reference case. Only *AEO2011* and INFORUM show growth in coal consumption; the other projections show declines ranging between 10 percent and 38 percent from 2009 levels by the end of their respective projection horizons.

Of the six coal projections, only ICF and WM explicitly state that they include a price on carbon. In the ICF projection, coal consumption in 2015 (before implementation of the carbon price) is 3 percent higher than projected in *AEO2011*. In 2025, however, coal consumption in the ICF projection is 19 percent lower than ICF's projection for 2015 and 27 percent lower than the *AEO2011* projection for 2025 (on a Btu basis); this difference is most likely attributable to inclusion of the carbon price in 2025 along with other assumed regulations affecting coal use that are specified in the notes for Table 18. In 2030 and 2035, ICF's outlook for coal consumption is the lowest of the projections.

For most years, the WM projection shows less coal consumption and production than in the *AEO2011* projection, consistent with the impact of a carbon price. The WM projection also showed a decline in regional coal production, again consistent with the assumed carbon price. Coal production both east and west of the Mississippi declines in 2025 relative to 2015 in the WM projection. In 2030, total coal production (excluding coking coal) in the WM projection is 27 percent lower than in the *AEO2011* projection. (WM provides projections only for thermal coal, thus excluding coking coal, which is used in steelmaking. In 2009, coking coal production occurred only in the East, and it accounted for 11 percent of eastern coal production.)

Excluding coking coal, the average minemouth price of coal per ton in 2015 in the WM projection is 19 percent higher than the corresponding price in the *AEO2011* projection. The price difference narrows after 2015, however, and in 2030 the *AEO2011* and WM prices are nearly identical, despite very different coal production outlooks. The WM projection has generally lower production levels than the *AEO2011* projection throughout the period, implying that WM includes higher production costs.

The *AEO2011* and WM projections show similar levels of eastern coal production (excluding coking coal) in 2030, differing by only 0.5 percent, which is noteworthy given the carbon price assumption in the WM projection. It appears that production west of the Mississippi falls more (in terms of tonnage) in the WM projection as a result of the carbon price, but the regional shares of total production remain constant over the projection. Coal production east of the Mississippi (excluding coking coal) represents 38 to 39 percent of total production in all years in the WM projection, consistent with the historical share, but in the *AEO2011* projection coal production east of the Mississippi falls to a 28-percent share in 2030. In *AEO2011*, more favorable pricing of western coal than eastern coal facilitates growth in western coal's share of total production.

Steam coal exports fall to only 8 million tons in 2015 in the WM projection, a decline of 63 percent from 2009 levels, and then exceed 2009 levels by 2025. While steam coal exports show modest gains after 2015, they never reach the higher levels seen in 2008. In contrast, steam coal exports in the *AEO2011* projection vary little, ranging between 18 and 20 million tons from 2009 to 2035 and remaining well below the volumes exported in 2008.

In the INFORUM projection, coal exports total 177 million tons in 2035, the equivalent of about 11 percent of total U.S. production in 2035 and 64 million tons higher than the historical record set in 1981. Total coal exports in 2035 in the INFORUM case are more than double the total in the *AEO2011* projection. Imports are also notably higher in the INFORUM projection, at 113 million tons in 2035—triple the highest historical level of U.S. imports.

Although ICF does not explicitly provide a coal export projection, coal consumption (in Btu) declines at a far faster rate than coal production (provided in tons only), implying strong growth in exports. For example, from 2015 to 2025, coal production east of the Mississippi—historically, where most U.S. coal exports originate—rises by nearly 100 million tons; and while total coal production falls by 4 percent (47 million tons), coal consumption (in Btu) declines by a much larger 19 percent. The gap between production and consumption closes somewhat by 2035, with production 29 percent lower and consumption 39 percent lower than ICF's projection for 2015. EVA also projects strong coal exports that remain in the range of 80 million tons, similar to 2008 export levels, for the projection years shown. In the *AEO2011* Reference case, exports hover in the 70 million ton range.

Table 17. Comparison of liquids projections, 2015, 2025, and 2035 (million barrels per day, except where noted)

Projection	2009	*AEO2011* Reference case	Other projections: DB	ICF	IHSGI	INFORUM	P&G
		2015					
Average U.S. imported RAC (2009 dollars per barrel)	59.04	86.83	78.22	70.00	85.02	90.97	--
Domestic production	5.36	5.81	5.52	--	4.89	5.33	4.62
Total net imports	**9.72**	**9.85**	**--**	**--**	**10.25**	**10.26**	**11.19**
Crude oil	8.97	8.70	8.30	--	9.61	8.86	11.07
Petroleum products	0.75	1.14	--	--	0.64	1.41	0.12
Liquids demand	18.81	20.44	--	--	--	--	20.63
Net import share of petroleum demand (percent)	52	49	--	--	--	--	54
Biofuel supply	0.76	1.12	--	--	--	--	0.90
Product prices (2009 dollars per gallon)							
Gasoline	2.349	3.13	--	--	3.01	3.74	--
Diesel	2.441	3.08	--	--	3.12	3.55	--
		2025					
Average U.S. imported RAC (2009 dollars per barrel)	59.04	107.40	96.43	70.00	78.36	108.91	--
Domestic production	5.36	5.88	4.48	--	3.68	5.77	3.56
Total net imports	**9.72**	**9.06**	**--**	**--**	**11.27**	**10.47**	**12.06**
Crude oil	8.97	8.25	8.46	--	10.40	8.80	11.63
Petroleum products	0.75	0.81	--	--	0.87	1.66	0.43
Liquids demand	18.81	20.99	--	--	--	--	20.77
Net import share of petroleum demand (percent)	52	44	--	--	--	--	58
Biofuel supply	0.76	1.92	--	--	--	--	0.92
Product prices (2009 dollars per gallon)							
Gasoline	2.349	3.54	--	--	2.69	4.23	--
Diesel	2.441	3.73	--	--	2.83	3.84	--
		2035					
Average U.S. imported RAC (2009 dollars per barrel)	59.04	113.70	106.36	70.00	77.37	125.07	--
Domestic production	5.36	5.95	3.57	--	3.38	5.73	--
Total net imports	**9.72**	**8.89**	**--**	**--**	**11.54**	**10.62**	**--**
Crude oil	8.97	8.25	7.24	--	11.02	8.76	--
Petroleum products	0.75	0.64	--	--	0.52	1.86	--
Liquids demand	18.81	21.93	--	--	--	--	--
Net import share of petroleum demand (percent)	52	42	--	--	--	--	--
Biofuel supply	0.76	2.48	--	--	--	--	--
Product prices (2009 dollars per gallon)							
Gasoline	2.349	3.71	--	--	2.53	4.87	--
Diesel	2.441	3.89	--	--	2.61	4.48	--

-- = not reported.

Table 18. Comparison of coal projections, 2015, 2025, 2030, and 2035 (million short tons, except where noted)

Projection	2009	*AEO2011* Reference case	*AEO2011* Reference case (thermal coal only)[a]	Other projections: DB	EVA	ICF[b, c]	INFORUM	WM (thermal coal only)[b, d]
				2015				
Production	**1,075**	**1,040**	**969**	--	**1,060**	**1,150**	**1,321**	**1,111**
East of the Mississippi	450	387	319	--	413	505	--	423
West of the Mississippi	625	653	650	--	646	645	--	688
Consumption								
Electric power	937	928	928	--	929	--	--	--
Coke plants	15	22	--	--	18	--	--	--
Coal-to-liquids	0	11	11	--	0	--	--	--
Other industrial/buildings	49	52	52	--	49	--	--	--
Total consumption (quadrillion Btu)[e]	**19.69**	**19.73**	**19.14**	**19.66**		**20.33**	--	--
Total consumption (million short tons)	**1,000**	**1,013**	**991**	--	**996**	--	**1,252[f]**	**1,123[f]**
Net coal exports	**38**	**40**	**-9**	--	**73**	--	**69**	**-12**
Exports	59	70	20	--	85	--	107	8
Imports	21	30	29	--	13	--	38	20
Minemouth price								
2009 dollars per ton	33.26	32.36	27.53	--	--	32.14	57.05	32.85
2009 dollars per Btu	1.67	1.62	1.41	--	--	1.48	--	1.67
Average delivered price to electricity generators								
2009 dollars per ton	43.48	40.94	40.94	--	--	--	--	51.64
2009 dollars per Btu	2.20	2.11	2.11	--	--	2.15	--	2.63
				2025				
Production	**1,075**	**1,188**	**1,111**	--	**980**	**1,103**	**1,538**	**985**
East of the Mississippi	450	406	333	--	363	600	--	370
West of the Mississippi	625	782	778	--	616	503	--	615
Consumption								
Electric power	937	1,066	1,066	--	857	--	--	--
Coke plants	15	21	--	--	14	--	--	--
Coal-to-liquids	0	44	44	--	0	--	--	--
Other industrial/buildings	49	51	51	--	40	--	--	--
Total consumption (quadrillion Btu)[e]	**19.69**	**22.61**	**22.06**	**18.7**	--	**16.48**	--	--
Total consumption (million short tons)	**1,000**	**1,182**	**1,161**	--	**910**	--	**1,463[f]**	**978[f]**
Net coal exports	**38**	**19**	**-37**	--	**71**	--	**75**	**7**
Exports	59	75	18	--	83	--	138	33
Imports	21	56	55	--	12	--	63	26
Minemouth price								
2009 dollars per ton	33.26	33.22	27.92	--	--	33.95	63.29	30.09
2009 dollars per Btu	1.67	1.68	1.45	--	--	1.55	--	1.54
Average delivered price to electricity generators								
2009 dollars per ton	43.48	43.33	43.33	--	--	--	--	50.12
2009 dollars per Btu	2.20	2.24	2.24	--		2.04	--	2.57

-- = not reported.
See notes at end of table.

(continued on page 103)

Table 18. Comparison of coal projections, 2015, 2025, 2030, and 2035 (million short tons, except where noted) (continued)

Projection	2009	*AEO2011* Reference case	*AEO2011* Reference case (thermal coal only)[a]	Other projections: DB	EVA	ICF[b, c]	INFORUM	WM (thermal coal only)[b, d]
				2030				
Production	**1,075**	**1,252**	**1,180**	--	**962**	**916**	**1,591**	**862**
East of the Mississippi	450	402	335	--	353	500	--	337
West of the Mississippi	625	850	845	--	609	416	--	525
Consumption								
Electric power	937	1094	1094	--	847	--	--	--
Coke plants	15	20	--	--	12	--	--	--
Coal-to-liquids	0	82	82	--	0	--	--	--
Other industrial/buildings	49	51	51	--	36	--	--	--
Total consumption (quadrillion Btu)[e]	**19.69**	**23.39**	**22.88**	**18.23**		**13.85**	--	--
Total consumption (million short tons)	**1,000**	**1,247**	**1,227**	--	**895**	--	**1,517[f]**	**855[f]**
Net coal exports	**38**	**20**	**-33**	--	**69**	--	**74**	**7**
Exports	59	74	20	--	81	--	156	33
Imports	21	54	53	--	12	--	82	26
Minemouth price								
2009 dollars per ton	33.26	33.25	28.47	--		34.54	73.37	28.86
2009 dollars per Btu	1.67	1.69	1.48	--		1.58	--	1.48
Average delivered price to electricity generators								
2009 dollars per ton	43.48	44.63	44.63	--		--	--	48.41
2009 dollars per Btu	2.20	2.32	2.32	--		1.99	--	2.48
				2035				
Production	**1,075**	**1,319**	**1,252**	--		**822**	**1,632**	--
East of the Mississippi	450	415	354	--		464	--	--
West of the Mississippi	625	904	898	--		359	--	--
Consumption								
Electric power	937	1119	1119	--		--	--	--
Coke plants	15	18	--	--		--	--	--
Coal-to-liquids	0	128	128	--		--	--	--
Other industrial/buildings	49	50	50	--		--	--	--
Total consumption (quadrillion Btu)[e]	**19.69**	**24.30**	**23.83**	**17.78**		**12.30**	--	--
Total consumption (million short tons)	**1,000**	**1,315**	**1,297**	--		--	**1,568[f]**	--
Net coal exports	**38**	**18**	**-31**	--		--	**64**	--
Exports	59	71	21	--		--	177	--
Imports	21	53	52	--		--	113	--
Minemouth price								
2009 dollars per ton	33.26	33.92	29.68	--		36.73	79.43	--
2009 dollars per Btu	1.67	1.73	1.54	--		1.67	--	--
Average delivered price to electricity generators								
2009 dollars per ton	43.48	46.36	46.36	--		--	--	--
2009 dollars per Btu	2.20	2.40	2.40	--		1.97	--	--

[a]Excludes coking coal for all data items to facilitate comparison with Wood Mackenzie projections.
[b]ICF includes a carbon price beginning in 2018.
WM includes a carbon price beginning in 2016.
[c]Aside from a price on carbon, the ICF projection also differs from *AEO2011* by representing certain proposed regulations, including Maximum Achievable Control Standards for Hazardous Air Pollutants, regulations for cooling water intake structures under Section 316(b) of the Clean Water Act, and regulations for coal combustion residuals under the authority of the Resource Conservation and Recovery Act. ICF represents the Clean Air Transport Rule, whereas *AEO2011* represents the Clean Air Interstate Rule.
[d]Wood Mackenzie projections exclude coking coal for all data items.
[e]For *AEO2011*, excludes coal converted to coal-based synthetic liquids.
[f]Calculated as *consumption* = (*production* – *exports* + *imports*).

In the INFORUM projection, the average minemouth price of coal (in constant 2009 dollars) increases by about 140 percent from 2009 to 2035. The rise may be due in part to higher mining costs and expectations of growth in domestic coal demand, but it may also be due to strong international demand for U.S. coal. Larger exports of coking coal—which typically command higher prices than thermal coal exports—might also explain some of the increase in the average coal minemouth price in the INFORUM projection.

ICF projects a minemouth coal price on 2015 that is 8 percent lower on a Btu basis than the *AEO2011* price in 2015, although coal production in 2015 is 11 percent higher in the ICF projection. All of the increase in production in 2015 relative to *AEO2011* is attributed to production east of the Mississippi, possibly for export. Over the projection, as ICF's total production falls relative to *AEO2011*, its average minemouth price still continues to rise, so that in 2035 it is only 4 percent lower than the corresponding price in *AEO2011*. The rise in minemouth prices in the ICF projection could be the result of strong international demand, a larger share of higher-cost eastern production, or rising mining costs. In contrast, ICF's delivered coal price to the electricity sector falls slightly from 2015 levels, possibly reflecting either a larger proportion of eastern coal production, which would have lower total transport costs, or generally lower transportation rates for all U.S. coal shipments. *AEO2011* projects an increase in the delivered price of coal to the electricity sector, reflecting higher transportation costs for western coal, as well as higher projected minemouth prices for coal from most basins.

The strongest growth in coal production is projected by INFORUM. In 2035, coal production in the INFORUM projection is 24 percent above the *AEO2011* projection. Similarly, coal consumption in the INFORUM projection is the highest among all the projections regardless of the projection year.

Total coal consumption declines at a rate of 0.5 percent per year (on a tonnage basis) from 2009 to 2030 in the EVA projection, as compared with an average increase of 1.1 percent per year in *AEO2011*. For the same period, thermal coal consumption (excluding coking coal) declines by 0.7 percent per year in the WM projection but increases by 1.1 percent per year in the *AEO2011* projection. From 2009 to 2035, coal consumption increases by 1.7 percent per year (on a tonnage basis) in the INFORUM projection and by 1.1 percent per year in the *AEO2011* Reference case. Also over the 2009-2035 period, coal consumption in the DB and ICF projections (on a Btu basis) declines at by 0.4 percent per year and 1.8 percent per year, respectively, compared with an increase of 0.8 percent per year in the *AEO2011* projection.

List of acronyms

AB	Assembly Bill
ACI	Activated carbon injection
AEO	*Annual Energy Outlook*
AEO2011	*Annual Energy Outlook 2011*
ARI	Advanced Resources International
ARRA	American Recovery and Reinvestment Act of 2009
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BLS	Bureau of Labor Statistics
BOEM	Bureau of Ocean Energy Management
BTA	Best technology available
BTL	Biomass-to-liquid
Btu	British thermal unit
CAA	Clean Air Act
CAAA90	Clean Air Act Amendments of 1990
CAFE	Corporate average fuel economy
CAIR	Clean Air Interstate Rule
CAMR	Clean Air Mercury Rule
CARB	California Air Resources Board
CBO	Congressional Budget Office
CBTL	Coal- and biomass-to-liquids
CCR	Coal combustion residual
CCS	Carbon capture and storage
CHP	Combined heat and power
CMM	Coal Market Module
CO_2	Carbon dioxide
CTL	Coal-to-liquids
CWA	Clean Water Act
DB	Deutsche Bank
DG	Distributed generation
DOE	U.S. Department of Energy
DSI	Direct sorbent injection
DSIRE	Database of State Incentives for Renewables & Efficiency
E10	Motor gasoline blend containing up to 10 percent ethanol
E15	Motor gasoline blend containing up to 15 percent ethanol
E85	Motor fuel containing up to 85 percent ethanol
EIA	U.S. Energy Information Administration
EISA2007	Energy Independence and Security Act of 2007
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
EPACT2005	Energy Policy Act of 2005
EUR	Estimated ultimate recovery
EVA	Energy Ventures Analysis
FEMP	Federal Energy Management Program
FFV	Flex-fuel vehicle
FGD	Flue gas desulfurization
GDP	Gross domestic product
GEM	Greenhouse Gas Emissions Model
GHG	Greenhouse gas
GSHP	Ground-source heat pump
GTL	Gas-to-liquids
GVWR	Gross vehicle weight rating
HAP	Hazardous air pollutant
HB	House Bill
HCl	Hydrogen chloride
HDV	Heavy-duty vehicle
ICF	ICF International
IDM	Industrial Demand Module
IEA	International Energy Agency
IECC	International Energy Conservation Code
IEM	International Energy Module
IHSGI	IHS Global Insight
ILUC	Indirect land-use change
INFORUM	Interindustry Forecasting Project at the University of Maryland
ITC	Investment tax credit
LCFS	Low Carbon Fuel Standard
LDV	Light-duty vehicle
LED	Light-emitting diode
LNG	Liquefied natural gas
MAM	Macroeconomic Activity Module
mpg	Miles per gallon
MY	Model year
NAAQS	National Ambient Air Quality Standards
NEMS	National Energy Modeling System
NERC	North American Electric Reliability Council
NGL	Natural gas liquids
NGTDM	Natural Gas Transmission and Distribution Module
NHTSA	National Highway Traffic Safety Administration
NO_x	Nitrous oxide
OCS	Outer continental shelf
OECD	Organization for Economic Cooperation and Development
OMB	Office of Management and Budget
OPEC	Organization of the Petroleum Exporting Countries
PADD	Petroleum Administration for Defense District
PCs	Personal computers
P&G	Purvin & Gertz
PM	Particulate matter
PMM	Petroleum Market Module
$PM_{2.5}$	Particulate matter less than 2.5 microns diameter
PTC	Production tax credit
PV	Solar photovoltaic
RCRA	Resource Conservation and Recovery Act
RFM	Renewable Fuels Module
RFS	Renewable fuels standard
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable portfolio standard
SCNR	Selective noncatalytic converter
SCR	Selective catalytic converter
SEP	State Energy Program
SNCR	Selective noncatalytic converter
SO_2	Sulfur dioxide
TVA	Tennessee Valley Authority
VIUS	U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey
VMT	Vehicle miles traveled
WM	Wood Mackenzie
WTI	West Texas Intermediate

Notes and sources

Table notes and sources

Table 1. Coal-fired plant retirements in alternative cases, 2010-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A, TRMA05.D021811A, TRMA20.D021811A, BAMA05.D021811A, BAMA20.D021811A, LGBAMA05.D021811A, LGBAMA20.D021811A, and HSHLEUR.D020911A.

Table 2. Renewable portfolio standards in the 30 States with current mandates: U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting. Based on a review of enabling legislation and regulatory actions from the various States of policies identified by the Database of State Incentives for Renewable Energy as of September 30, 2010, website www.dsireuse.org.

Table 3. Key analyses of interest from Issues in focus in recent *AEO*s: U.S. Energy Information Administration, *Annual Energy Outlook 2010*, DOE/EIA-0383(2010) (Washington, DC, April 2010); U.S. Energy Information Administration, *Annual Energy Outlook 2009*, DOE/EIA-0383(2009) (Washington, DC, March 2009); U.S. Energy Information Administration, *Annual Energy Outlook 2008*, DOE/EIA-0383(2008) (Washington, DC, June 2008).

Table 4. Unconventional light-duty vehicle types: U.S. Energy Information Administration, Office of Energy Analysis.

Table 5. Vehicle categories for the HDV standards: U.S. Environmental Protection Agency, "Heavy-Duty Regulations," website www.epa.gov/oms/climate/regulations.htm#1-2; and U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," *Federal Register*, Vol. 75, No. 229 (November 30, 2010), pp. 74451-74456, website http://edocket.access.gpo.gov/2010/2010-28120.htm.

Table 6. Technically recoverable undiscovered U.S. offshore oil and natural gas resources assumed in two cases: AEO2011 National Energy Modeling System, runs REF2011.D020911A and OCSHRES3S.D032911A.

Table 7. First year of available offshore leasing in two cases: U.S. Energy Information Administration, Office of Energy Analysis.

Table 8. Natural gas prices, production, imports, and consumption in five cases, 2035: AEO2011 National Energy Modeling System, runs REF2011.D020911A, HSHLEUR.D020911A, HSHLDRL.D020911A, LSHLEUR.D020911A, and LSHLDRL.D020911A.

Table 9. Commercial-scale CCS projects operating in 2010: International Energy Agency, *Carbon Capture and Storage: Progress and Next Steps*, website www.iea.org/papers/2010/ccs_g8.pdf.

Table 10. Transport Rule emissions targets, 2012 and 2014: "Federal Implementation Plans To Reduce Interstate Transport of Fine Particulate Matter and Ozone," *Federal Register*, Vol. 75, No. 147 (August 2, 2010), p. 45217, website www.gpo.gov/fdsys/pkg/FR-2010-08-02/pdf/2010-17007.pdf#page=1.

Table 11. Coal-fired plant retirements in nine cases, 2010-2035: AEO2011 National Energy Modeling System, runs REF2011.D020911A, TRMA05.D021811A, TRMA20.D021811A, BAMA05.D021811A, BAMA20.D021811A, LGBAMA05.D021811A, LGBAMA20.D021811A, HSHLEUR.D020911A, and POLMAX.D031411A.

Table 12. Projections of average annual economic growth, 2009-2035: *AEO2010* (Reference case): AEO2010 National Energy Modeling System, run AEO2010R.D111809A. ***AEO2011* (Reference case):** AEO2011 National Energy Modeling System, run AEO2011.D020911A. **IHSGI (August 2010):** IHS/Global Insight, Inc., *U.S. Macroeconomic 30 Year Trend Forecast* (Lexington, MA, August 2010). **OMB (July 2009):** Office of Management and Budget, *Budget of the United States Government Fiscal Year 2012* (Washington, DC, January 2011). **CBO (January 2011):** Congressional Budget Office, *The Budget and Economic Outlook* (Washington, DC, January 2011). **INFORUM (December 2010):** Inforum Long-term Interindustry Forecasting Tool (Lift) Model (2010). **SSA (May 2010):** Social Security Administration, *OASDI Trustees Report* (Washington, DC, May 2010). **BLS (December 2009):** Bureau of Labor Statistics, *Macro Projections 2009*. **IEA (2010):** International Energy Agency, *World Energy Outlook 2010* (Paris, France, September 2010). **Blue Chip Consensus (March 2010):** *Blue Chip Economic Indicators* (Aspen Publishers, March 10, 2010). **Exxon/Mobil 2010**: Exxon Mobil Corporation, *The Outlook for Energy: A View to 2030* (Irving, TX, 2010). **ICF Quarter 4 2010 Integrated Energy Outlook**: ICF International, ICD Integrated Energy Outlook (Fourth Quarter, 2010).

Table 13. Projections of world oil prices, 2015-2035: *AEO2011* (Reference case): AEO2011 National Energy Modeling System, run REF2011.D020911A. ***AEO2010* (Reference case):** AEO2010 National Energy Modeling System, run AEO2010.D1111809A. **DB:** Deutsche Bank AG, e-mail from Adam Sieminski (January 11, 2011). **ICF Q4 2010 Integrated Energy Outlook:** ICF International, ICD Integrated Energy Outlook (Fourth Quarter, 2010). **INFORUM:** INFORUM Long-term Interindustry Forecasting Tool (Lift) Model (2010). **IEA (current policies scenario):** International Energy Agency, *World Energy Outlook 2010* (Paris, France, November 2010), Reference Scenario. **EVA:** Energy Ventures Analysis, Inc., *Fuel Cast Long Term* (February 2010). **IHSGI:** IHS/Global Insight, Inc., *U.S. Energy Outlook* (Lexington, MA, September 2010).

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Table 18. Comparison of coal projections, 2015, 2025, 2030, and 2035: ***AEO2011***: AEO2011 National Energy Modeling System, run REF2011.D020911A. **DB**: Deutsche Bank AG, email from Adam Sieminski (January 11, 2011). **EVA**: Energy Ventures Analysis, Inc., *FUELCAST: Long-Term Outlook* (February 2011). **ICF**: ICF International, ICD Integrated Energy Outlook (Fourth Quarter, 2010). **INFORUM**: INFORUM Long-term Interindustry Forecasting Tool (Lift) Model (2010). **WM**: Wood Mackenzie, *Fall 2010 Long-Term US Thermal Coal Outlook.*

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Figure 79. Additions to electricity generation capacity, 1985-2035: History: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report." **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 80. Electricity sales and power sector generating capacity, 1949-2035: History: U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 81. Levelized electricity costs for new power plants, 2020 and 2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 82. Electricity generating capacity at U.S. nuclear power plants in two cases, 2009, 2020, and 2035: AEO2011 National Energy Modeling System, runs REF2011.D020911A and POLMAX.D031411A.

Figure 83. Nonhydropower renewable electricity generation by energy source, 2009-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 84. Nonhydropower renewable electricity generation capacity by source, 2009-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 85. Regional growth in nonhydroelectric renewable electricity generation capacity, including end-use capacity, 2009-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 86. Annual average lower 48 wellhead and Henry Hub spot market prices for natural gas, 1990-2035: History: Based on U.S. Energy Information Administration, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). **Henry Hub natural gas prices:** U.S. Energy Information Administration, *Short-Term Energy Outlook* Query System, Monthly Natural Gas Data, Variable NGHHUUS. **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 87. Ratio of low-sulfur light crude oil price to Henry Hub natural gas price on an energy equivalent basis, 1990-2035: History: U.S. Energy Information Administration, *Short-Term Energy Outlook* Query System, Monthly Natural Gas Data, Variable NGHHUUS. **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 88. Annual average lower 48 wellhead prices for natural gas in seven cases, 1990-2035: History: U.S. Energy Information Administration, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). **Projections:** AEO2011 National Energy Modeling System, runs REF2011.D020911A, LM2011.D020911A, HM2011.D020911A, OGLTEC11.D020911A, OGHTEC11.D020911A, LTRKITEN.D030111A, and HTRKITEN.D030111A.

Figure 89. Natural gas production by source, 1990-2035: History: Based on U.S. Energy Information Administration, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010); and HPDI Production Data Applications database, Office of Petroleum, Gas, and Biofuels Analysis. **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 90. Total U.S. natural gas production in five cases, 1990-2035: History: U.S. Energy Information Administration, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). **Projections:** AEO2011 National Energy Modeling System, runs REF2011.D020911A, LM2011.D020911A, HM2011.D020911A, OGLTEC11.D020911A, and OGHTEC11.D020911A.

Figure 91. Lower 48 onshore natural gas production by region, 2009 and 2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 92. U.S. net imports of natural gas by source, 1990-2035: History: U.S. Energy Information Administration, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 93. Liquid fuels consumption by sector, 1990-2035: History: U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 94. U.S. domestic liquids production by source, 2009-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 95. Domestic crude oil production by source, 1990-2035: History: U.S. Energy Information Administration, *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2010) (Washington, DC, August 2009). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 96. Total U.S. crude oil production in five cases, 1990-2035: History: U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** AEO2011 National Energy Modeling System, runs REF2011.D020911A, LP2011LNO.D022511A, HP2011HNO.D022511A, OGLTEC11.D020911A, and OGHTEC11.D020911A.

Figure 97. Net import share of U.S. liquid fuels consumption in three cases, 1990-2035: History: U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** AEO2011 National Energy Modeling System, runs REF2011.D020911A, LP2011LNO.D022511A, and HP2011HNO.D022511A.

Figure 98. EISA2007 renewable fuels standard, 2010-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 99. U.S. motor gasoline and diesel fuel consumption, 2000-2035: History:

U.S. Energy Information Administration, *Petroleum Supply Annual 2009, Volume 1*, DOE/EIA-0340(2010) (Washington, DC, July 2010). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 100. U.S. ethanol use in gasoline and E85, 2000-2035: History: U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 101. Coal production by region, 1970-2035: History (short tons): 1970-1990: U.S. Energy Information Administration, *The U.S. Coal Industry, 1970-1990: Two Decades of Change*, DOE/EIA-0559 (Washington, DC, November 2002). **1991-2000:** U.S. Energy Information Administration, *Coal Industry Annual*, DOE/EIA-0584 (various years). **2001-2009:** U.S. Energy Information Administration, *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, February 2011), and previous issues. **History (conversion to quadrillion Btu): 1970-2009: Estimation Procedure:** U.S. Energy Information Administration, Office of Electricity, Coal, Nuclear and Renewables Analysis. Estimates of average heat content by region and year are based on coal quality data collected through various energy surveys (see sources) and national-level estimates of U.S. coal production by year in units of quadrillion Btu, published in EIA's *Annual Energy Review*. **Sources:** U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010), Table 1.2; Form EIA-3, "Quarterly Coal Consumption and Quality Report, Manufacturing Plants"; Form EIA-5, "Quarterly Coal Consumption and Quality Report, Coke Plants"; Form EIA-6A, "Coal Distribution Report"; Form EIA-7A, "Coal Production Report"; Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"; Form EIA-906, "Power Plant Report"; Form EIA-920, "Combined Heat and Power Plant Report"; Form EIA-923, "Power Plant Operations Report"; U.S. Department of Commerce, Bureau of the Census, "Monthly Report EM 545"; and Federal Energy Regulatory Commission, Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants." **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A. **Note:** For 1989-2035, coal production includes waste coal.

Figure 102. U.S. coal production in six cases, 2007, 2009, 2020, and 2035: AEO2011 National Energy Modeling System, runs REF2011.D020911A, LCCST11.D020911A, HCCST11.D020911A, LM2011.D020911A, HM2011.D020911A, and HP2011HNO.D022511A. **Note:** Coal production includes waste coal.

Figure 103. Average annual minemouth coal prices by region, 1990-2035: History (dollars per short ton): 1990-2000: U.S. Energy Information Administration, *Coal Industry Annual*, DOE/EIA-0584 (various years). **2001-2009:** U.S. Energy Information Administration, *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, February 2011), and previous issues. **History (conversion to dollars per million Btu): 1970-2009: Estimation Procedure:** U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting. Estimates of average heat content by region and year based on coal quality data collected through various energy surveys (see sources) and national-level estimates of U.S. coal production by year in units of quadrillion Btu published in EIA's *Annual Energy Review*. **Sources:** U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010), Table 1.2; Form EIA-3, "Quarterly Coal Consumption and Quality Report, Manufacturing Plants"; Form EIA-5, "Quarterly Coal Consumption and Quality Report, Coke Plants"; Form EIA-6A, "Coal Distribution Report"; Form EIA-7A, "Coal Production Report"; Form EIA-423, "Monthly Cost and Quality of Fuels for Electric Plants Report"; Form EIA-906, "Power Plant Report"; and Form EIA-920, "Combined Heat and Power Plant Report"; Form EIA-923, "Power Plant Operations Report"; U.S. Department of Commerce, Bureau of the Census, "Monthly Report EM 545"; and Federal Energy Regulatory Commission, Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants." **Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A. **Note:** Includes reported prices for both open-market and captive mines.

Figure 104. Average annual delivered coal prices in four cases, 1990-2035: History: **1990-2009:** U.S. Energy Information Administration, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010), and previous issues; *Electric Power Monthly, October 2010*, DOE/EIA-0226(2009/10) (Washington, DC, October 2010); and *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections**: AEO2011 National Energy Modeling System, runs REF2011.D020911A, LCCST11.D020911A, HCCST11.D020911A, and HP2011HNO.D022511A.

Figure 105. Change in annual U.S. coal consumption by end use in two cases, 2009-2035: AEO2011 National Energy Modeling System, run REF2011.D020911A and NORSK2011.D020911A.

Figure 106. U.S. carbon dioxide emissions by sector and fuel, 2005 and 2035: AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 107. Sulfur dioxide emissions from electricity generation, 2000-2035: 1995: U.S. Environmental Protection Agency, *National Air Pollutant Emissions Trends, 1990-1998*, EPA-454/R-00-002 (Washington, DC, March 2000). **2000:** U.S. Environmental Protection Agency, *Acid Rain Program Preliminary Summary Emissions Report, Fourth Quarter 2004*, website www.epa.gov/airmarkets/emissions/prelimarp/index.html. **2009 and Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Figure 108. Nitrogen oxide emissions from electricity generation, 2000-2035: History: 1995: U.S. Environmental Protection Agency, *National Air Pollutant Emissions Trends, 1990-1998*, EPA-454/R-00-002 (Washington, DC, March 2000). **2000:** U.S. Environmental Protection Agency, *Acid Rain Program Preliminary Summary Emissions Report, Fourth Quarter 2004*, web site www.epa.gov/airmarkets/emissions/prelimarp/index.html. **2009 and Projections:** AEO2011 National Energy Modeling System, run REF2011.D020911A.

Table A1. Total energy supply, disposition, and price summary
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Production								
Crude Oil and Lease Condensate	10.51	11.34	12.51	13.07	12.64	12.49	12.80	0.5%
Natural Gas Plant Liquids	2.41	2.57	2.86	3.06	3.55	3.71	3.92	1.6%
Dry Natural Gas	20.83	21.50	23.01	24.04	24.60	25.75	27.00	0.9%
Coal[1]	23.85	21.58	20.94	22.05	23.64	24.77	26.01	0.7%
Nuclear Power	8.43	8.35	8.77	9.17	9.17	9.17	9.14	0.3%
Hydropower	2.53	2.69	2.92	3.00	3.04	3.07	3.09	0.5%
Biomass[2]	3.94	3.52	4.70	5.77	7.20	8.15	8.63	3.5%
Other Renewable Energy[3]	1.12	1.29	2.14	2.30	2.58	2.97	3.22	3.6%
Other[4]	0.19	0.34	0.78	0.96	0.88	0.81	0.78	3.2%
Total	**73.80**	**73.18**	**78.63**	**83.42**	**87.29**	**90.88**	**94.59**	**1.0%**
Imports								
Crude Oil	21.39	19.70	19.25	18.46	18.35	18.30	18.44	-0.3%
Liquid Fuels and Other Petroleum[5]	6.32	5.40	5.33	5.34	5.18	5.26	5.33	-0.1%
Natural Gas	4.08	3.82	4.01	3.80	3.20	3.07	2.87	-1.1%
Other Imports[6]	0.96	0.61	0.82	0.98	1.39	1.30	1.27	2.9%
Total	**32.76**	**29.53**	**29.41**	**28.57**	**28.13**	**27.93**	**27.92**	**-0.2%**
Exports								
Petroleum[7]	3.78	4.17	3.27	3.54	3.62	3.75	3.92	-0.2%
Natural Gas	1.01	1.09	1.24	1.82	2.07	2.24	2.64	3.5%
Coal	2.07	1.51	1.76	1.92	1.89	1.86	1.78	0.6%
Total	**6.86**	**6.77**	**6.27**	**7.28**	**7.58**	**7.85**	**8.34**	**0.8%**
Discrepancy[8]	**-0.44**	**1.16**	**-0.24**	**-0.21**	**-0.12**	**-0.07**	**-0.02**	**- -**
Consumption								
Liquid Fuels and Other Petroleum[9]	38.46	36.62	39.10	39.38	39.84	40.55	41.70	0.5%
Natural Gas	23.85	23.31	25.77	26.00	25.73	26.58	27.24	0.6%
Coal[10]	22.38	19.69	19.73	20.85	22.61	23.39	24.30	0.8%
Nuclear Power	8.43	8.35	8.77	9.17	9.17	9.17	9.14	0.3%
Hydropower	2.53	2.69	2.92	3.00	3.04	3.07	3.09	0.5%
Biomass[11]	3.07	2.52	3.27	3.93	4.71	5.05	5.25	2.9%
Other Renewable Energy[3]	1.12	1.29	2.14	2.30	2.58	2.97	3.22	3.6%
Other[12]	0.31	0.32	0.31	0.29	0.27	0.24	0.25	-0.9%
Total	**100.14**	**94.79**	**102.02**	**104.92**	**107.95**	**111.03**	**114.19**	**0.7%**
Prices (2009 dollars per unit)								
Petroleum (dollars per barrel)								
Imported Low Sulfur Light Crude Oil Price[13]	100.51	61.66	94.58	108.10	117.54	123.09	124.94	2.8%
Imported Crude Oil Price[13]	93.44	59.04	86.83	98.65	107.40	112.38	113.70	2.6%
Natural Gas (dollars per million Btu)								
Price at Henry Hub	8.94	3.95	4.66	5.05	5.97	6.40	7.07	2.3%
Wellhead Price[14]	7.96	3.62	4.13	4.47	5.29	5.66	6.26	2.1%
Natural Gas (dollars per thousand cubic feet)								
Wellhead Price[14]	8.18	3.71	4.24	4.59	5.43	5.81	6.42	2.1%
Coal (dollars per ton)								
Minemouth Price[15]	31.54	33.26	32.36	32.85	33.22	33.25	33.92	0.1%
Coal (dollars per million Btu)								
Minemouth Price[15]	1.56	1.67	1.62	1.65	1.68	1.69	1.73	0.2%
Average Delivered Price[16]	2.18	2.31	2.26	2.30	2.36	2.42	2.47	0.3%
Average Electricity Price (cents per kilowatthour)	9.8	9.8	8.9	8.8	8.9	9.0	9.2	-0.2%

Table A1. Total energy supply, disposition, and price summary (continued)
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Prices (nominal dollars per unit)								
Petroleum (dollars per barrel)								
Imported Low Sulfur Light Crude Oil Price[13]	99.57	61.66	103.24	130.60	155.46	178.45	199.37	4.6%
Imported Crude Oil Price[13]	92.57	59.04	94.78	119.18	142.05	162.92	181.43	4.4%
Natural Gas (dollars per million Btu)								
Price at Henry Hub	8.86	3.95	5.09	6.10	7.90	9.28	11.28	4.1%
Wellhead Price[14]	7.89	3.62	4.51	5.40	6.99	8.21	9.99	4.0%
Natural Gas (dollars per thousand cubic feet)								
Wellhead Price[14]	8.10	3.71	4.63	5.55	7.18	8.43	10.24	4.0%
Coal (dollars per ton)								
Minemouth Price[15]	31.25	33.26	35.32	39.69	43.93	48.21	54.13	1.9%
Coal (dollars per million Btu)								
Minemouth Price[15]	1.55	1.67	1.77	1.99	2.22	2.45	2.76	2.0%
Average Delivered Price[16]	2.16	2.31	2.47	2.78	3.12	3.50	3.95	2.1%
Average Electricity Price (cents per kilowatthour)	9.7	9.8	9.7	10.7	11.8	13.0	14.7	1.6%

[1]Includes waste coal.
[2]Includes grid-connected electricity from wood and wood waste; biomass, such as corn, used for liquid fuels production; and non-electric energy demand from wood. Refer to Table A17 for details.
[3]Includes grid-connected electricity from landfill gas; biogenic municipal waste; wind; photovoltaic and solar thermal sources; and non-electric energy from renewable sources, such as active and passive solar systems. Excludes electricity imports using renewable sources and nonmarketed renewable energy. See Table A17 for selected nonmarketed residential and commercial renewable energy.
[4]Includes non-biogenic municipal waste, liquid hydrogen, methanol, and some domestic inputs to refineries.
[5]Includes imports of finished petroleum products, unfinished oils, alcohols, ethers, blending components, and renewable fuels such as ethanol.
[6]Includes coal, coal coke (net), and electricity (net).
[7]Includes crude oil and petroleum products.
[8]Balancing item. Includes unaccounted for supply, losses, gains, and net storage withdrawals.
[9]Includes petroleum-derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids and crude oil consumed as a fuel. Refer to Table A17 for detailed renewable liquid fuels consumption.
[10]Excludes coal converted to coal-based synthetic liquids and natural gas.
[11]Includes grid-connected electricity from wood and wood waste, non-electric energy from wood, and biofuels heat and coproducts used in the production of liquid fuels, but excludes the energy content of the liquid fuels.
[12]Includes non-biogenic municipal waste and net electricity imports.
[13]Weighted average price delivered to U.S. refiners.
[14]Represents lower 48 onshore and offshore supplies.
[15]Includes reported prices for both open market and captive mines.
[16]Prices weighted by consumption; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
Btu = British thermal unit.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 natural gas supply values: U.S. Energy Information Administration (EIA), *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 natural gas supply values and natural gas wellhead price: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 natural gas wellhead price: Bureau of Energy Management, Regulation and Enforcement; and EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2008 and 2009 coal minemouth and delivered coal prices: EIA, *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010). 2009 petroleum supply values and 2008 crude oil and lease condensate production: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). Other 2008 petroleum supply values: EIA, *Petroleum Supply Annual 2008,* DOE/EIA-0340(2008)/1 (Washington, DC, June 2009). 2008 and 2009 low sulfur light crude oil price: EIA, Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." Other 2008 and 2009 coal values: *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010). Other 2008 and 2009 values: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A2. Energy consumption by sector and source
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Energy Consumption								
Residential								
Liquefied Petroleum Gases	0.52	0.53	0.49	0.48	0.48	0.48	0.48	-0.4%
Kerosene	0.02	0.03	0.02	0.02	0.02	0.02	0.02	-1.5%
Distillate Fuel Oil	0.66	0.61	0.56	0.50	0.44	0.40	0.37	-1.9%
Liquid Fuels and Other Petroleum Subtotal	1.20	1.16	1.07	0.99	0.94	0.90	0.86	-1.1%
Natural Gas	5.00	4.87	4.94	4.98	4.96	4.95	4.90	0.0%
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-1.1%
Renewable Energy[1]	0.44	0.43	0.40	0.42	0.42	0.42	0.42	-0.1%
Electricity	4.71	4.65	4.60	4.75	4.98	5.25	5.51	0.7%
Delivered Energy	**11.36**	**11.12**	**11.02**	**11.15**	**11.32**	**11.53**	**11.70**	**0.2%**
Electricity Related Losses	10.17	9.96	9.46	9.80	10.24	10.67	11.06	0.4%
Total	**21.53**	**21.08**	**20.48**	**20.95**	**21.56**	**22.20**	**22.76**	**0.3%**
Commercial								
Liquefied Petroleum Gases	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.2%
Motor Gasoline[2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.3%
Kerosene	0.00	0.01	0.01	0.01	0.01	0.01	0.01	2.8%
Distillate Fuel Oil	0.37	0.34	0.28	0.27	0.26	0.25	0.25	-1.2%
Residual Fuel Oil	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.3%
Liquid Fuels and Other Petroleum Subtotal	0.64	0.60	0.55	0.54	0.53	0.53	0.53	-0.5%
Natural Gas	3.22	3.20	3.47	3.59	3.66	3.78	3.92	0.8%
Coal	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.0%
Renewable Energy[3]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.0%
Electricity	4.56	4.51	4.83	5.21	5.58	6.01	6.43	1.4%
Delivered Energy	**8.60**	**8.49**	**9.02**	**9.50**	**9.94**	**10.49**	**11.05**	**1.0%**
Electricity Related Losses	9.85	9.66	9.94	10.73	11.47	12.21	12.93	1.1%
Total	**18.44**	**18.15**	**18.96**	**20.24**	**21.41**	**22.70**	**23.98**	**1.1%**
Industrial[4]								
Liquefied Petroleum Gases	2.08	2.01	2.36	2.39	2.38	2.29	2.18	0.3%
Motor Gasoline[2]	0.25	0.25	0.33	0.33	0.33	0.32	0.32	1.0%
Distillate Fuel Oil	1.27	1.16	1.16	1.16	1.16	1.14	1.13	-0.1%
Residual Fuel Oil	0.20	0.17	0.17	0.17	0.17	0.16	0.16	-0.3%
Petrochemical Feedstocks	1.12	0.90	1.29	1.33	1.34	1.30	1.26	1.3%
Other Petroleum[5]	3.98	3.45	3.97	3.82	3.79	3.77	3.88	0.5%
Liquid Fuels and Other Petroleum Subtotal	8.91	7.94	9.29	9.20	9.16	8.98	8.94	0.5%
Natural Gas	6.83	6.31	8.27	8.46	8.32	8.30	8.23	1.0%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Lease and Plant Fuel[6]	1.26	1.19	1.24	1.24	1.22	1.24	1.28	0.3%
Natural Gas Subtotal	8.09	7.50	9.51	9.70	9.54	9.53	9.51	0.9%
Metallurgical Coal	0.58	0.40	0.58	0.58	0.55	0.51	0.47	0.6%
Other Industrial Coal	1.16	0.94	0.98	0.98	0.97	0.96	0.94	0.0%
Coal-to-Liquids Heat and Power	0.00	0.00	0.10	0.13	0.40	0.77	1.19	- -
Net Coal Coke Imports	0.04	-0.02	0.01	0.01	0.00	-0.00	-0.00	-7.2%
Coal Subtotal	1.78	1.32	1.67	1.69	1.93	2.24	2.60	2.6%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Renewable Energy[7]	1.52	1.42	1.89	1.98	2.05	2.06	2.04	1.4%
Electricity	3.44	3.01	3.54	3.57	3.52	3.40	3.28	0.3%
Delivered Energy	**24.72**	**21.85**	**26.75**	**27.34**	**28.11**	**28.54**	**28.89**	**1.1%**
Electricity Related Losses	7.44	6.44	7.28	7.36	7.23	6.92	6.59	0.1%
Total	**32.16**	**28.29**	**34.03**	**34.70**	**35.33**	**35.46**	**35.49**	**0.9%**

Table A2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Transportation								
Liquefied Petroleum Gases	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.4%
E85[8]	0.00	0.00	0.01	0.32	0.93	1.18	1.23	26.3%
Motor Gasoline[2]	16.87	16.82	17.02	16.53	15.93	16.08	16.69	-0.0%
Jet Fuel[9]	3.21	3.20	3.20	3.34	3.47	3.56	3.62	0.5%
Distillate Fuel Oil[10]	6.04	5.54	6.57	7.04	7.45	7.88	8.35	1.6%
Residual Fuel Oil	0.92	0.78	0.79	0.80	0.81	0.81	0.82	0.2%
Other Petroleum[11]	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.1%
Liquid Fuels and Other Petroleum Subtotal	27.24	26.52	27.76	28.20	28.76	29.69	30.89	0.6%
Pipeline Fuel Natural Gas	0.67	0.65	0.67	0.65	0.64	0.65	0.67	0.1%
Compressed Natural Gas	0.03	0.03	0.04	0.07	0.10	0.14	0.16	7.4%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Electricity	0.02	0.02	0.03	0.04	0.05	0.06	0.07	4.6%
Delivered Energy	**27.95**	**27.23**	**28.50**	**28.96**	**29.56**	**30.54**	**31.80**	**0.6%**
Electricity Related Losses	0.05	0.05	0.06	0.07	0.09	0.12	0.15	4.4%
Total	**28.00**	**27.28**	**28.56**	**29.04**	**29.65**	**30.66**	**31.95**	**0.6%**
Delivered Energy Consumption for All Sectors								
Liquefied Petroleum Gases	2.77	2.71	3.02	3.04	3.03	2.94	2.84	0.2%
E85[8]	0.00	0.00	0.01	0.32	0.93	1.18	1.23	26.3%
Motor Gasoline[2]	17.17	17.11	17.39	16.91	16.31	16.45	17.06	-0.0%
Jet Fuel[9]	3.21	3.20	3.20	3.34	3.47	3.56	3.62	0.5%
Kerosene	0.03	0.04	0.03	0.03	0.03	0.03	0.03	-0.4%
Distillate Fuel Oil	8.34	7.65	8.57	8.96	9.31	9.67	10.10	1.1%
Residual Fuel Oil	1.19	1.02	1.03	1.03	1.04	1.04	1.05	0.1%
Petrochemical Feedstocks	1.12	0.90	1.29	1.33	1.34	1.30	1.26	1.3%
Other Petroleum[12]	4.15	3.60	4.13	3.98	3.94	3.92	4.04	0.4%
Liquid Fuels and Other Petroleum Subtotal	37.99	36.23	38.67	38.94	39.39	40.10	41.22	0.5%
Natural Gas	15.07	14.41	16.72	17.10	17.05	17.17	17.22	0.7%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Lease and Plant Fuel[6]	1.26	1.19	1.24	1.24	1.22	1.24	1.28	0.3%
Pipeline Natural Gas	0.67	0.65	0.67	0.65	0.64	0.65	0.67	0.1%
Natural Gas Subtotal	17.00	16.25	18.62	18.99	18.91	19.05	19.17	0.6%
Metallurgical Coal	0.58	0.40	0.58	0.58	0.55	0.51	0.47	0.6%
Other Coal	1.24	1.01	1.05	1.05	1.04	1.03	1.01	-0.0%
Coal-to-Liquids Heat and Power	0.00	0.00	0.10	0.13	0.40	0.77	1.19	- -
Net Coal Coke Imports	0.04	-0.02	0.01	0.01	0.00	-0.00	-0.00	-7.2%
Coal Subtotal	1.86	1.39	1.74	1.76	2.00	2.31	2.66	2.5%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Renewable Energy[13]	2.07	1.96	2.41	2.51	2.59	2.59	2.58	1.1%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Electricity	12.73	12.20	13.00	13.57	14.13	14.72	15.29	0.9%
Delivered Energy	**72.63**	**68.68**	**75.29**	**76.96**	**78.92**	**81.10**	**83.45**	**0.8%**
Electricity Related Losses	27.51	26.11	26.73	27.97	29.03	29.93	30.74	0.6%
Total	**100.14**	**94.79**	**102.02**	**104.92**	**107.95**	**111.03**	**114.19**	**0.7%**
Electric Power[14]								
Distillate Fuel Oil	0.11	0.10	0.09	0.10	0.10	0.10	0.10	0.4%
Residual Fuel Oil	0.37	0.30	0.34	0.35	0.35	0.36	0.37	0.8%
Liquid Fuels and Other Petroleum Subtotal	0.47	0.40	0.43	0.45	0.45	0.46	0.47	0.7%
Natural Gas	6.85	7.06	7.15	7.02	6.82	7.53	8.07	0.5%
Steam Coal	20.51	18.30	17.99	19.09	20.61	21.09	21.64	0.6%
Nuclear Power	8.43	8.35	8.77	9.17	9.17	9.17	9.14	0.3%
Renewable Energy[15]	3.67	3.89	5.08	5.52	5.84	6.16	6.47	2.0%
Electricity Imports	0.11	0.12	0.11	0.09	0.07	0.04	0.05	-3.4%
Total[16]	**40.24**	**38.31**	**39.73**	**41.53**	**43.17**	**44.64**	**46.03**	**0.7%**

Table A2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Total Energy Consumption								
Liquefied Petroleum Gases	2.77	2.71	3.02	3.04	3.03	2.94	2.84	0.2%
E85[8]	0.00	0.00	0.01	0.32	0.93	1.18	1.23	26.3%
Motor Gasoline[2]	17.17	17.11	17.39	16.91	16.31	16.45	17.06	-0.0%
Jet Fuel[9]	3.21	3.20	3.20	3.34	3.47	3.56	3.62	0.5%
Kerosene	0.03	0.04	0.03	0.03	0.03	0.03	0.03	-0.4%
Distillate Fuel Oil	8.45	7.75	8.66	9.06	9.40	9.76	10.20	1.1%
Residual Fuel Oil	1.56	1.32	1.37	1.38	1.40	1.40	1.41	0.3%
Petrochemical Feedstocks	1.12	0.90	1.29	1.33	1.34	1.30	1.26	1.3%
Other Petroleum[12]	4.15	3.60	4.13	3.98	3.94	3.92	4.04	0.4%
Liquid Fuels and Other Petroleum Subtotal	38.46	36.62	39.10	39.38	39.84	40.55	41.70	0.5%
Natural Gas	21.92	21.47	23.87	24.11	23.87	24.69	25.29	0.6%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Lease and Plant Fuel[6]	1.26	1.19	1.24	1.24	1.22	1.24	1.28	0.3%
Pipeline Natural Gas	0.67	0.65	0.67	0.65	0.64	0.65	0.67	0.1%
Natural Gas Subtotal	23.85	23.31	25.77	26.00	25.73	26.58	27.24	0.6%
Metallurgical Coal	0.58	0.40	0.58	0.58	0.55	0.51	0.47	0.6%
Other Coal	21.75	19.31	19.04	20.13	21.65	22.12	22.64	0.6%
Coal-to-Liquids Heat and Power	0.00	0.00	0.10	0.13	0.40	0.77	1.19	- -
Net Coal Coke Imports	0.04	-0.02	0.01	0.01	0.00	-0.00	-0.00	-7.2%
Coal Subtotal	22.38	19.69	19.73	20.85	22.61	23.39	24.30	0.8%
Nuclear Power	8.43	8.35	8.77	9.17	9.17	9.17	9.14	0.3%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Renewable Energy[17]	5.74	5.85	7.49	8.04	8.43	8.76	9.04	1.7%
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Electricity Imports	0.11	0.12	0.11	0.09	0.07	0.04	0.05	-3.4%
Total	**100.14**	**94.79**	**102.02**	**104.92**	**107.95**	**111.03**	**114.19**	**0.7%**
Energy Use and Related Statistics								
Delivered Energy Use	72.63	68.68	75.29	76.96	78.92	81.10	83.45	0.8%
Total Energy Use	100.14	94.79	102.02	104.92	107.95	111.03	114.19	0.7%
Ethanol Consumed in Motor Gasoline and E85	0.77	0.95	1.33	1.70	2.07	2.26	2.37	3.6%
Population (millions)	305.17	307.84	326.16	342.01	358.06	374.08	390.09	0.9%
Gross Domestic Product (billion 2005 dollars)	13229	12881	15336	17421	20020	22731	25692	2.7%
Carbon Dioxide Emissions (million metric tons)	5838.0	5425.5	5679.9	5776.7	5937.8	6107.5	6310.8	0.6%

[1]Includes wood used for residential heating. See Table A4 and/or Table A17 for estimates of nonmarketed renewable energy consumption for geothermal heat pumps, solar thermal hot water heating, and electricity generation from wind and solar photovoltaic sources.
[2]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[3]Excludes ethanol. Includes commercial sector consumption of wood and wood waste, landfill gas, municipal waste, and other biomass for combined heat and power. See Table A5 and/or Table A17 for estimates of nonmarketed renewable energy consumption for solar thermal hot water heating and electricity generation from wind and solar photovoltaic sources.
[4]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[5]Includes petroleum coke, asphalt, road oil, lubricants, still gas, and miscellaneous petroleum products.
[6]Represents natural gas used in well, field, and lease operations, and in natural gas processing plant machinery.
[7]Includes consumption of energy produced from hydroelectric, wood and wood waste, municipal waste, and other biomass sources. Excludes ethanol blends (10 percent or less) in motor gasoline.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[9]Includes only kerosene type.
[10]Diesel fuel for on- and off- road use.
[11]Includes aviation gasoline and lubricants.
[12]Includes unfinished oils, natural gasoline, motor gasoline blending components, aviation gasoline, lubricants, still gas, asphalt, road oil, petroleum coke, and miscellaneous petroleum products.
[13]Includes electricity generated for sale to the grid and for own use from renewable sources, and non-electric energy from renewable sources. Excludes ethanol and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
[14]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[15]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes net electricity imports.
[16]Includes non-biogenic municipal waste not included above.
[17]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes ethanol, net electricity imports, and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
Btu = British thermal unit.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 consumption based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 population and gross domestic product: IHS Global Insight Industry and Employment models, September 2010. 2008 and 2009 carbon dioxide emissions: EIA, *Emissions of Greenhouse Gases in the United States 2009,* DOE/EIA-0573(2009) (Washington, DC, December 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A3. Energy prices by sector and source (continued)
(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Residential								
Liquefied Petroleum Gases	29.18	24.63	32.51	38.92	44.84	50.56	55.86	3.2%
Distillate Fuel Oil	24.52	18.12	23.07	29.32	34.28	39.05	43.93	3.5%
Natural Gas	13.49	11.88	11.05	13.13	15.65	18.14	21.37	2.3%
Electricity	32.85	33.62	34.72	37.89	41.27	45.25	50.54	1.6%
Commercial								
Liquefied Petroleum Gases	26.45	21.49	28.73	34.72	40.22	45.46	50.23	3.3%
Distillate Fuel Oil	21.61	15.97	21.04	26.98	31.77	36.23	40.72	3.7%
Residual Fuel Oil	15.66	13.45	14.47	18.35	22.55	25.62	28.93	3.0%
Natural Gas	11.88	9.68	9.14	10.81	12.92	14.92	17.52	2.3%
Electricity	30.22	29.51	29.12	32.04	35.25	38.56	43.06	1.5%
Industrial[1]								
Liquefied Petroleum Gases	24.72	20.59	25.45	31.19	36.40	41.18	45.52	3.1%
Distillate Fuel Oil	22.36	16.56	21.12	27.10	32.01	36.45	40.95	3.5%
Residual Fuel Oil	16.11	12.05	16.15	20.11	24.05	26.98	29.88	3.6%
Natural Gas[2]	9.00	5.25	5.42	6.47	8.15	9.54	11.50	3.1%
Metallurgical Coal	4.49	5.43	6.56	7.65	8.54	9.44	10.50	2.6%
Other Industrial Coal	2.90	3.05	3.17	3.55	3.96	4.43	5.01	1.9%
Coal to Liquids	- -	- -	1.96	2.30	2.36	2.87	3.27	- -
Electricity	19.79	19.79	19.30	21.43	23.79	26.45	29.88	1.6%
Transportation								
Liquefied Petroleum Gases[3]	29.95	25.52	33.36	39.83	45.80	51.56	56.90	3.1%
E85[4]	35.03	20.50	28.80	34.79	39.01	43.98	49.35	3.4%
Motor Gasoline[5]	26.81	19.28	28.35	34.01	39.01	43.98	49.31	3.7%
Jet Fuel[6]	23.09	12.59	20.76	26.62	31.16	35.80	40.35	4.6%
Diesel Fuel (distillate fuel oil)[7]	27.71	17.79	24.56	31.04	35.96	40.57	45.30	3.7%
Residual Fuel Oil	14.43	10.57	13.80	17.57	21.19	24.21	26.24	3.6%
Natural Gas[8]	17.04	12.71	13.06	14.80	16.98	19.05	21.66	2.1%
Electricity	34.36	34.92	31.83	33.91	39.01	44.74	51.66	1.5%
Electric Power[9]								
Distillate Fuel Oil	19.38	14.33	18.38	23.89	28.04	32.34	36.45	3.7%
Residual Fuel Oil	14.61	8.96	14.37	17.83	21.50	24.46	26.66	4.3%
Natural Gas	9.02	4.82	5.10	6.05	7.62	9.00	10.86	3.2%
Steam Coal	2.05	2.20	2.31	2.60	2.96	3.36	3.83	2.2%

Table A3. Energy prices by sector and source (continued)
(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Average Price to All Users[10]								
Liquefied Petroleum Gases	20.51	17.43	23.65	28.84	33.64	38.28	42.49	3.5%
E85[4]	35.03	20.50	28.80	34.79	39.01	43.98	49.35	3.4%
Motor Gasoline[5]	26.63	19.23	28.35	34.00	39.01	43.98	49.31	3.7%
Jet Fuel	23.09	12.59	20.76	26.62	31.16	35.80	40.35	4.6%
Distillate Fuel Oil	26.28	17.51	23.83	30.24	35.20	39.83	44.57	3.7%
Residual Fuel Oil	14.75	10.53	14.27	17.98	21.67	24.66	26.88	3.7%
Natural Gas	10.46	7.28	7.04	8.39	10.33	11.98	14.21	2.6%
Metallurgical Coal	4.49	5.43	6.56	7.65	8.54	9.44	10.50	2.6%
Other Coal	2.10	2.25	2.36	2.66	3.02	3.41	3.89	2.1%
Coal to Liquids	- -	- -	1.96	2.30	2.36	2.87	3.27	- -
Electricity	28.38	28.69	28.43	31.30	34.53	38.17	42.97	1.6%
Non-Renewable Energy Expenditures by Sector (billion nominal dollars)								
Residential	253.79	238.63	243.63	279.35	320.68	367.88	426.84	2.3%
Commercial	190.06	174.64	185.21	221.24	262.27	308.62	368.78	2.9%
Industrial	247.19	179.22	244.72	295.03	341.84	377.94	417.29	3.3%
Transportation	710.71	474.91	725.73	889.64	1022.56	1184.56	1382.69	4.2%
Total Non-Renewable Expenditures	1401.75	1067.41	1399.29	1685.26	1947.34	2239.00	2595.61	3.5%
Transportation Renewable Expenditures	0.04	0.06	0.25	11.06	36.34	51.81	60.53	30.6%
Total Expenditures	**1401.79**	**1067.47**	**1399.54**	**1696.32**	**1983.68**	**2290.81**	**2656.14**	**3.6%**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Excludes use for lease and plant fuel.
[3]Includes Federal and State taxes while excluding county and local taxes.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[6]Kerosene-type jet fuel. Includes Federal and State taxes while excluding county and local taxes.
[7]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[8]Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
[9]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[10]Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.
Btu = British thermal unit.
- - = Not applicable.
Note: Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on prices in the U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2008 residential and commercial natural gas delivered prices: EIA,*Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 residential and commercial natural gas delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 and 2009 industrial natural gas delivered prices are estimated based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 transportation sector natural gas delivered prices are based on: EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and estimated State taxes, Federal taxes, and dispensing costs or charges. 2009 transportation sector natural gas delivered prices are model results. 2008 and 2009 electric power sector distillate and residual fuel oil prices: EIA, *Monthly Energy Review*, DOE/EIA-0035(2010/09) (Washington, DC, September 2010). 2008 and 2009 electric power sector natural gas prices: EIA, *Electric Power Monthly*, DOE/EIA-0226, April 2009 and April 2010, Table 4.2. 2008 and 2009 coal prices based on: EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010) and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. 2008 and 2009 electricity prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A3. Energy prices by sector and source (continued)

(2009 dollars per million Btu, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Average Price to All Users[10]								
Liquefied Petroleum Gases	20.51	17.43	23.65	28.84	33.64	38.28	42.49	3.5%
E85[4]	35.03	20.50	28.80	34.79	39.01	43.98	49.35	3.4%
Motor Gasoline[5]	26.63	19.23	28.35	34.00	39.01	43.98	49.31	3.7%
Jet Fuel	23.09	12.59	20.76	26.62	31.16	35.80	40.35	4.6%
Distillate Fuel Oil	26.28	17.51	23.83	30.24	35.20	39.83	44.57	3.7%
Residual Fuel Oil	14.75	10.53	14.27	17.98	21.67	24.66	26.88	3.7%
Natural Gas	10.46	7.28	7.04	8.39	10.33	11.98	14.21	2.6%
Metallurgical Coal	4.49	5.43	6.56	7.65	8.54	9.44	10.50	2.6%
Other Coal	2.10	2.25	2.36	2.66	3.02	3.41	3.89	2.1%
Coal to Liquids	- -	- -	1.96	2.30	2.36	2.87	3.27	- -
Electricity	28.38	28.69	28.43	31.30	34.53	38.17	42.97	1.6%
Non-Renewable Energy Expenditures by Sector (billion nominal dollars)								
Residential	253.79	238.63	243.63	279.35	320.68	367.88	426.84	2.3%
Commercial	190.06	174.64	185.21	221.24	262.27	308.62	368.78	2.9%
Industrial	247.19	179.22	244.72	295.03	341.84	377.94	417.29	3.3%
Transportation	710.71	474.91	725.73	889.64	1022.56	1184.56	1382.69	4.2%
Total Non-Renewable Expenditures	1401.75	1067.41	1399.29	1685.26	1947.34	2239.00	2595.61	3.5%
Transportation Renewable Expenditures	0.04	0.06	0.25	11.06	36.34	51.81	60.53	30.6%
Total Expenditures	**1401.79**	**1067.47**	**1399.54**	**1696.32**	**1983.68**	**2290.81**	**2656.14**	**3.6%**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Excludes use for lease and plant fuel.
[3]Includes Federal and State taxes while excluding county and local taxes.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[6]Kerosene-type jet fuel. Includes Federal and State taxes while excluding county and local taxes.
[7]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[8]Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
[9]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[10]Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.
Btu = British thermal unit.
- - = Not applicable.
Note: Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.

Sources: 2008 and 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on prices in the U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2008 residential and commercial natural gas delivered prices: EIA,*Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 residential and commercial natural gas delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 and 2009 industrial natural gas delivered prices are estimated based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 transportation sector natural gas delivered prices are based on: EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and estimated State taxes, Federal taxes, and dispensing costs or charges. 2009 transportation sector natural gas delivered prices are model results. 2008 and 2009 electric power sector distillate and residual fuel oil prices: EIA, *Monthly Energy Review*, DOE/EIA-0035(2010/09) (Washington, DC, September 2010). 2008 and 2009 electric power sector natural gas prices: EIA, *Electric Power Monthly*, DOE/EIA-0226, April 2009 and April 2010, Table 4.2. 2008 and 2009 coal prices based on: EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010) and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. 2008 and 2009 electricity prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A4. Residential sector key indicators and consumption
(quadrillion Btu per year, unless otherwise noted)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Key Indicators								
Households (millions)								
Single-Family	80.95	81.48	87.91	92.69	97.10	101.16	104.70	1.0%
Multifamily	25.12	25.32	26.87	28.65	30.69	32.77	34.81	1.2%
Mobile Homes	6.69	6.63	6.53	6.78	7.04	7.25	7.39	0.4%
Total	**112.76**	**113.43**	**121.32**	**128.12**	**134.83**	**141.18**	**146.90**	**1.0%**
Average House Square Footage	**1656**	**1669**	**1765**	**1831**	**1888**	**1938**	**1981**	**0.7%**
Energy Intensity								
(million Btu per household)								
Delivered Energy Consumption	100.8	98.0	90.8	87.0	83.9	81.7	79.7	-0.8%
Total Energy Consumption	191.0	185.8	168.8	163.5	159.9	157.3	155.0	-0.7%
(thousand Btu per square foot)								
Delivered Energy Consumption	60.9	58.7	51.5	47.5	44.5	42.1	40.2	-1.4%
Total Energy Consumption	115.3	111.3	95.6	89.3	84.7	81.2	78.2	-1.3%
Delivered Energy Consumption by Fuel								
Electricity								
Space Heating	0.28	0.28	0.28	0.30	0.30	0.31	0.31	0.4%
Space Cooling	0.87	0.83	0.82	0.86	0.90	0.95	0.99	0.7%
Water Heating	0.43	0.43	0.47	0.49	0.50	0.49	0.48	0.4%
Refrigeration	0.37	0.37	0.35	0.35	0.35	0.36	0.38	0.1%
Cooking	0.10	0.11	0.12	0.12	0.13	0.14	0.15	1.3%
Clothes Dryers	0.19	0.19	0.18	0.18	0.18	0.19	0.20	0.3%
Freezers	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.4%
Lighting	0.72	0.71	0.57	0.54	0.52	0.53	0.54	-1.0%
Clothes Washers[1]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	-0.4%
Dishwashers[1]	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.8%
Color Televisions and Set-Top Boxes	0.33	0.34	0.33	0.34	0.36	0.39	0.42	0.8%
Personal Computers and Related Equipment	0.17	0.18	0.17	0.17	0.18	0.19	0.19	0.3%
Furnace Fans and Boiler Circulation Pumps	0.14	0.14	0.15	0.17	0.18	0.19	0.20	1.3%
Other Uses[2]	0.89	0.88	0.95	1.05	1.17	1.30	1.42	1.9%
Delivered Energy	**4.71**	**4.65**	**4.60**	**4.75**	**4.98**	**5.25**	**5.51**	**0.7%**
Natural Gas								
Space Heating	3.40	3.28	3.28	3.30	3.29	3.29	3.28	0.0%
Space Cooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Water Heating	1.33	1.33	1.38	1.40	1.39	1.37	1.33	-0.0%
Cooking	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.5%
Clothes Dryers	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.3%
Delivered Energy	**5.00**	**4.87**	**4.94**	**4.98**	**4.96**	**4.95**	**4.90**	**0.0%**
Distillate Fuel Oil								
Space Heating	0.56	0.50	0.48	0.43	0.39	0.36	0.33	-1.7%
Water Heating	0.11	0.10	0.08	0.06	0.05	0.05	0.04	-3.4%
Delivered Energy	**0.66**	**0.61**	**0.56**	**0.50**	**0.44**	**0.40**	**0.37**	**-1.9%**
Liquefied Petroleum Gases								
Space Heating	0.26	0.26	0.23	0.22	0.21	0.20	0.19	-1.1%
Water Heating	0.09	0.08	0.06	0.05	0.04	0.04	0.03	-3.5%
Cooking	0.03	0.03	0.03	0.03	0.03	0.03	0.03	-0.7%
Other Uses[3]	0.14	0.16	0.17	0.18	0.20	0.21	0.23	1.5%
Delivered Energy	**0.52**	**0.53**	**0.49**	**0.48**	**0.48**	**0.48**	**0.48**	**-0.4%**
Marketed Renewables (wood)[4]	0.44	0.43	0.40	0.42	0.42	0.42	0.42	-0.1%
Other Fuels[5]	0.03	0.03	0.03	0.03	0.02	0.02	0.02	-1.4%

Table A4. Residential sector key indicators and consumption (continued)
(quadrillion Btu per year, unless otherwise noted)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Delivered Energy Consumption by End Use								
Space Heating	4.97	4.78	4.71	4.69	4.64	4.61	4.55	-0.2%
Space Cooling	0.87	0.83	0.82	0.86	0.90	0.95	0.99	0.7%
Water Heating	1.96	1.95	1.99	2.00	1.99	1.94	1.88	-0.1%
Refrigeration	0.37	0.37	0.35	0.35	0.35	0.36	0.38	0.1%
Cooking	0.35	0.35	0.36	0.38	0.39	0.40	0.41	0.6%
Clothes Dryers	0.24	0.24	0.24	0.23	0.24	0.25	0.26	0.3%
Freezers	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.4%
Lighting	0.72	0.71	0.57	0.54	0.52	0.53	0.54	-1.0%
Clothes Washers[1]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	-0.4%
Dishwashers[1]	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.8%
Color Televisions and Set-Top Boxes	0.33	0.34	0.33	0.34	0.36	0.39	0.42	0.8%
Personal Computers and Related Equipment	0.17	0.18	0.17	0.17	0.18	0.19	0.19	0.3%
Furnace Fans and Boiler Circulation Pumps	0.14	0.14	0.15	0.17	0.18	0.19	0.20	1.3%
Other Uses[6]	1.03	1.03	1.12	1.23	1.37	1.51	1.65	1.8%
Delivered Energy	**11.36**	**11.12**	**11.02**	**11.15**	**11.32**	**11.53**	**11.70**	**0.2%**
Electricity Related Losses	**10.17**	**9.96**	**9.46**	**9.80**	**10.24**	**10.67**	**11.06**	**0.4%**
Total Energy Consumption by End Use								
Space Heating	5.59	5.39	5.30	5.30	5.26	5.23	5.18	-0.2%
Space Cooling	2.75	2.62	2.52	2.62	2.75	2.88	2.99	0.5%
Water Heating	2.89	2.88	2.96	3.01	3.01	2.94	2.84	-0.1%
Refrigeration	1.18	1.15	1.08	1.06	1.07	1.10	1.15	-0.0%
Cooking	0.58	0.58	0.60	0.63	0.66	0.69	0.71	0.8%
Clothes Dryers	0.65	0.64	0.62	0.60	0.61	0.63	0.66	0.1%
Freezers	0.25	0.25	0.24	0.25	0.25	0.26	0.26	0.2%
Lighting	2.28	2.23	1.74	1.64	1.59	1.60	1.63	-1.2%
Clothes Washers[1]	0.11	0.10	0.09	0.08	0.08	0.09	0.09	-0.6%
Dishwashers[1]	0.29	0.29	0.28	0.28	0.30	0.32	0.34	0.7%
Color Televisions and Set-Top Boxes	1.05	1.05	1.01	1.03	1.10	1.17	1.25	0.7%
Personal Computers and Related Equipment	0.55	0.56	0.52	0.53	0.54	0.56	0.58	0.2%
Furnace Fans and Boiler Circulation Pumps	0.43	0.44	0.47	0.51	0.55	0.58	0.59	1.1%
Other Uses[6]	2.94	2.91	3.06	3.40	3.78	4.16	4.50	1.7%
Total	**21.53**	**21.08**	**20.48**	**20.95**	**21.56**	**22.20**	**22.76**	**0.3%**
Nonmarketed Renewables[7]								
Geothermal Heat Pumps	0.00	0.01	0.02	0.03	0.04	0.04	0.05	8.7%
Solar Hot Water Heating	0.00	0.00	0.00	0.00	0.00	0.01	0.01	2.0%
Solar Photovoltaic	0.00	0.00	0.04	0.04	0.04	0.05	0.05	9.7%
Wind	0.00	0.00	0.01	0.01	0.01	0.01	0.01	11.1%
Total	**0.01**	**0.01**	**0.07**	**0.09**	**0.09**	**0.10**	**0.11**	**8.3%**

[1]Does not include water heating portion of load.
[2]Includes small electric devices, heating elements, and motors not listed above.
[3]Includes such appliances as outdoor grills and mosquito traps.
[4]Includes wood used for primary and secondary heating in wood stoves or fireplaces as reported in the *Residential Energy Consumption Survey 2005*.
[5]Includes kerosene and coal.
[6]Includes all other uses listed above.
[7]Represents delivered energy displaced.
Btu = British thermal unit.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A5. Commercial sector key indicators and consumption
(quadrillion Btu per year, unless otherwise noted)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Key Indicators								
Total Floorspace (billion square feet)								
Surviving	76.4	77.9	83.4	89.3	95.1	101.1	107.3	1.2%
New Additions	2.4	2.3	2.0	2.2	2.3	2.4	2.5	0.4%
Total	**78.8**	**80.2**	**85.4**	**91.5**	**97.4**	**103.5**	**109.8**	**1.2%**
Energy Consumption Intensity (thousand Btu per square foot)								
Delivered Energy Consumption	109.1	105.9	105.6	103.9	102.1	101.3	100.7	-0.2%
Electricity Related Losses	125.0	120.6	116.3	117.3	117.8	118.0	117.8	-0.1%
Total Energy Consumption	234.1	226.4	221.8	221.2	219.9	219.2	218.4	-0.1%
Delivered Energy Consumption by Fuel								
Purchased Electricity								
Space Heating[1]	0.18	0.18	0.17	0.17	0.17	0.17	0.18	-0.0%
Space Cooling[1]	0.49	0.47	0.53	0.54	0.56	0.59	0.61	1.0%
Water Heating[1]	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.1%
Ventilation	0.50	0.50	0.56	0.60	0.64	0.68	0.71	1.4%
Cooking	0.02	0.02	0.02	0.02	0.02	0.02	0.02	-0.0%
Lighting	1.04	1.03	1.04	1.09	1.14	1.20	1.25	0.7%
Refrigeration	0.40	0.40	0.36	0.36	0.36	0.37	0.39	-0.1%
Office Equipment (PC)	0.22	0.22	0.19	0.19	0.19	0.21	0.21	-0.1%
Office Equipment (non-PC)	0.24	0.25	0.32	0.37	0.40	0.44	0.47	2.5%
Other Uses[2]	1.37	1.35	1.55	1.77	1.99	2.23	2.49	2.4%
Delivered Energy	**4.56**	**4.51**	**4.83**	**5.21**	**5.58**	**6.01**	**6.43**	**1.4%**
Natural Gas								
Space Heating[1]	1.56	1.61	1.72	1.76	1.76	1.77	1.77	0.4%
Space Cooling[1]	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.6%
Water Heating[1]	0.44	0.45	0.51	0.56	0.58	0.62	0.64	1.4%
Cooking	0.17	0.17	0.20	0.21	0.22	0.23	0.25	1.4%
Other Uses[3]	1.02	0.94	1.00	1.02	1.05	1.12	1.23	1.0%
Delivered Energy	**3.22**	**3.20**	**3.47**	**3.59**	**3.66**	**3.78**	**3.92**	**0.8%**
Distillate Fuel Oil								
Space Heating[1]	0.15	0.16	0.13	0.12	0.11	0.11	0.10	-1.6%
Water Heating[1]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	-0.3%
Other Uses[4]	0.20	0.16	0.13	0.13	0.13	0.13	0.13	-1.0%
Delivered Energy	**0.37**	**0.34**	**0.28**	**0.27**	**0.26**	**0.25**	**0.25**	**-1.2%**
Marketed Renewables (biomass)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.0%
Other Fuels[5]	0.34	0.33	0.33	0.33	0.34	0.34	0.35	0.2%
Delivered Energy Consumption by End Use								
Space Heating[1]	1.89	1.94	2.02	2.05	2.04	2.05	2.05	0.2%
Space Cooling[1]	0.52	0.51	0.56	0.58	0.60	0.62	0.65	1.0%
Water Heating[1]	0.55	0.56	0.63	0.67	0.70	0.73	0.75	1.1%
Ventilation	0.50	0.50	0.56	0.60	0.64	0.68	0.71	1.4%
Cooking	0.19	0.20	0.22	0.24	0.25	0.26	0.27	1.2%
Lighting	1.04	1.03	1.04	1.09	1.14	1.20	1.25	0.7%
Refrigeration	0.40	0.40	0.36	0.36	0.36	0.37	0.39	-0.1%
Office Equipment (PC)	0.22	0.22	0.19	0.19	0.19	0.21	0.21	-0.1%
Office Equipment (non-PC)	0.24	0.25	0.32	0.37	0.40	0.44	0.47	2.5%
Other Uses[6]	3.04	2.89	3.12	3.36	3.62	3.93	4.31	1.6%
Delivered Energy	**8.60**	**8.49**	**9.02**	**9.50**	**9.94**	**10.49**	**11.05**	**1.0%**

Table A5. Commercial sector key indicators and consumption (continued)
(quadrillion Btu per year, unless otherwise noted)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Electricity Related Losses	**9.85**	**9.66**	**9.94**	**10.73**	**11.47**	**12.21**	**12.93**	**1.1%**
Total Energy Consumption by End Use								
Space Heating[1]	2.28	2.32	2.37	2.41	2.40	2.41	2.40	0.1%
Space Cooling[1]	1.58	1.52	1.65	1.70	1.76	1.82	1.89	0.8%
Water Heating[1]	0.75	0.76	0.82	0.86	0.89	0.92	0.94	0.8%
Ventilation	1.57	1.58	1.70	1.84	1.96	2.06	2.15	1.2%
Cooking	0.24	0.25	0.27	0.28	0.29	0.30	0.32	1.0%
Lighting	3.29	3.24	3.18	3.34	3.49	3.63	3.75	0.6%
Refrigeration	1.28	1.25	1.11	1.09	1.10	1.13	1.17	-0.3%
Office Equipment (PC)	0.70	0.68	0.58	0.58	0.60	0.62	0.64	-0.2%
Office Equipment (non-PC)	0.75	0.78	0.97	1.12	1.23	1.34	1.41	2.3%
Other Uses[6]	6.00	5.77	6.32	7.00	7.70	8.47	9.32	1.9%
Total	**18.44**	**18.15**	**18.96**	**20.24**	**21.41**	**22.70**	**23.98**	**1.1%**
Nonmarketed Renewable Fuels[7]								
Solar Thermal	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.6%
Solar Photovoltaic	0.00	0.00	0.00	0.01	0.01	0.01	0.01	3.9%
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.8%
Total	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.04**	**0.04**	**1.3%**

[1]Includes fuel consumption for district services.
[2]Includes miscellaneous uses, such as service station equipment, automated teller machines, telecommunications equipment, and medical equipment.
[3]Includes miscellaneous uses, such as pumps, emergency generators, combined heat and power in commercial buildings, and manufacturing performed in commercial buildings.
[4]Includes miscellaneous uses, such as cooking, emergency generators, and combined heat and power in commercial buildings.
[5]Includes residual fuel oil, liquefied petroleum gases, coal, motor gasoline, and kerosene.
[6]Includes miscellaneous uses, such as service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency generators, combined heat and power in commercial buildings, manufacturing performed in commercial buildings, and cooking (distillate), plus residual fuel oil, liquefied petroleum gases, coal, motor gasoline, and kerosene.
[7]Represents delivered energy displaced by solar thermal space heating and water heating, and electricity generation by solar photovoltaic systems.
Btu = British thermal unit.
PC = Personal computer.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A6. Industrial sector key indicators and consumption

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Key Indicators								
Value of Shipments (billion 2005 dollars)								
Manufacturing	4680	4197	5279	5643	6016	6393	6770	1.9%
Nonmanufacturing	2039	1821	2193	2308	2381	2433	2521	1.3%
Total	**6720**	**6017**	**7472**	**7951**	**8396**	**8826**	**9292**	**1.7%**
Energy Prices								
(2009 dollars per million Btu)								
Liquefied Petroleum Gases	24.95	20.59	23.31	25.82	27.52	28.41	28.52	1.3%
Motor Gasoline	16.48	16.59	25.95	28.10	29.48	30.32	30.89	2.4%
Distillate Fuel Oil	22.57	16.56	19.34	22.43	24.20	25.14	25.66	1.7%
Residual Fuel Oil	16.26	12.05	14.80	16.65	18.19	18.61	18.73	1.7%
Asphalt and Road Oil	8.35	6.52	7.40	8.40	9.04	9.24	9.14	1.3%
Natural Gas Heat and Power	8.17	4.48	4.17	4.60	5.45	5.93	6.60	1.5%
Natural Gas Feedstocks	9.86	6.03	5.74	6.14	6.93	7.33	7.95	1.1%
Metallurgical Coal	4.53	5.43	6.01	6.33	6.46	6.51	6.58	0.7%
Other Industrial Coal	2.93	3.05	2.91	2.94	2.99	3.05	3.14	0.1%
Coal for Liquids	- -	- -	1.79	1.91	1.78	1.98	2.05	- -
Electricity	19.97	19.79	17.68	17.74	17.99	18.25	18.73	-0.2%
(nominal dollars per million Btu)								
Liquefied Petroleum Gases	24.72	20.59	25.45	31.19	36.40	41.18	45.52	3.1%
Motor Gasoline	16.33	16.59	28.33	33.95	38.99	43.96	49.30	4.3%
Distillate Fuel Oil	22.36	16.56	21.12	27.10	32.01	36.45	40.95	3.5%
Residual Fuel Oil	16.11	12.05	16.15	20.11	24.05	26.98	29.88	3.6%
Asphalt and Road Oil	8.27	6.52	8.08	10.15	11.96	13.39	14.59	3.1%
Natural Gas Heat and Power	8.10	4.48	4.55	5.56	7.21	8.60	10.53	3.3%
Natural Gas Feedstocks	9.77	6.03	6.27	7.42	9.16	10.62	12.68	2.9%
Metallurgical Coal	4.49	5.43	6.56	7.65	8.54	9.44	10.50	2.6%
Other Industrial Coal	2.90	3.05	3.17	3.55	3.96	4.43	5.01	1.9%
Coal for Liquids	- -	- -	1.96	2.30	2.36	2.87	3.27	- -
Electricity	19.79	19.79	19.30	21.43	23.79	26.45	29.88	1.6%
Energy Consumption (quadrillion Btu)[1]								
Industrial Consumption Excluding Refining								
Liquefied Petroleum Gases Heat and Power	0.23	0.21	0.25	0.25	0.25	0.24	0.24	0.5%
Liquefied Petroleum Gases Feedstocks	1.85	1.79	2.07	2.10	2.09	2.00	1.90	0.2%
Motor Gasoline	0.25	0.25	0.33	0.33	0.33	0.32	0.32	1.0%
Distillate Fuel Oil	1.26	1.16	1.16	1.16	1.16	1.14	1.13	-0.1%
Residual Fuel Oil	0.19	0.16	0.17	0.17	0.17	0.16	0.16	-0.1%
Petrochemical Feedstocks	1.12	0.90	1.29	1.33	1.34	1.30	1.26	1.3%
Petroleum Coke	0.35	0.28	0.22	0.21	0.21	0.21	0.20	-1.3%
Asphalt and Road Oil	1.01	0.87	1.08	1.05	1.01	0.96	0.94	0.3%
Miscellaneous Petroleum[2]	0.48	0.27	0.36	0.35	0.35	0.33	0.31	0.6%
Petroleum Subtotal	6.74	5.88	6.93	6.96	6.90	6.66	6.46	0.4%
Natural Gas Heat and Power	4.99	4.43	6.24	6.34	6.30	6.29	6.29	1.4%
Natural Gas Feedstocks	0.59	0.55	0.61	0.60	0.56	0.51	0.47	-0.6%
Lease and Plant Fuel[3]	1.26	1.19	1.24	1.24	1.22	1.24	1.28	0.3%
Natural Gas Subtotal	6.84	6.16	8.09	8.18	8.08	8.03	8.04	1.0%
Metallurgical Coal and Coke[4]	0.62	0.38	0.59	0.58	0.56	0.51	0.47	0.8%
Other Industrial Coal	1.10	0.88	0.92	0.92	0.91	0.90	0.88	0.0%
Coal Subtotal	1.72	1.26	1.51	1.50	1.47	1.41	1.35	0.3%
Renewables[5]	1.52	1.42	1.89	1.98	2.05	2.06	2.04	1.4%
Purchased Electricity	3.27	2.82	3.37	3.39	3.34	3.22	3.09	0.3%
Delivered Energy	**20.09**	**17.55**	**21.79**	**22.01**	**21.84**	**21.38**	**20.98**	**0.7%**
Electricity Related Losses	7.06	6.04	6.93	6.99	6.86	6.54	6.20	0.1%
Total	**27.15**	**23.59**	**28.73**	**29.00**	**28.70**	**27.92**	**27.19**	**0.5%**

Table A6. Industrial sector key indicators and consumption (continued)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Refining Consumption								
Liquefied Petroleum Gases Heat and Power	0.01	0.01	0.04	0.04	0.04	0.05	0.05	6.0%
Distillate Fuel Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Residual Fuel Oil	0.01	0.01	0.00	0.00	0.00	0.00	0.00	- -
Petroleum Coke	0.51	0.52	0.59	0.55	0.55	0.57	0.58	0.4%
Still Gas	1.60	1.50	1.70	1.63	1.64	1.68	1.82	0.7%
Miscellaneous Petroleum[2]	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.5%
Petroleum Subtotal	2.16	2.05	2.36	2.25	2.26	2.32	2.47	0.7%
Natural Gas Heat and Power	1.25	1.34	1.42	1.52	1.46	1.50	1.47	0.4%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Natural Gas Subtotal	1.25	1.34	1.42	1.52	1.46	1.50	1.47	0.4%
Other Industrial Coal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.0%
Coal-to-Liquids Heat and Power	0.00	0.00	0.10	0.13	0.40	0.77	1.19	32.7%
Coal Subtotal	0.06	0.06	0.16	0.19	0.46	0.83	1.25	12.4%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Purchased Electricity	0.17	0.19	0.17	0.18	0.18	0.19	0.19	0.2%
Delivered Energy	**4.63**	**4.30**	**4.96**	**5.33**	**6.26**	**7.16**	**7.91**	**2.4%**
Electricity Related Losses	0.38	0.40	0.35	0.37	0.37	0.38	0.39	-0.1%
Total	**5.00**	**4.69**	**5.30**	**5.70**	**6.63**	**7.54**	**8.30**	**2.2%**
Total Industrial Sector Consumption								
Liquefied Petroleum Gases Heat and Power	0.24	0.22	0.30	0.29	0.29	0.29	0.28	1.1%
Liquefied Petroleum Gases Feedstocks	1.85	1.79	2.07	2.10	2.09	2.00	1.90	0.2%
Motor Gasoline	0.25	0.25	0.33	0.33	0.33	0.32	0.32	1.0%
Distillate Fuel Oil	1.27	1.16	1.16	1.16	1.16	1.14	1.13	-0.1%
Residual Fuel Oil	0.20	0.17	0.17	0.17	0.17	0.16	0.16	-0.3%
Petrochemical Feedstocks	1.12	0.90	1.29	1.33	1.34	1.30	1.26	1.3%
Petroleum Coke	0.87	0.80	0.81	0.77	0.76	0.78	0.78	-0.1%
Asphalt and Road Oil	1.01	0.87	1.08	1.05	1.01	0.96	0.94	0.3%
Still Gas	1.60	1.50	1.70	1.63	1.64	1.68	1.82	0.7%
Miscellaneous Petroleum[2]	0.50	0.28	0.38	0.37	0.37	0.35	0.34	0.7%
Petroleum Subtotal	8.91	7.94	9.29	9.20	9.16	8.98	8.94	0.5%
Natural Gas Heat and Power	6.24	5.76	7.66	7.86	7.76	7.79	7.76	1.2%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Natural Gas Feedstocks	0.59	0.55	0.61	0.60	0.56	0.51	0.47	-0.6%
Lease and Plant Fuel[3]	1.26	1.19	1.24	1.24	1.22	1.24	1.28	0.3%
Natural Gas Subtotal	8.09	7.50	9.51	9.70	9.54	9.53	9.51	0.9%
Metallurgical Coal and Coke[4]	0.62	0.38	0.59	0.58	0.56	0.51	0.47	0.8%
Other Industrial Coal	1.16	0.94	0.98	0.98	0.97	0.96	0.94	0.0%
Coal-to-Liquids Heat and Power	0.00	0.00	0.10	0.13	0.40	0.77	1.19	32.7%
Coal Subtotal	1.78	1.32	1.67	1.69	1.93	2.24	2.60	2.6%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Renewables[5]	1.52	1.42	1.89	1.98	2.05	2.06	2.04	1.4%
Purchased Electricity	3.44	3.01	3.54	3.57	3.52	3.40	3.28	0.3%
Delivered Energy	**24.72**	**21.85**	**26.75**	**27.34**	**28.11**	**28.54**	**28.89**	**1.1%**
Electricity Related Losses	7.44	6.44	7.28	7.36	7.23	6.92	6.59	0.1%
Total	**32.16**	**28.29**	**34.03**	**34.70**	**35.33**	**35.46**	**35.49**	**0.9%**

Table A6. Industrial sector key indicators and consumption (continued)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Energy Consumption per dollar of Shipment (thousand Btu per 2005 dollars)								
Liquefied Petroleum Gases Heat and Power	0.04	0.04	0.04	0.04	0.03	0.03	0.03	-0.6%
Liquefied Petroleum Gases Feedstocks	0.27	0.30	0.28	0.26	0.25	0.23	0.20	-1.4%
Motor Gasoline	0.04	0.04	0.04	0.04	0.04	0.04	0.03	-0.7%
Distillate Fuel Oil	0.19	0.19	0.15	0.15	0.14	0.13	0.12	-1.8%
Residual Fuel Oil	0.03	0.03	0.02	0.02	0.02	0.02	0.02	-1.9%
Petrochemical Feedstocks	0.17	0.15	0.17	0.17	0.16	0.15	0.14	-0.4%
Petroleum Coke	0.13	0.13	0.11	0.10	0.09	0.09	0.08	-1.7%
Asphalt and Road Oil	0.15	0.14	0.14	0.13	0.12	0.11	0.10	-1.3%
Still Gas	0.24	0.25	0.23	0.21	0.20	0.19	0.20	-0.9%
Miscellaneous Petroleum[2]	0.07	0.05	0.05	0.05	0.04	0.04	0.04	-1.0%
Petroleum Subtotal	1.33	1.32	1.24	1.16	1.09	1.02	0.96	-1.2%
Natural Gas Heat and Power	0.93	0.96	1.03	0.99	0.92	0.88	0.84	-0.5%
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Natural Gas Feedstocks	0.09	0.09	0.08	0.08	0.07	0.06	0.05	-2.2%
Lease and Plant Fuel[3]	0.19	0.20	0.17	0.16	0.15	0.14	0.14	-1.4%
Natural Gas Subtotal	1.20	1.25	1.27	1.22	1.14	1.08	1.02	-0.8%
Metallurgical Coal and Coke[4]	0.09	0.06	0.08	0.07	0.07	0.06	0.05	-0.9%
Other Industrial Coal	0.17	0.16	0.13	0.12	0.12	0.11	0.10	-1.7%
Coal-to-Liquids Heat and Power	0.00	0.00	0.01	0.02	0.05	0.09	0.13	30.5%
Coal Subtotal	0.27	0.22	0.22	0.21	0.23	0.25	0.28	0.9%
Biofuels Heat and Coproducts	0.15	0.11	0.11	0.15	0.23	0.26	0.27	3.6%
Renewables[5]	0.23	0.24	0.25	0.25	0.24	0.23	0.22	-0.3%
Purchased Electricity	0.51	0.50	0.47	0.45	0.42	0.39	0.35	-1.3%
Delivered Energy	**3.68**	**3.63**	**3.58**	**3.44**	**3.35**	**3.23**	**3.11**	**-0.6%**
Electricity Related Losses	1.11	1.07	0.97	0.93	0.86	0.78	0.71	-1.6%
Total	**4.79**	**4.70**	**4.55**	**4.36**	**4.21**	**4.02**	**3.82**	**-0.8%**
Industrial Combined Heat and Power								
Capacity (gigawatts)	25.73	27.99	38.78	43.54	54.01	63.20	71.40	3.7%
Generation (billion kilowatthours)	135.57	152.63	227.87	263.44	344.91	413.49	475.49	4.5%

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes lubricants and miscellaneous petroleum products.
[3]Represents natural gas used in well, field, and lease operations, and in natural gas processing plant machinery.
[4]Includes net coal coke imports.
[5]Includes consumption of energy produced from hydroelectric, wood and wood waste, municipal waste, and other biomass sources.
Btu = British thermal unit.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 prices for motor gasoline and distillate fuel oil are based on: U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2008 and 2009 petrochemical feedstock and asphalt and road oil prices are based on: EIA, *State Energy Data Report 2008*, DOE/EIA-0214(2008) (Washington, DC, June 2010). 2008 and 2009 coal prices are based on: EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010) and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. 2008 and 2009 electricity prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 natural gas prices are based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 refining consumption values are based on: *Petroleum Supply Annual 2008,* DOE/EIA-0340(2008)/1 (Washington, DC, June 2009). 2009 refining consumption based on: *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). Other 2008 and 2009 consumption values are based on: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 shipments: IHS Global Insight Industry model, September 2010. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A7. Transportation sector key indicators and delivered energy consumption

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Key Indicators								
Travel Indicators								
(billion vehicle miles traveled)								
Light-Duty Vehicles less than 8,500 pounds	2690	2707	2947	3199	3467	3755	4043	1.6%
Commercial Light Trucks[1]	72	67	81	86	92	98	104	1.7%
Freight Trucks greater than 10,000 pounds	228	207	250	269	291	313	335	1.9%
(billion seat miles available)								
Air	1014	960	1059	1122	1180	1234	1282	1.1%
(billion ton miles traveled)								
Rail	1777	1677	1886	2025	2143	2255	2328	1.3%
Domestic Shipping	521	486	521	544	559	577	596	0.8%
Energy Efficiency Indicators								
(miles per gallon)								
New Light-Duty Vehicle CAFE Standard[2]	25.2	25.4	32.6	35.4	35.6	35.8	35.9	1.3%
New Car[2]	28.4	28.4	37.9	40.4	40.4	40.4	40.4	1.4%
New Light Truck[2]	22.4	23.0	28.0	29.7	29.7	29.7	29.7	1.0%
Compliance New Light-Duty Vehicle[3]	28.0	29.1	32.5	35.8	36.6	37.2	37.8	1.0%
New Car[3]	32.5	33.7	37.8	40.7	41.2	41.6	42.0	0.9%
New Light Truck[3]	24.2	25.5	27.8	30.3	30.8	31.3	31.8	0.9%
Tested New Light-Duty Vehicle[4]	28.0	28.0	31.3	34.5	35.3	36.0	36.5	1.0%
New Car[4]	32.5	32.7	36.5	39.4	40.0	40.4	40.8	0.9%
New Light Truck[4]	24.2	24.3	26.6	29.1	29.6	30.1	30.6	0.9%
On-Road New Light-Duty Vehicle[5]	23.2	23.2	26.0	28.8	29.5	30.2	30.6	1.1%
New Car[5]	26.5	26.7	30.1	32.6	33.3	33.8	34.2	1.0%
New Light Truck[5]	20.3	20.4	22.3	24.4	24.8	25.3	25.7	0.9%
Light-Duty Stock[6]	20.8	20.8	22.1	23.9	25.7	27.0	27.9	1.1%
New Commercial Light Truck[1]	15.4	15.6	16.4	17.7	17.9	18.0	18.1	0.6%
Stock Commercial Light Truck[1]	14.3	14.4	15.2	16.3	17.2	17.7	18.0	0.9%
Freight Truck	6.1	6.1	6.1	6.2	6.4	6.5	6.6	0.3%
(seat miles per gallon)								
Aircraft	61.8	62.0	62.8	64.1	65.6	67.5	69.9	0.5%
(ton miles per thousand Btu)								
Rail	3.3	3.3	3.3	3.3	3.3	3.4	3.4	0.1%
Domestic Shipping	2.4	2.4	2.4	2.5	2.5	2.5	2.5	0.2%
Energy Use by Mode (quadrillion Btu)								
Light-Duty Vehicles	16.14	16.13	16.36	16.29	16.40	16.89	17.66	0.3%
Commercial Light Trucks[1]	0.63	0.58	0.66	0.66	0.67	0.69	0.73	0.8%
Bus Transportation	0.27	0.27	0.28	0.29	0.30	0.32	0.33	0.8%
Freight Trucks	4.70	4.26	5.11	5.43	5.73	6.02	6.35	1.5%
Rail, Passenger	0.05	0.05	0.05	0.06	0.06	0.06	0.07	1.1%
Rail, Freight	0.58	0.51	0.57	0.61	0.64	0.67	0.69	1.2%
Shipping, Domestic	0.23	0.20	0.22	0.22	0.23	0.23	0.24	0.6%
Shipping, International	0.90	0.78	0.78	0.79	0.79	0.80	0.80	0.1%
Recreational Boats	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.6%
Air	2.70	2.66	2.71	2.84	2.95	3.03	3.07	0.6%
Military Use	0.71	0.75	0.69	0.70	0.72	0.74	0.76	0.0%
Lubricants	0.14	0.13	0.12	0.12	0.13	0.13	0.13	0.1%
Pipeline Fuel	0.67	0.65	0.67	0.65	0.64	0.65	0.67	0.1%
Total	**27.95**	**27.23**	**28.50**	**28.96**	**29.55**	**30.54**	**31.80**	**0.6%**

Table A7. Transportation sector key indicators and delivered energy consumption (continued)

Key Indicators and Consumption	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Energy Use by Mode (million barrels per day oil equivalent)								
Light-Duty Vehicles	8.55	8.62	8.83	8.90	9.10	9.41	9.83	0.5%
Commercial Light Trucks[1]	0.32	0.30	0.34	0.34	0.34	0.36	0.37	0.9%
Bus Transportation	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.8%
Freight Trucks	2.26	2.05	2.46	2.61	2.75	2.90	3.05	1.5%
Rail, Passenger	0.02	0.02	0.03	0.03	0.03	0.03	0.03	1.1%
Rail, Freight	0.27	0.24	0.27	0.29	0.31	0.32	0.33	1.2%
Shipping, Domestic	0.11	0.09	0.10	0.10	0.11	0.11	0.11	0.6%
Shipping, International	0.39	0.34	0.34	0.35	0.35	0.35	0.35	0.1%
Recreational Boats	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.7%
Air	1.31	1.29	1.31	1.38	1.43	1.47	1.49	0.6%
Military Use	0.34	0.36	0.33	0.34	0.34	0.35	0.36	0.1%
Lubricants	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.1%
Pipeline Fuel	0.31	0.31	0.31	0.31	0.30	0.31	0.32	0.1%
Total	**14.22**	**13.95**	**14.67**	**15.00**	**15.42**	**15.98**	**16.64**	**0.7%**

[1]Commercial trucks 8,500 to 10,000 pounds.
[2]CAFE standard based on projected new vehicle sales.
[3]Includes CAFE credits for alternative fueled vehicle sales, but does not include banked credits used for compliance.
[4]Environmental Protection Agency rated miles per gallon.
[5]Tested new vehicle efficiency revised for on-road performance.
[6]Combined car and light truck "on-the-road" estimate.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.

Sources: 2008 and 2009: U.S. Energy Information Administration (EIA), *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010); EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010); Federal Highway Administration, *Highway Statistics 2008* (Washington, DC, April 2010); Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 29 and Annual* (Oak Ridge, TN, 2010); National Highway Traffic and Safety Administration, *Summary of Fuel Economy Performance* (Washington, DC, December 9, 2009); U.S. Department of Commerce, Bureau of the Census, "Vehicle Inventory and Use Survey," EC02TV (Washington, DC, December 2004); EIA, Alternatives to Traditional Transportation Fuels 2008 (Part II - User and Fuel Data), April 2010; EIA, *State Energy Data Report 2008*, DOE/EIA-0214(2008) (Washington, DC, June 2010); U.S. Department of Transportation, Research and Special Programs Administration, *Air Carrier Statistics Monthly, December 2009/2008* (Washington, DC, December ; EIA, *Fuel Oil and Kerosene Sales 2008*, DOE/EIA-0535(2008) (Washington, DC, December 2009); and United States Department of Defense, Defense Fuel Supply Center, Fact Book (January, 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A8. Electricity supply, disposition, prices, and emissions
(billion kilowatthours, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Generation by Fuel Type								
Electric Power Sector[1]								
Power Only[2]								
Coal	1932	1719	1746	1849	1987	2028	2076	0.7%
Petroleum	39	32	37	39	39	40	41	1.0%
Natural Gas[3]	683	722	729	716	701	817	921	0.9%
Nuclear Power	806	799	839	877	877	877	874	0.3%
Pumped Storage/Other[4]	0	2	-0	-0	-0	-0	-0	- -
Renewable Sources[5]	347	380	491	521	541	554	569	1.6%
Distributed Generation (Natural Gas)	0	0	1	2	3	4	5	- -
Total	**3807**	**3653**	**3843**	**4004**	**4148**	**4319**	**4485**	**0.8%**
Combined Heat and Power[6]								
Coal	37	30	23	26	29	30	31	0.1%
Petroleum	4	4	0	0	0	0	0	-9.1%
Natural Gas	119	119	129	125	119	120	113	-0.2%
Renewable Sources	4	4	3	4	4	3	3	-1.0%
Total	**167**	**161**	**155**	**155**	**153**	**153**	**148**	**-0.3%**
Total Net Generation	**3974**	**3814**	**3998**	**4158**	**4300**	**4472**	**4633**	**0.8%**
Less Direct Use	35	35	33	33	33	33	33	-0.2%
Net Available to the Grid	**3939**	**3779**	**3965**	**4125**	**4267**	**4439**	**4600**	**0.8%**
End-Use Generation[7]								
Coal	19	23	30	32	52	79	111	6.3%
Petroleum	3	5	5	5	5	5	5	-0.3%
Natural Gas	80	90	141	160	180	211	250	4.0%
Other Gaseous Fuels[8]	11	11	15	15	15	15	15	1.4%
Renewable Sources[9]	34	36	63	82	128	147	152	5.7%
Other[10]	2	2	1	1	1	1	1	-1.8%
Total	**149**	**167**	**255**	**295**	**381**	**458**	**533**	**4.6%**
Less Direct Use	120	135	205	230	276	334	392	4.2%
Total Sales to the Grid	**29**	**31**	**49**	**65**	**105**	**124**	**142**	**6.0%**
Total Electricity Generation by Fuel								
Coal	1987	1772	1799	1907	2069	2137	2218	0.9%
Petroleum	46	41	43	44	44	45	46	0.5%
Natural Gas	882	931	1000	1002	1003	1152	1288	1.3%
Nuclear Power	806	799	839	877	877	877	874	0.3%
Renewable Sources[5,9]	385	420	556	608	673	703	724	2.1%
Other[11]	16	18	16	16	16	16	16	-0.3%
Total Electricity Generation	**4123**	**3981**	**4253**	**4453**	**4682**	**4930**	**5167**	**1.0%**
Total Net Generation to the Grid	**3968**	**3810**	**4014**	**4190**	**4372**	**4563**	**4742**	**0.8%**
Net Imports	**33**	**34**	**33**	**27**	**22**	**13**	**14**	**-3.4%**
Electricity Sales by Sector								
Residential	1380	1363	1348	1394	1461	1538	1613	0.7%
Commercial	1336	1323	1416	1526	1636	1761	1886	1.4%
Industrial	1009	882	1038	1046	1031	997	962	0.3%
Transportation	7	7	8	10	13	18	22	4.6%
Total	**3732**	**3574**	**3811**	**3976**	**4142**	**4314**	**4483**	**0.9%**
Direct Use	154	170	239	263	309	367	425	3.6%
Total Electricity Use	**3886**	**3745**	**4049**	**4240**	**4451**	**4681**	**4908**	**1.0%**

Table A8. Electricity supply, disposition, prices, and emissions (continued)
(billion kilowatthours, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
End-Use Prices								
(2009 cents per kilowatthour)								
Residential	11.3	11.5	10.9	10.7	10.6	10.6	10.8	-0.2%
Commercial	10.4	10.1	9.1	9.0	9.1	9.1	9.2	-0.3%
Industrial	6.8	6.8	6.0	6.1	6.1	6.2	6.4	-0.2%
Transportation	11.8	11.9	10.0	9.6	10.1	10.5	11.0	-0.3%
All Sectors Average	**9.8**	**9.8**	**8.9**	**8.8**	**8.9**	**9.0**	**9.2**	**-0.2%**
(nominal cents per kilowatthour)								
Residential	11.2	11.5	11.8	12.9	14.1	15.4	17.2	1.6%
Commercial	10.3	10.1	9.9	10.9	12.0	13.2	14.7	1.5%
Industrial	6.8	6.8	6.6	7.3	8.1	9.0	10.2	1.6%
Transportation	11.7	11.9	10.9	11.6	13.3	15.3	17.6	1.5%
All Sectors Average	**9.7**	**9.8**	**9.7**	**10.7**	**11.8**	**13.0**	**14.7**	**1.6%**
Prices by Service Category								
(2009 cents per kilowatthour)								
Generation	6.1	6.0	5.0	5.3	5.6	5.8	6.0	0.0%
Transmission	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.5%
Distribution	2.9	3.0	3.0	2.8	2.6	2.4	2.3	-1.0%
(nominal cents per kilowatthour)								
Generation	6.1	6.0	5.5	6.4	7.4	8.4	9.6	1.8%
Transmission	0.7	0.7	0.9	1.0	1.1	1.2	1.4	2.3%
Distribution	2.9	3.0	3.3	3.4	3.4	3.5	3.7	0.8%
Electric Power Sector Emissions[1]								
Sulfur Dioxide (million tons)	7.62	5.72	3.77	3.68	4.09	3.97	3.94	-1.4%
Nitrogen Oxide (million tons)	3.01	1.99	1.99	1.98	2.00	2.03	2.05	0.1%
Mercury (tons)	45.27	40.66	26.88	26.82	28.21	29.08	29.91	-1.2%

[1]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes plants that only produce electricity.
[3]Includes electricity generation from fuel cells.
[4]Includes non-biogenic municipal waste. The U.S. Energy Information Administration estimates approximately 7 billion kilowatthours of electricity were generated from a municipal waste stream containing petroleum-derived plastics and other non-renewable sources. See U.S. Energy Information Administration, *Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy*, (Washington, DC, May 2007).
[5]Includes conventional hydroelectric, geothermal, wood, wood waste, biogenic municipal waste, landfill gas, other biomass, solar, and wind power.
[6]Includes combined heat and power plants whose primary business is to sell electricity and heat to the public (i.e., those that report North American Industry Classification System code 22).
[7]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
[8]Includes refinery gas and still gas.
[9]Includes conventional hydroelectric, geothermal, wood, wood waste, all municipal waste, landfill gas, other biomass, solar, and wind power.
[10]Includes batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.
[11]Includes pumped storage, non-biogenic municipal waste, refinery gas, still gas, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 electric power sector generation; sales to utilities; net imports; electricity sales; electricity end-use prices; and emissions: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010), and supporting databases. 2008 and 2009 prices: EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. **Projections**: EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A9. Electricity generating capacity
(gigawatts)

Net Summer Capacity[1]	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Electric Power Sector[2]								
Power Only[3]								
Coal	304.4	308.2	312.5	313.1	313.1	313.1	313.4	0.1%
Oil and Natural Gas Steam[4]	114.6	114.0	99.5	92.6	92.4	92.4	88.4	-1.0%
Combined Cycle	157.1	165.4	170.7	170.9	177.2	202.7	226.8	1.2%
Combustion Turbine/Diesel	131.7	134.6	137.6	140.4	152.3	162.5	178.6	1.1%
Nuclear Power[5]	100.6	101.0	105.7	110.5	110.5	110.5	110.5	0.3%
Pumped Storage	21.8	21.8	21.8	21.8	21.8	21.8	21.8	0.0%
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Renewable Sources[6]	109.7	116.3	135.7	136.6	141.1	144.9	147.9	0.9%
Distributed Generation[7]	0.0	0.0	0.5	0.8	1.3	2.0	3.1	- -
Total	**939.8**	**961.5**	**984.0**	**986.8**	**1009.7**	**1050.0**	**1090.4**	**0.5%**
Combined Heat and Power[8]								
Coal	4.7	4.7	4.5	4.5	4.5	4.5	4.5	-0.1%
Oil and Natural Gas Steam[4]	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.0%
Combined Cycle	31.8	31.8	32.8	32.8	32.8	32.8	32.8	0.1%
Combustion Turbine/Diesel	2.8	2.9	3.0	3.0	3.0	3.0	3.0	0.2%
Renewable Sources[6]	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.0%
Total	**40.4**	**40.4**	**41.3**	**41.3**	**41.3**	**41.3**	**41.3**	**0.1%**
Cumulative Planned Additions[9]								
Coal	0.0	0.0	11.5	11.5	11.5	11.5	11.5	- -
Oil and Natural Gas Steam[4]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Combined Cycle	0.0	0.0	6.4	6.4	6.4	6.4	6.4	- -
Combustion Turbine/Diesel	0.0	0.0	2.0	2.0	2.0	2.0	2.0	- -
Nuclear Power	0.0	0.0	1.1	1.1	1.1	1.1	1.1	- -
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Renewable Sources[6]	0.0	0.0	0.7	0.8	1.0	1.1	1.1	- -
Distributed Generation[7]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Total	**0.0**	**0.0**	**21.7**	**21.8**	**21.9**	**22.0**	**22.1**	**- -**
Cumulative Unplanned Additions[9]								
Coal	0.0	0.0	0.0	2.0	2.0	2.0	2.3	- -
Oil and Natural Gas Steam[4]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Combined Cycle	0.0	0.0	0.3	0.4	6.7	32.3	56.3	- -
Combustion Turbine/Diesel	0.0	0.0	4.1	7.7	19.6	29.9	45.9	- -
Nuclear Power	0.0	0.0	0.0	5.2	5.2	5.2	5.2	- -
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Renewable Sources[6]	0.0	0.0	18.7	19.5	23.9	27.6	30.5	- -
Distributed Generation[7]	0.0	0.0	0.5	0.8	1.3	2.0	3.1	- -
Total	**0.0**	**0.0**	**23.5**	**35.7**	**58.7**	**98.9**	**143.3**	**- -**
Cumulative Electric Power Sector Additions	**0.0**	**0.0**	**45.2**	**57.5**	**80.6**	**120.9**	**165.4**	**- -**
Cumulative Retirements[10]								
Coal	0.0	0.0	7.4	8.8	8.8	8.8	8.8	- -
Oil and Natural Gas Steam[4]	0.0	0.0	14.5	21.4	21.6	21.6	25.7	- -
Combined Cycle	0.0	0.0	0.4	0.4	0.4	0.4	0.4	- -
Combustion Turbine/Diesel	0.0	0.0	2.9	3.8	3.8	3.8	3.8	- -
Nuclear Power	0.0	0.0	0.0	0.6	0.6	0.6	0.6	- -
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -
Renewable Sources[6]	0.0	0.0	0.1	0.1	0.1	0.1	0.1	- -
Total	**0.0**	**0.0**	**25.4**	**35.0**	**35.2**	**35.2**	**39.3**	**- -**
Total Electric Power Sector Capacity	**980.2**	**1001.9**	**1025.3**	**1028.2**	**1051.0**	**1091.3**	**1131.7**	**0.5%**

Table A9. Electricity generating capacity (continued)
(gigawatts)

Net Summer Capacity[1]	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
End-Use Generators[11]								
Coal	3.5	4.0	4.9	5.2	7.9	11.5	15.7	5.4%
Petroleum	0.9	1.2	1.2	1.2	1.2	1.2	1.2	0.2%
Natural Gas	14.8	16.1	23.0	25.5	28.2	32.4	37.5	3.3%
Other Gaseous Fuels	1.9	1.9	2.7	2.7	2.7	2.7	2.7	1.3%
Renewable Sources[6]	6.7	7.5	17.5	21.3	27.4	30.3	31.6	5.7%
Other	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.0%
Total	**28.4**	**31.5**	**50.0**	**56.6**	**68.1**	**78.9**	**89.5**	**4.1%**
Cumulative Capacity Additions[9]	**0.0**	**0.0**	**18.5**	**25.1**	**36.6**	**47.4**	**58.0**	**- -**

[1]Net summer capacity is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.
[2]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[3]Includes plants that only produce electricity. Includes capacity increases (uprates) at existing units.
[4]Includes oil-, gas-, and dual-fired capacity.
[5]Nuclear capacity includes 3.8 gigawatts of uprates through 2035.
[6]Includes conventional hydroelectric, geothermal, wood, wood waste, all municipal waste, landfill gas, other biomass, solar, and wind power. Facilities co-firing biomass and coal are classified as coal.
[7]Primarily peak load capacity fueled by natural gas.
[8]Includes combined heat and power plants whose primary business is to sell electricity and heat to the public (i.e., those that report North American Industry Classification System code 22).
[9]Cumulative additions after December 31, 2009.
[10]Cumulative retirements after December 31, 2009.
[11]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 capacity and projected planned additions: U.S. Energy Information Administration (EIA), Form EIA-860, "Annual Electric Generator Report" (preliminary). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A10. Electricity trade
(billion kilowatthours, unless otherwise noted)

Electricity Trade	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Interregional Electricity Trade								
Gross Domestic Sales								
Firm Power	181.3	185.6	172.7	123.5	65.6	54.1	54.1	-4.6%
Economy	303.1	279.2	290.0	241.3	286.6	287.1	301.1	0.3%
Total	**484.4**	**464.7**	**462.7**	**364.7**	**352.2**	**341.1**	**355.2**	**-1.0%**
Gross Domestic Sales (million 2009 dollars)								
Firm Power	10738.4	10992.8	10232.4	7313.8	3888.3	3203.2	3203.2	-4.6%
Economy	24158.0	11225.8	11949.4	11042.4	15126.4	15068.1	17376.4	1.7%
Total	**34896.4**	**22218.6**	**22181.8**	**18356.2**	**19014.6**	**18271.3**	**20579.6**	**-0.3%**
International Electricity Trade								
Imports from Canada and Mexico								
Firm Power	19.9	19.3	28.4	16.9	3.1	0.4	0.4	-14.0%
Economy	37.1	33.1	24.4	29.1	36.0	29.2	30.0	-0.4%
Total	**57.0**	**52.4**	**52.8**	**46.0**	**39.2**	**29.6**	**30.4**	**-2.1%**
Exports to Canada and Mexico								
Firm Power	3.3	3.3	0.9	0.5	0.1	0.0	0.0	- -
Economy	20.7	14.7	18.7	18.1	17.5	17.0	16.4	0.4%
Total	**24.1**	**18.1**	**19.6**	**18.6**	**17.6**	**17.0**	**16.4**	**-0.4%**

- - = Not applicable.

Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports. Firm Power Sales are capacity sales, meaning the delivery of the power is scheduled as part of the normal operating conditions of the affected electric systems. Economy Sales are subject to curtailment or cessation of delivery by the supplier in accordance with prior agreements or under specified conditions.

Sources: 2008 and 2009 interregional firm electricity trade data: North American Electric Reliability Council (NERC), Electricity Sales and Demand Database 2007. 2008 and 2009 Mexican electricity trade data: U.S. Energy Information Administration (EIA), *Electric Power Annual 2009* DOE/EIA-0348(2009) (Washington, DC, January 2011). 2008 Canadian international electricity trade data: National Energy Board, *Electricity Exports and Imports Statistics, 2008*. 2009 Canadian electricity trade data: National Energy Board, *Electricity Exports and Imports Statistics, 2009*. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A11. Liquid fuels supply and disposition
(million barrels per day, unless otherwise noted)

Supply and Disposition	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Crude Oil								
Domestic Crude Production[1]	4.96	5.36	5.81	6.08	5.88	5.82	5.95	0.4%
Alaska	0.69	0.65	0.49	0.42	0.41	0.27	0.39	-1.9%
Lower 48 States	4.28	4.71	5.32	5.66	5.47	5.54	5.56	0.6%
Net Imports	9.75	8.97	8.70	8.30	8.25	8.21	8.25	-0.3%
Gross Imports	9.78	9.01	8.74	8.34	8.28	8.24	8.28	-0.3%
Exports	0.03	0.04	0.03	0.03	0.03	0.03	0.03	-1.2%
Other Crude Supply[2]	-0.06	0.01	0.00	0.00	0.00	0.00	0.00	- -
Total Crude Supply	**14.66**	**14.33**	**14.52**	**14.38**	**14.13**	**14.02**	**14.20**	**-0.0%**
Other Petroleum Supply	**4.10**	**3.59**	**4.38**	**4.34**	**4.41**	**4.40**	**4.46**	**0.8%**
Natural Gas Plant Liquids	1.78	1.91	2.23	2.36	2.68	2.79	2.94	1.7%
Net Product Imports	1.39	0.75	1.14	0.96	0.81	0.73	0.64	-0.6%
Gross Refined Product Imports[3]	1.54	1.27	1.04	0.99	0.92	0.90	0.84	-1.6%
Unfinished Oil Imports	0.76	0.68	0.80	0.78	0.75	0.74	0.76	0.5%
Blending Component Imports	0.79	0.72	0.81	0.81	0.80	0.81	0.83	0.6%
Exports	1.71	1.91	1.50	1.62	1.67	1.72	1.80	-0.2%
Refinery Processing Gain[4]	1.00	0.98	1.01	1.02	0.92	0.88	0.88	-0.4%
Product Stock Withdrawal	-0.07	-0.04	0.00	0.00	0.00	0.00	0.00	- -
Other Non-petroleum Supply	**0.76**	**0.81**	**1.42**	**1.86**	**2.40**	**2.92**	**3.28**	**5.5%**
Supply from Renewable Sources	0.66	0.76	1.12	1.47	1.92	2.30	2.48	4.7%
Ethanol	0.64	0.73	1.03	1.32	1.60	1.75	1.83	3.6%
Domestic Production	0.61	0.72	0.97	1.20	1.44	1.52	1.58	3.1%
Net Imports	0.03	0.01	0.06	0.11	0.16	0.23	0.26	12.2%
Biodiesel	0.02	0.02	0.08	0.10	0.12	0.13	0.13	7.1%
Domestic Production	0.04	0.03	0.07	0.10	0.12	0.12	0.13	5.2%
Net Imports	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00	- -
Other Biomass-derived Liquids[5]	0.00	0.00	0.02	0.05	0.19	0.42	0.52	- -
Liquids from Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Liquids from Coal	0.00	0.00	0.05	0.06	0.19	0.35	0.55	- -
Other[6]	0.10	0.05	0.25	0.33	0.30	0.27	0.25	6.3%
Total Primary Supply[7]	**19.51**	**18.73**	**20.32**	**20.58**	**20.94**	**21.34**	**21.94**	**0.6%**
Liquid Fuels Consumption								
by Fuel								
Liquefied Petroleum Gases	2.04	2.13	2.32	2.34	2.33	2.26	2.19	0.1%
E85[8]	0.00	0.00	0.01	0.22	0.64	0.81	0.84	26.3%
Motor Gasoline[9]	8.99	9.00	9.40	9.19	8.87	8.95	9.28	0.1%
Jet Fuel[10]	1.54	1.39	1.55	1.62	1.68	1.72	1.75	0.9%
Distillate Fuel Oil[11]	3.94	3.63	4.13	4.32	4.49	4.66	4.87	1.1%
Diesel	3.44	3.18	3.68	3.90	4.09	4.29	4.51	1.4%
Residual Fuel Oil	0.62	0.51	0.60	0.60	0.61	0.61	0.62	0.7%
Other[12]	2.38	2.15	2.43	2.39	2.38	2.35	2.38	0.4%
by Sector								
Residential and Commercial	1.06	1.04	0.95	0.91	0.88	0.86	0.85	-0.8%
Industrial[13]	4.69	4.25	4.99	4.96	4.94	4.83	4.77	0.5%
Transportation	13.87	13.61	14.31	14.61	14.96	15.47	16.10	0.6%
Electric Power[14]	0.21	0.18	0.19	0.20	0.20	0.20	0.21	0.7%
Total	**19.52**	**18.81**	**20.44**	**20.68**	**20.99**	**21.36**	**21.93**	**0.6%**
Discrepancy[15]	**-0.01**	**-0.08**	**-0.12**	**-0.10**	**-0.04**	**-0.02**	**0.01**	**- -**

Table A11. Liquid fuels supply and disposition (continued)
(million barrels per day, unless otherwise noted)

Supply and Disposition	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Domestic Refinery Distillation Capacity[16]	17.6	17.7	17.5	16.5	16.0	15.8	15.8	-0.4%
Capacity Utilization Rate (percent)[17]	85.0	83.0	84.9	89.0	90.1	90.6	91.9	0.4%
Net Import Share of Product Supplied (percent)	57.2	51.9	48.8	45.6	44.0	43.0	41.7	-0.8%
Net Expenditures for Imported Crude Oil and Petroleum Products (billion 2009 dollars)	272.65	203.65	296.22	325.04	347.74	363.62	370.10	2.3%

[1]Includes lease condensate.
[2]Strategic petroleum reserve stock additions plus unaccounted for crude oil and crude stock withdrawals minus crude product supplied.
[3]Includes other hydrocarbons and alcohols.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks used for the production of green diesel and gasoline.
[6]Includes domestic sources of other blending components, other hydrocarbons, and ethers.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[9]Includes ethanol and ethers blended into gasoline.
[10]Includes only kerosene type.
[11]Includes distillate fuel oil and kerosene from petroleum and biomass feedstocks.
[12]Includes aviation gasoline, petrochemical feedstocks, lubricants, waxes, asphalt, road oil, still gas, special naphthas, petroleum coke, crude oil product supplied, methanol, and miscellaneous petroleum products.
[13]Includes consumption for combined heat and power, which produces electricity and other useful thermal energy.
[14]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[15]Balancing item. Includes unaccounted for supply, losses, and gains.
[16]End-of-year operable capacity.
[17]Rate is calculated by dividing the gross annual input to atmospheric crude oil distillation units by their operable refining capacity in barrels per calendar day.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 petroleum product supplied based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). Other 2008 data: EIA, *Petroleum Supply Annual 2008,* DOE/EIA-0340(2008)/1 (Washington, DC, June 2009). Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A12. Petroleum product prices

(2009 dollars per gallon, unless otherwise noted)

Sector and Fuel	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Crude Oil Prices (2009 dollars per barrel)								
Imported Low Sulfur Light Crude Oil[1]	100.51	61.66	94.58	108.10	117.54	123.09	124.94	2.8%
Imported Crude Oil[1]	93.44	59.04	86.83	98.65	107.40	112.38	113.70	2.6%
Delivered Sector Product Prices								
Residential								
Liquefied Petroleum Gases	2.525	2.087	2.523	2.729	2.872	2.954	2.965	1.4%
Distillate Fuel Oil	3.432	2.514	2.931	3.366	3.595	3.736	3.818	1.6%
Commercial								
Distillate Fuel Oil	3.010	2.205	2.654	3.074	3.306	3.440	3.512	1.8%
Residual Fuel Oil	2.366	2.013	1.984	2.274	2.552	2.646	2.714	1.2%
Residual Fuel Oil (2009 dollars per barrel)	99.36	84.54	83.33	95.50	107.19	111.12	113.99	1.2%
Industrial[2]								
Liquefied Petroleum Gases	2.139	1.744	1.975	2.187	2.331	2.406	2.416	1.3%
Distillate Fuel Oil	3.108	2.281	2.656	3.079	3.322	3.452	3.523	1.7%
Residual Fuel Oil	2.434	1.804	2.215	2.492	2.722	2.786	2.803	1.7%
Residual Fuel Oil (2009 dollars per barrel)	102.24	75.79	93.04	104.68	114.34	117.02	117.73	1.7%
Transportation								
Liquefied Petroleum Gases	2.591	2.161	2.589	2.792	2.933	3.012	3.021	1.3%
Ethanol (E85)[3]	3.355	1.945	2.503	2.732	2.798	2.878	2.934	1.6%
Ethanol Wholesale Price	2.475	2.028	2.448	2.484	2.369	2.095	2.073	0.1%
Motor Gasoline[4]	3.327	2.349	3.134	3.378	3.539	3.640	3.707	1.8%
Jet Fuel[5]	3.146	1.700	2.568	2.974	3.181	3.334	3.413	2.7%
Diesel Fuel (distillate fuel oil)[6]	3.837	2.441	3.084	3.521	3.726	3.834	3.890	1.8%
Residual Fuel Oil	2.181	1.582	1.893	2.176	2.398	2.500	2.461	1.7%
Residual Fuel Oil (2009 dollars per barrel)	91.59	66.44	79.51	91.41	100.70	105.01	103.37	1.7%
Electric Power[7]								
Distillate Fuel Oil	2.713	1.988	2.336	2.743	2.940	3.094	3.168	1.8%
Residual Fuel Oil	2.208	1.342	1.971	2.209	2.433	2.525	2.501	2.4%
Residual Fuel Oil (2009 dollars per barrel)	92.73	56.36	82.79	92.77	102.20	106.05	105.03	2.4%
Refined Petroleum Product Prices[8]								
Liquefied Petroleum Gases	1.774	1.477	1.836	2.022	2.154	2.237	2.255	1.6%
Motor Gasoline[4]	3.305	2.344	3.134	3.378	3.539	3.640	3.707	1.8%
Jet Fuel[5]	3.146	1.700	2.568	2.974	3.181	3.334	3.413	2.7%
Distillate Fuel Oil	3.648	2.408	2.995	3.434	3.651	3.769	3.831	1.8%
Residual Fuel Oil	2.228	1.576	1.957	2.227	2.453	2.547	2.522	1.8%
Residual Fuel Oil (2009 dollars per barrel)	93.58	66.20	82.19	93.55	103.03	106.96	105.92	1.8%
Average	**3.098**	**2.155**	**2.822**	**3.114**	**3.289**	**3.406**	**3.478**	**1.9%**

Table A12. Petroleum product prices (continued)
(nominal dollars per gallon, unless otherwise noted)

Sector and Fuel	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Crude Oil Prices (nominal dollars per barrel)								
Imported Low Sulfur Light Crude Oil[1]	99.57	61.66	103.24	130.60	155.46	178.45	199.37	4.6%
Imported Crude Oil[1]	92.57	59.04	94.78	119.18	142.05	162.92	181.43	4.4%
Delivered Sector Product Prices								
Residential								
Liquefied Petroleum Gases	2.501	2.087	2.754	3.297	3.798	4.283	4.732	3.2%
Distillate Fuel Oil	3.400	2.514	3.200	4.067	4.754	5.416	6.092	3.5%
Commercial								
Distillate Fuel Oil	2.982	2.205	2.897	3.713	4.373	4.987	5.605	3.7%
Residual Fuel Oil	2.344	2.013	2.166	2.747	3.376	3.836	4.331	3.0%
Residual Fuel Oil (nominal dollars per barrel)	98.43	84.54	90.96	115.37	141.78	161.10	181.90	3.0%
Industrial[2]								
Liquefied Petroleum Gases	2.119	1.744	2.155	2.642	3.083	3.489	3.855	3.1%
Distillate Fuel Oil	3.079	2.281	2.899	3.720	4.394	5.004	5.621	3.5%
Residual Fuel Oil	2.412	1.804	2.418	3.011	3.601	4.039	4.473	3.6%
Residual Fuel Oil (nominal dollars per barrel)	101.29	75.79	101.55	126.46	151.23	169.65	187.86	3.6%
Transportation								
Liquefied Petroleum Gases	2.567	2.161	2.826	3.373	3.879	4.367	4.820	3.1%
Ethanol (E85)[3]	3.323	1.945	2.732	3.300	3.701	4.173	4.682	3.4%
Ethanol Wholesale Price	2.451	2.028	2.672	3.001	3.133	3.037	3.308	1.9%
Motor Gasoline[4]	3.297	2.349	3.421	4.081	4.681	5.277	5.915	3.6%
Jet Fuel[5]	3.116	1.700	2.803	3.594	4.207	4.833	5.447	4.6%
Diesel Fuel (distillate fuel oil)[6]	3.801	2.441	3.366	4.253	4.928	5.559	6.207	3.7%
Residual Fuel Oil	2.161	1.582	2.066	2.629	3.171	3.625	3.928	3.6%
Residual Fuel Oil (nominal dollars per barrel)	90.74	66.44	86.79	110.43	133.20	152.24	164.96	3.6%
Electric Power[7]								
Distillate Fuel Oil	2.688	1.988	2.550	3.314	3.889	4.486	5.055	3.7%
Residual Fuel Oil	2.187	1.342	2.152	2.669	3.219	3.661	3.990	4.3%
Residual Fuel Oil (nominal dollars per barrel)	91.87	56.36	90.37	112.08	135.18	153.75	167.60	4.3%
Refined Petroleum Product Prices[8]								
Liquefied Petroleum Gases	1.758	1.477	2.004	2.443	2.849	3.242	3.599	3.5%
Motor Gasoline[4]	3.274	2.344	3.421	4.081	4.681	5.277	5.915	3.6%
Jet Fuel[5]	3.116	1.700	2.803	3.594	4.207	4.833	5.447	4.6%
Distillate Fuel Oil	3.614	2.408	3.269	4.149	4.829	5.464	6.113	3.6%
Residual Fuel Oil	2.207	1.576	2.136	2.691	3.245	3.692	4.024	3.7%
Residual Fuel Oil (nominal dollars per barrel)	92.71	66.20	89.71	113.02	136.27	155.06	169.02	3.7%
Average	**3.069**	**2.155**	**3.080**	**3.762**	**4.350**	**4.938**	**5.550**	**3.7%**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[3]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[4]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[5]Includes only kerosene type.
[6]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[7]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[8]Weighted averages of end-use fuel prices are derived from the prices in each sector and the corresponding sectoral consumption.
Note: Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 imported low sulfur light crude oil price: U.S. Energy Information Administration (EIA), Form EIA-856, “Monthly Foreign Crude Oil Acquisition Report.” 2008 and 2009 imported crude oil price: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on: EIA, *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2008 and 2009 residential, commercial, industrial, and transportation sector petroleum product prices are derived from: EIA, Form EIA-782A, “Refiners’/Gas Plant Operators’ Monthly Petroleum Product Sales Report.” 2008 and 2009 electric power prices based on: EIA, *Monthly Energy Review*, DOE/EIA-0035(2010/09) (Washington, DC, September 2010). 2008 and 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. 2008 and 2009 wholesale ethanol prices derived from Bloomberg U.S. average rack price. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A13. Natural gas supply, disposition, and prices
(trillion cubic feet per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Production								
Dry Gas Production[1]	20.29	20.96	22.43	23.43	23.98	25.10	26.32	0.9%
Supplemental Natural Gas[2]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	-0.0%
Net Imports	**2.98**	**2.64**	**2.69**	**1.90**	**1.08**	**0.78**	**0.18**	**-9.7%**
Pipeline[3]	2.68	2.23	2.33	1.40	0.74	0.64	0.04	-14.0%
Liquefied Natural Gas	0.30	0.41	0.36	0.50	0.34	0.14	0.14	-4.1%
Total Supply	**23.33**	**23.66**	**25.18**	**25.40**	**25.12**	**25.94**	**26.57**	**0.4%**
Consumption by Sector								
Residential	4.87	4.75	4.81	4.85	4.83	4.82	4.78	0.0%
Commercial	3.13	3.11	3.38	3.49	3.56	3.68	3.82	0.8%
Industrial[4]	6.65	6.14	8.05	8.24	8.10	8.08	8.02	1.0%
Natural-Gas-to-Liquids Heat and Power[5]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Natural Gas to Liquids Production[6]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Electric Power[7]	6.67	6.89	6.98	6.84	6.66	7.34	7.88	0.5%
Transportation[8]	0.03	0.03	0.04	0.07	0.10	0.14	0.16	7.5%
Pipeline Fuel	0.65	0.64	0.65	0.64	0.62	0.64	0.65	0.1%
Lease and Plant Fuel[9]	1.22	1.16	1.20	1.21	1.19	1.20	1.25	0.3%
Total	**23.22**	**22.71**	**25.11**	**25.34**	**25.07**	**25.90**	**26.55**	**0.6%**
Discrepancy[10]	**0.11**	**0.95**	**0.07**	**0.06**	**0.05**	**0.04**	**0.02**	**- -**
Natural Gas Prices								
(2009 dollars per million Btu)								
Henry Hub Spot Price	8.94	3.95	4.66	5.05	5.97	6.40	7.07	2.3%
Average Lower 48 Wellhead Price[11]	7.96	3.62	4.13	4.47	5.29	5.66	6.26	2.1%
(2009 dollars per thousand cubic feet)								
Average Lower 48 Wellhead Price[11]	8.18	3.71	4.24	4.59	5.43	5.81	6.42	2.1%
Delivered Prices								
(2009 dollars per thousand cubic feet)								
Residential	13.99	12.20	10.39	11.16	12.15	12.85	13.76	0.5%
Commercial	12.32	9.94	8.60	9.19	10.03	10.57	11.28	0.5%
Industrial[4]	9.32	5.39	5.10	5.50	6.33	6.76	7.40	1.2%
Electric Power[7]	9.35	4.94	4.79	5.13	5.91	6.36	6.97	1.3%
Transportation[12]	17.67	13.05	12.29	12.58	13.19	13.49	13.94	0.3%
Average[13]	**10.84**	**7.47**	**6.62**	**7.13**	**8.01**	**8.48**	**9.14**	**0.8%**

Table A13. Natural gas supply, disposition, and prices (continued)
(trillion cubic feet per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Natural Gas Prices								
(nominal dollars per million Btu)								
Henry Hub Spot Price	8.86	3.95	5.09	6.10	7.90	9.28	11.28	4.1%
Average Lower 48 Wellhead Price[11]	7.89	3.62	4.51	5.40	6.99	8.21	9.99	4.0%
(nominal dollars per thousand cubic feet)								
Average Lower 48 Wellhead Price[11]	8.10	3.71	4.63	5.55	7.18	8.43	10.24	4.0%
Delivered Prices								
(nominal dollars per thousand cubic feet)								
Residential	13.86	12.20	11.34	13.48	16.08	18.63	21.95	2.3%
Commercial	12.20	9.94	9.38	11.10	13.27	15.32	18.00	2.3%
Industrial[4]	9.24	5.39	5.56	6.65	8.38	9.80	11.82	3.1%
Electric Power[7]	9.26	4.94	5.23	6.20	7.81	9.22	11.13	3.2%
Transportation[12]	17.50	13.05	13.42	15.20	17.44	19.56	22.25	2.1%
Average[13]	**10.74**	**7.47**	**7.22**	**8.61**	**10.60**	**12.29**	**14.58**	**2.6%**

[1]Marketed production (wet) minus extraction losses.
[2]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.
[3]Includes any natural gas regasified in the Bahamas and transported via pipeline to Florida, as well as gas from Canada and Mexico.
[4]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[5]Includes any natural gas used in the process of converting natural gas to liquid fuel that is not actually converted.
[6]Includes any natural gas that is converted into liquid fuel.
[7]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[8]Compressed natural gas used as vehicle fuel.
[9]Represents natural gas used in well, field, and lease operations, and in natural gas processing plant machinery.
[10]Balancing item. Natural gas lost as a result of converting flow data measured at varying temperatures and pressures to a standard temperature and pressure and the merger of different data reporting systems which vary in scope, format, definition, and respondent type. In addition, 2008 and 2009 values include net storage injections.
[11]Represents lower 48 onshore and offshore supplies.
[12]Compressed natural gas used as a vehicle fuel. Price includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
[13]Weighted average prices. Weights used are the sectoral consumption values excluding lease, plant, and pipeline fuel.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 supply values; and lease, plant, and pipeline fuel consumption: U.S. Energy Information Administration (EIA), *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 supply values; and lease, plant, and pipeline fuel consumption; and wellhead price: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). Other 2008 and 2009 consumption based on: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 wellhead price: Bureau of Energy Management, Regulation and Enforcement; and EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2008 residential and commercial delivered prices: EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 residential and commercial delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 and 2009 electric power prices: EIA, *Electric Power Monthly*, DOE/EIA-0226, April 2009 and April 2010, Table 4.2. 2008 and 2009 industrial delivered prices are estimated based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2008 transportation sector delivered prices are based on: EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and estimated state taxes, federal taxes, and dispensing costs or charges. 2009 transportation sector delivered prices are model results. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A14. Oil and gas supply

Production and Supply	Reference Case 2008	2009	2015	2020	2025	2030	2035	Annual Growth 2009-2035 (percent)
Crude Oil								
Lower 48 Average Wellhead Price[1] (2009 dollars per barrel)	**96.13**	**89.64**	**94.99**	**107.36**	**115.15**	**119.56**	**119.45**	**1.1%**
Production (million barrels per day)[2]								
United States Total	4.96	5.36	5.81	6.08	5.88	5.82	5.95	0.4%
Lower 48 Onshore	3.01	3.00	3.51	3.72	3.92	3.83	3.65	0.8%
Lower 48 Offshore	1.27	1.71	1.81	1.94	1.55	1.71	1.91	0.4%
Alaska	0.69	0.64	0.49	0.42	0.41	0.27	0.39	-1.9%
Lower 48 End of Year Reserves[2] (billion barrels)	**17.05**	**17.88**	**19.69**	**21.57**	**21.89**	**22.32**	**22.76**	**0.9%**
Natural Gas								
Lower 48 Average Wellhead Price[1] (2009 dollars per million Btu)								
Henry Hub Spot Price	8.94	3.95	4.66	5.05	5.97	6.40	7.07	2.3%
Average Lower 48 Wellhead Price[1]	7.96	3.62	4.13	4.47	5.29	5.66	6.26	2.1%
(2009 dollars per thousand cubic feet)								
Average Lower 48 Wellhead Price[1]	8.18	3.71	4.24	4.59	5.43	5.81	6.42	2.1%
Dry Production (trillion cubic feet)[3]								
United States Total	20.29	20.96	22.43	23.43	23.98	25.10	26.32	0.9%
Lower 48 Onshore	17.22	17.88	20.00	20.21	21.31	22.01	23.05	1.0%
Associated-Dissolved[4]	1.42	1.40	1.48	1.43	1.36	1.20	1.02	-1.2%
Non-Associated	15.81	16.48	18.51	18.78	19.95	20.81	22.04	1.1%
Tight gas	6.75	6.59	5.90	5.72	5.74	5.71	5.84	-0.5%
Shale Gas	2.23	3.28	7.20	8.21	9.69	10.94	12.25	5.2%
Coalbed Methane	1.87	1.80	1.67	1.66	1.72	1.71	1.72	-0.2%
Other	4.95	4.80	3.74	3.19	2.81	2.44	2.23	-2.9%
Lower 48 Offshore	2.69	2.70	2.15	2.96	2.42	2.86	3.05	0.5%
Associated-Dissolved[4]	0.62	0.64	0.64	0.87	0.68	0.71	0.80	0.8%
Non-Associated	2.07	2.05	1.51	2.09	1.74	2.15	2.26	0.4%
Alaska	0.37	0.37	0.28	0.26	0.24	0.22	0.21	-2.1%
Lower 48 End of Year Dry Reserves[3] (trillion cubic feet)	**236.96**	**261.37**	**279.40**	**293.61**	**299.51**	**308.52**	**314.16**	**0.7%**
Supplemental Gas Supplies (trillion cubic feet)[5]	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**-0.0%**
Total Lower 48 Wells Drilled (thousands)	**56.20**	**35.06**	**37.10**	**40.23**	**45.34**	**49.05**	**53.63**	**1.6%**

[1]Represents lower 48 onshore and offshore supplies.
[2]Includes lease condensate.
[3]Marketed production (wet) minus extraction losses.
[4]Gas which occurs in crude oil reservoirs either as free gas (associated) or as gas in solution with crude oil (dissolved).
[5]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.

Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.

Sources: 2008 and 2009 crude oil lower 48 average wellhead price: U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2008 and 2009 lower 48 onshore, lower 48 offshore, and Alaska crude oil production: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). 2008 U.S. crude oil and natural gas reserves: EIA, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*, DOE/EIA-0216(2009) (Washington, DC, October 2010). 2008 Alaska and total natural gas production, and supplemental gas supplies: EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2008 natural gas lower 48 average wellhead price: Bureau of Energy Management, Regulation and Enforcement; and EIA, *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010). 2009 natural gas lower 48 average wellhead price, Alaska and total natural gas production, and supplemental gas supplies: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). Other 2008 and 2009 values: EIA, Office of Energy Analysis. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A15. Coal supply, disposition, and prices
(million short tons per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Production[1]								
Appalachia	391	343	274	279	282	278	282	-0.8%
Interior	147	147	156	160	166	167	177	0.7%
West	634	585	610	661	739	807	860	1.5%
East of the Mississippi	493	450	387	396	406	402	415	-0.3%
West of the Mississippi	678	625	653	704	782	850	904	1.4%
Total	**1172**	**1075**	**1040**	**1100**	**1188**	**1252**	**1319**	**0.8%**
Waste Coal Supplied[2]	**14**	**12**	**14**	**14**	**14**	**14**	**14**	**0.6%**
Net Imports								
Imports[3]	32	21	30	38	56	54	53	3.6%
Exports	82	59	70	76	75	74	71	0.7%
Total	**-49**	**-38**	**-40**	**-38**	**-19**	**-20**	**-18**	**-2.8%**
Total Supply[4]	**1136**	**1049**	**1014**	**1076**	**1183**	**1247**	**1315**	**0.9%**
Consumption by Sector								
Residential and Commercial	4	3	3	3	3	3	3	-0.2%
Coke Plants	22	15	22	22	21	20	18	0.6%
Other Industrial[5]	54	45	49	49	48	48	47	0.1%
Coal-to-Liquids Heat and Power	0	0	6	7	23	42	66	- -
Coal to Liquids Production	0	0	5	6	21	40	62	- -
Electric Power[6]	1041	937	928	989	1066	1094	1119	0.7%
Total	**1121**	**1000**	**1013**	**1076**	**1182**	**1247**	**1315**	**1.1%**
Discrepancy and Stock Change[7]	**16**	**49**	**1**	**0**	**1**	**0**	**-0**	**- -**
Average Minemouth Price[8]								
(2009 dollars per short ton)	31.54	33.26	32.36	32.85	33.22	33.25	33.92	0.1%
(2009 dollars per million Btu)	1.56	1.67	1.62	1.65	1.68	1.69	1.73	0.2%
Delivered Prices (2009 dollars per short ton)[9]								
Coke Plants	119.20	143.01	157.51	165.95	169.26	170.64	172.38	0.7%
Other Industrial[5]	64.03	64.87	61.78	62.45	63.58	64.89	66.89	0.1%
Coal to Liquids	- -	- -	30.96	35.63	31.66	35.84	36.68	- -
Electric Power								
(2009 dollars per short ton)	41.07	43.48	40.94	41.57	43.33	44.63	46.36	0.2%
(2009 dollars per million Btu)	2.07	2.20	2.11	2.15	2.24	2.32	2.40	0.3%
Average	**43.77**	**46.03**	**44.40**	**45.00**	**45.97**	**46.81**	**47.87**	**0.2%**
Exports[10]	98.60	101.44	123.13	132.67	136.16	134.51	133.36	1.1%

Table A15. Coal supply, disposition, and prices (continued)
(million short tons per year, unless otherwise noted)

Supply, Disposition, and Prices	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Average Minemouth Price[8]								
(nominal dollars per short ton)	31.25	33.26	35.32	39.69	43.93	48.21	54.13	1.9%
(nominal dollars per million Btu)	1.55	1.67	1.77	1.99	2.22	2.45	2.76	2.0%
Delivered Prices (nominal dollars per short ton)[9]								
Coke Plants	118.09	143.01	171.93	200.49	223.88	247.39	275.08	2.5%
Other Industrial[5]	63.44	64.87	67.44	75.45	84.09	94.08	106.75	1.9%
Coal to Liquids	- -	- -	33.79	43.05	41.88	51.96	58.54	- -
Electric Power								
(nominal dollars per short ton)	40.69	43.48	44.69	50.23	57.30	64.71	73.98	2.1%
(nominal dollars per million Btu)	2.05	2.20	2.31	2.60	2.96	3.36	3.83	2.2%
Average	**43.37**	**46.03**	**48.47**	**54.37**	**60.80**	**67.86**	**76.40**	**2.0%**
Exports[10]	97.68	101.44	134.40	160.28	180.10	195.00	212.81	2.9%

[1]Includes anthracite, bituminous coal, subbituminous coal, and lignite.
[2]Includes waste coal consumed by the electric power and industrial sectors. Waste coal supplied is counted as a supply-side item to balance the same amount of waste coal included in the consumption data.
[3]Excludes imports to Puerto Rico and the U.S. Virgin Islands.
[4]Production plus waste coal supplied plus net imports.
[5]Includes consumption for combined heat and power plants, except those plants whose primary business is to sell electricity, or electricity and heat, to the public. Excludes all coal use in the coal-to-liquids process.
[6]Includes all electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Balancing item: the sum of production, net imports, and waste coal supplied minus total consumption.
[8]Includes reported prices for both open market and captive mines.
[9]Prices weighted by consumption; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
[10]F.a.s. price at U.S. port of exit.
- - = Not applicable.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 data based on: U.S. Energy Information Administration (EIA), *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010); EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010); and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A16. Renewable energy generating capacity and generation
(gigawatts, unless otherwise noted)

Capacity and Generation	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Electric Power Sector[1]								
Net Summer Capacity								
Conventional Hydropower	76.87	76.87	77.52	77.61	78.59	79.28	79.85	0.1%
Geothermal[2]	2.42	2.42	2.75	3.38	4.21	5.58	6.42	3.8%
Municipal Waste[3]	3.37	3.37	3.37	3.37	3.37	3.37	3.37	-0.0%
Wood and Other Biomass[4]	2.19	2.19	2.19	2.19	2.19	2.19	2.19	0.0%
Solar Thermal	0.53	0.61	1.26	1.28	1.30	1.32	1.35	3.1%
Solar Photovoltaic[5]	0.05	0.07	0.15	0.23	0.32	0.43	0.52	7.9%
Wind	24.89	31.45	48.90	49.01	51.56	53.17	54.63	2.1%
Offshore Wind	0.00	0.00	0.20	0.20	0.20	0.20	0.20	- -
Total	**110.31**	**116.98**	**136.33**	**137.27**	**141.75**	**145.53**	**148.53**	**0.9%**
Generation (billion kilowatthours)								
Conventional Hydropower	253.09	270.20	293.22	301.20	305.17	308.11	310.59	0.5%
Geothermal[2]	14.95	15.21	19.63	24.68	31.36	42.34	49.19	4.6%
Biogenic Municipal Waste[6]	15.68	16.39	14.80	14.80	14.80	14.80	14.80	-0.4%
Wood and Other Biomass	10.46	10.39	20.51	38.57	38.41	30.86	32.64	4.5%
Dedicated Plants	8.58	8.73	7.06	10.13	8.54	7.07	8.15	-0.3%
Cofiring	1.88	1.66	13.45	28.45	29.87	23.79	24.49	10.9%
Solar Thermal	0.83	0.76	2.49	2.52	2.56	2.60	2.66	4.9%
Solar Photovoltaic[5]	0.04	0.04	0.36	0.56	0.80	1.06	1.31	13.9%
Wind	55.42	70.82	141.77	142.16	150.73	155.92	160.13	3.2%
Offshore Wind	0.00	0.00	0.75	0.75	0.75	0.75	0.75	- -
Total	**350.47**	**383.82**	**493.52**	**525.25**	**544.58**	**556.44**	**572.06**	**1.5%**
End-Use Generators[7]								
Net Summer Capacity								
Conventional Hydropower[8]	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.0%
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Municipal Waste[9]	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.0%
Biomass	4.86	4.86	7.26	9.46	15.14	17.50	18.06	5.2%
Solar Photovoltaic[5]	0.77	1.50	7.73	9.14	9.51	10.05	10.68	7.8%
Wind	0.08	0.18	1.45	1.68	1.70	1.76	1.83	9.2%
Total	**6.70**	**7.55**	**17.46**	**21.29**	**27.36**	**30.31**	**31.58**	**5.7%**
Generation (billion kilowatthours)								
Conventional Hydropower[8]	3.33	3.34	3.49	3.49	3.49	3.49	3.49	0.2%
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	- -
Municipal Waste[9]	1.94	1.96	2.56	2.56	2.56	2.56	2.56	1.0%
Biomass	27.88	27.88	42.60	59.73	104.98	122.36	126.57	6.0%
Solar Photovoltaic[5]	1.22	2.34	11.99	14.25	14.86	15.75	16.79	7.9%
Wind	0.10	0.24	1.97	2.30	2.34	2.42	2.53	9.5%
Total	**34.47**	**35.76**	**62.61**	**82.34**	**128.22**	**146.57**	**151.94**	**5.7%**

Table A16. Renewable energy generating capacity and generation (continued)
(gigawatts, unless otherwise noted)

Capacity and Generation	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Total, All Sectors								
Net Summer Capacity								
Conventional Hydropower	77.58	77.57	78.23	78.32	79.30	79.99	80.56	0.1%
Geothermal	2.42	2.42	2.75	3.38	4.21	5.58	6.42	3.8%
Municipal Waste	3.66	3.67	3.67	3.67	3.67	3.67	3.67	-0.0%
Wood and Other Biomass[4]	7.04	7.04	9.45	11.64	17.33	19.68	20.24	4.1%
Solar[5]	1.35	2.18	9.14	10.65	11.13	11.80	12.56	7.0%
Wind	24.96	31.64	50.55	50.89	53.46	55.13	56.66	2.3%
Total	**117.02**	**124.53**	**153.79**	**158.55**	**169.11**	**175.84**	**180.11**	**1.4%**
Generation (billion kilowatthours)								
Conventional Hydropower	256.42	273.54	296.71	304.69	308.66	311.59	314.08	0.5%
Geothermal	14.95	15.21	19.63	24.68	31.36	42.34	49.19	4.6%
Municipal Waste	17.62	18.36	17.36	17.36	17.36	17.36	17.36	-0.2%
Wood and Other Biomass	38.34	38.27	63.11	98.30	143.39	153.22	159.21	5.6%
Solar[5]	2.08	3.15	14.84	17.34	18.21	19.41	20.76	7.5%
Wind	55.52	71.06	144.49	145.22	153.82	159.09	163.41	3.3%
Total	**384.94**	**419.59**	**556.13**	**607.59**	**672.80**	**703.01**	**724.00**	**2.1%**

[1]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes both hydrothermal resources (hot water and steam) and near-field enhanced geothermal systems (EGS). Near-field EGS potential occurs on known hydrothermal sites, however this potential requires the addition of external fluids for electricity generation and is only available after 2025.
[3]Includes municipal waste, landfill gas, and municipal sewage sludge. Incremental growth is assumed to be for landfill gas facilities. All municipal waste is included, although a portion of the municipal waste stream contains petroleum-derived plastics and other non-renewable sources.
[4]Facilities co-firing biomass and coal are classified as coal.
[5]Does not include off-grid photovoltaics (PV). Based on annual PV shipments from 1989 through 2008, EIA estimates that as much as 237 megawatts of remote electricity generation PV applications (i.e., off-grid power systems) were in service in 2008, plus an additional 550 megawatts in communications, transportation, and assorted other non-grid-connected, specialized applications. See U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010), Table 10.9 (annual PV shipments, 1989-2008). The approach used to develop the estimate, based on shipment data, provides an upper estimate of the size of the PV stock, including both grid-based and off-grid PV. It will overestimate the size of the stock, because shipments include a substantial number of units that are exported, and each year some of the PV units installed earlier will be retired from service or abandoned.
[6]Includes biogenic municipal waste, landfill gas, and municipal sewage sludge. Incremental growth is assumed to be for landfill gas facilities. Only biogenic municipal waste is included. The U.S. Energy Information Administration estimates that in 2007 approximately 6 billion kilowatthours of electricity were generated from a municipal waste stream containing petroleum-derived plastics and other non-renewable sources. See U.S. Energy Information Administration, *Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy* (Washington, DC, May 2007).
[7]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
[8]Represents own-use industrial hydroelectric power.
[9]Includes municipal waste, landfill gas, and municipal sewage sludge. All municipal waste is included, although a portion of the municipal waste stream contains petroleum-derived plastics and other non-renewable sources.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 capacity: U.S. Energy Information Administration (EIA), Form EIA-860, "Annual Electric Generator Report" (preliminary). 2008 and 2009 generation: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A17. Renewable energy consumption by sector and source
(quadrillion Btu per year)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Marketed Renewable Energy[1]								
Residential (wood)	**0.44**	**0.43**	**0.40**	**0.42**	**0.42**	**0.42**	**0.42**	**-0.1%**
Commercial (biomass)	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.0%**
Industrial[2]	**2.50**	**2.08**	**2.74**	**3.18**	**3.96**	**4.39**	**4.57**	**3.1%**
Conventional Hydroelectric	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.0%
Municipal Waste[3]	0.16	0.17	0.18	0.18	0.18	0.18	0.18	0.1%
Biomass	1.33	1.22	1.68	1.77	1.84	1.85	1.83	1.6%
Biofuels Heat and Coproducts	0.98	0.66	0.85	1.19	1.90	2.33	2.52	5.3%
Transportation	**0.87**	**0.99**	**1.51**	**2.00**	**2.72**	**3.41**	**3.73**	**5.2%**
Ethanol used in E85[4]	0.00	0.00	0.01	0.21	0.61	0.77	0.81	26.3%
Ethanol used in Gasoline Blending	0.83	0.95	1.33	1.49	1.46	1.48	1.56	1.9%
Biodiesel used in Distillate Blending	0.04	0.04	0.15	0.20	0.24	0.25	0.25	7.1%
Liquids from Biomass	0.00	0.00	0.02	0.09	0.39	0.89	1.10	- -
Renewable Diesel and Gasoline[5]	0.00	0.00	0.01	0.01	0.02	0.02	0.02	- -
Electric Power[6]	**3.67**	**3.89**	**5.08**	**5.52**	**5.84**	**6.16**	**6.47**	**2.0%**
Conventional Hydroelectric	2.49	2.66	2.89	2.97	3.01	3.04	3.06	0.5%
Geothermal	0.31	0.32	0.44	0.59	0.79	1.12	1.32	5.6%
Biogenic Municipal Waste[7]	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.0%
Biomass	0.21	0.11	0.23	0.43	0.43	0.34	0.37	4.8%
Dedicated Plants	0.13	0.12	0.10	0.15	0.13	0.10	0.11	-0.2%
Cofiring	0.08	-0.01	0.13	0.29	0.30	0.24	0.25	- -
Solar Thermal	0.01	0.01	0.02	0.02	0.03	0.03	0.03	4.9%
Solar Photovoltaic	0.00	0.00	0.00	0.01	0.01	0.01	0.01	13.9%
Wind	0.55	0.70	1.40	1.41	1.49	1.54	1.59	3.2%
Total Marketed Renewable Energy	**7.58**	**7.50**	**9.85**	**11.23**	**13.05**	**14.50**	**15.29**	**2.8%**
Sources of Ethanol								
From Corn and Other Starch	0.78	0.93	1.24	1.40	1.38	1.49	1.56	2.0%
From Cellulose	0.00	0.00	0.01	0.15	0.48	0.47	0.47	48.6%
Net Imports	0.04	0.02	0.07	0.15	0.21	0.30	0.33	12.2%
Total	**0.83**	**0.95**	**1.33**	**1.70**	**2.07**	**2.26**	**2.37**	**3.6%**

Table A17. Renewable energy consumption by sector and source (continued)
(quadrillion Btu per year)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Nonmarketed Renewable Energy[8] Selected Consumption								
Residential	**0.01**	**0.01**	**0.07**	**0.09**	**0.09**	**0.10**	**0.11**	**8.3%**
Solar Hot Water Heating	0.00	0.00	0.00	0.00	0.00	0.01	0.01	2.0%
Geothermal Heat Pumps	0.00	0.01	0.02	0.03	0.04	0.04	0.05	8.7%
Solar Photovoltaic	0.00	0.00	0.04	0.04	0.04	0.05	0.05	9.7%
Wind	0.00	0.00	0.01	0.01	0.01	0.01	0.01	11.1%
Commercial	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.04**	**0.04**	**1.3%**
Solar Thermal	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.6%
Solar Photovoltaic	0.00	0.00	0.00	0.01	0.01	0.01	0.01	3.9%
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.8%

[1]Includes nonelectric renewable energy groups for which the energy source is bought and sold in the marketplace, although all transactions may not necessarily be marketed, and marketed renewable energy inputs for electricity entering the marketplace on the electric power grid. Excludes electricity imports; see Table A2.
[2]Includes all electricity production by industrial and other combined heat and power for the grid and for own use.
[3]Includes municipal waste, landfill gas, and municipal sewage sludge. All municipal waste is included, although a portion of the municipal waste stream contains petroleum-derived plastics and other non-renewable sources.
[4]Excludes motor gasoline component of E85.
[5]Renewable feedstocks for the on-site production of diesel and gasoline.
[6]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators. Actual heat rates used to determine fuel consumption for all renewable fuels except hydropower, solar, and wind. Consumption at hydroelectric, solar, and wind facilities determined by using the fossil fuel equivalent of 9,854 Btu per kilowatthour.
[7]Includes biogenic municipal waste, landfill gas, and municipal sewage sludge. Incremental growth is assumed to be for landfill gas facilities. Only biogenic municipal waste is included. The U.S. Energy Information Administration estimates that in 2007 approximately 0.3 quadrillion Btus were consumed from a municipal waste stream containing petroleum-derived plastics and other non-renewable sources. See U.S. Energy Information Administration, *Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy* (Washington, DC, May 2007).
[8]Includes selected renewable energy consumption data for which the energy is not bought or sold, either directly or indirectly as an input to marketed energy. The U.S. Energy Information Administration does not estimate or project total consumption of nonmarketed renewable energy.
- - = Not applicable.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 ethanol: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 and 2009 electric power sector: EIA, Form EIA-860, "Annual Electric Generator Report" (preliminary). Other 2008 and 2009 values: EIA, Office of Energy Analysis.
Projections: EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A18. Carbon dioxide emissions by sector and source
(million metric tons, unless otherwise noted)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Residential								
Petroleum	85	83	73	68	64	61	58	-1.3%
Natural Gas	266	259	262	264	263	263	260	0.0%
Coal	1	1	1	1	1	1	0	-1.1%
Electricity[1]	878	824	757	780	833	872	909	0.4%
Total	**1229**	**1166**	**1092**	**1112**	**1160**	**1196**	**1228**	**0.2%**
Commercial								
Petroleum	46	44	39	38	38	37	37	-0.6%
Natural Gas	171	169	184	190	194	200	208	0.8%
Coal	7	6	6	6	6	6	6	0.0%
Electricity[1]	850	800	795	854	933	998	1063	1.1%
Total	**1074**	**1018**	**1023**	**1088**	**1170**	**1241**	**1314**	**1.0%**
Industrial[2]								
Petroleum	376	343	410	402	402	400	405	0.6%
Natural Gas[3]	407	383	489	500	492	493	493	1.0%
Coal	173	128	162	164	187	215	249	2.6%
Electricity[1]	642	533	582	586	588	565	542	0.1%
Total	**1598**	**1387**	**1643**	**1651**	**1668**	**1673**	**1689**	**0.8%**
Transportation								
Petroleum[4]	1896	1816	1878	1881	1892	1945	2023	0.4%
Natural Gas[5]	37	34	38	38	40	42	44	1.0%
Electricity[1]	4	4	5	6	8	10	12	4.3%
Total	**1937**	**1854**	**1921**	**1925**	**1940**	**1997**	**2080**	**0.4%**
Electric Power[6]								
Petroleum	40	34	33	35	35	35	37	0.3%
Natural Gas	362	373	379	372	362	399	428	0.5%
Coal	1959	1742	1714	1806	1951	1998	2049	0.6%
Other[7]	12	12	12	12	12	12	12	0.0%
Total	**2374**	**2160**	**2138**	**2225**	**2360**	**2444**	**2526**	**0.6%**
Total by Fuel								
Petroleum[3]	2444	2319	2434	2423	2430	2478	2561	0.4%
Natural Gas	1243	1218	1352	1365	1351	1398	1434	0.6%
Coal	2139	1877	1882	1977	2144	2219	2304	0.8%
Other[7]	12	12	12	12	12	12	12	0.0%
Total	**5838**	**5426**	**5680**	**5777**	**5938**	**6107**	**6311**	**0.6%**
Carbon Dioxide Emissions (tons per person)	**19.1**	**17.6**	**17.4**	**16.9**	**16.6**	**16.3**	**16.2**	**-0.3%**

[1]Emissions from the electric power sector are distributed to the end-use sectors.
[2]Fuel consumption includes energy for combined heat and power plants, except those plants whose primary business is to sell electricity, or electricity and heat, to the public.
[3]Includes lease and plant fuel.
[4]This includes carbon dioxide from international bunker fuels, both civilian and military, which are excluded from the accounting of carbon dioxide emissions under the United Nations convention. From 1990 through 2008, international bunker fuels accounted for 86 to 130 million metric tons annually.
[5]Includes pipeline fuel natural gas and compressed natural gas used as vehicle fuel.
[6]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes emissions from geothermal power and nonbiogenic emissions from municipal waste.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 emissions and emission factors: U.S. Energy Information Administration (EIA), *Emissions of Greenhouse Gases in the United States 2009,* DOE/EIA-0573(2009) (Washington, DC, December 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A19. Energy-related carbon dioxide emissions by end use
(million metric tons)

Sector and Source	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Residential								
Space Heating	292.69	279.60	272.85	270.86	268.47	266.39	263.11	-0.2%
Space Cooling	162.47	147.72	135.39	140.24	150.37	157.54	164.20	0.4%
Water Heating	164.41	160.32	160.36	162.26	163.49	159.75	154.66	-0.1%
Refrigeration	69.77	65.09	58.06	56.92	58.36	60.38	62.88	-0.1%
Cooking	32.95	32.03	32.51	34.07	35.91	37.39	38.70	0.7%
Clothes Dryers	37.79	35.69	33.17	32.37	33.23	34.56	35.96	0.0%
Freezers	14.84	13.90	12.91	13.13	13.71	14.06	14.43	0.1%
Lighting	134.22	125.70	93.51	88.06	87.22	87.55	89.23	-1.3%
Clothes Washers[1]	6.31	5.85	4.91	4.41	4.48	4.70	4.89	-0.7%
Dishwashers[1]	17.17	16.09	14.89	15.25	16.50	17.58	18.65	0.6%
Color Televisions and Set-Top Boxes	62.03	59.44	54.35	55.38	59.93	64.15	68.61	0.6%
Personal Computers and Related Equipment	32.17	31.33	27.80	28.37	29.72	30.85	31.71	0.0%
Furnace Fans and Boiler Circulation Pumps	25.57	24.67	25.43	27.38	30.24	31.49	32.26	1.0%
Other Uses	174.01	165.12	166.34	183.70	208.58	229.34	249.04	1.6%
Discrepancy[2]	2.85	3.79	-0.00	0.00	0.00	0.00	0.00	-28.5%
Total Residential	**1229.24**	**1166.35**	**1092.49**	**1112.42**	**1160.21**	**1195.73**	**1228.32**	**0.2%**
Commercial								
Space Heating[3]	127.32	128.25	128.76	130.33	130.33	130.73	130.54	0.1%
Space Cooling[3]	92.96	85.70	88.59	91.17	95.98	99.38	103.41	0.7%
Water Heating[3]	42.12	41.58	44.00	46.26	48.12	49.69	50.80	0.8%
Ventilation	92.45	89.19	91.42	98.49	106.96	112.72	118.04	1.1%
Cooking	13.16	13.28	14.38	15.09	15.71	16.30	16.87	0.9%
Lighting	194.26	182.85	171.08	179.04	190.65	198.63	206.01	0.5%
Refrigeration	75.47	70.56	59.86	58.46	60.25	61.96	64.22	-0.4%
Office Equipment (PC)	41.33	38.12	30.95	31.31	32.55	34.14	34.85	-0.3%
Office Equipment (non-PC)	44.27	44.13	51.94	60.16	67.37	73.13	77.41	2.2%
Other Uses[4]	350.35	324.36	342.43	377.83	422.03	464.68	511.60	1.8%
Total Commercial	**1073.69**	**1018.02**	**1023.40**	**1088.13**	**1169.96**	**1241.34**	**1313.74**	**1.0%**
Industrial								
Manufacturing								
Refining								
Food Products	260.03	258.29	288.28	290.06	314.11	356.19	405.68	1.8%
Paper Products	107.09	102.49	105.47	110.03	116.18	119.76	122.70	0.7%
Bulk Chemicals	100.00	89.65	95.56	93.28	90.78	87.05	82.98	-0.3%
Glass	282.56	263.03	296.76	296.24	290.00	269.58	250.33	-0.2%
Cement Manufacturing	24.31	20.02	22.83	24.06	25.94	26.14	26.04	1.0%
Iron and Steel	36.59	28.55	32.98	33.48	33.83	32.75	30.04	0.2%
Aluminum	118.67	75.90	107.58	110.31	107.52	99.37	91.23	0.7%
Fabricated Metal Products	31.20	30.82	29.30	28.22	26.72	24.94	23.17	-1.1%
Machinery	43.03	38.34	45.61	45.86	47.05	45.89	45.03	0.6%
Computers and Electronics	26.22	22.37	28.08	29.54	31.97	31.88	32.02	1.4%
Transportation Equipment	37.33	32.51	39.99	42.57	45.67	47.67	48.93	1.6%
Electrical Equipment	52.05	45.41	63.50	59.55	59.07	61.20	63.60	1.3%
Wood Products	8.42	7.45	9.31	9.15	9.90	10.16	10.49	1.3%
Plastics	19.15	17.64	23.03	22.59	21.92	20.77	19.55	0.4%
Balance of Manufacturing	42.80	37.75	41.50	42.12	42.41	41.02	40.40	0.3%
Total Manufacturing	159.81	143.04	152.19	156.28	153.93	150.44	146.27	0.1%
Nonmanufacturing	1349.26	1213.26	1381.97	1393.31	1416.98	1424.82	1438.46	0.7%
Agriculture								
Construction	76.78	74.57	74.55	74.39	74.88	74.74	74.38	-0.0%
Mining	94.04	78.52	96.81	97.43	96.54	94.14	93.58	0.7%
Total Nonmanufacturing	56.28	49.39	50.85	50.28	50.19	50.26	50.44	0.1%
Discrepancy[2]	227.10	202.47	222.21	222.09	221.61	219.13	218.40	0.3%
Total Industrial	**21.41**	**-28.42**	**39.28**	**35.75**	**29.52**	**29.47**	**31.76**	**- -**
	1597.78	**1387.31**	**1643.46**	**1651.16**	**1668.11**	**1673.42**	**1688.61**	**0.8%**

Table A19. Energy-related carbon dioxide emissions by end use (continued)
(million metric tons)

Sector and Source	Reference Case 2008	2009	2015	2020	2025	2030	2035	Annual Growth 2009-2035 (percent)
Transportation								
Light-Duty Vehicles	1100.28	1072.82	1070.91	1040.63	1023.05	1045.89	1094.14	0.1%
Commercial Light Trucks[5]	44.05	40.28	45.08	44.73	45.06	46.60	48.85	0.7%
Bus Transportation	18.85	18.92	18.92	18.94	18.98	19.08	19.28	0.1%
Freight Trucks	339.28	306.68	362.87	383.43	402.21	423.36	446.65	1.5%
Rail, Passenger	6.19	5.96	6.15	6.49	6.93	7.25	7.55	0.9%
Rail, Freight	41.80	37.09	40.84	43.41	45.53	47.72	49.09	1.1%
Shipping, Domestic	17.11	15.14	15.85	16.32	16.55	16.95	17.35	0.5%
Shipping, International	70.20	60.78	61.39	61.78	62.14	62.52	62.90	0.1%
Recreational Boats	17.54	17.86	18.30	18.65	19.21	19.80	20.47	0.5%
Air	191.53	188.34	191.86	201.45	209.37	214.62	217.94	0.6%
Military Use	50.75	53.27	48.79	49.61	50.96	52.34	53.69	0.0%
Lubricants	5.20	4.75	4.58	4.64	4.72	4.81	4.88	0.1%
Pipeline Fuel	35.31	34.65	35.34	34.73	34.02	34.63	35.42	0.1%
Discrepancy[2]	-0.74	-2.69	-0.35	0.20	0.79	1.39	1.96	- -
Total Transportation	**1937.33**	**1853.85**	**1920.52**	**1924.99**	**1939.51**	**1996.96**	**2080.16**	**0.4%**
Biogenic Energy Combustion[6]								
Biomass	196.75	174.96	227.61	256.86	262.92	255.30	256.31	1.5%
Biogenic Waste	8.26	8.27	8.27	8.27	8.27	8.27	8.27	0.0%
Biofuels Heat and Coproducts	91.62	61.59	79.61	111.90	178.58	218.60	236.59	5.3%
Ethanol	56.60	64.87	91.11	116.47	141.63	154.48	161.98	3.6%
Biodiesel	2.93	3.07	10.88	14.41	17.46	17.96	18.18	7.1%
Liquids from Biomass	0.00	0.00	1.51	6.33	28.66	65.12	80.22	- -
Renewable Diesel and Gasoline	0.00	0.00	0.90	1.01	1.12	1.12	1.11	- -
Total	**356.17**	**312.75**	**419.88**	**515.25**	**638.65**	**720.84**	**762.66**	**3.5%**

[1]Does not include water heating portion of load.
[2]Represents differences between total emissions by end-use and total emissions by fuel as reported in Table A18. Emissions by fuel may reflect benchmarking and other modeling adjustments to energy use and the associated emissions that are not assigned to specific end uses.
[3]Includes emissions related to fuel consumption for district services.
[4]Includes miscellaneous uses, such as service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency generators, combined heat and power in commercial buildings, manufacturing performed in commercial buildings, and cooking (distillate), plus emissions from residual fuel oil, liquefied petroleum gases, coal, motor gasoline, and kerosene.
[5]Commercial trucks 8,500 to 10,000 pounds.
[6]By convention, the direct emissions from biogenic energy sources are excluded from energy-related CO_2 emissions. The release of carbon from these sources is assumed to be balanced by the uptake of carbon when the feedstock is grown, resulting in zero net emissions over some period of time. If, however, increased use of biomass energy results in a decline in terrestrial carbon stocks, a net positive release of carbon may occur. Accordingly, the emissions from biogenic energy sources are reported here as an indication of the potential net release of carbon dioxide in the absence of offsetting sequestration.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 emissions and emission factors: U.S. Energy Information Administration (EIA), *Emissions of Greenhouse Gases in the United States 2009,* DOE/EIA-0573(2009) (Washington, DC, December 2010). **Projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A20. Macroeconomic indicators

(billion 2005 chain-weighted dollars, unless otherwise noted)

Indicators	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Real Gross Domestic Product	**13229**	**12881**	**15336**	**17421**	**20020**	**22731**	**25692**	**2.7%**
Components of Real Gross Domestic Product								
Real Consumption	9265	9154	10443	11669	13280	15046	16976	2.4%
Real Investment	1957	1516	2592	2992	3548	4128	4849	4.6%
Real Government Spending	2503	2543	2555	2664	2796	2934	3069	0.7%
Real Exports	1648	1491	2437	3382	4485	5761	7334	6.3%
Real Imports	2152	1854	2624	3153	3840	4730	5902	4.6%
Energy Intensity								
(thousand Btu per 2005 dollar of GDP)								
Delivered Energy	5.49	5.33	4.91	4.42	3.94	3.57	3.25	-1.9%
Total Energy	7.57	7.36	6.65	6.02	5.39	4.88	4.44	-1.9%
Price Indices								
GDP Chain-type Price Index (2005=1.000)	1.086	1.096	1.197	1.324	1.450	1.589	1.749	1.8%
Consumer Price Index (1982-4=1.00)								
All-urban	2.15	2.15	2.39	2.69	2.97	3.29	3.66	2.1%
Energy Commodities and Services	2.36	1.93	2.44	2.86	3.25	3.64	4.10	2.9%
Wholesale Price Index (1982=1.00)								
All Commodities	1.90	1.73	2.00	2.19	2.38	2.54	2.74	1.8%
Fuel and Power	2.14	1.59	2.05	2.43	2.84	3.22	3.68	3.3%
Metals and Metal Products	2.13	1.87	2.48	2.68	2.77	2.83	2.87	1.7%
Industrial Commodities excluding Energy	1.81	1.76	2.00	2.14	2.25	2.34	2.43	1.2%
Interest Rates (percent, nominal)								
Federal Funds Rate	1.93	0.16	5.15	4.96	4.86	4.94	5.04	- -
10-Year Treasury Note	3.67	3.26	5.76	5.88	5.78	5.76	5.89	- -
AA Utility Bond Rate	6.19	5.75	7.41	7.69	7.69	7.73	7.93	- -
Value of Shipments (billion 2005 dollars)								
Service Sectors	20737	19555	23155	25591	28648	31685	34664	2.2%
Total Industrial	6720	6017	7472	7951	8396	8826	9292	1.7%
Nonmanufacturing	2039	1821	2193	2308	2381	2433	2521	1.3%
Manufacturing	4680	4197	5279	5643	6016	6393	6770	1.9%
Energy-Intensive	1635	1551	1792	1875	1940	1977	2015	1.0%
Non-energy Intensive	3046	2646	3487	3768	4075	4416	4756	2.3%
Total Shipments	**27456**	**25573**	**30627**	**33542**	**37044**	**40510**	**43956**	**2.1%**
Population and Employment (millions)								
Population, with Armed Forces Overseas	305.2	307.8	326.2	342.0	358.1	374.1	390.1	0.9%
Population, aged 16 and over	239.4	241.8	256.5	269.4	282.6	296.2	309.6	1.0%
Population, over age 65	38.9	39.7	47.1	55.1	64.2	72.3	77.7	2.6%
Employment, Nonfarm	136.7	130.9	142.2	148.7	156.2	164.2	170.8	1.0%
Employment, Manufacturing	13.4	11.9	17.4	17.1	15.8	14.3	13.1	0.4%
Key Labor Indicators								
Labor Force (millions)	154.3	154.2	160.7	166.2	170.6	175.8	182.6	0.7%
Nonfarm Labor Productivity (1992=1.00)	1.04	1.07	1.18	1.31	1.47	1.62	1.79	2.0%
Unemployment Rate (percent)	5.82	9.27	6.87	5.47	4.98	4.94	5.20	- -
Key Indicators for Energy Demand								
Real Disposable Personal Income	10043	10100	11533	13181	15118	17123	19224	2.5%
Housing Starts (millions)	0.98	0.60	1.85	1.90	1.93	1.83	1.74	4.2%
Commercial Floorspace (billion square feet)	78.8	80.2	85.4	91.5	97.4	103.5	109.8	1.2%
Unit Sales of Light-Duty Vehicles (millions)	13.19	10.40	17.03	16.81	18.24	19.64	20.64	2.7%

GDP = Gross domestic product.
Btu = British thermal unit.
- - = Not applicable.
Sources: 2008 and 2009: IHS Global Insight Industry and Employment models, September 2010. **Projections:** U.S. Energy Information Administration, AEO2011 National Energy Modeling System run REF2011.D020911A.

Table A21. International liquids supply and disposition summary
(million barrels per day, unless otherwise noted)

Supply and Disposition	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Crude Oil Prices (2009 dollars per barrel)[1]								
Imported Low Sulfur Light Crude Oil	100.51	61.66	94.58	108.10	117.54	123.09	124.94	2.8%
Imported Crude Oil	93.44	59.04	86.83	98.65	107.40	112.38	113.70	2.6%
Crude Oil Prices (nominal dollars per barrel)[1]								
Imported Low Sulfur Light Crude Oil	99.57	61.66	103.24	130.60	155.46	178.45	199.37	4.6%
Imported Crude Oil	92.57	59.04	94.78	119.18	142.05	162.92	181.43	4.4%
Conventional Production (Conventional)[2]								
OPEC[3]								
Middle East	24.24	22.61	25.66	26.96	28.64	30.93	33.87	1.6%
North Africa	4.05	3.92	4.32	3.96	3.84	3.85	3.98	0.1%
West Africa	4.18	4.06	5.10	5.18	5.10	5.10	5.31	1.0%
South America	2.50	2.31	2.00	1.80	1.73	1.65	1.64	-1.3%
Total OPEC	**34.98**	**32.91**	**37.08**	**37.91**	**39.32**	**41.53**	**44.80**	**1.2%**
Non-OPEC								
OECD								
United States (50 states)	7.71	8.26	9.30	9.79	9.78	9.70	9.89	0.7%
Canada	1.84	1.96	1.80	1.78	1.78	1.79	1.78	-0.4%
Mexico and Chile	3.19	2.90	2.05	1.52	1.22	1.30	1.48	-2.6%
OECD Europe[4]	4.96	4.62	3.36	2.83	2.67	2.62	2.66	-2.1%
Japan	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.6%
Australia and New Zealand	0.65	0.65	0.56	0.53	0.52	0.52	0.54	-0.8%
Total OECD	**18.48**	**18.52**	**17.20**	**16.58**	**16.13**	**16.08**	**16.49**	**-0.4%**
Non-OECD								
Russia	9.79	9.66	10.02	10.34	10.86	11.64	12.64	1.0%
Other Europe and Eurasia[5]	2.88	3.08	3.54	3.72	3.97	4.22	4.47	1.4%
China	3.97	3.93	3.80	3.81	4.02	4.22	4.22	0.3%
Other Asia[6]	3.75	3.70	3.47	3.17	2.99	2.87	2.85	-1.0%
Middle East	1.54	1.54	1.57	1.40	1.24	1.14	1.10	-1.3%
Africa	2.39	2.34	2.71	2.76	2.85	2.96	3.16	1.2%
Brazil	1.95	2.05	2.76	3.34	3.87	4.38	4.93	3.4%
Other Central and South America	1.82	1.87	2.10	2.10	2.24	2.49	2.59	1.3%
Total Non-OECD	**28.09**	**28.17**	**29.96**	**30.64**	**32.03**	**33.92**	**35.95**	**0.9%**
Total Conventional Production	**81.55**	**79.60**	**84.24**	**85.14**	**87.47**	**91.53**	**97.24**	**0.8%**
Unconventional Production[7]								
United States (50 states)	0.65	0.75	1.11	1.41	1.94	2.47	2.90	5.3%
Other North America	1.54	1.68	2.39	2.93	3.57	4.35	5.27	4.5%
OECD Europe[4]	0.21	0.22	0.23	0.24	0.26	0.27	0.28	1.0%
Middle East	0.00	0.01	0.17	0.21	0.24	0.24	0.24	14.0%
Africa.	0.21	0.21	0.28	0.37	0.39	0.44	0.44	2.9%
Central and South America	1.18	1.14	1.78	2.31	2.61	2.90	3.17	4.0%
Other	0.11	0.12	0.17	0.30	0.64	0.98	1.22	9.4%
Total Unconventional Production	**3.91**	**4.14**	**6.13**	**7.77**	**9.66**	**11.65**	**13.54**	**4.7%**
Total Production	**85.45**	**83.74**	**90.37**	**92.91**	**97.13**	**103.18**	**110.78**	**1.1%**

Table A21. International liquids supply and disposition summary (continued)
(million barrels per day, unless otherwise noted)

Supply and Disposition	Reference Case							Annual Growth 2009-2035 (percent)
	2008	2009	2015	2020	2025	2030	2035	
Consumption[8]								
OECD								
United States (50 states)	19.52	18.81	20.44	20.68	20.99	21.36	21.93	0.6%
United States Territories	0.28	0.27	0.31	0.30	0.30	0.31	0.32	0.7%
Canada	2.24	2.15	2.24	2.14	2.14	2.18	2.24	0.2%
Mexico and Chile	2.21	2.13	2.17	2.19	2.30	2.46	2.63	0.8%
OECD Europe[4]	15.36	14.49	13.55	13.03	12.82	12.85	12.95	-0.4%
Japan	4.79	4.37	4.18	4.07	3.98	3.91	3.88	-0.5%
South Korea	2.35	2.32	2.44	2.49	2.63	2.85	3.13	1.1%
Australia and New Zealand	1.14	1.19	1.18	1.14	1.13	1.14	1.17	-0.1%
Total OECD	**47.89**	**45.73**	**46.50**	**46.03**	**46.29**	**47.07**	**48.25**	**0.2%**
Non-OECD								
Russia	2.91	2.83	2.90	2.75	2.66	2.66	2.78	-0.1%
Other Europe and Eurasia[5]	2.23	2.16	2.25	2.20	2.25	2.35	2.48	0.5%
China	7.83	8.32	11.10	12.60	14.36	16.55	19.13	3.3%
India	2.97	3.06	3.68	4.13	4.54	5.05	5.64	2.4%
Other Non-OECD Asia[6]	6.35	6.13	6.72	7.27	7.98	8.77	9.75	1.8%
Middle East	6.55	6.64	7.47	8.06	8.76	9.76	11.02	2.0%
Africa	3.15	3.31	3.50	3.56	3.76	4.07	4.45	1.2%
Brazil	2.49	2.46	2.82	3.00	3.20	3.49	3.79	1.7%
Other Central and South America	3.10	3.09	3.41	3.32	3.33	3.41	3.51	0.5%
Total Non-OECD	**37.59**	**38.01**	**43.87**	**46.88**	**50.84**	**56.11**	**62.54**	**1.9%**
Total Consumption	**85.48**	**83.74**	**90.37**	**92.91**	**97.13**	**103.19**	**110.79**	**1.1%**
OPEC Production[9]	35.63	33.45	38.08	39.23	40.77	43.10	46.50	1.3%
Non-OPEC Production[9]	49.82	50.29	52.30	53.68	56.37	60.08	64.28	0.9%
Net Eurasia Exports	9.48	9.80	11.16	12.45	13.80	15.22	16.78	2.1%
OPEC Market Share (percent)	41.7	39.9	42.1	42.2	42.0	41.8	42.0	- -

[1]Weighted average price delivered to U.S. refiners.
[2]Includes production of crude oil (including lease condensate), natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol and other sources, and refinery gains.
[3]OPEC = Organization of Petroleum Exporting Countries - Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.
[4]OECD Europe = Organization for Economic Cooperation and Development - Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.
[5]Other Europe and Eurasia = Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Malta, Moldova, Montenegro, Romania, Serbia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
[6]Other Asia = Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia (Kampuchea), Fiji, French Polynesia, Guam, Hong Kong, Indonesia, Kiribati, Laos, Malaysia, Macau, Maldives, Mongolia, Myanmar (Burma), Nauru, Nepal, New Caledonia, Niue, North Korea, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand, Tonga, Vanuatu, and Vietnam.
[7]Includes liquids produced from energy crops, natural gas, coal, extra-heavy oil, oil sands, and shale. Includes both OPEC and non-OPEC producers in the regional breakdown.
[8]Includes both OPEC and non-OPEC consumers in the regional breakdown.
[9]Includes both conventional and unconventional liquids production.
- - = Not applicable.
Note: Totals may not equal sum of components due to independent rounding. Data for 2008 and 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2008 and 2009 low sulfur light crude oil price: U.S. Energy Information Administration (EIA), Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." 2008 and 2009 imported crude oil price: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2008 quantities derived from: EIA, International Energy Statistics database as of November 2009. **2009 quantities and projections:** EIA, AEO2011 National Energy Modeling System run REF2011.D020911A and EIA, Generate World Oil Balance Model.

Economic growth case comparisons

Table B1. Total energy supply, disposition, and price summary
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Production										
Crude Oil and Lease Condensate	11.34	12.53	12.51	12.55	12.44	12.64	12.62	12.13	12.80	12.87
Natural Gas Plant Liquids	2.57	2.79	2.86	2.89	3.39	3.55	3.70	3.59	3.92	4.11
Dry Natural Gas	21.50	22.50	23.01	23.30	23.58	24.60	25.54	24.92	27.00	30.16
Coal[1]	21.58	20.87	20.94	21.35	22.73	23.64	25.07	24.57	26.01	27.02
Nuclear Power	8.35	8.77	8.77	8.77	9.02	9.17	9.17	8.99	9.14	9.14
Hydropower	2.69	2.92	2.92	2.93	3.00	3.04	3.06	3.03	3.09	3.10
Biomass[2]	3.52	4.67	4.70	4.79	6.99	7.20	7.40	8.28	8.63	9.58
Other Renewable Energy[3]	1.29	2.03	2.14	2.18	2.36	2.58	2.74	2.79	3.22	3.46
Other[4]	0.34	0.79	0.78	0.75	0.81	0.88	0.88	0.77	0.78	0.88
Total	**73.18**	**77.87**	**78.63**	**79.51**	**84.32**	**87.29**	**90.17**	**89.07**	**94.59**	**100.33**
Imports										
Crude Oil	19.70	18.75	19.25	19.84	17.24	18.35	19.70	16.92	18.44	20.43
Liquid Fuels and Other Petroleum[5]	5.40	5.21	5.33	5.52	4.87	5.18	5.65	4.78	5.33	6.22
Natural Gas	3.82	3.97	4.01	4.09	3.10	3.20	3.33	2.79	2.87	2.79
Other Imports[6]	0.61	0.82	0.82	0.83	1.04	1.39	1.40	1.14	1.27	1.25
Total	**29.53**	**28.75**	**29.41**	**30.28**	**26.25**	**28.13**	**30.09**	**25.63**	**27.92**	**30.69**
Exports										
Petroleum[7]	4.17	3.26	3.27	3.29	3.55	3.62	3.70	3.79	3.92	4.05
Natural Gas	1.09	1.25	1.24	1.23	2.12	2.07	2.03	2.74	2.64	2.55
Coal	1.51	1.76	1.76	1.76	1.89	1.89	1.89	1.79	1.78	1.77
Total	**6.77**	**6.26**	**6.27**	**6.28**	**7.56**	**7.58**	**7.62**	**8.32**	**8.34**	**8.37**
Discrepancy[8]	**1.16**	**-0.23**	**-0.24**	**-0.29**	**-0.13**	**-0.12**	**-0.18**	**0.03**	**-0.02**	**0.01**
Consumption										
Liquid Fuels and Other Petroleum[9]	36.62	38.46	39.10	39.94	37.91	39.84	41.96	38.41	41.70	45.43
Natural Gas	23.31	25.21	25.77	26.14	24.55	25.73	26.84	24.97	27.24	30.41
Coal[10]	19.69	19.65	19.73	20.16	21.47	22.61	23.91	22.92	24.30	25.12
Nuclear Power	8.35	8.77	8.77	8.77	9.02	9.17	9.17	8.99	9.14	9.14
Hydropower	2.69	2.92	2.92	2.93	3.00	3.04	3.06	3.03	3.09	3.10
Biomass[11]	2.52	3.24	3.27	3.35	4.57	4.71	4.86	5.00	5.25	5.73
Other Renewable Energy[3]	1.29	2.03	2.14	2.18	2.36	2.58	2.74	2.79	3.22	3.46
Other[12]	0.32	0.31	0.31	0.31	0.27	0.27	0.28	0.24	0.25	0.25
Total	**94.79**	**100.59**	**102.02**	**103.79**	**103.15**	**107.95**	**112.82**	**106.35**	**114.19**	**122.64**
Prices (2009 dollars per unit)										
Petroleum (dollars per barrel)										
Imported Low Sulfur Light Crude Oil Price[13]	61.66	93.59	94.58	95.66	115.30	117.54	120.09	122.17	124.94	128.52
Imported Crude Oil Price[13]	59.04	86.00	86.83	88.20	104.56	107.40	110.70	110.20	113.70	118.34
Natural Gas (dollars per million Btu)										
Price at Henry Hub	3.95	4.52	4.66	4.84	5.59	5.97	6.50	6.29	7.07	7.50
Wellhead Price[14]	3.62	4.00	4.13	4.29	4.95	5.29	5.76	5.57	6.26	6.64
Natural Gas (dollars per thousand cubic feet)										
Wellhead Price[14]	3.71	4.11	4.24	4.40	5.07	5.43	5.91	5.71	6.42	6.81
Coal (dollars per ton)										
Minemouth Price[15]	33.26	32.25	32.36	32.87	32.95	33.22	34.20	33.12	33.92	34.82
Coal (dollars per million Btu)										
Minemouth Price[15]	1.67	1.61	1.62	1.64	1.66	1.68	1.73	1.69	1.73	1.77
Average Delivered Price[16]	2.31	2.25	2.26	2.30	2.32	2.36	2.42	2.39	2.47	2.52
Average Electricity Price (cents per kilowatthour)	9.8	8.8	8.9	9.0	8.6	8.9	9.3	8.7	9.2	9.6

Table B1. Total energy supply, disposition, and price summary (continued)
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Prices (nominal dollars per unit)										
Petroleum (dollars per barrel)										
Imported Low Sulfur Light Crude Oil Price[13]	61.66	104.03	103.24	101.79	165.41	155.46	144.96	220.15	199.37	178.52
Imported Crude Oil Price[13]	59.04	95.59	94.78	93.85	149.99	142.05	133.62	198.58	181.43	164.38
Natural Gas (dollars per million Btu)										
Price at Henry Hub	3.95	5.02	5.09	5.15	8.01	7.90	7.85	11.33	11.28	10.41
Wellhead Price[14]	3.62	4.45	4.51	4.56	7.10	6.99	6.95	10.03	9.99	9.22
Natural Gas (dollars per thousand cubic feet)										
Wellhead Price[14]	3.71	4.56	4.63	4.68	7.28	7.18	7.13	10.30	10.24	9.46
Coal (dollars per ton)										
Minemouth Price[15]	33.26	35.85	35.32	34.98	47.27	43.93	41.29	59.67	54.13	48.37
Coal (dollars per million Btu)										
Minemouth Price[15]	1.67	1.79	1.77	1.75	2.38	2.22	2.09	3.04	2.76	2.46
Average Delivered Price[16]	2.31	2.50	2.47	2.44	3.33	3.12	2.93	4.30	3.95	3.50
Average Electricity Price (cents per kilowatthour)	9.8	9.8	9.7	9.6	12.4	11.8	11.2	15.7	14.7	13.3

[1]Includes waste coal.
[2]Includes grid-connected electricity from wood and wood waste; biomass, such as corn, used for liquid fuels production; and non-electric energy demand from wood. Refer to Table A17 for details.
[3]Includes grid-connected electricity from landfill gas; biogenic municipal waste; wind; photovoltaic and solar thermal sources; and non-electric energy from renewable sources, such as active and passive solar systems. Excludes electricity imports using renewable sources and nonmarketed renewable energy. See Table A17 for selected nonmarketed residential and commercial renewable energy.
[4]Includes non-biogenic municipal waste, liquid hydrogen, methanol, and some domestic inputs to refineries.
[5]Includes imports of finished petroleum products, unfinished oils, alcohols, ethers, blending components, and renewable fuels such as ethanol.
[6]Includes coal, coal coke (net), and electricity (net).
[7]Includes crude oil and petroleum products.
[8]Balancing item. Includes unaccounted for supply, losses, gains, and net storage withdrawals.
[9]Includes petroleum-derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids and crude oil consumed as a fuel. Refer to Table A17 for detailed renewable liquid fuels consumption.
[10]Excludes coal converted to coal-based synthetic liquids and natural gas.
[11]Includes grid-connected electricity from wood and wood waste, non-electric energy from wood, and biofuels heat and coproducts used in the production of liquid fuels, but excludes the energy content of the liquid fuels.
[12]Includes non-biogenic municipal waste and net electricity imports.
[13]Weighted average price delivered to U.S. refiners.
[14]Represents lower 48 onshore and offshore supplies.
[15]Includes reported prices for both open market and captive mines.
[16]Prices weighted by consumption; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 natural gas supply values and natural gas wellhead price: U.S. Energy Information Administration (EIA), *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 coal minemouth and delivered coal prices: EIA, *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010). 2009 petroleum supply values: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). 2009 low sulfur light crude oil price: EIA, Form EIA-856, “Monthly Foreign Crude Oil Acquisition Report.” Other 2009 coal values: *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010). Other 2009 values: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LM2011.D020911A, REF2011.D020911A, and HM2011.D020911A.

Table B2. Energy consumption by sector and source
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Energy Consumption										
Residential										
Liquefied Petroleum Gases	0.53	0.49	0.49	0.49	0.47	0.48	0.48	0.46	0.48	0.50
Kerosene	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Distillate Fuel Oil	0.61	0.56	0.56	0.56	0.44	0.44	0.44	0.36	0.37	0.37
Liquid Fuels and Other Petroleum Subtotal	1.16	1.07	1.07	1.07	0.93	0.94	0.95	0.84	0.86	0.89
Natural Gas	4.87	4.92	4.94	4.96	4.84	4.96	5.09	4.64	4.90	5.19
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Renewable Energy[1]	0.43	0.40	0.40	0.41	0.41	0.42	0.44	0.40	0.42	0.45
Electricity	4.65	4.55	4.60	4.65	4.78	4.98	5.18	5.09	5.51	5.93
Delivered Energy	**11.12**	**10.95**	**11.02**	**11.10**	**10.97**	**11.32**	**11.66**	**10.98**	**11.70**	**12.47**
Electricity Related Losses	9.96	9.39	9.46	9.55	9.87	10.24	10.57	10.38	11.06	11.61
Total	**21.08**	**20.33**	**20.48**	**20.65**	**20.83**	**21.56**	**22.22**	**21.36**	**22.76**	**24.08**
Commercial										
Liquefied Petroleum Gases	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.16
Motor Gasoline[2]	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Kerosene	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Distillate Fuel Oil	0.34	0.28	0.28	0.28	0.25	0.26	0.26	0.24	0.25	0.25
Residual Fuel Oil	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
Liquid Fuels and Other Petroleum Subtotal	0.60	0.55	0.55	0.55	0.53	0.53	0.54	0.52	0.53	0.54
Natural Gas	3.20	3.45	3.47	3.48	3.59	3.66	3.70	3.82	3.92	4.05
Coal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Renewable Energy[3]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Electricity	4.51	4.80	4.83	4.87	5.41	5.58	5.74	6.16	6.43	6.74
Delivered Energy	**8.49**	**8.97**	**9.02**	**9.07**	**9.70**	**9.94**	**10.15**	**10.68**	**11.05**	**11.50**
Electricity Related Losses	9.66	9.89	9.94	10.01	11.16	11.47	11.73	12.57	12.93	13.20
Total	**18.15**	**18.86**	**18.96**	**19.07**	**20.87**	**21.41**	**21.88**	**23.25**	**23.98**	**24.70**
Industrial[4]										
Liquefied Petroleum Gases	2.01	2.35	2.36	2.39	2.26	2.38	2.48	1.99	2.18	2.35
Motor Gasoline[2]	0.25	0.32	0.33	0.35	0.31	0.33	0.35	0.29	0.32	0.36
Distillate Fuel Oil	1.16	1.09	1.16	1.23	1.05	1.16	1.27	0.99	1.13	1.28
Residual Fuel Oil	0.17	0.17	0.17	0.18	0.16	0.17	0.18	0.14	0.16	0.17
Petrochemical Feedstocks	0.90	1.28	1.29	1.30	1.27	1.34	1.39	1.15	1.26	1.35
Other Petroleum[5]	3.45	3.82	3.97	4.16	3.48	3.79	4.11	3.44	3.88	4.35
Liquid Fuels and Other Petroleum Subtotal	7.94	9.03	9.29	9.60	8.53	9.16	9.79	8.00	8.94	9.86
Natural Gas	6.31	8.11	8.27	8.48	7.88	8.32	8.81	7.55	8.23	9.01
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lease and Plant Fuel[6]	1.19	1.21	1.24	1.25	1.18	1.22	1.26	1.18	1.28	1.44
Natural Gas Subtotal	7.50	9.32	9.51	9.72	9.06	9.54	10.06	8.73	9.51	10.45
Metallurgical Coal	0.40	0.56	0.58	0.62	0.48	0.55	0.63	0.38	0.47	0.58
Other Industrial Coal	0.94	0.97	0.98	1.00	0.94	0.97	1.01	0.90	0.94	0.98
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.10	0.28	0.40	0.56	0.97	1.19	1.37
Net Coal Coke Imports	-0.02	0.00	0.01	0.01	-0.00	0.00	0.01	-0.01	-0.00	0.01
Coal Subtotal	1.32	1.63	1.67	1.73	1.70	1.93	2.21	2.23	2.60	2.95
Biofuels Heat and Coproducts	0.66	0.84	0.85	0.86	1.86	1.90	1.93	2.45	2.52	2.80
Renewable Energy[7]	1.42	1.86	1.89	1.94	1.95	2.05	2.15	1.89	2.04	2.19
Electricity	3.01	3.45	3.54	3.65	3.27	3.52	3.75	2.92	3.28	3.64
Delivered Energy	**21.85**	**26.13**	**26.75**	**27.49**	**26.37**	**28.11**	**29.90**	**26.22**	**28.89**	**31.88**
Electricity Related Losses	6.44	7.11	7.28	7.49	6.75	7.23	7.66	5.96	6.59	7.13
Total	**28.29**	**33.24**	**34.03**	**34.97**	**33.12**	**35.33**	**37.56**	**32.18**	**35.49**	**39.01**

Table B2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Transportation										
Liquefied Petroleum Gases	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03
E85[8]	0.00	0.01	0.01	0.01	0.99	0.93	0.87	1.23	1.23	1.01
Motor Gasoline[2]	16.82	16.84	17.02	17.28	15.19	15.93	16.77	15.33	16.69	18.43
Jet Fuel[9]	3.20	3.17	3.20	3.24	3.34	3.47	3.62	3.37	3.62	3.89
Distillate Fuel Oil[10]	5.54	6.39	6.57	6.79	6.98	7.45	7.98	7.66	8.35	9.29
Residual Fuel Oil	0.78	0.79	0.79	0.80	0.80	0.81	0.81	0.81	0.82	0.83
Other Petroleum[11]	0.16	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17
Liquid Fuels and Other Petroleum Subtotal	26.52	27.38	27.76	28.29	27.48	28.76	30.23	28.57	30.89	33.64
Pipeline Fuel Natural Gas	0.65	0.65	0.67	0.68	0.62	0.64	0.66	0.62	0.67	0.78
Compressed Natural Gas	0.03	0.04	0.04	0.04	0.10	0.10	0.11	0.15	0.16	0.18
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.07	0.07	0.08
Delivered Energy	**27.23**	**28.10**	**28.50**	**29.03**	**28.23**	**29.56**	**31.05**	**29.42**	**31.80**	**34.69**
Electricity Related Losses	0.05	0.06	0.06	0.06	0.09	0.09	0.10	0.14	0.15	0.16
Total	**27.28**	**28.16**	**28.56**	**29.09**	**28.32**	**29.65**	**31.15**	**29.56**	**31.95**	**34.85**
Delivered Energy Consumption for All Sectors										
Liquefied Petroleum Gases	2.71	3.00	3.02	3.04	2.89	3.03	3.14	2.62	2.84	3.04
E85[8]	0.00	0.01	0.01	0.01	0.99	0.93	0.87	1.23	1.23	1.01
Motor Gasoline[2]	17.11	17.21	17.39	17.67	15.54	16.31	17.17	15.66	17.06	18.84
Jet Fuel[9]	3.20	3.17	3.20	3.24	3.34	3.47	3.62	3.37	3.62	3.89
Kerosene	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Distillate Fuel Oil	7.65	8.33	8.57	8.86	8.73	9.31	9.95	9.25	10.10	11.19
Residual Fuel Oil	1.02	1.02	1.03	1.04	1.03	1.04	1.06	1.02	1.05	1.07
Petrochemical Feedstocks	0.90	1.28	1.29	1.30	1.27	1.34	1.39	1.15	1.26	1.35
Other Petroleum[12]	3.60	3.97	4.13	4.31	3.64	3.94	4.27	3.59	4.04	4.51
Liquid Fuels and Other Petroleum Subtotal	36.23	38.03	38.67	39.50	37.45	39.39	41.50	37.94	41.22	44.93
Natural Gas	14.41	16.52	16.72	16.96	16.41	17.05	17.71	16.16	17.22	18.44
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lease and Plant Fuel[6]	1.19	1.21	1.24	1.25	1.18	1.22	1.26	1.18	1.28	1.44
Pipeline Natural Gas	0.65	0.65	0.67	0.68	0.62	0.64	0.66	0.62	0.67	0.78
Natural Gas Subtotal	16.25	18.39	18.62	18.89	18.20	18.91	19.63	17.96	19.17	20.66
Metallurgical Coal	0.40	0.56	0.58	0.62	0.48	0.55	0.63	0.38	0.47	0.58
Other Coal	1.01	1.03	1.05	1.07	1.01	1.04	1.08	0.97	1.01	1.05
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.10	0.28	0.40	0.56	0.97	1.19	1.37
Net Coal Coke Imports	-0.02	0.00	0.01	0.01	-0.00	0.00	0.01	-0.01	-0.00	0.01
Coal Subtotal	1.39	1.69	1.74	1.80	1.76	2.00	2.28	2.30	2.66	3.01
Biofuels Heat and Coproducts	0.66	0.84	0.85	0.86	1.86	1.90	1.93	2.45	2.52	2.80
Renewable Energy[13]	1.96	2.37	2.41	2.46	2.48	2.59	2.70	2.40	2.58	2.74
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	12.20	12.83	13.00	13.19	13.51	14.13	14.72	14.25	15.29	16.40
Delivered Energy	**68.68**	**74.15**	**75.29**	**76.69**	**75.27**	**78.92**	**82.77**	**77.30**	**83.45**	**90.55**
Electricity Related Losses	26.11	26.44	26.73	27.10	27.87	29.03	30.05	29.05	30.74	32.09
Total	**94.79**	**100.59**	**102.02**	**103.79**	**103.15**	**107.95**	**112.82**	**106.35**	**114.19**	**122.64**
Electric Power[14]										
Distillate Fuel Oil	0.10	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.10	0.12
Residual Fuel Oil	0.30	0.34	0.34	0.35	0.35	0.35	0.36	0.36	0.37	0.38
Liquid Fuels and Other Petroleum Subtotal	0.40	0.43	0.43	0.44	0.46	0.45	0.46	0.47	0.47	0.50
Natural Gas	7.06	6.82	7.15	7.25	6.35	6.82	7.21	7.01	8.07	9.75
Steam Coal	18.30	17.96	17.99	18.37	19.71	20.61	21.63	20.62	21.64	22.11
Nuclear Power	8.35	8.77	8.77	8.77	9.02	9.17	9.17	8.99	9.14	9.14
Renewable Energy[15]	3.89	4.98	5.08	5.15	5.59	5.84	6.02	5.98	6.47	6.74
Electricity Imports	0.12	0.11	0.11	0.11	0.07	0.07	0.08	0.03	0.05	0.05
Total[16]	**38.31**	**39.27**	**39.73**	**40.29**	**41.39**	**43.17**	**44.77**	**43.29**	**46.03**	**48.49**

Table B2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Total Energy Consumption										
Liquefied Petroleum Gases	2.71	3.00	3.02	3.04	2.89	3.03	3.14	2.62	2.84	3.04
E85[8]	0.00	0.01	0.01	0.01	0.99	0.93	0.87	1.23	1.23	1.01
Motor Gasoline[2]	17.11	17.21	17.39	17.67	15.54	16.31	17.17	15.66	17.06	18.84
Jet Fuel[9]	3.20	3.17	3.20	3.24	3.34	3.47	3.62	3.37	3.62	3.89
Kerosene	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Distillate Fuel Oil	7.75	8.42	8.66	8.95	8.83	9.40	10.05	9.36	10.20	11.31
Residual Fuel Oil	1.32	1.36	1.37	1.38	1.38	1.40	1.42	1.39	1.41	1.45
Petrochemical Feedstocks	0.90	1.28	1.29	1.30	1.27	1.34	1.39	1.15	1.26	1.35
Other Petroleum[12]	3.60	3.97	4.13	4.31	3.64	3.94	4.27	3.59	4.04	4.51
Liquid Fuels and Other Petroleum Subtotal	36.62	38.46	39.10	39.94	37.91	39.84	41.96	38.41	41.70	45.43
Natural Gas	21.47	23.34	23.87	24.21	22.76	23.87	24.92	23.17	25.29	28.19
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lease and Plant Fuel[6]	1.19	1.21	1.24	1.25	1.18	1.22	1.26	1.18	1.28	1.44
Pipeline Natural Gas	0.65	0.65	0.67	0.68	0.62	0.64	0.66	0.62	0.67	0.78
Natural Gas Subtotal	23.31	25.21	25.77	26.14	24.55	25.73	26.84	24.97	27.24	30.41
Metallurgical Coal	0.40	0.56	0.58	0.62	0.48	0.55	0.63	0.38	0.47	0.58
Other Coal	19.31	18.99	19.04	19.43	20.72	21.65	22.70	21.59	22.64	23.16
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.10	0.28	0.40	0.56	0.97	1.19	1.37
Net Coal Coke Imports	-0.02	0.00	0.01	0.01	-0.00	0.00	0.01	-0.01	-0.00	0.01
Coal Subtotal	19.69	19.65	19.73	20.16	21.47	22.61	23.91	22.92	24.30	25.12
Nuclear Power	8.35	8.77	8.77	8.77	9.02	9.17	9.17	8.99	9.14	9.14
Biofuels Heat and Coproducts	0.66	0.84	0.85	0.86	1.86	1.90	1.93	2.45	2.52	2.80
Renewable Energy[17]	5.85	7.35	7.49	7.60	8.06	8.43	8.72	8.38	9.04	9.49
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Imports	0.12	0.11	0.11	0.11	0.07	0.07	0.08	0.03	0.05	0.05
Total	**94.79**	**100.59**	**102.02**	**103.79**	**103.15**	**107.95**	**112.82**	**106.35**	**114.19**	**122.64**
Energy Use and Related Statistics										
Delivered Energy Use	68.68	74.15	75.29	76.69	75.27	78.92	82.77	77.30	83.45	90.55
Total Energy Use	94.79	100.59	102.02	103.79	103.15	107.95	112.82	106.35	114.19	122.64
Ethanol Consumed in Motor Gasoline and E85	0.95	1.32	1.33	1.35	2.04	2.07	2.11	2.24	2.37	2.40
Population (millions)	307.84	324.28	326.16	330.09	343.66	358.06	374.90	359.21	390.09	422.90
Gross Domestic Product (billion 2005 dollars)	12881	14820	15336	15941	18388	20020	21728	22163	25692	29231
Carbon Dioxide Emissions (million metric tons)	5425.5	5605.0	5679.9	5789.0	5652.0	5937.8	6248.7	5863.8	6310.8	6794.9

[1]Includes wood used for residential heating. See Table A4 and/or Table A17 for estimates of nonmarketed renewable energy consumption for geothermal heat pumps, solar thermal hot water heating, and electricity generation from wind and solar photovoltaic sources.
[2]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[3]Excludes ethanol. Includes commercial sector consumption of wood and wood waste, landfill gas, municipal waste, and other biomass for combined heat and power. See Table A5 and/or Table A17 for estimates of nonmarketed renewable energy consumption for solar thermal hot water heating and electricity generation from wind and solar photovoltaic sources.
[4]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[5]Includes petroleum coke, asphalt, road oil, lubricants, still gas, and miscellaneous petroleum products.
[6]Represents natural gas used in well, field, and lease operations, and in natural gas processing plant machinery.
[7]Includes consumption of energy produced from hydroelectric, wood and wood waste, municipal waste, and other biomass sources. Excludes ethanol blends (10 percent or less) in motor gasoline.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[9]Includes only kerosene type.
[10]Diesel fuel for on- and off- road use.
[11]Includes aviation gasoline and lubricants.
[12]Includes unfinished oils, natural gasoline, motor gasoline blending components, aviation gasoline, lubricants, still gas, asphalt, road oil, petroleum coke, and miscellaneous petroleum products.
[13]Includes electricity generated for sale to the grid and for own use from renewable sources, and non-electric energy from renewable sources. Excludes ethanol and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
[14]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[15]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes net electricity imports.
[16]Includes non-biogenic municipal waste not included above.
[17]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes ethanol, net electricity imports, and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 consumption based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 population and gross domestic product: IHS Global Insight Industry and Employment models, September 2010. 2009 carbon dioxide emissions: EIA, *Emissions of Greenhouse Gases in the United States 2009,* DOE/EIA-0573(2009) (Washington, DC, December 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LM2011.D020911A, REF2011.D020911A, and HM2011.D020911A.

Table B3. Energy prices by sector and source
(2009 dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Residential										
Liquefied Petroleum Gases	24.63	29.63	29.79	30.04	33.37	33.90	34.49	34.42	35.01	35.91
Distillate Fuel Oil	18.12	20.81	21.14	21.63	25.42	25.92	27.03	26.28	27.53	28.76
Natural Gas	11.88	9.97	10.12	10.31	11.40	11.83	12.42	12.51	13.39	13.83
Electricity	33.62	31.52	31.80	32.12	30.43	31.20	32.37	30.25	31.67	32.89
Commercial										
Liquefied Petroleum Gases	21.49	26.17	26.32	26.58	29.88	30.41	30.98	30.91	31.48	32.35
Distillate Fuel Oil	15.97	18.98	19.28	19.74	23.54	24.02	25.13	24.32	25.52	26.74
Residual Fuel Oil	13.45	13.09	13.25	13.41	16.79	17.05	17.45	17.81	18.13	18.68
Natural Gas	9.68	8.22	8.37	8.56	9.34	9.77	10.34	10.15	10.98	11.41
Electricity	29.51	26.27	26.67	27.11	25.69	26.65	27.91	25.28	26.99	28.36
Industrial[1]										
Liquefied Petroleum Gases	20.59	23.14	23.31	23.60	26.97	27.52	28.15	27.90	28.52	29.43
Distillate Fuel Oil	16.56	19.06	19.34	19.80	23.73	24.20	25.31	24.45	25.66	26.91
Residual Fuel Oil	12.05	14.64	14.80	14.98	17.79	18.19	18.93	18.18	18.73	19.37
Natural Gas[2]	5.25	4.84	4.96	5.12	5.84	6.17	6.65	6.52	7.21	7.61
Metallurgical Coal	5.43	6.00	6.01	6.07	6.42	6.46	6.50	6.51	6.58	6.65
Other Industrial Coal	3.05	2.90	2.91	2.93	2.96	2.99	3.05	3.06	3.14	3.18
Coal to Liquids	- -	1.79	1.79	1.81	1.85	1.78	1.90	1.93	2.05	2.08
Electricity	19.79	17.35	17.68	18.01	17.33	17.99	18.91	17.46	18.73	19.85
Transportation										
Liquefied Petroleum Gases[3]	25.52	30.40	30.56	30.82	34.08	34.62	35.22	35.08	35.66	36.56
E85[4]	20.50	26.19	26.38	26.53	29.05	29.49	30.71	29.52	30.93	32.31
Motor Gasoline[5]	19.28	25.79	25.97	26.12	29.07	29.49	30.71	29.57	30.90	32.12
Jet Fuel[6]	12.59	18.70	19.02	19.51	22.97	23.56	24.72	24.05	25.28	26.57
Diesel Fuel (distillate fuel oil)[7]	17.79	22.21	22.50	23.00	26.63	27.19	28.45	27.05	28.39	29.82
Residual Fuel Oil	10.57	12.53	12.65	12.83	15.61	16.02	16.84	16.01	16.44	17.18
Natural Gas[8]	12.71	11.80	11.97	12.19	12.36	12.84	13.49	12.71	13.57	14.13
Electricity	34.92	28.84	29.16	29.39	28.19	29.49	31.15	30.07	32.37	34.49
Electric Power[9]										
Distillate Fuel Oil	14.33	16.55	16.84	17.32	20.73	21.20	22.18	21.71	22.84	24.00
Residual Fuel Oil	8.96	13.05	13.17	13.35	15.86	16.26	16.98	16.35	16.71	17.31
Natural Gas	4.82	4.51	4.67	4.84	5.36	5.76	6.28	6.02	6.80	7.32
Steam Coal	2.20	2.10	2.11	2.14	2.20	2.24	2.30	2.32	2.40	2.43
Average Price to All Users[10]										
Liquefied Petroleum Gases	17.43	21.53	21.67	21.90	24.99	25.43	25.93	26.19	26.62	27.39
E85[4]	20.50	26.19	26.38	26.53	29.05	29.49	30.71	29.52	30.93	32.31
Motor Gasoline[5]	19.23	25.79	25.97	26.12	29.07	29.49	30.71	29.57	30.90	32.12
Jet Fuel	12.59	18.70	19.02	19.51	22.97	23.56	24.72	24.05	25.28	26.57
Distillate Fuel Oil	17.51	21.53	21.83	22.31	26.07	26.61	27.84	26.62	27.93	29.33
Residual Fuel Oil	10.53	12.94	13.07	13.26	15.98	16.39	17.17	16.41	16.85	17.54
Natural Gas	7.28	6.34	6.45	6.61	7.47	7.81	8.30	8.21	8.91	9.24
Metallurgical Coal	5.43	6.00	6.01	6.07	6.42	6.46	6.50	6.51	6.58	6.65
Other Coal	2.25	2.15	2.16	2.18	2.24	2.28	2.34	2.36	2.43	2.47
Coal to Liquids	- -	1.79	1.79	1.81	1.85	1.78	1.90	1.93	2.05	2.08
Electricity	28.69	25.74	26.04	26.37	25.35	26.11	27.20	25.47	26.93	28.14
Non-Renewable Energy Expenditures by Sector (billion 2009 dollars)										
Residential	238.63	219.18	223.20	227.80	228.09	242.45	259.97	237.98	267.49	296.15
Commercial	174.64	166.09	169.68	173.77	185.95	198.28	212.97	208.42	231.11	252.68
Industrial	179.22	215.61	224.19	234.84	233.84	258.44	288.83	221.28	261.51	302.29
Transportation	474.91	649.53	664.86	685.06	722.46	773.10	851.85	761.88	866.49	996.25
Total Non-Renewable Expenditures	1067.41	1250.40	1281.92	1321.47	1370.34	1472.27	1613.61	1429.57	1626.60	1847.37
Transportation Renewable Expenditures	0.06	0.22	0.23	0.24	28.63	27.48	26.58	36.43	37.93	32.69
Total Expenditures	**1067.47**	**1250.63**	**1282.15**	**1321.71**	**1398.97**	**1499.75**	**1640.20**	**1466.00**	**1664.53**	**1880.05**

Table B3. Energy prices by sector and source (continued)
(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Residential										
Liquefied Petroleum Gases	24.63	32.94	32.51	31.97	47.87	44.84	41.63	62.02	55.86	49.88
Distillate Fuel Oil	18.12	23.13	23.07	23.02	36.46	34.28	32.63	47.36	43.93	39.96
Natural Gas	11.88	11.09	11.05	10.97	16.36	15.65	14.99	22.54	21.37	19.21
Electricity	33.62	35.04	34.72	34.18	43.66	41.27	39.07	54.51	50.54	45.69
Commercial										
Liquefied Petroleum Gases	21.49	29.09	28.73	28.28	42.87	40.22	37.39	55.70	50.23	44.94
Distillate Fuel Oil	15.97	21.10	21.04	21.01	33.76	31.77	30.33	43.82	40.72	37.15
Residual Fuel Oil	13.45	14.55	14.47	14.27	24.09	22.55	21.07	32.09	28.93	25.94
Natural Gas	9.68	9.14	9.14	9.11	13.40	12.92	12.48	18.29	17.52	15.85
Electricity	29.51	29.21	29.12	28.85	36.85	35.25	33.69	45.55	43.06	39.39
Industrial[1]										
Liquefied Petroleum Gases	20.59	25.72	25.45	25.12	38.69	36.40	33.98	50.27	45.52	40.88
Distillate Fuel Oil	16.56	21.19	21.12	21.07	34.05	32.01	30.55	44.06	40.95	37.38
Residual Fuel Oil	12.05	16.28	16.15	15.94	25.52	24.05	22.85	32.76	29.88	26.90
Natural Gas[2]	5.25	5.38	5.42	5.45	8.37	8.15	8.03	11.74	11.50	10.57
Metallurgical Coal	5.43	6.66	6.56	6.46	9.20	8.54	7.84	11.73	10.50	9.24
Other Industrial Coal	3.05	3.23	3.17	3.12	4.25	3.96	3.68	5.52	5.01	4.41
Coal to Liquids	- -	1.99	1.96	1.93	2.65	2.36	2.29	3.49	3.27	2.90
Electricity	19.79	19.29	19.30	19.17	24.86	23.79	22.83	31.46	29.88	27.58
Transportation										
Liquefied Petroleum Gases[3]	25.52	33.80	33.36	32.80	48.89	45.80	42.51	63.21	56.90	50.79
E85[4]	20.50	29.12	28.80	28.23	41.68	39.01	37.07	53.20	49.35	44.87
Motor Gasoline[5]	19.28	28.66	28.35	27.79	41.70	39.01	37.07	53.28	49.31	44.61
Jet Fuel[6]	12.59	20.78	20.76	20.76	32.95	31.16	29.83	43.33	40.35	36.91
Diesel Fuel (distillate fuel oil)[7]	17.79	24.68	24.56	24.47	38.20	35.96	34.34	48.75	45.30	41.42
Residual Fuel Oil	10.57	13.93	13.80	13.65	22.39	21.19	20.33	28.85	26.24	23.86
Natural Gas[8]	12.71	13.12	13.06	12.97	17.73	16.98	16.29	22.90	21.66	19.63
Electricity	34.92	32.06	31.83	31.27	40.45	39.01	37.61	54.18	51.66	47.91
Electric Power[9]										
Distillate Fuel Oil	14.33	18.39	18.38	18.43	29.74	28.04	26.77	39.12	36.45	33.34
Residual Fuel Oil	8.96	14.50	14.37	14.21	22.76	21.50	20.50	29.46	26.66	24.04
Natural Gas	4.82	5.01	5.10	5.15	7.69	7.62	7.58	10.85	10.86	10.16
Steam Coal	2.20	2.33	2.31	2.27	3.16	2.96	2.78	4.19	3.83	3.38

Table B3. Energy prices by sector and source (continued)
(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Average Price to All Users[10]										
Liquefied Petroleum Gases	17.43	23.93	23.65	23.31	35.85	33.64	31.30	47.19	42.49	38.05
E85[4]	20.50	29.12	28.80	28.23	41.68	39.01	37.07	53.20	49.35	44.87
Motor Gasoline[5]	19.23	28.66	28.35	27.79	41.70	39.01	37.07	53.28	49.31	44.61
Jet Fuel	12.59	20.78	20.76	20.76	32.95	31.16	29.83	43.33	40.35	36.91
Distillate Fuel Oil	17.51	23.94	23.83	23.74	37.40	35.20	33.60	47.96	44.57	40.74
Residual Fuel Oil	10.53	14.39	14.27	14.11	22.92	21.67	20.73	29.57	26.88	24.36
Natural Gas	7.28	7.05	7.04	7.03	10.71	10.33	10.02	14.79	14.21	12.84
Metallurgical Coal	5.43	6.66	6.56	6.46	9.20	8.54	7.84	11.73	10.50	9.24
Other Coal	2.25	2.39	2.36	2.32	3.22	3.02	2.82	4.25	3.89	3.43
Coal to Liquids	- -	1.99	1.96	1.93	2.65	2.36	2.29	3.49	3.27	2.90
Electricity	28.69	28.61	28.43	28.06	36.37	34.53	32.83	45.90	42.97	39.09
Non-Renewable Energy Expenditures by Sector (billion nominal dollars)										
Residential	238.63	243.64	243.63	242.40	327.21	320.68	313.80	428.83	426.84	411.36
Commercial	174.64	184.62	185.21	184.91	266.76	262.27	257.06	375.56	368.78	350.97
Industrial	179.22	239.67	244.72	249.89	335.45	341.84	348.63	398.73	417.29	419.90
Transportation	474.91	722.01	725.73	728.96	1036.41	1022.56	1028.23	1372.86	1382.69	1383.82
Total Non-Renewable Expenditures	1067.41	1389.94	1399.29	1406.16	1965.83	1947.34	1947.72	2575.99	2595.61	2566.06
Transportation Renewable Expenditures	0.06	0.25	0.25	0.25	41.08	36.34	32.09	65.64	60.53	45.40
Total Expenditures	**1067.47**	**1390.19**	**1399.54**	**1406.41**	**2006.91**	**1983.68**	**1979.81**	**2641.63**	**2656.14**	**2611.46**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Excludes use for lease and plant fuel.
[3]Includes Federal and State taxes while excluding county and local taxes.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[6]Kerosene-type jet fuel. Includes Federal and State taxes while excluding county and local taxes.
[7]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[8]Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
[9]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[10]Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.
Btu = British thermal unit.
- - = Not applicable.
Note: Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on prices in the U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2009 residential and commercial natural gas delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 industrial natural gas delivered prices are estimated based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 transportation sector natural gas delivered prices are model results. 2009 electric power sector natural gas prices: EIA, *Electric Power Monthly*, DOE/EIA-0226, April 2009 and April 2010, Table 4.2. 2009 coal prices based on: EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010) and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. 2009 electricity prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. **Projections:** EIA, AEO2011 National Energy Modeling System runs LM2011.D020911A, REF2011.D020911A, and HM2011.D020911A.

Table B4. Macroeconomic indicators
(billion 2005 chain-weighted dollars, unless otherwise noted)

Indicators	2009	Projections								
		2015			2025			2035		
		Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth	Low Economic Growth	Reference	High Economic Growth
Real Gross Domestic Product	**12881**	**14820**	**15336**	**15941**	**18388**	**20020**	**21728**	**22163**	**25692**	**29231**
Components of Real Gross Domestic Product										
Real Consumption	9154	10165	10443	10787	12313	13280	14276	14940	16976	19034
Real Investment	1516	2346	2592	2850	3110	3548	4018	3881	4849	5816
Real Government Spending	2543	2503	2555	2619	2610	2796	2996	2691	3069	3445
Real Exports	1491	2403	2437	2490	4008	4485	5020	6194	7334	8502
Real Imports	1854	2552	2624	2703	3658	3840	3982	5533	5902	6241
Energy Intensity										
(thousand Btu per 2005 dollar of GDP)										
Delivered Energy	5.33	5.00	4.91	4.81	4.09	3.94	3.81	3.49	3.25	3.10
Total Energy	7.36	6.79	6.65	6.51	5.61	5.39	5.19	4.80	4.44	4.20
Price Indices										
GDP Chain-Type Price Index (2005=1.000)	1.096	1.219	1.197	1.166	1.573	1.450	1.323	1.975	1.749	1.523
Consumer Price Index (1982-4=1)										
All-urban	2.15	2.44	2.39	2.33	3.23	2.97	2.72	4.12	3.66	3.19
Energy Commodities and Services	1.93	2.46	2.44	2.40	3.46	3.25	3.10	4.42	4.10	3.71
Wholesale Price Index (1982=1.00)										
All Commodities	1.73	2.05	2.00	1.94	2.63	2.38	2.14	3.16	2.74	2.30
Fuel and Power	1.59	2.06	2.05	2.03	3.00	2.84	2.72	3.93	3.68	3.33
Metals and Metal Products	1.87	2.51	2.48	2.43	2.97	2.77	2.56	3.19	2.87	2.54
Industrial Commodities excluding Energy	**1.76**	**2.04**	**2.00**	**1.95**	**2.44**	**2.25**	**2.05**	**2.74**	**2.43**	**2.11**
Interest Rates (percent, nominal)										
Federal Funds Rate	0.16	5.50	5.15	4.76	5.37	4.86	4.38	5.53	5.04	4.40
10-Year Treasury Note	3.26	6.21	5.76	5.23	6.37	5.78	5.23	6.46	5.89	5.20
AA Utility Bond Rate	5.75	7.71	7.41	7.04	8.39	7.69	7.07	8.62	7.93	7.16
Value of Shipments (billion 2005 dollars)										
Service Sectors	19555	22738	23155	23669	27266	28648	30049	32411	34664	36924
Total Industrial	6017	7186	7472	7796	7702	8396	9103	8128	9292	10535
Non-manufacturing	1821	2038	2193	2361	2117	2381	2651	2161	2521	2896
Manufacturing	4197	5148	5279	5435	5585	6016	6452	5967	6770	7639
Energy-Intensive	1551	1760	1792	1833	1827	1940	2056	1829	2015	2205
Non-Energy Intensive	2646	3388	3487	3602	3758	4075	4395	4138	4756	5434
Total Shipments	**25573**	**29924**	**30627**	**31465**	**34967**	**37044**	**39152**	**40539**	**43956**	**47459**
Population and Employment (millions)										
Population with Armed Forces Overseas	307.8	324.3	326.2	330.1	343.7	358.1	374.9	359.2	390.1	422.9
Population, aged 16 and over	241.8	254.7	256.5	260.1	272.9	282.6	293.6	289.4	309.6	331.1
Population, over age 65	39.7	46.9	47.1	47.4	63.1	64.2	65.4	75.2	77.7	80.4
Employment, Nonfarm	130.9	136.1	142.2	149.1	145.1	156.2	166.9	155.4	170.8	186.0
Employment, Manufacturing	11.9	17.2	17.4	17.7	15.4	15.8	15.9	12.7	13.1	13.4
Key Labor Indicators										
Labor Force (millions)	154.2	158.7	160.7	163.5	164.7	170.6	177.3	172.9	182.6	192.5
Non-farm Labor Productivity (1992=1.00)	1.07	1.16	1.18	1.20	1.38	1.47	1.57	1.60	1.79	1.98
Unemployment Rate (percent)	9.27	7.02	6.87	6.70	5.18	4.98	4.84	5.34	5.20	5.07
Key Indicators for Energy Demand										
Real Disposable Personal Income	10100	11235	11533	11891	14171	15118	16080	17306	19224	21138
Housing Starts (millions)	0.60	1.54	1.85	2.16	1.50	1.93	2.37	1.20	1.74	2.29
Commercial Floorspace (billion square feet)	80.2	84.5	85.4	86.5	93.3	97.4	101.5	103.3	109.8	116.9
Unit Sales of Light-Duty Vehicles (millions)	10.40	16.51	17.03	17.86	16.92	18.24	19.70	18.37	20.64	23.26

GDP = Gross domestic product.
Btu = British thermal unit.
Sources: 2009: IHS Global Insight Industry and Employment models, September 2010. **Projections:** U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs LM2011.D020911A, REF2011.D020911A, and HM2011.D020911A.

Price case comparisons

Table C1. Total energy supply, disposition, and price summary
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Production										
Crude Oil and Lease Condensate	11.34	12.35	12.51	12.76	11.19	12.64	15.18	9.32	12.80	15.31
Natural Gas Plant Liquids	2.57	2.88	2.86	2.90	3.50	3.55	3.62	3.85	3.92	3.86
Dry Natural Gas	21.50	23.05	23.01	23.23	24.24	24.60	25.20	26.91	27.00	27.63
Coal[1]	21.58	20.63	20.94	20.83	23.30	23.64	24.98	23.82	26.01	30.33
Nuclear Power	8.35	8.77	8.77	8.77	9.08	9.17	9.17	9.05	9.14	9.14
Hydropower	2.69	2.92	2.92	2.92	3.01	3.04	3.03	3.06	3.09	3.09
Biomass[2]	3.52	4.71	4.70	4.95	6.46	7.20	8.55	7.97	8.63	11.88
Other Renewable Energy[3]	1.29	2.09	2.14	2.14	2.52	2.58	2.61	3.01	3.22	3.22
Other[4]	0.34	0.59	0.78	0.92	0.65	0.88	0.90	0.62	0.78	1.02
Total	**73.18**	**77.99**	**78.63**	**79.43**	**83.95**	**87.29**	**93.24**	**87.62**	**94.59**	**105.48**
Imports										
Crude Oil	19.70	20.90	19.25	17.61	22.46	18.35	12.86	25.74	18.44	10.15
Liquid Fuels and Other Petroleum[5]	5.40	5.58	5.33	5.01	6.09	5.18	4.56	6.77	5.33	4.42
Natural Gas	3.82	4.21	4.01	3.98	3.60	3.20	2.77	3.04	2.87	2.46
Other Imports[6]	0.61	0.82	0.82	0.82	1.22	1.39	1.39	1.05	1.27	1.38
Total	**29.53**	**31.51**	**29.41**	**27.42**	**33.37**	**28.13**	**21.58**	**36.61**	**27.92**	**18.41**
Exports										
Petroleum[7]	4.17	3.23	3.27	3.38	3.45	3.62	3.64	3.73	3.92	3.93
Natural Gas	1.09	1.24	1.24	1.24	2.10	2.07	2.06	2.71	2.64	2.62
Coal	1.51	1.76	1.76	1.76	1.89	1.89	1.86	1.65	1.78	1.92
Total	**6.77**	**6.23**	**6.27**	**6.37**	**7.45**	**7.58**	**7.57**	**8.09**	**8.34**	**8.47**
Discrepancy[8]	**1.16**	**-0.27**	**-0.24**	**-0.18**	**-0.11**	**-0.12**	**-0.05**	**-0.05**	**-0.02**	**0.19**
Consumption										
Liquid Fuels and Other Petroleum[9]	36.62	40.72	39.10	37.62	42.67	39.84	37.88	45.61	41.70	39.11
Natural Gas	23.31	25.99	25.77	25.97	25.70	25.73	25.93	27.21	27.24	27.33
Coal[10]	19.69	19.44	19.73	19.59	22.34	22.61	23.12	22.95	24.30	26.46
Nuclear Power	8.35	8.77	8.77	8.77	9.08	9.17	9.17	9.05	9.14	9.14
Hydropower	2.69	2.92	2.92	2.92	3.01	3.04	3.03	3.06	3.09	3.09
Biomass[11]	2.52	3.30	3.27	3.33	4.39	4.71	5.29	5.05	5.25	6.62
Other Renewable Energy[3]	1.29	2.09	2.14	2.14	2.52	2.58	2.61	3.01	3.22	3.22
Other[12]	0.32	0.31	0.31	0.31	0.27	0.27	0.28	0.24	0.25	0.25
Total	**94.79**	**103.55**	**102.02**	**100.66**	**109.98**	**107.95**	**107.30**	**116.19**	**114.19**	**115.23**
Prices (2009 dollars per unit)										
Petroleum (dollars per barrel)										
Imported Low Sulfur Light Crude Oil Price[13]	61.66	55.00	94.58	146.10	51.28	117.54	185.87	50.07	124.94	199.95
Imported Crude Oil Price[13]	59.04	48.46	86.83	136.84	41.36	107.40	175.09	39.66	113.70	187.79
Natural Gas (dollars per million Btu)										
Price at Henry Hub	3.95	4.60	4.66	4.74	5.63	5.97	6.19	6.66	7.07	7.20
Wellhead Price[14]	3.62	4.07	4.13	4.20	4.98	5.29	5.48	5.90	6.26	6.37
Natural Gas (dollars per thousand cubic feet)										
Wellhead Price[14]	3.71	4.18	4.24	4.31	5.11	5.43	5.62	6.05	6.42	6.54
Coal (dollars per ton)										
Minemouth Price[15]	33.26	31.65	32.36	33.61	31.30	33.22	35.10	31.42	33.92	36.56
Coal (dollars per million Btu)										
Minemouth Price[15]	1.67	1.58	1.62	1.68	1.59	1.68	1.77	1.60	1.73	1.87
Average Delivered Price[16]	2.31	2.20	2.26	2.37	2.22	2.36	2.52	2.29	2.47	2.68
Average Electricity Price (cents per kilowatthour)	9.8	8.8	8.9	9.0	8.7	8.9	9.1	8.8	9.2	9.3

Table C1. Total energy supply, disposition, and price summary (continued)
(quadrillion Btu per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Prices (nominal dollars per unit)										
Petroleum (dollars per barrel)										
Imported Low Sulfur Light Crude Oil Price[13]	61.66	59.99	103.24	159.83	68.94	155.46	246.11	81.59	199.37	321.76
Imported Crude Oil Price[13]	59.04	52.86	94.78	149.70	55.61	142.05	231.84	64.62	181.43	302.20
Natural Gas (dollars per million Btu)										
Price at Henry Hub	3.95	5.01	5.09	5.19	7.56	7.90	8.19	10.85	11.28	11.58
Wellhead Price[14]	3.62	4.44	4.51	4.59	6.70	6.99	7.25	9.61	9.99	10.25
Natural Gas (dollars per thousand cubic feet)										
Wellhead Price[14]	3.71	4.56	4.63	4.71	6.87	7.18	7.44	9.86	10.24	10.52
Coal (dollars per ton)										
Minemouth Price[15]	33.26	34.52	35.32	36.77	42.08	43.93	46.48	51.20	54.13	58.83
Coal (dollars per million Btu)										
Minemouth Price[15]	1.67	1.73	1.77	1.84	2.13	2.22	2.35	2.61	2.76	3.01
Average Delivered Price[16]	2.31	2.40	2.47	2.60	2.98	3.12	3.33	3.72	3.95	4.31
Average Electricity Price (cents per kilowatthour)	9.8	9.5	9.7	9.9	11.7	11.8	12.1	14.4	14.7	15.0

[1]Includes waste coal.
[2]Includes grid-connected electricity from wood and wood waste; biomass, such as corn, used for liquid fuels production; and non-electric energy demand from wood. Refer to Table A17 for details.
[3]Includes grid-connected electricity from landfill gas; biogenic municipal waste; wind; photovoltaic and solar thermal sources; and non-electric energy from renewable sources, such as active and passive solar systems. Excludes electricity imports using renewable sources and nonmarketed renewable energy. See Table A17 for selected nonmarketed residential and commercial renewable energy.
[4]Includes non-biogenic municipal waste, liquid hydrogen, methanol, and some domestic inputs to refineries.
[5]Includes imports of finished petroleum products, unfinished oils, alcohols, ethers, blending components, and renewable fuels such as ethanol.
[6]Includes coal, coal coke (net), and electricity (net).
[7]Includes crude oil and petroleum products.
[8]Balancing item. Includes unaccounted for supply, losses, gains, and net storage withdrawals.
[9]Includes petroleum-derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids and crude oil consumed as a fuel. Refer to Table A17 for detailed renewable liquid fuels consumption.
[10]Excludes coal converted to coal-based synthetic liquids and natural gas.
[11]Includes grid-connected electricity from wood and wood waste, non-electric energy from wood, and biofuels heat and coproducts used in the production of liquid fuels, but excludes the energy content of the liquid fuels.
[12]Includes non-biogenic municipal waste and net electricity imports.
[13]Weighted average price delivered to U.S. refiners.
[14]Represents lower 48 onshore and offshore supplies.
[15]Includes reported prices for both open market and captive mines.
[16]Prices weighted by consumption; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 natural gas supply values and natural gas wellhead price: U.S. Energy Information Administration (EIA), *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 coal minemouth and delivered coal prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 petroleum supply values: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). 2009 low sulfur light crude oil price: EIA, Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." Other 2009 coal values: *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010). Other 2009 values: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A.

Table C2. Energy consumption by sector and source
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Energy Consumption										
Residential										
Liquefied Petroleum Gases	0.53	0.52	0.49	0.46	0.53	0.48	0.44	0.54	0.48	0.43
Kerosene	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Distillate Fuel Oil	0.61	0.61	0.56	0.51	0.52	0.44	0.40	0.45	0.37	0.32
Liquid Fuels and Other Petroleum Subtotal	1.16	1.15	1.07	0.99	1.07	0.94	0.85	1.01	0.86	0.77
Natural Gas	4.87	4.95	4.94	4.93	4.98	4.96	4.95	4.91	4.90	4.91
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Renewable Energy[1]	0.43	0.36	0.40	0.45	0.35	0.42	0.48	0.34	0.42	0.48
Electricity	4.65	4.62	4.60	4.57	5.03	4.98	4.95	5.57	5.51	5.48
Delivered Energy	**11.12**	**11.08**	**11.02**	**10.95**	**11.43**	**11.32**	**11.24**	**11.83**	**11.70**	**11.65**
Electricity Related Losses	9.96	9.45	9.46	9.39	10.38	10.24	10.05	11.21	11.06	10.85
Total	**21.08**	**20.53**	**20.48**	**20.35**	**21.81**	**21.56**	**21.29**	**23.04**	**22.76**	**22.50**
Commercial										
Liquefied Petroleum Gases	0.15	0.15	0.15	0.15	0.16	0.15	0.15	0.16	0.16	0.15
Motor Gasoline[2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Kerosene	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Distillate Fuel Oil	0.34	0.32	0.28	0.25	0.31	0.26	0.23	0.30	0.25	0.22
Residual Fuel Oil	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.07	0.07
Liquid Fuels and Other Petroleum Subtotal	0.60	0.58	0.55	0.52	0.59	0.53	0.50	0.59	0.53	0.50
Natural Gas	3.20	3.48	3.47	3.46	3.69	3.66	3.63	3.95	3.92	3.91
Coal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Renewable Energy[3]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Electricity	4.51	4.85	4.83	4.80	5.63	5.58	5.54	6.51	6.43	6.41
Delivered Energy	**8.49**	**9.08**	**9.02**	**8.96**	**10.07**	**9.94**	**9.85**	**11.22**	**11.05**	**10.99**
Electricity Related Losses	9.66	9.91	9.94	9.87	11.62	11.47	11.25	13.12	12.93	12.68
Total	**18.15**	**19.00**	**18.96**	**18.82**	**21.69**	**21.41**	**21.10**	**24.34**	**23.98**	**23.67**
Industrial[4]										
Liquefied Petroleum Gases	2.01	2.46	2.36	2.32	2.50	2.38	2.31	2.29	2.18	2.11
Motor Gasoline[2]	0.25	0.34	0.33	0.33	0.34	0.33	0.33	0.34	0.32	0.32
Distillate Fuel Oil	1.16	1.19	1.16	1.13	1.20	1.16	1.14	1.20	1.13	1.11
Residual Fuel Oil	0.17	0.20	0.17	0.15	0.21	0.17	0.15	0.24	0.16	0.14
Petrochemical Feedstocks	0.90	1.21	1.29	1.28	1.26	1.34	1.32	1.19	1.26	1.25
Other Petroleum[5]	3.45	4.31	3.97	3.63	4.41	3.79	3.35	4.73	3.88	3.27
Liquid Fuels and Other Petroleum Subtotal	7.94	9.71	9.29	8.84	9.92	9.16	8.59	9.99	8.94	8.20
Natural Gas	6.31	8.19	8.27	8.48	8.12	8.32	8.59	7.98	8.23	8.54
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Lease and Plant Fuel[6]	1.19	1.24	1.24	1.25	1.21	1.22	1.26	1.25	1.28	1.34
Natural Gas Subtotal	7.50	9.43	9.51	9.73	9.33	9.54	9.86	9.23	9.51	9.99
Metallurgical Coal	0.40	0.59	0.58	0.58	0.55	0.55	0.55	0.46	0.47	0.46
Other Industrial Coal	0.94	0.99	0.98	0.97	0.98	0.97	0.97	0.94	0.94	0.93
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.15	0.16	0.40	1.33	0.20	1.19	3.45
Net Coal Coke Imports	-0.02	0.01	0.01	0.01	0.00	0.00	0.00	-0.00	-0.00	-0.00
Coal Subtotal	1.32	1.68	1.67	1.71	1.69	1.93	2.85	1.60	2.60	4.84
Biofuels Heat and Coproducts	0.66	0.87	0.85	0.91	1.47	1.90	2.49	2.11	2.52	3.87
Renewable Energy[7]	1.42	1.91	1.89	1.88	2.09	2.05	2.02	2.12	2.04	2.00
Electricity	3.01	3.60	3.54	3.52	3.53	3.52	3.49	3.29	3.28	3.25
Delivered Energy	**21.85**	**27.18**	**26.75**	**26.57**	**28.02**	**28.11**	**29.30**	**28.34**	**28.89**	**32.15**
Electricity Related Losses	6.44	7.36	7.28	7.22	7.28	7.23	7.08	6.63	6.59	6.44
Total	**28.29**	**34.54**	**34.03**	**33.80**	**35.31**	**35.33**	**36.38**	**34.97**	**35.49**	**38.59**

Table C2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Transportation										
Liquefied Petroleum Gases	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
E85[8]	0.00	0.01	0.01	0.33	0.19	0.93	2.55	0.19	1.23	3.61
Motor Gasoline[2]	16.82	17.87	17.02	15.86	18.21	15.93	13.00	19.76	16.69	12.55
Jet Fuel[9]	3.20	3.22	3.20	3.18	3.49	3.47	3.46	3.64	3.62	3.61
Distillate Fuel Oil[10]	5.54	6.63	6.57	6.51	7.53	7.45	7.48	8.40	8.35	8.38
Residual Fuel Oil	0.78	0.79	0.79	0.79	0.81	0.81	0.81	0.82	0.82	0.82
Other Petroleum[11]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Liquid Fuels and Other Petroleum Subtotal	26.52	28.70	27.76	26.85	30.39	28.76	27.48	32.98	30.89	29.16
Pipeline Fuel Natural Gas	0.65	0.67	0.67	0.67	0.64	0.64	0.65	0.65	0.67	0.66
Compressed Natural Gas	0.03	0.03	0.04	0.06	0.04	0.10	0.19	0.04	0.16	0.30
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	0.02	0.03	0.03	0.04	0.04	0.05	0.07	0.06	0.07	0.11
Delivered Energy	**27.23**	**29.43**	**28.50**	**27.62**	**31.11**	**29.56**	**28.39**	**33.73**	**31.80**	**30.24**
Electricity Related Losses	0.05	0.05	0.06	0.08	0.07	0.09	0.14	0.11	0.15	0.22
Total	**27.28**	**29.48**	**28.56**	**27.69**	**31.18**	**29.65**	**28.53**	**33.84**	**31.95**	**30.46**
Delivered Energy Consumption for All Sectors										
Liquefied Petroleum Gases	2.71	3.14	3.02	2.94	3.20	3.03	2.91	3.01	2.84	2.72
E85[8]	0.00	0.01	0.01	0.33	0.19	0.93	2.55	0.19	1.23	3.61
Motor Gasoline[2]	17.11	18.26	17.39	16.24	18.59	16.31	13.38	20.15	17.06	12.92
Jet Fuel[9]	3.20	3.22	3.20	3.18	3.49	3.47	3.46	3.64	3.62	3.61
Kerosene	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Distillate Fuel Oil	7.65	8.75	8.57	8.40	9.56	9.31	9.25	10.34	10.10	10.03
Residual Fuel Oil	1.02	1.06	1.03	1.01	1.09	1.04	1.02	1.12	1.05	1.03
Petrochemical Feedstocks	0.90	1.21	1.29	1.28	1.26	1.34	1.32	1.19	1.26	1.25
Other Petroleum[12]	3.60	4.46	4.13	3.78	4.56	3.94	3.50	4.89	4.04	3.43
Liquid Fuels and Other Petroleum Subtotal	36.23	40.13	38.67	37.19	41.96	39.39	37.42	44.57	41.22	38.63
Natural Gas	14.41	16.64	16.72	16.94	16.82	17.05	17.37	16.89	17.22	17.66
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Lease and Plant Fuel[6]	1.19	1.24	1.24	1.25	1.21	1.22	1.26	1.25	1.28	1.34
Pipeline Natural Gas	0.65	0.67	0.67	0.67	0.64	0.64	0.65	0.65	0.67	0.66
Natural Gas Subtotal	16.25	18.56	18.62	18.85	18.67	18.91	19.28	18.78	19.17	19.77
Metallurgical Coal	0.40	0.59	0.58	0.58	0.55	0.55	0.55	0.46	0.47	0.46
Other Coal	1.01	1.05	1.05	1.04	1.05	1.04	1.04	1.01	1.01	1.00
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.15	0.16	0.40	1.33	0.20	1.19	3.45
Net Coal Coke Imports	-0.02	0.01	0.01	0.01	0.00	0.00	0.00	-0.00	-0.00	-0.00
Coal Subtotal	1.39	1.75	1.74	1.77	1.76	2.00	2.92	1.67	2.66	4.90
Biofuels Heat and Coproducts	0.66	0.87	0.85	0.91	1.47	1.90	2.49	2.11	2.52	3.87
Renewable Energy[13]	1.96	2.38	2.41	2.45	2.55	2.59	2.61	2.58	2.58	2.59
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	12.20	13.09	13.00	12.93	14.22	14.13	14.06	15.42	15.29	15.26
Delivered Energy	**68.68**	**76.77**	**75.29**	**74.10**	**80.63**	**78.92**	**78.78**	**85.13**	**83.45**	**85.03**
Electricity Related Losses	26.11	26.77	26.73	26.56	29.35	29.03	28.52	31.07	30.74	30.19
Total	**94.79**	**103.55**	**102.02**	**100.66**	**109.98**	**107.95**	**107.30**	**116.19**	**114.19**	**115.23**
Electric Power[14]										
Distillate Fuel Oil	0.10	0.11	0.09	0.09	0.11	0.10	0.10	0.12	0.10	0.11
Residual Fuel Oil	0.30	0.48	0.34	0.34	0.59	0.35	0.36	0.93	0.37	0.37
Liquid Fuels and Other Petroleum Subtotal	0.40	0.59	0.43	0.43	0.70	0.45	0.46	1.05	0.47	0.48
Natural Gas	7.06	7.44	7.15	7.12	7.04	6.82	6.65	8.43	8.07	7.56
Steam Coal	18.30	17.69	17.99	17.82	20.58	20.61	20.20	21.28	21.64	21.55
Nuclear Power	8.35	8.77	8.77	8.77	9.08	9.17	9.17	9.05	9.14	9.14
Renewable Energy[15]	3.89	5.06	5.08	5.03	5.90	5.84	5.82	6.44	6.47	6.47
Electricity Imports	0.12	0.11	0.11	0.11	0.07	0.07	0.08	0.04	0.05	0.05
Total[16]	**38.31**	**39.87**	**39.73**	**39.49**	**43.57**	**43.17**	**42.58**	**46.49**	**46.03**	**45.45**

Table C2. Energy consumption by sector and source (continued)
(quadrillion Btu per year, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Total Energy Consumption										
Liquefied Petroleum Gases	2.71	3.14	3.02	2.94	3.20	3.03	2.91	3.01	2.84	2.72
E85[8]	0.00	0.01	0.01	0.33	0.19	0.93	2.55	0.19	1.23	3.61
Motor Gasoline[2]	17.11	18.26	17.39	16.24	18.59	16.31	13.38	20.15	17.06	12.92
Jet Fuel[9]	3.20	3.22	3.20	3.18	3.49	3.47	3.46	3.64	3.62	3.61
Kerosene	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Distillate Fuel Oil	7.75	8.85	8.66	8.49	9.68	9.40	9.35	10.47	10.20	10.14
Residual Fuel Oil	1.32	1.54	1.37	1.35	1.67	1.40	1.38	2.05	1.41	1.40
Petrochemical Feedstocks	0.90	1.21	1.29	1.28	1.26	1.34	1.32	1.19	1.26	1.25
Other Petroleum[12]	3.60	4.46	4.13	3.78	4.56	3.94	3.50	4.89	4.04	3.43
Liquid Fuels and Other Petroleum Subtotal	36.62	40.72	39.10	37.62	42.67	39.84	37.88	45.61	41.70	39.11
Natural Gas	21.47	24.08	23.87	24.05	23.86	23.87	24.02	25.31	25.29	25.22
Natural-Gas-to-Liquids Heat and Power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Lease and Plant Fuel[6]	1.19	1.24	1.24	1.25	1.21	1.22	1.26	1.25	1.28	1.34
Pipeline Natural Gas	0.65	0.67	0.67	0.67	0.64	0.64	0.65	0.65	0.67	0.66
Natural Gas Subtotal	23.31	25.99	25.77	25.97	25.70	25.73	25.93	27.21	27.24	27.33
Metallurgical Coal	0.40	0.59	0.58	0.58	0.55	0.55	0.55	0.46	0.47	0.46
Other Coal	19.31	18.74	19.04	18.86	21.62	21.65	21.23	22.29	22.64	22.56
Coal-to-Liquids Heat and Power	0.00	0.10	0.10	0.15	0.16	0.40	1.33	0.20	1.19	3.45
Net Coal Coke Imports	-0.02	0.01	0.01	0.01	0.00	0.00	0.00	-0.00	-0.00	-0.00
Coal Subtotal	19.69	19.44	19.73	19.59	22.34	22.61	23.12	22.95	24.30	26.46
Nuclear Power	8.35	8.77	8.77	8.77	9.08	9.17	9.17	9.05	9.14	9.14
Biofuels Heat and Coproducts	0.66	0.87	0.85	0.91	1.47	1.90	2.49	2.11	2.52	3.87
Renewable Energy[17]	5.85	7.44	7.49	7.48	8.45	8.43	8.43	9.01	9.04	9.06
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity Imports	0.12	0.11	0.11	0.11	0.07	0.07	0.08	0.04	0.05	0.05
Total	**94.79**	**103.55**	**102.02**	**100.66**	**109.98**	**107.95**	**107.30**	**116.19**	**114.19**	**115.23**
Energy Use and Related Statistics										
Delivered Energy Use	68.68	76.77	75.29	74.10	80.63	78.92	78.78	85.13	83.45	85.03
Total Energy Use	94.79	103.55	102.02	100.66	109.98	107.95	107.30	116.19	114.19	115.23
Ethanol Consumed in Motor Gasoline and E85	0.95	1.36	1.33	1.46	1.77	2.07	2.83	1.89	2.37	3.54
Population (millions)	307.84	326.16	326.16	326.16	358.06	358.06	358.06	390.09	390.09	390.09
Gross Domestic Product (billion 2005 dollars)	12881	15411	15336	15260	20029	20020	20122	25735	25692	25813
Carbon Dioxide Emissions (million metric tons)	5425.5	5777.8	5679.9	5557.7	6136.1	5937.8	5799.7	6497.0	6310.8	6243.9

[1]Includes wood used for residential heating. See Table A4 and/or Table A17 for estimates of nonmarketed renewable energy consumption for geothermal heat pumps, solar thermal hot water heating, and electricity generation from wind and solar photovoltaic sources.
[2]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[3]Excludes ethanol. Includes commercial sector consumption of wood and wood waste, landfill gas, municipal waste, and other biomass for combined heat and power. See Table A5 and/or Table A17 for estimates of nonmarketed renewable energy consumption for solar thermal hot water heating and electricity generation from wind and solar photovoltaic sources.
[4]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[5]Includes petroleum coke, asphalt, road oil, lubricants, still gas, and miscellaneous petroleum products.
[6]Represents natural gas used in well, field, and lease operations, and in natural gas processing plant machinery.
[7]Includes consumption of energy produced from hydroelectric, wood and wood waste, municipal waste, and other biomass sources. Excludes ethanol blends (10 percent or less) in motor gasoline.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[9]Includes only kerosene type.
[10]Diesel fuel for on- and off- road use.
[11]Includes aviation gasoline and lubricants.
[12]Includes unfinished oils, natural gasoline, motor gasoline blending components, aviation gasoline, lubricants, still gas, asphalt, road oil, petroleum coke, and miscellaneous petroleum products.
[13]Includes electricity generated for sale to the grid and for own use from renewable sources, and non-electric energy from renewable sources. Excludes ethanol and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
[14]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[15]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes net electricity imports.
[16]Includes non-biogenic municipal waste not included above.
[17]Includes conventional hydroelectric, geothermal, wood and wood waste, biogenic municipal waste, other biomass, wind, photovoltaic, and solar thermal sources. Excludes ethanol, net electricity imports, and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 consumption based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 population and gross domestic product: IHS Global Insight Industry and Employment models, September 2010. 2009 carbon dioxide emissions: EIA, *Emissions of Greenhouse Gases in the United States 2009,* DOE/EIA-0573(2009) (Washington, DC, December 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A.

Table C3. Energy prices by sector and source
(2009 dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections 2015 Low Oil Price	2015 Reference	2015 High Oil Price	2025 Low Oil Price	2025 Reference	2025 High Oil Price	2035 Low Oil Price	2035 Reference	2035 High Oil Price
Residential										
Liquefied Petroleum Gases	24.63	22.24	29.79	40.74	21.24	33.90	48.64	21.22	35.01	51.15
Distillate Fuel Oil	18.12	14.62	21.14	30.42	14.75	25.92	37.19	15.51	27.53	39.66
Natural Gas	11.88	10.04	10.12	10.21	11.49	11.83	12.11	12.91	13.39	13.52
Electricity	33.62	31.38	31.80	32.28	30.45	31.20	31.88	30.66	31.67	32.04
Commercial										
Liquefied Petroleum Gases	21.49	18.79	26.32	37.27	17.77	30.41	45.14	17.73	31.48	47.62
Distillate Fuel Oil	15.97	13.05	19.28	28.36	13.20	24.02	35.23	13.77	25.52	37.59
Residual Fuel Oil	13.45	6.19	13.25	22.12	5.72	17.05	28.17	5.50	18.13	29.29
Natural Gas	9.68	8.29	8.37	8.45	9.45	9.77	10.02	10.52	10.98	11.09
Electricity	29.51	26.25	26.67	27.24	25.82	26.65	27.40	25.81	26.99	27.37
Industrial[1]										
Liquefied Petroleum Gases	20.59	16.02	23.31	34.44	14.99	27.52	42.49	15.00	28.52	45.04
Distillate Fuel Oil	16.56	13.34	19.34	28.33	13.66	24.20	35.46	14.18	25.66	37.78
Residual Fuel Oil	12.05	8.24	14.80	23.52	7.62	18.19	28.51	6.99	18.73	29.90
Natural Gas[2]	5.25	4.89	4.96	5.00	5.84	6.17	6.36	6.92	7.21	7.32
Metallurgical Coal	5.43	5.98	6.01	6.14	6.32	6.46	6.59	6.36	6.58	6.76
Other Industrial Coal	3.05	2.84	2.91	3.02	2.85	2.99	3.16	2.93	3.14	3.38
Coal to Liquids	- -	1.70	1.79	1.86	1.83	1.78	2.23	1.67	2.05	2.41
Electricity	19.79	17.47	17.68	17.98	17.52	17.99	18.43	18.04	18.73	18.87
Transportation										
Liquefied Petroleum Gases[3]	25.52	23.03	30.56	41.52	21.99	34.62	49.36	21.91	35.66	51.81
E85[4]	20.50	18.30	26.38	32.25	19.64	29.49	40.12	19.81	30.93	41.77
Motor Gasoline[5]	19.28	17.94	25.97	35.39	17.65	29.49	42.68	17.64	30.90	44.69
Jet Fuel[6]	12.59	11.85	19.02	28.84	11.45	23.56	35.38	12.43	25.28	38.31
Diesel Fuel (distillate fuel oil)[7]	17.79	16.60	22.50	31.48	16.70	27.19	38.58	16.83	28.39	40.67
Residual Fuel Oil	10.57	6.11	12.65	21.30	5.45	16.02	25.93	4.47	16.44	27.74
Natural Gas[8]	12.71	11.82	11.97	12.10	12.34	12.84	13.12	12.97	13.57	13.69
Electricity	34.92	29.92	29.16	29.64	27.32	29.49	32.92	29.35	32.37	35.04
Electric Power[9]										
Distillate Fuel Oil	14.33	9.97	16.84	26.07	9.74	21.20	32.26	10.41	22.84	34.70
Residual Fuel Oil	8.96	5.72	13.17	21.87	4.91	16.26	26.11	4.13	16.71	27.49
Natural Gas	4.82	4.62	4.67	4.73	5.47	5.76	5.95	6.44	6.80	6.90
Steam Coal	2.20	2.04	2.11	2.22	2.08	2.24	2.41	2.18	2.40	2.64
Average Price to All Users[10]										
Liquefied Petroleum Gases	17.43	14.69	21.67	31.69	13.75	25.43	38.99	13.92	26.62	41.50
E85[4]	20.50	18.30	26.38	32.25	19.64	29.49	40.12	19.81	30.93	41.77
Motor Gasoline[5]	19.23	17.94	25.97	35.39	17.65	29.49	42.68	17.63	30.90	44.69
Jet Fuel	12.59	11.85	19.02	28.84	11.45	23.56	35.38	12.43	25.28	38.31
Distillate Fuel Oil	17.51	15.82	21.83	30.85	16.03	26.61	37.98	16.40	27.93	40.19
Residual Fuel Oil	10.53	6.27	13.07	21.73	5.55	16.39	26.36	4.64	16.85	27.96
Natural Gas	7.28	6.36	6.45	6.50	7.48	7.81	8.04	8.50	8.91	9.07
Metallurgical Coal	5.43	5.98	6.01	6.14	6.32	6.46	6.59	6.36	6.58	6.76
Other Coal	2.25	2.09	2.16	2.27	2.12	2.28	2.45	2.22	2.43	2.68
Coal to Liquids	- -	1.70	1.79	1.86	1.83	1.78	2.23	1.67	2.05	2.41
Electricity	28.69	25.65	26.04	26.51	25.40	26.11	26.78	25.91	26.93	27.29
Non-Renewable Energy Expenditures by Sector (billion 2009 dollars)										
Residential	238.63	215.39	223.20	232.94	229.49	242.45	254.58	252.80	267.49	277.66
Commercial	174.64	164.57	169.68	176.23	188.46	198.28	207.60	218.12	231.11	239.14
Industrial	179.22	182.20	224.19	280.05	185.38	258.44	333.95	184.42	261.51	336.85
Transportation	474.91	476.48	664.86	880.88	494.49	773.10	997.03	543.73	866.49	1076.77
Total Non-Renewable Expenditures	1067.41	1038.64	1281.92	1570.10	1097.82	1472.27	1793.16	1199.08	1626.60	1930.42
Transportation Renewable Expenditures	0.06	0.17	0.23	10.75	3.67	27.48	102.20	3.69	37.93	150.74
Total Expenditures	**1067.47**	**1038.82**	**1282.15**	**1580.85**	**1101.49**	**1499.75**	**1895.36**	**1202.77**	**1664.53**	**2081.17**

Table C3. Energy prices by sector and source (continued)
(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Residential										
Liquefied Petroleum Gases	24.63	24.25	32.51	44.57	28.55	44.84	64.40	34.58	55.86	82.31
Distillate Fuel Oil	18.12	15.95	23.07	33.28	19.84	34.28	49.25	25.27	43.93	63.83
Natural Gas	11.88	10.94	11.05	11.16	15.45	15.65	16.04	21.04	21.37	21.76
Electricity	33.62	34.22	34.72	35.32	40.94	41.27	42.22	49.95	50.54	51.55
Commercial										
Liquefied Petroleum Gases	21.49	20.50	28.73	40.77	23.90	40.22	59.76	28.89	50.23	76.63
Distillate Fuel Oil	15.97	14.23	21.04	31.02	17.75	31.77	46.65	22.43	40.72	60.49
Residual Fuel Oil	13.45	6.76	14.47	24.20	7.70	22.55	37.29	8.97	28.93	47.13
Natural Gas	9.68	9.04	9.14	9.24	12.71	12.92	13.27	17.14	17.52	17.84
Electricity	29.51	28.63	29.12	29.79	34.71	35.25	36.28	42.05	43.06	44.05
Industrial[1]										
Liquefied Petroleum Gases	20.59	17.47	25.45	37.68	20.16	36.40	56.27	24.43	45.52	72.48
Distillate Fuel Oil	16.56	14.55	21.12	30.99	18.37	32.01	46.95	23.11	40.95	60.80
Residual Fuel Oil	12.05	8.98	16.15	25.73	10.24	24.05	37.75	11.39	29.88	48.11
Natural Gas[2]	5.25	5.33	5.42	5.47	7.85	8.15	8.42	11.27	11.50	11.79
Metallurgical Coal	5.43	6.53	6.56	6.71	8.50	8.54	8.72	10.36	10.50	10.88
Other Industrial Coal	3.05	3.10	3.17	3.30	3.84	3.96	4.18	4.77	5.01	5.44
Coal to Liquids	- -	1.85	1.96	2.04	2.46	2.36	2.95	2.72	3.27	3.89
Electricity	19.79	19.05	19.30	19.67	23.55	23.79	24.40	29.39	29.88	30.36
Transportation										
Liquefied Petroleum Gases[3]	25.52	25.12	33.36	45.42	29.56	45.80	65.36	35.70	56.90	83.37
E85[4]	20.50	19.96	28.80	35.28	26.41	39.01	53.12	32.28	49.35	67.22
Motor Gasoline[5]	19.28	19.57	28.35	38.71	23.73	39.01	56.52	28.74	49.31	71.92
Jet Fuel[6]	12.59	12.92	20.76	31.55	15.40	31.16	46.85	20.25	40.35	61.65
Diesel Fuel (distillate fuel oil)[7]	17.79	18.11	24.56	34.44	22.46	35.96	51.08	27.42	45.30	65.44
Residual Fuel Oil	10.57	6.66	13.80	23.30	7.33	21.19	34.33	7.28	26.24	44.64
Natural Gas[8]	12.71	12.89	13.06	13.24	16.58	16.98	17.38	21.14	21.66	22.03
Electricity	34.92	32.63	31.83	32.42	36.73	39.01	43.59	47.82	51.66	56.39
Electric Power[9]										
Distillate Fuel Oil	14.33	10.88	18.38	28.52	13.09	28.04	42.71	16.96	36.45	55.84
Residual Fuel Oil	8.96	6.24	14.37	23.93	6.61	21.50	34.58	6.73	26.66	44.25
Natural Gas	4.82	5.04	5.10	5.17	7.35	7.62	7.88	10.50	10.86	11.11
Steam Coal	2.20	2.22	2.31	2.43	2.80	2.96	3.19	3.55	3.83	4.25

Table C3. Energy prices by sector and source (continued)

(nominal dollars per million Btu, unless otherwise noted)

Sector and Source	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Average Price to All Users[10]										
Liquefied Petroleum Gases	17.43	16.02	23.65	34.67	18.48	33.64	51.63	22.68	42.49	66.79
E85[4]	20.50	19.96	28.80	35.28	26.41	39.01	53.12	32.28	49.35	67.22
Motor Gasoline[5]	19.23	19.57	28.35	38.71	23.72	39.01	56.52	28.73	49.31	71.92
Jet Fuel	12.59	12.92	20.76	31.55	15.40	31.16	46.85	20.25	40.35	61.65
Distillate Fuel Oil	17.51	17.26	23.83	33.75	21.55	35.20	50.29	26.72	44.57	64.67
Residual Fuel Oil	10.53	6.84	14.27	23.77	7.46	21.67	34.90	7.56	26.88	45.00
Natural Gas	7.28	6.94	7.04	7.11	10.05	10.33	10.65	13.84	14.21	14.59
Metallurgical Coal	5.43	6.53	6.56	6.71	8.50	8.54	8.72	10.36	10.50	10.88
Other Coal	2.25	2.28	2.36	2.48	2.86	3.02	3.24	3.61	3.89	4.31
Coal to Liquids	- -	1.85	1.96	2.04	2.46	2.36	2.95	2.72	3.27	3.89
Electricity	28.69	27.98	28.43	29.00	34.15	34.53	35.46	42.22	42.97	43.92
Non-Renewable Energy Expenditures by Sector (billion nominal dollars)										
Residential	238.63	234.91	243.63	254.83	308.53	320.68	337.10	411.91	426.84	446.82
Commercial	174.64	179.48	185.21	192.79	253.37	262.27	274.89	355.41	368.78	384.83
Industrial	179.22	198.71	244.72	306.36	249.23	341.84	442.19	300.50	417.29	542.07
Transportation	474.91	519.66	725.73	963.65	664.79	1022.56	1320.19	885.96	1382.69	1732.75
Total Non-Renewable Expenditures	1067.41	1132.76	1399.29	1717.63	1475.92	1947.34	2374.37	1953.78	2595.61	3106.48
Transportation Renewable Expenditures	0.06	0.19	0.25	11.76	4.93	36.34	135.33	6.01	60.53	242.58
Total Expenditures	**1067.47**	**1132.95**	**1399.54**	**1729.39**	**1480.85**	**1983.68**	**2509.69**	**1959.79**	**2656.14**	**3349.05**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Excludes use for lease and plant fuel.
[3]Includes Federal and State taxes while excluding county and local taxes.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[6]Kerosene-type jet fuel. Includes Federal and State taxes while excluding county and local taxes.
[7]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[8]Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.
[9]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[10]Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.
Btu = British thermal unit.
- - = Not applicable.
Note: Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on prices in the U.S. Energy Information Administration (EIA), *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2009 residential and commercial natural gas delivered prices: EIA, *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 industrial natural gas delivered prices are estimated based on: EIA, *Manufacturing Energy Consumption Survey* and industrial and wellhead prices from the *Natural Gas Annual 2008*, DOE/EIA-0131(2008) (Washington, DC, March 2010) and the *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 transportation sector natural gas delivered prices are model results. 2009 electric power sector natural gas prices: EIA, *Electric Power Monthly*, DOE/EIA-0226, April 2009 and April 2010, Table 4.2. 2009 coal prices based on: EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010) and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. 2009 electricity prices: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. **Projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A.

Table C4. Liquid fuels supply and disposition
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Crude Oil										
Domestic Crude Production[1]	5.36	5.74	5.81	5.93	5.20	5.88	7.06	4.33	5.95	7.13
Alaska	0.65	0.49	0.49	0.49	0.41	0.41	0.79	0.19	0.39	0.48
Lower 48 States	4.71	5.25	5.32	5.44	4.79	5.47	6.27	4.14	5.56	6.65
Net Imports	8.97	9.46	8.70	7.93	10.12	8.25	5.69	11.59	8.25	4.45
Gross Imports	9.01	9.49	8.74	7.96	10.15	8.28	5.73	11.62	8.28	4.49
Exports	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	0.04
Other Crude Supply[2]	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Crude Supply	**14.33**	**15.20**	**14.52**	**13.86**	**15.32**	**14.13**	**12.75**	**15.92**	**14.20**	**11.58**
Other Petroleum Supply	**3.59**	**4.57**	**4.38**	**4.19**	**4.97**	**4.41**	**4.07**	**5.33**	**4.46**	**3.65**
Natural Gas Plant Liquids	1.91	2.24	2.23	2.25	2.65	2.68	2.74	2.89	2.94	2.90
Net Product Imports	0.75	1.26	1.14	0.92	1.29	0.81	0.46	1.40	0.64	0.06
Gross Refined Product Imports[3]	1.27	1.03	1.04	0.97	1.12	0.92	0.80	1.24	0.84	0.68
Unfinished Oil Imports	0.68	0.89	0.80	0.72	0.90	0.75	0.59	0.97	0.76	0.44
Blending Component Imports	0.72	0.82	0.81	0.77	0.86	0.80	0.74	0.92	0.83	0.75
Exports	1.91	1.47	1.50	1.54	1.59	1.67	1.66	1.73	1.80	1.81
Refinery Processing Gain[4]	0.98	1.07	1.01	1.02	1.03	0.92	0.87	1.04	0.88	0.69
Product Stock Withdrawal	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Non-petroleum Supply	**0.81**	**1.35**	**1.42**	**1.66**	**1.90**	**2.40**	**3.51**	**2.40**	**3.28**	**5.88**
Supply from Renewable Sources	0.76	1.13	1.12	1.27	1.63	1.92	2.59	2.12	2.48	3.84
Ethanol	0.73	1.06	1.03	1.13	1.37	1.60	2.19	1.46	1.83	2.74
Domestic Production	0.72	1.00	0.97	1.05	1.21	1.44	1.91	1.21	1.58	2.26
Net Imports	0.01	0.06	0.06	0.08	0.16	0.16	0.28	0.26	0.26	0.49
Biodiesel	0.02	0.06	0.08	0.12	0.11	0.12	0.13	0.12	0.13	0.14
Domestic Production	0.03	0.05	0.07	0.12	0.11	0.12	0.13	0.12	0.13	0.14
Net Imports	-0.01	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	-0.00
Other Biomass-derived Liquids[5]	0.00	0.02	0.02	0.02	0.15	0.19	0.26	0.54	0.52	0.95
Liquids from Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Liquids from Coal	0.00	0.05	0.05	0.07	0.08	0.19	0.62	0.09	0.55	1.60
Other[6]	0.05	0.17	0.25	0.32	0.19	0.30	0.31	0.18	0.25	0.36
Total Primary Supply[7]	**18.73**	**21.12**	**20.32**	**19.70**	**22.19**	**20.94**	**20.33**	**23.65**	**21.94**	**21.11**
Liquid Fuels Consumption										
by Fuel										
Liquefied Petroleum Gases	2.13	2.42	2.32	2.27	2.46	2.33	2.24	2.32	2.19	2.09
E85[8]	0.00	0.01	0.01	0.23	0.13	0.64	1.75	0.13	0.84	2.48
Motor Gasoline[9]	9.00	9.86	9.40	8.78	10.11	8.87	7.28	10.95	9.28	7.04
Jet Fuel[10]	1.39	1.55	1.55	1.54	1.69	1.68	1.67	1.76	1.75	1.74
Distillate Fuel Oil[11]	3.63	4.22	4.13	4.05	4.62	4.49	4.46	4.99	4.87	4.84
Diesel	3.18	3.73	3.68	3.63	4.17	4.09	4.09	4.57	4.51	4.50
Residual Fuel Oil	0.51	0.67	0.60	0.59	0.73	0.61	0.60	0.89	0.62	0.61
Other[12]	2.15	2.54	2.43	2.28	2.61	2.38	2.18	2.72	2.38	2.11
by Sector										
Residential and Commercial	1.04	1.02	0.95	0.89	0.98	0.88	0.81	0.96	0.85	0.78
Industrial[13]	4.25	5.20	4.99	4.77	5.31	4.94	4.67	5.27	4.77	4.43
Transportation	13.61	14.80	14.31	13.87	15.74	14.96	14.49	17.07	16.10	15.49
Electric Power[14]	0.18	0.26	0.19	0.19	0.31	0.20	0.20	0.46	0.21	0.21
Total	**18.81**	**21.28**	**20.44**	**19.73**	**22.34**	**20.99**	**20.18**	**23.76**	**21.93**	**20.91**
Discrepancy[15]	**-0.08**	**-0.16**	**-0.12**	**-0.02**	**-0.15**	**-0.04**	**0.15**	**-0.11**	**0.01**	**0.19**

Table C4. Liquid fuels supply and disposition (continued)
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Domestic Refinery Distillation Capacity[16]	17.7	17.5	17.5	17.4	16.8	16.0	14.9	17.3	15.8	14.2
Capacity Utilization Rate (percent)[17]	83.0	88.8	84.9	81.5	93.4	90.1	87.6	93.8	91.9	83.8
Net Import Share of Product Supplied (percent)	51.9	51.1	48.8	45.3	52.2	44.0	31.7	56.0	41.7	23.7
Net Expenditures for Imported Crude Oil and Petroleum Products (billion 2009 dollars)	203.65	183.33	296.22	424.15	178.54	347.74	400.15	192.05	370.10	348.26

[1]Includes lease condensate.
[2]Strategic petroleum reserve stock additions plus unaccounted for crude oil and crude stock withdrawals minus crude product supplied.
[3]Includes other hydrocarbons and alcohols.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks used for the production of green diesel and gasoline.
[6]Includes domestic sources of other blending components, other hydrocarbons, and ethers.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[9]Includes ethanol and ethers blended into gasoline.
[10]Includes only kerosene type.
[11]Includes distillate fuel oil and kerosene from petroleum and biomass feedstocks.
[12]Includes aviation gasoline, petrochemical feedstocks, lubricants, waxes, asphalt, road oil, still gas, special naphthas, petroleum coke, crude oil product supplied, methanol, and miscellaneous petroleum products.
[13]Includes consumption for combined heat and power, which produces electricity and other useful thermal energy.
[14]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[15]Balancing item. Includes unaccounted for supply, losses, and gains.
[16]End-of-year operable capacity.
[17]Rate is calculated by dividing the gross annual input to atmospheric crude oil distillation units by their operable refining capacity in barrels per calendar day.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 petroleum product supplied based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A.

Table C5. Petroleum product prices
(2009 dollars per gallon, unless otherwise noted)

Sector and Fuel	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Crude Oil Prices (2009 dollars per barrel)										
Imported Low Sulfur Light Crude Oil[1]	61.66	55.00	94.58	146.10	51.28	117.54	185.87	50.07	124.94	199.95
Imported Crude Oil[1]	59.04	48.46	86.83	136.84	41.36	107.40	175.09	39.66	113.70	187.79
Delivered Sector Product Prices										
Residential										
Liquefied Petroleum Gases	2.087	1.884	2.523	3.451	1.799	2.872	4.120	1.798	2.965	4.333
Distillate Fuel Oil	2.514	2.028	2.931	4.219	2.046	3.595	5.158	2.151	3.818	5.501
Commercial										
Distillate Fuel Oil	2.205	1.796	2.654	3.904	1.817	3.306	4.849	1.895	3.512	5.174
Residual Fuel Oil	2.013	0.927	1.984	3.311	0.857	2.552	4.216	0.824	2.714	4.384
Residual Fuel Oil (2009 dollars per barrel)	84.54	38.94	83.33	139.07	35.99	107.19	177.07	34.60	113.99	184.12
Industrial[2]										
Liquefied Petroleum Gases	1.744	1.357	1.975	2.917	1.270	2.331	3.599	1.270	2.416	3.815
Distillate Fuel Oil	2.281	1.831	2.656	3.889	1.876	3.322	4.867	1.947	3.523	5.187
Residual Fuel Oil	1.804	1.233	2.215	3.520	1.140	2.722	4.267	1.046	2.803	4.475
Residual Fuel Oil (2009 dollars per barrel)	75.79	51.78	93.04	147.85	47.89	114.34	179.22	43.94	117.73	187.97
Transportation										
Liquefied Petroleum Gases	2.161	1.951	2.589	3.517	1.863	2.933	4.181	1.856	3.021	4.388
Ethanol (E85)[3]	1.945	1.736	2.503	3.060	1.863	2.798	3.806	1.880	2.934	3.963
Ethanol Wholesale Price	2.028	2.345	2.448	2.689	2.230	2.369	2.645	2.013	2.073	2.698
Motor Gasoline[4]	2.349	2.167	3.134	4.271	2.118	3.539	5.123	2.117	3.707	5.362
Jet Fuel[5]	1.700	1.599	2.568	3.894	1.546	3.181	4.777	1.678	3.413	5.172
Diesel Fuel (distillate fuel oil)[6]	2.441	2.275	3.084	4.314	2.289	3.726	5.286	2.306	3.890	5.573
Residual Fuel Oil	1.582	0.914	1.893	3.188	0.816	2.398	3.881	0.669	2.461	4.152
Residual Fuel Oil (2009 dollars per barrel)	66.44	38.38	79.51	133.90	34.28	100.70	163.02	28.10	103.37	174.39
Electric Power[7]										
Distillate Fuel Oil	1.988	1.383	2.336	3.615	1.350	2.940	4.474	1.444	3.168	4.812
Residual Fuel Oil	1.342	0.856	1.971	3.274	0.735	2.433	3.909	0.618	2.501	4.116
Residual Fuel Oil (2009 dollars per barrel)	56.36	35.97	82.79	137.52	30.89	102.20	164.18	25.96	105.03	172.86
Refined Petroleum Product Prices[8]										
Liquefied Petroleum Gases	1.477	1.244	1.836	2.684	1.164	2.154	3.303	1.179	2.255	3.516
Motor Gasoline[4]	2.344	2.167	3.134	4.271	2.118	3.539	5.123	2.117	3.707	5.362
Jet Fuel[5]	1.700	1.599	2.568	3.894	1.546	3.181	4.777	1.678	3.413	5.172
Distillate Fuel Oil	2.408	2.171	2.995	4.233	2.199	3.651	5.210	2.250	3.831	5.511
Residual Fuel Oil	1.576	0.938	1.957	3.253	0.830	2.453	3.946	0.695	2.522	4.186
Residual Fuel Oil (2009 dollars per barrel)	66.20	39.40	82.19	136.61	34.88	103.03	165.72	29.18	105.92	175.81
Average	**2.155**	**1.933**	**2.822**	**3.956**	**1.894**	**3.289**	**4.783**	**1.920**	**3.478**	**5.072**

Table C5. Petroleum product prices (continued)

(2009 dollars per gallon, unless otherwise noted)

Sector and Fuel	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Crude Oil Prices (nominal dollars per barrel)										
Imported Low Sulfur Light Crude Oil[1]	61.66	59.99	103.24	159.83	68.94	155.46	246.11	81.59	199.37	321.76
Imported Crude Oil[1]	59.04	52.86	94.78	149.70	55.61	142.05	231.84	64.62	181.43	302.20
Delivered Sector Product Prices										
Residential										
Liquefied Petroleum Gases	2.087	2.054	2.754	3.775	2.419	3.798	5.455	2.929	4.732	6.972
Distillate Fuel Oil	2.514	2.212	3.200	4.615	2.751	4.754	6.830	3.505	6.092	8.852
Commercial										
Distillate Fuel Oil	2.205	1.959	2.897	4.270	2.443	4.373	6.420	3.087	5.605	8.326
Residual Fuel Oil	2.013	1.011	2.166	3.622	1.152	3.376	5.583	1.342	4.331	7.055
Industrial[2]										
Liquefied Petroleum Gases	1.744	1.480	2.155	3.191	1.707	3.083	4.766	2.070	3.855	6.140
Distillate Fuel Oil	2.281	1.997	2.899	4.254	2.522	4.394	6.445	3.172	5.621	8.346
Residual Fuel Oil	1.804	1.345	2.418	3.851	1.533	3.601	5.650	1.705	4.473	7.202
Transportation										
Liquefied Petroleum Gases	2.161	2.128	2.826	3.847	2.504	3.879	5.536	3.024	4.820	7.062
Ethanol (E85)[3]	1.945	1.893	2.732	3.348	2.505	3.701	5.040	3.063	4.682	6.378
Ethanol Wholesale Price	2.028	2.557	2.672	2.942	2.998	3.133	3.502	3.279	3.308	4.342
Motor Gasoline[4]	2.349	2.363	3.421	4.672	2.847	4.681	6.784	3.449	5.915	8.629
Jet Fuel[5]	1.700	1.744	2.803	4.260	2.079	4.207	6.325	2.734	5.447	8.323
Diesel Fuel (distillate fuel oil)[6]	2.441	2.481	3.366	4.719	3.077	4.928	7.000	3.758	6.207	8.968
Residual Fuel Oil	1.582	0.997	2.066	3.488	1.097	3.171	5.139	1.090	3.928	6.682
Electric Power[7]										
Distillate Fuel Oil	1.988	1.508	2.550	3.955	1.815	3.889	5.924	2.352	5.055	7.744
Residual Fuel Oil	1.342	0.934	2.152	3.582	0.989	3.219	5.176	1.007	3.990	6.623
Refined Petroleum Product Prices[8]										
Liquefied Petroleum Gases	1.477	1.357	2.004	2.937	1.565	2.849	4.373	1.921	3.599	5.657
Motor Gasoline[4]	2.344	2.363	3.421	4.672	2.847	4.681	6.784	3.449	5.915	8.629
Jet Fuel[5]	1.700	1.744	2.803	4.260	2.079	4.207	6.325	2.734	5.447	8.323
Distillate Fuel Oil	2.408	2.368	3.269	4.631	2.957	4.829	6.899	3.666	6.113	8.869
Residual Fuel Oil (nominal dollars per barrel)	66.20	42.97	89.71	149.44	46.89	136.27	219.43	47.55	169.02	282.92
Average	**2.155**	**2.108**	**3.080**	**4.328**	**2.547**	**4.350**	**6.333**	**3.128**	**5.550**	**8.162**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[3]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[4]Sales weighted-average price for all grades. Includes Federal, State and local taxes.
[5]Includes only kerosene type.
[6]Diesel fuel for on-road use. Includes Federal and State taxes while excluding county and local taxes.
[7]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[8]Weighted averages of end-use fuel prices are derived from the prices in each sector and the corresponding sectoral consumption.
Note: Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 imported low sulfur light crude oil price: U.S. Energy Information Administration (EIA), Form EIA-856, “Monthly Foreign Crude Oil Acquisition Report.” 2009 imported crude oil price: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 prices for motor gasoline, distillate fuel oil, and jet fuel are based on: EIA, *Petroleum Marketing Annual 2009*, DOE/EIA-0487(2009) (Washington, DC, August 2010). 2009 residential, commercial, industrial, and transportation sector petroleum product prices are derived from: EIA, Form EIA-782A, “Refiners’/Gas Plant Operators’ Monthly Petroleum Product Sales Report.” 2009 electric power prices based on: Federal Energy Regulatory Commission, FERC Form 423, “Monthly Report of Cost and Quality of Fuels for Electric Plants.” 2009 E85 prices derived from monthly prices in the Clean Cities Alternative Fuel Price Report. 2009 wholesale ethanol prices derived from Bloomberg U.S. average rack price. **Projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A.

Table C6. International liquids supply and disposition summary
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Crude Oil Prices (2009 dollars per barrel)[1]										
Imported Low Sulfur Light Crude Oil Price	61.66	55.00	94.58	146.10	51.28	117.54	185.87	50.07	124.94	199.95
Imported Crude Oil Price	59.04	48.46	86.83	136.84	41.36	107.40	175.09	39.66	113.70	187.79
Crude Oil Prices (nominal dollars per barrel)[1]										
Imported Low Sulfur Light Crude Oil Price	61.66	59.99	103.24	159.83	68.94	155.46	246.11	81.59	199.37	321.76
Imported Crude Oil Price	59.04	52.86	94.78	149.70	55.61	142.05	231.84	64.62	181.43	302.20
Conventional Production (Conventional)[2]										
OPEC[3]										
Middle East	22.61	28.19	25.66	23.16	31.81	28.64	27.48	34.74	33.87	30.24
North Africa	3.92	4.70	4.32	3.83	4.15	3.84	3.72	3.94	3.98	3.70
West Africa	4.06	5.80	5.10	4.44	6.54	5.10	4.90	6.81	5.31	4.86
South America	2.31	2.18	2.00	1.77	1.86	1.73	1.68	1.62	1.64	1.54
Total OPEC	**32.91**	**40.87**	**37.08**	**33.20**	**44.35**	**39.32**	**37.78**	**47.10**	**44.80**	**40.33**
Non-OPEC										
OECD										
United States (50 states)	8.26	9.22	9.30	9.52	9.07	9.78	10.89	8.45	9.89	10.70
Canada	1.96	1.83	1.80	1.82	1.78	1.78	1.84	1.71	1.78	1.94
Mexico	2.90	2.17	2.05	2.00	1.35	1.22	1.19	1.50	1.48	1.52
OECD Europe[4]	4.62	3.49	3.36	3.30	2.73	2.67	2.61	2.48	2.66	2.73
Japan	0.13	0.14	0.14	0.13	0.15	0.14	0.14	0.16	0.15	0.14
Australia and New Zealand	0.65	0.58	0.56	0.55	0.53	0.52	0.51	0.49	0.54	0.55
Total OECD	**18.52**	**17.43**	**17.20**	**17.33**	**15.62**	**16.13**	**17.18**	**14.79**	**16.49**	**17.59**
Non-OECD										
Russia	9.66	10.71	10.02	9.74	12.43	10.86	10.41	12.90	12.64	13.15
Other Europe and Eurasia[5]	3.08	3.77	3.54	3.44	4.47	3.97	3.81	4.48	4.47	4.64
China	3.93	3.96	3.80	3.72	4.10	4.02	3.89	3.83	4.22	4.40
Other Asia[6]	3.70	3.59	3.47	3.41	3.03	2.99	2.91	2.63	2.85	2.94
Middle East	1.54	1.63	1.57	1.54	1.26	1.24	1.20	0.98	1.10	1.15
Africa	2.34	2.82	2.71	2.65	2.89	2.85	2.75	2.82	3.16	3.32
Brazil	2.05	2.95	2.76	2.68	4.41	3.87	3.72	5.02	4.93	5.11
Other Central and South America	1.87	2.17	2.10	2.06	2.27	2.24	2.17	2.35	2.59	2.70
Total Non-OECD	**28.17**	**31.60**	**29.96**	**29.24**	**34.86**	**32.03**	**30.85**	**35.00**	**35.95**	**37.41**
Total Conventional Production	**79.60**	**89.89**	**84.24**	**79.76**	**94.83**	**87.47**	**85.81**	**96.89**	**97.24**	**95.33**
Unconventional Production[7]										
United States (50 states)	0.75	1.11	1.11	1.26	1.55	1.94	3.01	1.95	2.90	5.42
Other North America	1.68	2.21	2.39	3.68	2.70	3.57	5.38	3.32	5.27	7.11
OECD Europe[3]	0.22	0.10	0.23	0.22	0.11	0.26	0.29	0.18	0.28	0.33
Middle East	0.01	0.14	0.17	0.14	0.19	0.24	0.21	0.19	0.24	0.21
Africa.	0.21	0.16	0.28	0.28	0.16	0.39	0.40	0.16	0.44	0.46
Central and South America	1.14	1.82	1.78	1.86	3.28	2.61	2.98	4.70	3.17	3.60
Other	0.12	0.08	0.17	0.17	0.25	0.64	0.88	0.50	1.22	2.61
Total Unconventional Production	**4.14**	**5.63**	**6.13**	**7.61**	**8.23**	**9.66**	**13.15**	**11.00**	**13.54**	**19.72**
Total Production	**83.74**	**95.52**	**90.37**	**87.38**	**103.06**	**97.13**	**98.96**	**107.90**	**110.78**	**115.06**

Table C6. International liquids supply and disposition summary (continued)
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	Projections								
		2015			2025			2035		
		Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price	Low Oil Price	Reference	High Oil Price
Consumption[8]										
OECD										
United States (50 states)	18.81	21.28	20.44	19.73	22.34	20.99	20.18	23.76	21.93	20.91
United States Territories	0.27	0.32	0.31	0.30	0.30	0.30	0.32	0.28	0.32	0.36
Canada	2.15	2.40	2.24	2.13	2.48	2.14	2.01	2.64	2.24	2.08
Mexico	2.13	2.29	2.17	2.09	2.57	2.30	2.20	3.02	2.63	2.51
OECD Europe[3]	14.49	14.47	13.55	12.95	14.61	12.82	12.14	14.91	12.95	12.11
Japan	4.37	4.47	4.18	4.03	4.49	3.98	3.75	4.37	3.88	3.55
South Korea	2.32	2.59	2.44	2.34	3.01	2.63	2.54	3.45	3.13	2.89
Australia and New Zealand	1.19	1.25	1.18	1.14	1.26	1.13	1.08	1.30	1.17	1.10
Total OECD	**45.73**	**49.07**	**46.50**	**44.70**	**51.06**	**46.29**	**44.23**	**53.72**	**48.25**	**45.51**
Non-OECD										
Russia	2.83	3.05	2.90	2.80	2.73	2.66	2.71	2.59	2.78	3.01
Other Europe and Eurasia[5]	2.16	2.43	2.25	2.18	2.41	2.25	2.36	2.33	2.48	2.70
China	8.32	11.99	11.10	10.80	15.60	14.36	15.97	16.50	19.13	20.68
India	3.06	3.97	3.68	3.55	4.80	4.54	4.82	4.96	5.64	6.12
Other Asia	6.13	7.11	6.72	6.51	8.01	7.98	8.46	8.69	9.75	10.94
Middle East	6.64	7.69	7.47	7.38	8.27	8.76	9.50	9.01	11.02	12.81
Africa	3.31	3.71	3.50	3.39	3.82	3.76	3.97	3.96	4.45	4.94
Brazil	2.46	2.96	2.82	2.74	3.10	3.20	3.42	3.16	3.79	4.40
Other Central and South America	3.09	3.55	3.41	3.33	3.27	3.33	3.52	3.00	3.51	3.94
Total Non-OECD	**38.01**	**46.45**	**43.87**	**42.67**	**52.00**	**50.84**	**54.73**	**54.20**	**62.54**	**69.54**
Total Consumption	**83.74**	**95.52**	**90.37**	**87.38**	**103.06**	**97.13**	**98.95**	**107.92**	**110.79**	**115.06**
OPEC Production[9]	33.45	42.41	38.08	34.29	47.25	40.77	39.34	50.88	46.50	42.14
Non-OPEC Production[9]	50.29	53.11	52.30	53.09	55.81	56.37	59.62	57.02	64.28	72.92
Net Eurasia Exports	9.80	11.95	11.16	10.90	16.17	13.80	12.87	17.48	16.78	17.18
OPEC Market Share (percent)	39.9	44.4	42.1	39.2	45.8	42.0	39.8	47.2	42.0	36.6

[1]Weighted average price delivered to U.S. refiners.
[2]Includes production of crude oil (including lease condensate), natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol and other sources, and refinery gains.
[3]OPEC = Organization of Petroleum Exporting Countries - Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.
[4]OECD Europe = Organization for Economic Cooperation and Development - Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.
[5]Other Europe and Eurasia = Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Malta, Moldova, Montenegro, Romania, Serbia, Slovenia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
[6]Other Asia = Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia (Kampuchea), Fiji, French Polynesia, Guam, Hong Kong, Indonesia, Kiribati, Laos, Malaysia, Macau, Maldives, Mongolia, Myanmar (Burma), Nauru, Nepal, New Caledonia, Niue, North Korea, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand, Tonga, Vanuatu, and Vietnam.
[7]Includes liquids produced from energy crops, natural gas, coal, extra-heavy oil, oil sands, and shale. Includes both OPEC and non-OPEC producers in the regional breakdown.
[8]Includes both OPEC and non-OPEC consumers in the regional breakdown.
[9]Includes both conventional and unconventional liquids production.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 low sulfur light crude oil price: U.S. Energy Information Administration (EIA), Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." 2009 imported crude oil price: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **2009 quantities and projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, REF2011.D020911A, and HP2011HNO.D022511A and EIA, Generate World Oil Balance Model.

Appendix D

Results from side cases

Table D1. Key results for residential and commercial sector technology cases

Energy Consumption	2009	2015 2010 Technology	2015 Reference	2015 High Technology	2015 Best Available Technology	2025 2010 Technology	2025 Reference	2025 High Technology	2025 Best Available Technology
Residential									
Energy Consumption									
(quadrillion Btu)									
Liquefied Petroleum Gases	0.53	0.50	0.49	0.48	0.48	0.49	0.48	0.45	0.45
Kerosene	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Distillate Fuel Oil	0.61	0.57	0.56	0.55	0.52	0.48	0.44	0.41	0.37
Liquid Fuels and Other Petroleum	1.16	1.09	1.07	1.05	1.02	0.99	0.94	0.88	0.83
Natural Gas	4.87	5.00	4.94	4.79	4.57	5.23	4.96	4.62	4.18
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Renewable Energy[1]	0.43	0.41	0.40	0.40	0.38	0.46	0.42	0.40	0.36
Electricity	4.65	4.69	4.60	4.26	4.02	5.27	4.98	4.42	3.96
Delivered Energy	**11.12**	**11.19**	**11.02**	**10.50**	**10.00**	**11.96**	**11.32**	**10.32**	**9.34**
Electricity Related Losses	9.96	9.64	9.46	8.75	8.27	10.83	10.24	9.07	8.14
Total	**21.08**	**20.83**	**20.48**	**19.25**	**18.27**	**22.79**	**21.56**	**19.39**	**17.48**
Delivered Energy Intensity									
(million Btu per household)	**98.0**	**92.2**	**90.8**	**86.5**	**82.4**	**88.7**	**83.9**	**76.5**	**69.3**
Nonmarketed Renewables									
Consumption (quadrillion Btu)	**0.01**	**0.07**	**0.07**	**0.07**	**0.08**	**0.10**	**0.09**	**0.10**	**0.11**
Commercial									
Energy Consumption									
(quadrillion Btu)									
Liquefied Petroleum Gases	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Motor Gasoline[2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Kerosene	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Distillate Fuel Oil	0.34	0.28	0.28	0.28	0.28	0.26	0.26	0.25	0.25
Residual Fuel Oil	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
Liquid Fuels and Other Petroleum	0.60	0.55	0.55	0.54	0.54	0.53	0.53	0.52	0.52
Natural Gas	3.20	3.47	3.47	3.35	3.34	3.68	3.66	3.42	3.41
Coal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Renewable Energy[3]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Electricity	4.51	4.90	4.83	4.60	4.41	5.83	5.58	4.93	4.47
Delivered Energy	**8.49**	**9.10**	**9.02**	**8.67**	**8.47**	**10.21**	**9.94**	**9.05**	**8.58**
Electricity Related Losses	9.66	10.08	9.94	9.46	9.07	11.97	11.47	10.13	9.19
Total	**18.15**	**19.18**	**18.96**	**18.13**	**17.54**	**22.18**	**21.41**	**19.18**	**17.77**
Delivered Energy Intensity									
(thousand Btu per square foot)	**105.9**	**106.5**	**105.6**	**101.4**	**99.1**	**104.9**	**102.1**	**92.9**	**88.1**
Commercial Sector Generation									
Net Summer Generation Capacity									
(megawatts)									
Natural Gas	653	781	809	842	842	1257	1702	2166	2263
Solar Photovoltaic	693	908	910	914	923	1159	1163	1355	1819
Wind	79	84	85	85	100	89	113	118	170
Electricity Generation									
(billion kilowatthours)									
Natural Gas	4.70	5.63	5.84	6.08	6.08	9.10	12.33	15.71	16.42
Solar Photovoltaic	1.09	1.44	1.45	1.46	1.47	1.84	1.88	2.20	2.96
Wind	0.10	0.11	0.11	0.11	0.13	0.11	0.15	0.16	0.23
Nonmarketed Renewables									
Consumption (quadrillion Btu)	**0.03**	**0.03**	**0.03**	**0.05**	**0.05**	**0.04**	**0.04**	**0.07**	**0.07**

[1]Includes wood used for residential heating. See Table A4 and/or Table A17 for estimates of nonmarketed renewable energy consumption for geothermal heat pumps, solar thermal hot water heating, and solar photovoltaic electricity generation.
[2]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[3]Includes commercial sector consumption of wood and wood waste, landfill gas, municipal solid waste, and other biomass for combined heat and power.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports. Side cases were run without the fully integrated modeling system, so not all feedbacks are captured. The reference case ratio of electricity losses to electricity use was used to compute electricity losses for the technology cases.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System, runs BLDFRZN.D021011A, REF2011.D020911A, BLDHIGH.D021011A, and BLDBEST.D021011A.

2035				Annual Growth 2009-2035 (percent)			
2010 Technology	Reference	High Technology	Best Available Technology	2010 Technology	Reference	High Technology	Best Available Technology
0.50	0.48	0.45	0.44	-0.2%	-0.4%	-0.6%	-0.7%
0.02	0.02	0.01	0.01	-1.0%	-1.5%	-2.1%	-2.4%
0.43	0.37	0.32	0.27	-1.4%	-1.9%	-2.4%	-3.0%
0.94	0.86	0.79	0.73	-0.8%	-1.1%	-1.5%	-1.8%
5.34	4.90	4.48	3.98	0.4%	0.0%	-0.3%	-0.8%
0.01	0.01	0.00	0.00	-0.5%	-1.1%	-1.4%	-1.8%
0.48	0.42	0.38	0.33	0.4%	-0.1%	-0.5%	-1.0%
5.96	5.51	4.85	4.25	1.0%	0.7%	0.2%	-0.3%
12.74	**11.70**	**10.51**	**9.29**	**0.5%**	**0.2%**	**-0.2%**	**-0.7%**
11.99	11.06	9.76	8.54	0.7%	0.4%	-0.1%	-0.6%
24.72	**22.76**	**20.26**	**17.83**	**0.6%**	**0.3%**	**-0.2%**	**-0.6%**
86.7	**79.7**	**71.5**	**63.2**	**-0.5%**	**-0.8%**	**-1.2%**	**-1.7%**
0.13	**0.11**	**0.13**	**0.16**	**9.0%**	**8.3%**	**9.0%**	**10.0%**
0.16	0.16	0.16	0.16	0.2%	0.2%	0.2%	0.2%
0.05	0.05	0.05	0.05	0.3%	0.3%	0.3%	0.3%
0.01	0.01	0.01	0.01	2.8%	2.8%	2.8%	2.8%
0.25	0.25	0.23	0.23	-1.2%	-1.2%	-1.4%	-1.4%
0.07	0.07	0.07	0.07	0.3%	0.3%	0.3%	0.3%
0.53	0.53	0.52	0.52	-0.5%	-0.5%	-0.6%	-0.6%
3.91	3.92	3.62	3.63	0.8%	0.8%	0.5%	0.5%
0.06	0.06	0.06	0.06	0.0%	0.0%	0.0%	0.0%
0.11	0.11	0.11	0.11	0.0%	0.0%	0.0%	0.0%
6.87	6.43	5.36	4.75	1.6%	1.4%	0.7%	0.2%
11.48	**11.05**	**9.67**	**9.07**	**1.2%**	**1.0%**	**0.5%**	**0.3%**
13.80	12.93	10.77	9.54	1.4%	1.1%	0.4%	-0.0%
25.28	**23.98**	**20.43**	**18.61**	**1.3%**	**1.1%**	**0.5%**	**0.1%**
104.6	**100.7**	**88.0**	**82.6**	**-0.0%**	**-0.2%**	**-0.7%**	**-0.9%**
2157	4361	5970	6187	4.7%	7.6%	8.9%	9.0%
1564	1789	2895	5943	3.2%	3.7%	5.7%	8.6%
131	240	260	335	2.0%	4.4%	4.7%	5.7%
15.64	31.68	43.39	44.96	4.7%	7.6%	8.9%	9.1%
2.47	2.93	4.74	9.74	3.2%	3.9%	5.8%	8.8%
0.18	0.34	0.37	0.47	2.2%	4.8%	5.1%	6.1%
0.04	**0.04**	**0.10**	**0.12**	**1.0%**	**1.3%**	**4.8%**	**5.5%**

Table D2. Key results for industrial sector technology cases

Consumption and Indicators	2009	2015			2025			2035		
		2010 Technology	Reference	High Technology	2010 Technology	Reference	High Technology	2010 Technology	Reference	High Technology
Value of Shipments (billion 2005 dollars)										
Manufacturing	4197	5279	5279	5279	6016	6016	6016	6770	6770	6770
Nonmanufacturing	1821	2193	2193	2193	2381	2381	2381	2521	2521	2521
Total	**6017**	**7472**	**7472**	**7472**	**8396**	**8396**	**8396**	**9292**	**9292**	**9292**
Energy Consumption excluding Refining[1] (quadrillion Btu)										
Liquefied Petroleum Gases	2.00	2.33	2.32	2.29	2.36	2.34	2.25	2.17	2.14	2.00
Heat and Power	0.21	0.26	0.25	0.25	0.26	0.25	0.24	0.26	0.24	0.22
Feedstocks	1.79	2.07	2.07	2.04	2.10	2.09	2.01	1.91	1.90	1.78
Motor Gasoline	0.25	0.34	0.33	0.32	0.37	0.33	0.30	0.38	0.32	0.28
Distillate Fuel Oil	1.16	1.19	1.16	1.13	1.27	1.16	1.07	1.32	1.13	0.99
Residual Fuel Oil	0.16	0.18	0.17	0.17	0.18	0.17	0.16	0.18	0.16	0.15
Petrochemical Feedstocks	0.90	1.29	1.29	1.27	1.34	1.34	1.28	1.26	1.26	1.17
Petroleum Coke	0.28	0.23	0.22	0.21	0.24	0.21	0.19	0.26	0.20	0.17
Asphalt and Road Oil	0.87	1.17	1.08	1.00	1.27	1.01	0.82	1.32	0.94	0.70
Miscellaneous Petroleum[2]	0.27	0.36	0.36	0.34	0.37	0.35	0.32	0.34	0.31	0.26
Petroleum Subtotal	5.88	7.10	6.93	6.74	7.40	6.90	6.38	7.22	6.46	5.72
Natural Gas Heat and Power	4.43	6.55	6.24	6.36	7.16	6.30	6.62	7.28	6.29	6.63
Natural Gas Feedstocks	0.55	0.61	0.61	0.60	0.57	0.56	0.54	0.47	0.47	0.43
Lease and Plant Fuel[3]	1.19	1.24	1.24	1.24	1.22	1.22	1.22	1.28	1.28	1.28
Natural Gas Subtotal	6.16	8.39	8.09	8.19	8.95	8.08	8.38	9.04	8.04	8.34
Metallurgical Coal and Coke[4]	0.38	0.62	0.59	0.56	0.63	0.56	0.47	0.56	0.47	0.37
Other Industrial Coal	0.88	0.94	0.92	0.92	0.97	0.91	0.90	0.95	0.88	0.86
Coal Subtotal	1.26	1.56	1.51	1.48	1.60	1.47	1.37	1.51	1.35	1.23
Renewables[5]	1.42	1.87	1.89	1.92	1.99	2.05	2.15	1.94	2.04	2.21
Purchased Electricity	2.82	3.40	3.37	3.27	3.44	3.34	3.03	3.37	3.09	2.71
Delivered Energy	**17.55**	**22.33**	**21.79**	**21.59**	**23.38**	**21.84**	**21.31**	**23.08**	**20.98**	**20.22**
Electricity Related Losses	6.04	7.00	6.93	6.72	7.07	6.86	6.23	6.77	6.20	5.46
Total	**23.59**	**29.33**	**28.73**	**28.31**	**30.45**	**28.70**	**27.54**	**29.85**	**27.19**	**25.67**
Delivered Energy Use per Dollar of Shipments (thousand Btu per 2005 dollar)	**3.63**	**3.65**	**3.58**	**3.55**	**3.53**	**3.35**	**3.28**	**3.33**	**3.11**	**3.03**
Onsite Industrial Combined Heat and Power										
Capacity (gigawatts)	23.07	33.91	32.07	35.95	42.07	37.14	48.54	45.61	43.77	57.17
Generation (billion kilowatthours)	123.62	201.42	186.37	215.73	262.97	222.04	308.82	290.17	271.90	373.87

[1]Fuel consumption includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes lubricants and miscellaneous petroleum products.
[3]Represents natural gas used in the field gathering and processing plant machinery.
[4]Includes net coal coke imports.
[5]Includes consumption of energy from hydroelectric, wood and wood waste, municipal solid waste, and other biomass.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports. Side cases were run without the fully integrated modeling system, so not all feedbacks are captured. The reference case ratio of electricity losses to electricity use was used to compute electricity losses for the technology cases.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs INDFRZN.D021011A, REF2011.D020911A, and INDHIGH.D021011A.

Table D3. Key results for transportation sector technology cases

Consumption and Indicators	2009	2015			2025			2035		
		Low Technology	Reference	High Technology	Low Technology	Reference	High Technology	Low Technology	Reference	High Technology
Level of Travel										
(billion vehicle miles traveled)										
Light-Duty Vehicles less than 8,500	2707	2946	2947	2949	3462	3467	3475	4036	4043	4056
Commercial Light Trucks[1]	67	81	81	81	92	92	92	104	104	105
Freight Trucks greater than 10,000	207	250	250	250	291	291	291	335	335	335
(billion seat miles available)										
Air	960	1059	1059	1059	1180	1180	1180	1282	1282	1282
(billion ton miles traveled)										
Rail	1677	1886	1886	1886	2143	2143	2143	2328	2328	2328
Domestic Shipping	486	521	521	521	559	559	559	596	596	596
Energy Efficiency Indicators										
(miles per gallon)										
Tested New Light-Duty Vehicle[2]	28.0	30.4	31.3	31.6	35.0	35.3	36.5	35.8	36.5	37.9
New Car[2]	32.7	35.5	36.5	37.2	39.7	40.0	41.6	40.1	40.8	42.7
New Light Truck[2]	24.3	25.9	26.6	26.9	29.0	29.6	30.4	29.5	30.6	31.7
Light-Duty Stock[3]	20.8	21.9	22.1	22.2	25.4	25.7	26.2	27.5	27.9	28.8
New Commercial Light Truck[1]	15.6	16.1	16.4	16.5	17.6	17.9	18.2	17.5	18.1	18.5
Stock Commercial Light Truck[1]	14.4	15.2	15.2	15.3	17.0	17.2	17.4	17.5	18.0	18.3
Freight Truck	6.1	6.0	6.1	6.2	6.1	6.4	6.6	6.3	6.6	6.9
(seat miles per gallon)										
Aircraft	62.0	62.8	62.8	63.0	64.8	65.6	66.7	67.7	69.9	71.7
(ton miles per thousand Btu)										
Rail	3.3	3.3	3.3	3.3	3.3	3.3	3.4	3.3	3.4	3.5
Domestic Shipping	2.4	2.4	2.4	2.4	2.4	2.5	2.5	2.4	2.5	2.6
Energy Use (quadrillion Btu)										
by Mode										
Light-Duty Vehicles	16.13	16.44	16.36	16.25	16.56	16.40	16.10	17.89	17.66	17.14
Commercial Light Trucks[1]	0.58	0.66	0.66	0.66	0.68	0.67	0.66	0.75	0.73	0.71
Bus Transportation	0.27	0.28	0.28	0.28	0.30	0.30	0.30	0.33	0.33	0.33
Freight Trucks	4.26	5.21	5.11	5.02	5.96	5.73	5.52	6.67	6.35	6.06
Rail, Passenger	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07
Rail, Freight	0.51	0.57	0.57	0.57	0.65	0.64	0.63	0.71	0.69	0.67
Shipping, Domestic	0.20	0.22	0.22	0.21	0.23	0.23	0.22	0.25	0.24	0.23
Shipping, International	0.78	0.79	0.78	0.78	0.80	0.79	0.79	0.81	0.80	0.80
Recreational Boats	0.26	0.27	0.27	0.27	0.29	0.29	0.29	0.31	0.31	0.31
Air	2.66	2.71	2.71	2.70	2.99	2.95	2.91	3.17	3.07	3.00
Military Use	0.75	0.69	0.69	0.69	0.72	0.72	0.72	0.76	0.76	0.76
Lubricants	0.13	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13
Pipeline Fuel	0.65	0.67	0.67	0.67	0.64	0.64	0.64	0.67	0.67	0.67
Total	**27.23**	**28.68**	**28.50**	**28.28**	**30.01**	**29.55**	**28.98**	**32.50**	**31.80**	**30.86**
by Fuel										
Liquefied Petroleum Gases	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
E85[4]	0.00	0.01	0.01	0.01	0.95	0.93	0.94	1.25	1.23	1.30
Motor Gasoline[5]	16.82	17.09	17.02	16.91	16.06	15.93	15.66	16.86	16.69	16.21
Jet Fuel[6]	3.20	3.20	3.20	3.19	3.50	3.47	3.43	3.71	3.62	3.54
Distillate Fuel Oil[7]	5.54	6.68	6.57	6.47	7.69	7.45	7.19	8.68	8.35	7.92
Residual Fuel Oil	0.78	0.80	0.79	0.79	0.81	0.81	0.80	0.83	0.82	0.81
Other Petroleum[8]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Liquid Fuels and Other Petroleum	26.52	27.95	27.76	27.54	29.19	28.76	28.19	31.52	30.89	29.97
Pipeline Fuel Natural Gas	0.65	0.67	0.67	0.67	0.64	0.64	0.64	0.67	0.67	0.67
Compressed Natural Gas	0.03	0.04	0.04	0.04	0.14	0.10	0.10	0.23	0.16	0.16
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.08	0.07	0.07
Delivered Energy	**27.23**	**28.68**	**28.50**	**28.28**	**30.01**	**29.56**	**28.98**	**32.50**	**31.80**	**30.87**
Electricity Related Losses	0.05	0.06	0.06	0.06	0.09	0.09	0.09	0.16	0.15	0.14
Total	**27.28**	**28.74**	**28.56**	**28.34**	**30.10**	**29.65**	**29.07**	**32.66**	**31.95**	**31.01**

[1]Commercial trucks 8,500 to 10,000 pounds.
[2]Environmental Protection Agency rated miles per gallon.
[3]Combined car and light truck "on-the-road" estimate.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[6]Includes only kerosene type.
[7]Diesel fuel for on- and off- road use.
[8]Includes aviation gasoline and lubricants.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports. Side cases were run without the fully integrated modeling system, so not all feedbacks are captured. The reference case ratio of electricity losses to electricity use was used to compute electricity losses for the technology cases.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs TRNLOW.D021011A, REF2011.D020911A, and TRNHIGH.D021011A.

Table D4. Key results for integrated technology cases

Consumption and Emissions	2009	2015			2025			2035		
		Low Technology	Reference	High Technology	Low Technology	Reference	High Technology	Low Technology	Reference	High Technology
Energy Consumption by Sector (quadrillion Btu)										
Residential	11.12	11.18	11.02	10.52	11.91	11.32	10.37	12.67	11.70	10.63
Commercial	8.49	9.08	9.02	8.73	10.13	9.94	9.14	11.36	11.05	9.83
Industrial[1]	21.85	26.75	26.75	26.81	27.47	28.11	28.45	28.07	28.89	29.92
Transportation	27.23	28.70	28.50	28.25	29.94	29.56	28.98	32.46	31.80	30.85
Electric Power[2]	38.31	40.15	39.73	38.15	44.46	43.17	39.74	47.68	46.03	41.72
Total	**94.79**	**102.71**	**102.02**	**100.00**	**109.35**	**107.95**	**103.68**	**116.23**	**114.19**	**109.15**
Energy Consumption by Fuel (quadrillion Btu)										
Liquid Fuels and Other Petroleum[3]	36.62	39.33	39.10	38.81	40.27	39.84	39.16	42.33	41.70	40.60
Natural Gas	23.31	25.97	25.77	24.94	26.52	25.73	24.05	28.94	27.24	24.85
Coal	19.69	19.91	19.73	18.72	22.98	22.61	21.01	24.43	24.30	22.27
Nuclear Power	8.35	8.77	8.77	8.77	9.17	9.17	8.54	9.14	9.14	8.60
Renewable Energy[4]	6.51	8.41	8.34	8.45	10.14	10.33	10.66	11.15	11.56	12.59
Other[5]	0.32	0.31	0.31	0.31	0.28	0.27	0.27	0.25	0.25	0.23
Total	**94.79**	**102.71**	**102.02**	**100.00**	**109.35**	**107.95**	**103.68**	**116.23**	**114.19**	**109.15**
Energy Intensity (thousand Btu per 2005 dollar of GDP)	**7.36**	**6.70**	**6.65**	**6.53**	**5.47**	**5.39**	**5.18**	**4.52**	**4.44**	**4.25**
Carbon Dioxide Emissions by Sector (million metric tons)										
Residential	343	340	336	328	345	328	307	348	319	293
Commercial	218	229	229	224	236	237	227	248	251	237
Industrial[1]	854	1063	1061	1058	1084	1080	1076	1150	1147	1136
Transportation	1850	1930	1916	1898	1980	1932	1891	2137	2068	1997
Electric Power[6]	2160	2163	2138	2008	2425	2360	2144	2606	2526	2245
Total	**5426**	**5724**	**5680**	**5516**	**6070**	**5938**	**5645**	**6489**	**6311**	**5908**
Carbon Dioxide Emissions by Fuel (million metric tons)										
Petroleum	2319	2450	2434	2412	2485	2430	2380	2633	2561	2478
Natural Gas	1218	1363	1352	1308	1393	1351	1262	1524	1434	1307
Coal	1877	1899	1882	1785	2180	2144	1991	2320	2304	2111
Other[7]	12	12	12	12	12	12	12	12	12	12
Total	**5426**	**5724**	**5680**	**5516**	**6070**	**5938**	**5645**	**6489**	**6311**	**5908**
Carbon Dioxide Emissions (tons per person)	**17.6**	**17.5**	**17.4**	**16.9**	**17.0**	**16.6**	**15.8**	**16.6**	**16.2**	**15.1**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[3]Includes petroleum-derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids, crude oil consumed as a fuel, and liquid hydrogen.
[4]Includes grid-connected electricity from conventional hydroelectric; wood and wood waste; landfill gas; biogenic municipal solid waste; other biomass; wind; photovoltaic and solar thermal sources; and non-electric energy from renewable sources, such as active and passive solar systems, and wood; and both the ethanol and gasoline components of E85, but not the ethanol component of blends less than 85 percent. Excludes electricity imports using renewable sources and nonmarketed renewable energy.
[5]Includes non-biogenic municipal waste and net electricity imports.
[6]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Btu = British thermal unit.
GDP = Gross domestic product.
Note: Includes end-use, fossil electricity, and renewable technology assumptions. Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs LTRKITEN.D030111A, REF2011.D020911A, and HTRKITEN.D030111A.

Table D5. Key results for expanded standards cases
(quadrillion Btu, unless otherwise noted)

Energy Consumption	2009	2015 Reference	2015 Expanded Standards	2015 Expanded Standards and Codes	2025 Reference	2025 Expanded Standards	2025 Expanded Standards and Codes	2035 Reference	2035 Expanded Standards	2035 Expanded Standards and Codes
Residential Energy Consumption										
by Fuel										
Liquefied Petroleum Gases	0.53	0.49	0.49	0.49	0.48	0.47	0.47	0.48	0.48	0.47
Kerosene	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Distillate Fuel Oil	0.61	0.56	0.56	0.56	0.44	0.44	0.43	0.37	0.35	0.34
Natural Gas	4.87	4.94	4.94	4.92	4.96	4.89	4.81	4.90	4.73	4.58
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Renewable Energy[1]	0.43	0.40	0.40	0.40	0.42	0.42	0.42	0.42	0.42	0.41
Electricity	4.65	4.60	4.57	4.56	4.98	4.69	4.65	5.51	4.91	4.85
by End Use										
Space Heating	4.78	4.71	4.71	4.69	4.64	4.57	4.46	4.55	4.39	4.20
Space Cooling	0.83	0.82	0.82	0.82	0.90	0.88	0.86	0.99	0.93	0.88
Water Heating	1.95	1.99	1.99	1.99	1.99	1.88	1.88	1.88	1.61	1.61
Refrigeration	0.37	0.35	0.35	0.35	0.35	0.34	0.34	0.38	0.36	0.36
Cooking	0.35	0.36	0.36	0.36	0.39	0.39	0.39	0.41	0.41	0.41
Clothes Dryers	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.26	0.25	0.25
Freezers	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08
Lighting	0.71	0.57	0.57	0.57	0.52	0.52	0.52	0.54	0.52	0.52
Clothes Washers[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Dishwashers[2]	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.10	0.10
Color Televisions and Set-Top Boxes	0.34	0.33	0.33	0.33	0.36	0.32	0.32	0.42	0.35	0.35
Personal Computers and Related Equipment	0.18	0.17	0.16	0.16	0.18	0.13	0.13	0.19	0.14	0.14
Furnace Fans and Boiler Circulation Pumps	0.14	0.15	0.15	0.15	0.18	0.18	0.18	0.20	0.20	0.20
Other Uses[3]	1.03	1.12	1.09	1.09	1.37	1.29	1.29	1.65	1.56	1.56
Delivered Energy	**11.12**	**11.02**	**10.99**	**10.96**	**11.32**	**10.94**	**10.80**	**11.70**	**10.91**	**10.68**
Residential Delivered Energy Intensity										
(million Btu per household)	98.0	90.8	90.6	90.3	83.9	81.1	80.1	79.7	74.3	72.7
(thousand Btu per square foot)	58.7	51.5	51.3	51.2	44.5	43.0	42.4	40.2	37.5	36.7
Commercial Energy Consumption										
by Fuel										
Distillate Fuel Oil	0.34	0.28	0.28	0.28	0.26	0.26	0.25	0.25	0.25	0.23
Other Liquid Fuels[4]	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.28	0.28
Natural Gas	3.20	3.47	3.47	3.46	3.66	3.62	3.50	3.92	3.86	3.59
Coal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Renewable Energy[5]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Electricity	4.51	4.83	4.83	4.83	5.58	5.42	5.37	6.43	6.18	6.05
by End Use										
Space Heating[6]	1.94	2.02	2.02	2.01	2.04	2.03	1.90	2.05	2.02	1.71
Space Cooling[6]	0.51	0.56	0.56	0.56	0.60	0.57	0.53	0.65	0.60	0.49
Water Heating[6]	0.56	0.63	0.63	0.63	0.70	0.66	0.66	0.75	0.69	0.69
Ventilation	0.50	0.56	0.56	0.56	0.64	0.64	0.64	0.71	0.71	0.71
Cooking	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.27	0.27	0.27
Lighting	1.03	1.04	1.04	1.04	1.14	1.11	1.11	1.25	1.20	1.20
Refrigeration	0.40	0.36	0.36	0.36	0.36	0.35	0.35	0.39	0.37	0.37
Office Equipment (Personal Computers)	0.22	0.19	0.19	0.19	0.19	0.14	0.14	0.21	0.15	0.15
Office Equipment (non-PC)	0.25	0.32	0.32	0.32	0.40	0.39	0.39	0.47	0.45	0.45
Other Uses[7]	2.89	3.12	3.12	3.12	3.62	3.61	3.61	4.31	4.29	4.29
Total Delivered Energy	**8.49**	**9.02**	**9.02**	**9.01**	**9.94**	**9.74**	**9.57**	**11.05**	**10.74**	**10.33**
Commercial Delivered Energy Intensity										
(thousand Btu per square foot)	105.9	105.6	105.5	105.4	102.1	100.0	98.2	100.7	97.8	94.0

[1]Includes wood used for residential heating.
[2]Does not include water heating portion of load..
[3]Includes small electric devices, heating elements, such outdoor appliances as grills and mosquito traps, motors not included above, and kerosene and coal.
[4]Includes liquefied petroleum gases, motor gasoline, kerosene, and residual fuel oil.
[5]Includes commercial sector consumption of wood and wood waste, landfill gas, municipal solid waste, and other biomass for combined heat and power.
[6]Includes fuel consumption for district services.
[7]Includes miscellaneous uses, such as service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency generation, combined heat and power in commercial buildings, manufacturing performed in commercial buildings, and cooking (distillate), plus residual fuel oil, liquefied petroleum gases, coal, motor gasoline, and kerosene.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports. Side cases were run without the fully integrated modeling system, so not all feedbacks are captured.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System, runs REF2011.D020911A, BLDEXPAND.D022811A, and BLDEXPANDCS.D022811A.

Table D6. Key results for transportation sector light-duty vehicle efficiency cases

Consumption and Indicators	2009	2015			2025			2035		
		Reference	CAFE 3% Growth	CAFE 6% Growth	Reference	CAFE 3% Growth	CAFE 6% Growth	Reference	CAFE 3% Growth	CAFE 6% Growth
Level of Travel										
(billion vehicle miles traveled)										
Light-Duty Vehicles less than 8,500	2707	2947	2944	2944	3467	3457	3490	4043	4035	4084
Commercial Light Trucks[1]	67	81	81	81	92	92	92	104	104	105
Freight Trucks greater than 10,000	207	250	250	250	291	291	291	335	335	336
(billion seat miles available)										
Air	960	1059	1059	1059	1180	1180	1180	1282	1282	1282
(billion ton miles traveled)										
Rail	1677	1886	1884	1881	2143	2142	2151	2328	2322	2337
Domestic Shipping	486	521	522	521	559	558	558	596	592	593
Energy Efficiency Indicators										
(miles per gallon)										
Tested New Light-Duty Vehicle[2]	28.0	31.3	31.4	31.4	35.3	44.6	55.0	36.5	46.4	58.5
New Car[2]	32.7	36.5	36.7	36.7	40.0	52.1	70.8	40.8	54.2	75.8
New Light Truck[2]	24.3	26.6	26.7	26.7	29.6	36.7	41.8	30.6	37.4	43.8
Light-Duty Stock[3]	20.8	22.1	22.1	22.1	25.7	28.6	30.2	27.9	34.0	39.4
New Commercial Light Truck[1]	15.6	16.4	16.4	16.4	17.9	20.7	22.2	18.1	20.8	22.8
Stock Commercial Light Truck[1]	14.4	15.2	15.2	15.2	17.2	18.2	18.8	18.0	20.5	22.2
Freight Truck	6.1	6.1	6.1	6.1	6.4	6.4	6.4	6.6	6.6	6.6
(seat miles per gallon)										
Aircraft	62.0	62.8	62.8	62.8	65.6	65.6	65.6	69.9	69.9	69.9
(ton miles per thousand Btu)										
Rail	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4
Domestic Shipping	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.5	2.5	2.5
Energy Use (quadrillion Btu)										
by Mode										
Light-Duty Vehicles	16.13	16.36	16.34	16.34	16.40	14.79	14.53	17.66	14.37	12.90
Commercial Light Trucks[1]	0.58	0.66	0.66	0.66	0.67	0.63	0.61	0.73	0.63	0.59
Bus Transportation	0.27	0.28	0.28	0.28	0.30	0.30	0.30	0.33	0.33	0.33
Freight Trucks	4.26	5.11	5.11	5.11	5.73	5.73	5.72	6.35	6.35	6.38
Rail, Passenger	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.06
Rail, Freight	0.51	0.57	0.57	0.57	0.64	0.64	0.64	0.69	0.69	0.69
Shipping, Domestic	0.20	0.22	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.24
Shipping, International	0.78	0.78	0.78	0.78	0.79	0.79	0.79	0.80	0.80	0.80
Recreational Boats	0.26	0.27	0.27	0.27	0.29	0.29	0.29	0.31	0.31	0.32
Air	2.66	2.71	2.71	2.71	2.95	2.96	2.96	3.07	3.08	3.08
Military Use	0.75	0.69	0.69	0.69	0.72	0.72	0.72	0.76	0.76	0.76
Lubricants	0.13	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14
Pipeline Fuel	0.65	0.67	0.66	0.66	0.64	0.64	0.64	0.67	0.66	0.67
Total	**27.23**	**28.50**	**28.48**	**28.48**	**29.55**	**27.92**	**27.63**	**31.80**	**28.42**	**26.95**
by Fuel										
Liquefied Petroleum Gases	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
E85[4]	0.00	0.01	0.01	0.01	0.93	1.22	1.25	1.23	1.56	1.74
Motor Gasoline[5]	16.82	17.02	16.97	16.97	15.93	13.39	12.93	16.69	12.03	9.82
Jet Fuel[6]	3.20	3.20	3.20	3.20	3.47	3.47	3.47	3.62	3.62	3.62
Distillate Fuel Oil[7]	5.54	6.57	6.60	6.60	7.45	8.06	8.13	8.35	9.28	9.56
Residual Fuel Oil	0.78	0.79	0.79	0.79	0.81	0.81	0.81	0.82	0.82	0.82
Other Petroleum[8]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
Liquid Fuels and Other Petroleum	26.52	27.76	27.74	27.74	28.76	27.13	26.76	30.89	27.50	25.76
Pipeline Fuel Natural Gas	0.65	0.67	0.66	0.66	0.64	0.64	0.64	0.67	0.66	0.67
Compressed Natural Gas	0.03	0.04	0.04	0.04	0.10	0.10	0.10	0.16	0.16	0.16
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	0.02	0.03	0.03	0.03	0.05	0.05	0.13	0.07	0.10	0.36
Delivered Energy	**27.23**	**28.50**	**28.48**	**28.48**	**29.56**	**27.92**	**27.63**	**31.80**	**28.42**	**26.95**
Electricity Related Losses	0.05	0.06	0.06	0.06	0.09	0.11	0.27	0.15	0.20	0.73
Total	**27.28**	**28.56**	**28.53**	**28.53**	**29.65**	**28.03**	**27.91**	**31.95**	**28.62**	**27.68**

[1]Commercial trucks 8,500 to 10,000 pounds.
[2]Environmental Protection Agency rated miles per gallon.
[3]Combined car and light truck "on-the-road" estimate.
[4]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.
[5]Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.
[6]Includes only kerosene type.
[7]Diesel fuel for on- and off- road use.
[8]Includes aviation gasoline and lubricants.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports. Side cases were run without the fully integrated modeling system, so not all feedbacks are captured. The reference case ratio of electricity losses to electricity use was used to compute electricity losses for the technology cases.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs REF2011.D020911A, CAFE3.D022211A, and CAFE6.D022211A.

Table D7. Key results for the transportation sector Heavy-Duty Vehicle Fuel Economy Standards case

Sales, Consumption, Supply, and Prices	2009	2015		2025		2035	
		Reference	Heavy-duty Vehicle Fuel Economy Standards	Reference	Heavy-duty Vehicle Fuel Economy Standards	Reference	Heavy-duty Vehicle Fuel Economy Standards
Truck Sales by Size Class (millions)	**0.31**	**0.62**	**0.62**	**0.75**	**0.76**	**0.93**	**0.93**
Medium	0.18	0.31	0.31	0.37	0.37	0.46	0.46
Diesel	0.13	0.22	0.22	0.26	0.27	0.32	0.33
Motor Gasoline	0.05	0.09	0.09	0.09	0.09	0.11	0.11
Liquefied Petroleum Gases	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Natural Gas	0.00	0.00	0.00	0.01	0.01	0.02	0.01
Heavy	0.13	0.31	0.31	0.38	0.38	0.47	0.47
Diesel	0.13	0.29	0.29	0.36	0.36	0.44	0.44
Motor Gasoline	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Liquefied Petroleum Gases	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Consumption by Size Class (quadrillion Btu)	**4.26**	**5.11**	**5.02**	**5.72**	**5.52**	**6.34**	**6.19**
Medium	0.81	1.05	1.03	1.23	1.14	1.42	1.30
Diesel	0.56	0.76	0.75	0.91	0.86	1.06	0.98
Motor Gasoline	0.24	0.27	0.27	0.28	0.26	0.29	0.27
Liquefied Petroleum Gases	0.00	0.01	0.01	0.01	0.01	0.02	0.01
Natural Gas	0.00	0.01	0.01	0.03	0.02	0.05	0.04
Heavy	3.45	4.06	3.99	4.49	4.38	4.93	4.88
Diesel	3.34	3.97	3.91	4.42	4.30	4.84	4.80
Motor Gasoline	0.09	0.07	0.07	0.05	0.05	0.05	0.05
Liquefied Petroleum Gases	0.01	0.01	0.01	0.00	0.00	0.01	0.01
Natural Gas	0.00	0.01	0.01	0.02	0.02	0.03	0.03
New Truck Fuel Efficiency by Size Class (gasoline equivalent miles per gallon)	**6.14**	**6.12**	**6.53**	**6.53**	**6.70**	**6.71**	**6.85**
Medium	7.89	7.85	8.31	7.84	8.46	7.84	8.45
Diesel	7.96	7.95	8.37	7.95	8.63	7.95	8.63
Motor Gasoline	7.60	7.64	8.16	7.79	8.26	7.84	8.26
Liquefied Petroleum Gases	7.60	7.63	8.13	7.63	8.19	7.63	8.16
Natural Gas	5.94	5.96	6.02	5.96	6.02	5.96	6.02
Heavy	5.60	5.70	6.06	6.18	6.24	6.40	6.42
Diesel	5.59	5.68	6.05	6.17	6.23	6.39	6.41
Motor Gasoline	8.41	8.40	8.45	8.40	8.45	8.40	8.45
Liquefied Petroleum Gases	5.30	5.30	5.51	5.33	5.51	5.33	5.51
Natural Gas	5.64	5.63	5.73	5.62	5.73	5.62	5.73
Stock Fuel Efficiency by Size Class (gasoline equivalent miles per gallon)	**6.09**	**6.12**	**6.23**	**6.36**	**6.60**	**6.61**	**6.78**
Medium	7.95	7.88	7.96	7.83	8.27	7.83	8.41
Diesel	8.05	7.99	8.07	7.96	8.45	7.95	8.60
Motor Gasoline	7.85	7.72	7.77	7.68	8.00	7.78	8.21
Liquefied Petroleum Gases	7.03	7.47	7.57	7.61	8.08	7.63	8.17
Natural Gas	6.00	5.97	5.98	5.96	6.02	5.96	6.02
Heavy	5.65	5.66	5.76	5.95	6.11	6.24	6.29
Diesel	5.58	5.62	5.71	5.92	6.09	6.22	6.28
Motor Gasoline	8.14	8.25	8.25	8.37	8.40	8.40	8.44
Liquefied Petroleum Gases	5.28	5.29	5.31	5.31	5.45	5.33	5.49
Natural Gas	5.63	5.63	5.70	5.62	5.73	5.62	5.73

[1]Includes lease condensate.
[2]Includes natural gas plant liquids, refinery processing gain, other crude oil supply, and stock withdrawals.
[3]Includes liquids, such as ethanol and biodiesel, derived from biomass, natural gas, and coal. Includes net imports of ethanol and biodiesel.
- - = Not applicable.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 data based on: Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 28 and Annual* (Oak Ridge, TN, 2009); U.S. Department of Commerce, Bureau of the Census, "Vehicle Inventory and Use Survey," EC02TV (Washington, DC, December 2004); Federal Highway Administration, *Highway Statistics 2007* (Washington, DC, October 2008); U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010); and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. **Projections:** EIA, AEO2011 National Energy Modeling System runs REF2011.D020911A and HDVCAFE.D030411A.

Table D8. Energy consumption and carbon dioxide emissions, extended policy cases

Consumption and Emissions	2009	2015			2025			2035		
		Reference	No Sunset	Extended Policies	Reference	No Sunset	Extended Policies	Reference	No Sunset	Extended Policies
Energy Consumption by Sector (quadrillion Btu)										
Residential	11.12	11.02	10.94	10.88	11.32	10.99	10.55	11.70	11.20	10.36
Commercial	8.49	9.02	9.03	9.02	9.94	9.95	9.61	11.05	11.08	10.45
Industrial[1]	21.85	26.75	26.81	26.65	28.11	28.36	28.01	28.89	29.51	28.49
Transportation	27.23	28.50	28.52	28.47	29.56	29.54	27.90	31.80	31.81	28.39
Electric Power[2]	38.31	39.73	39.66	39.50	43.17	42.52	40.92	46.03	45.28	42.70
Total	**94.79**	**102.02**	**101.99**	**101.60**	**107.95**	**107.43**	**103.60**	**114.19**	**113.93**	**106.35**
Energy Consumption by Fuel (quadrillion Btu)										
Liquid Fuels and Other Petroleum[3]	36.62	39.10	39.11	38.99	39.84	39.80	37.91	41.70	41.69	37.83
Natural Gas	23.31	25.77	25.78	25.61	25.73	25.66	24.86	27.24	26.70	25.28
Coal	19.69	19.73	19.80	19.81	22.61	22.39	21.64	24.30	24.09	23.22
Nuclear Power	8.35	8.77	8.77	8.77	9.17	9.17	8.97	9.14	9.14	8.94
Renewable Energy[4]	6.51	8.34	8.21	8.10	10.33	10.13	9.93	11.56	12.07	10.83
Other[5]	0.32	0.31	0.31	0.31	0.27	0.27	0.27	0.25	0.24	0.23
Total	**94.79**	**102.02**	**101.99**	**101.60**	**107.95**	**107.43**	**103.60**	**114.19**	**113.93**	**106.35**
Energy Intensity (thousand Btu per 2005 dollar of GDP)	**7.36**	**6.65**	**6.65**	**6.63**	**5.39**	**5.37**	**5.18**	**4.44**	**4.43**	**4.14**
Carbon Dioxide Emissions by Sector (million metric tons)										
Residential	343	336	333	332	328	320	313	319	308	294
Commercial	218	229	229	229	237	238	230	251	253	235
Industrial[1]	854	1061	1063	1056	1080	1092	1071	1147	1164	1128
Transportation	1850	1916	1912	1914	1932	1918	1815	2068	2062	1841
Electric Power[6]	2160	2138	2145	2141	2360	2329	2233	2526	2468	2346
Total	**5426**	**5680**	**5682**	**5671**	**5938**	**5897**	**5663**	**6311**	**6255**	**5843**
Carbon Dioxide Emissions by Fuel (million metric tons)										
Petroleum	2319	2434	2429	2427	2430	2414	2294	2561	2553	2300
Natural Gas	1218	1352	1352	1343	1351	1347	1305	1434	1405	1330
Coal	1877	1882	1889	1889	2144	2123	2052	2304	2285	2201
Other[7]	12	12	12	12	12	12	12	12	12	12
Total	**5426**	**5680**	**5682**	**5671**	**5938**	**5897**	**5663**	**6311**	**6255**	**5843**
Carbon Dioxide Emissions (tons per person)	**17.6**	**17.4**	**17.4**	**17.4**	**16.6**	**16.5**	**15.8**	**16.2**	**16.0**	**15.0**

[1]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[2]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[3]Includes petroleum-derived fuels and non-petroleum derived fuels, such as ethanol and biodiesel, and coal-based synthetic liquids. Petroleum coke, which is a solid, is included. Also included are natural gas plant liquids, crude oil consumed as a fuel, and liquid hydrogen.
[4]Includes grid-connected electricity from conventional hydroelectric; wood and wood waste; landfill gas; biogenic municipal solid waste; other biomass; wind; photovoltaic and solar thermal sources; and non-electric energy from renewable sources, such as active and passive solar systems, and wood; and both the ethanol and gasoline components of E85, but not the ethanol component of blends less than 85 percent. Excludes electricity imports using renewable sources and nonmarketed renewable energy.
[5]Includes non-biogenic municipal waste and net electricity imports.
[6]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Btu = British thermal unit.
GDP = Gross domestic product.
Note: Includes end-use, fossil electricity, and renewable technology assumptions. Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs REF2011.D020911A, NOSUNSET.D030711A, and EXTENDED.D031011A.

Table D9. Electricity generation and generating capacity, extended policy cases
(gigawatts, unless otherwise noted)

Net Summer Capacity, Generation Consumption, and Emissions	2009	2015			2025			2035		
		Reference	No Sunset	Extended Policies	Reference	No Sunset	Extended Policies	Reference	No Sunset	Extended Policies
Capacity	**1033.4**	**1075.0**	**1069.7**	**1056.4**	**1118.9**	**1117.9**	**1086.3**	**1221.0**	**1239.1**	**1155.5**
Electric Power Sector[1]	1001.9	1025.1	1019.6	1005.9	1050.8	1029.2	994.8	1131.5	1099.4	1014.2
Pulverized Coal	312.9	316.4	314.6	308.7	315.0	312.2	304.5	315.3	312.2	304.5
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	2.6	2.6	2.6	2.6	2.6	2.6
Conventional Natural Gas Combined-Cycle	197.2	203.2	203.2	203.2	203.9	203.5	203.2	205.0	204.8	203.3
Advanced Natural Gas Combined-Cycle	0.0	0.3	0.0	0.0	6.0	2.3	0.0	54.6	27.9	4.0
Conventional Combustion Turbine	137.5	136.7	136.2	134.6	135.8	135.4	131.1	135.8	135.4	131.1
Advanced Combustion Turbine	0.0	3.9	3.7	3.4	19.5	9.5	4.2	45.8	26.0	11.0
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	101.0	105.7	105.7	105.7	110.5	110.5	108.1	110.5	110.5	108.1
Oil and Natural Gas Steam	114.4	99.9	100.3	96.3	92.8	88.4	82.6	88.7	88.3	82.6
Renewable Sources	117.0	136.1	133.2	131.5	141.5	142.3	136.5	148.3	167.9	144.2
Pumped Storage	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
Distributed Generation	0.0	0.5	0.3	0.2	1.3	0.5	0.2	3.1	2.0	0.9
Combined Heat and Power[2]	31.5	50.0	50.1	50.5	68.1	88.7	91.5	89.5	139.7	141.3
Fossil Fuels/Other	24.0	32.5	32.7	33.1	40.7	43.2	44.7	57.9	62.3	64.4
Renewable Fuels	7.5	17.5	17.5	17.4	27.4	45.5	46.8	31.6	77.4	76.9
Cumulative Additions	**0.0**	**63.7**	**60.1**	**58.2**	**117.2**	**123.7**	**112.3**	**223.4**	**245.0**	**181.5**
Electric Power Sector[1]	0.0	45.3	41.4	39.3	80.6	66.5	52.4	165.4	136.8	71.8
Pulverized Coal	0.0	10.9	10.9	10.9	12.9	12.9	12.9	13.2	12.9	12.9
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Conventional Natural Gas Combined-Cycle	0.0	6.4	6.4	6.4	7.0	6.7	6.4	8.1	7.9	6.5
Advanced Natural Gas Combined-Cycle	0.0	0.3	0.0	0.0	6.0	2.3	0.0	54.6	27.9	4.0
Conventional Combustion Turbine	0.0	2.1	2.0	2.0	2.1	2.0	2.0	2.1	2.0	2.0
Advanced Combustion Turbine	0.0	3.9	3.7	3.4	19.5	9.5	4.2	45.8	26.0	11.0
Nuclear	0.0	1.1	1.1	1.1	6.3	6.3	6.3	6.3	6.3	6.3
Renewable Sources	0.0	19.4	16.5	14.8	24.8	25.6	19.8	31.6	51.2	27.5
Distributed Generation	0.0	0.5	0.3	0.2	1.3	0.5	0.2	3.1	2.0	0.9
Combined Heat and Power[2]	0.0	18.5	18.6	18.9	36.6	57.2	59.9	58.0	108.2	109.7
Fossil Fuels/Other	0.0	8.5	8.7	9.1	16.8	19.2	20.6	33.9	38.4	40.4
Renewable Fuels	0.0	9.9	9.9	9.8	19.8	38.0	39.3	24.0	69.8	69.3
Cumulative Retirements	**0.0**	**25.4**	**27.1**	**38.6**	**35.2**	**42.8**	**63.0**	**39.3**	**42.8**	**63.0**
Generation by Fuel (billion kilowatthours)	**3978**	**4253**	**4246**	**4230**	**4682**	**4661**	**4504**	**5167**	**5168**	**4886**
Electric Power Sector[1]	3811	3998	3991	3972	4300	4239	4063	4633	4529	4236
Coal	1749	1769	1775	1776	2016	1996	1925	2107	2090	2009
Petroleum	36	38	38	38	40	41	40	42	42	41
Natural Gas	841	858	858	846	820	788	727	1033	901	787
Nuclear Power	799	839	839	839	877	877	858	874	874	855
Renewable Sources	384	494	480	473	545	537	513	572	618	541
Pumped Storage	2	-0	-0	-0	-0	-0	-0	-0	-0	-0
Distributed Generation	0	1	0	0	3	1	0	5	4	2
Combined Heat and Power[2]	167	255	256	257	381	422	440	533	639	650
Fossil Fuels/Other	36	63	63	62	128	152	161	152	226	224
Renewable Fuels	131	192	193	195	253	270	279	381	413	426
Average Electricity Price (cents per kilowatthour)	**9.8**	**8.9**	**8.8**	**8.8**	**8.9**	**8.8**	**8.7**	**9.2**	**8.9**	**8.6**

[1]Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[2]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors. Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs REF2011.D020911A, NOSUNSET.D030711A, and EXTENDED.D031011A.

Table D10. Key results for advanced nuclear cost cases
(gigawatts, unless otherwise noted)

Net Summer Capacity, Generation, Emissions, and Fuel Prices	2009	2015			2025			2035		
		High Nuclear Cost	Reference	Low Nuclear Cost	High Nuclear Cost	Reference	Low Nuclear Cost	High Nuclear Cost	Reference	Low Nuclear Cost
Capacity										
Coal Steam	312.9	317.4	317.0	316.5	317.6	317.6	317.4	317.9	317.9	317.4
Oil and Natural Gas Steam	114.4	101.0	99.9	101.3	93.9	92.8	94.4	89.7	88.7	93.7
Combined Cycle	197.2	203.5	203.5	203.4	211.6	209.9	208.3	262.5	259.5	238.4
Combustion Turbine/Diesel	137.5	140.4	140.6	140.6	154.8	155.3	156.1	177.0	181.6	181.7
Nuclear Power	101.0	105.7	105.7	105.7	110.5	110.5	111.3	110.5	110.5	129.1
Pumped Storage	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renewable Sources	117.0	136.2	136.3	136.2	142.2	141.7	142.0	148.7	148.5	146.6
Distributed Generation (Natural Gas)	0.0	0.8	0.5	0.8	1.7	1.3	1.7	4.3	3.1	4.7
Combined Heat and Power[1]	31.5	50.0	50.0	50.0	68.8	68.1	68.0	90.3	89.5	89.5
Total	**1033.4**	**1076.9**	**1075.2**	**1076.3**	**1123.0**	**1119.1**	**1120.9**	**1222.5**	**1221.2**	**1222.8**
Cumulative Additions										
Coal Steam	0.0	11.5	11.5	11.5	13.5	13.5	13.5	13.8	13.8	13.5
Oil and Natural Gas Steam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle	0.0	6.6	6.6	6.5	14.8	13.1	11.5	65.6	62.7	41.5
Combustion Turbine/Diesel	0.0	5.9	6.1	6.0	21.1	21.6	22.4	43.3	47.9	48.0
Nuclear Power	0.0	1.1	1.1	1.1	6.3	6.3	7.1	6.3	6.3	25.0
Pumped Storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renewable Sources	0.0	19.3	19.4	19.3	25.3	24.8	25.1	31.8	31.6	29.7
Distributed Generation	0.0	0.8	0.5	0.8	1.7	1.3	1.7	4.3	3.1	4.7
Combined Heat and Power[1]	0.0	18.5	18.5	18.4	37.3	36.6	36.5	58.8	58.0	58.0
Total	**0.0**	**63.7**	**63.7**	**63.8**	**120.0**	**117.2**	**117.7**	**223.9**	**223.4**	**220.3**
Cumulative Retirements	**0.0**	**23.7**	**25.4**	**24.4**	**34.2**	**35.2**	**33.9**	**38.5**	**39.3**	**34.6**
Generation by Fuel (billion kilowatthours)										
Coal	1749	1754	1769	1783	2005	2016	2030	2104	2107	2087
Petroleum	36	38	38	38	40	40	40	42	42	42
Natural Gas	841	870	858	847	826	820	809	1034	1033	922
Nuclear Power	799	839	839	839	877	877	882	874	874	1019
Pumped Storage	2	-0	-0	-0	-0	-0	-0	-0	-0	-0
Renewable Sources	384	493	494	491	545	545	542	572	572	569
Distributed Generation	0	1	1	1	3	3	3	4	5	4
Combined Heat and Power[1]	167	255	255	254	387	381	380	540	533	534
Total	**3978**	**4250**	**4253**	**4254**	**4683**	**4682**	**4685**	**5171**	**5167**	**5176**
Carbon Dioxide Emissions by the Electric Power Sector (million metric tons)[2]										
Petroleum	34	33	33	33	36	35	35	37	37	37
Natural Gas	373	384	379	375	364	362	358	427	428	393
Coal	1742	1698	1714	1727	1939	1951	1967	2047	2049	2030
Other[3]	12	12	12	12	12	12	12	12	12	12
Total	**2160**	**2128**	**2138**	**2147**	**2351**	**2360**	**2372**	**2524**	**2526**	**2472**
Prices to the Electric Power Sector[2] (2009 dollars per million Btu)										
Petroleum	10.26	13.98	13.96	13.97	17.39	17.31	17.74	18.29	18.06	18.27
Natural Gas	4.82	4.72	4.67	4.65	5.79	5.76	5.77	6.83	6.80	6.52
Coal	2.20	2.12	2.11	2.12	2.26	2.24	2.24	2.40	2.40	2.38

[1]Includes combined heat and power plants and electricity-only plants in commercial and industrial sectors. Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
[2]Includes electricity-only and combined heat and power plants whose primary business to sell electricity, or electricity and heat, to the public.
[3]Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs HCNUC11.D020911A, REF2011.D020911A, and LCNUC11.D020911A.

Table D11. Key results for electric power sector fossil technology cases
(gigawatts, unless otherwise noted)

Net Summer Capacity, Generation Consumption, and Emissions	2009	2015			2025			2035		
		High Fossil Technology Cost	Reference	Low Fossil Technology Cost	High Fossil Technology Cost	Reference	Low Fossil Technology Cost	High Fossil Technology Cost	Reference	Low Fossil Technology Cost
Capacity										
Pulverized Coal	312.9	315.3	316.4	316.6	314.7	315.0	314.7	314.7	315.3	330.3
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	2.6	2.6	2.6	2.6	2.6	5.0
Conventional Natural Gas Combined-Cycle	197.2	203.3	203.2	203.3	204.0	203.9	204.9	205.9	205.0	205.6
Advanced Natural Gas Combined-Cycle	0.0	0.6	0.3	0.7	5.2	6.0	18.5	49.7	54.6	65.7
Conventional Combustion Turbine	137.5	136.7	136.7	137.3	135.9	135.8	136.6	135.9	135.8	135.7
Advanced Combustion Turbine	0.0	3.6	3.9	4.7	19.2	19.5	18.3	44.3	45.8	31.9
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	101.0	105.7	105.7	105.7	110.5	110.5	110.5	110.5	110.5	110.5
Oil and Natural Gas Steam	114.4	100.6	99.9	100.9	93.4	92.8	88.5	91.0	88.7	85.2
Renewable Sources/Pumped Storage	138.8	157.8	158.0	157.9	163.9	163.4	161.3	170.6	170.2	165.3
Distributed Generation	0.0	0.3	0.5	1.4	0.6	1.3	4.7	1.4	3.1	16.0
Combined Heat and Power[1]	31.5	50.0	50.0	50.0	68.1	68.1	67.4	90.1	89.5	88.1
Total	**1033.4**	**1074.4**	**1075.0**	**1079.0**	**1118.1**	**1118.9**	**1127.9**	**1216.6**	**1221.0**	**1239.3**
Cumulative Additions										
Pulverized Coal	0.0	10.9	10.9	10.9	12.9	12.9	12.9	12.9	13.2	28.5
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	3.0
Conventional Natural Gas Combined-Cycle	0.0	6.5	6.4	6.5	7.2	7.0	8.0	9.1	8.1	8.7
Advanced Natural Gas Combined-Cycle	0.0	0.6	0.3	0.7	5.2	6.0	18.5	49.7	54.6	65.7
Conventional Combustion Turbine	0.0	2.1	2.1	3.1	2.1	2.1	3.1	2.1	2.1	3.1
Advanced Combustion Turbine	0.0	3.6	3.9	4.7	19.2	19.5	18.3	44.3	45.8	31.9
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	0.0	1.1	1.1	1.1	6.3	6.3	6.3	6.3	6.3	6.3
Oil and Natural Gas Steam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renewable Sources	0.0	19.2	19.4	19.3	25.4	24.8	22.7	32.1	31.6	26.7
Distributed Generation	0.0	0.3	0.5	1.4	0.6	1.3	4.7	1.4	3.1	16.0
Combined Heat and Power[1]	0.0	18.5	18.5	18.5	36.6	36.6	35.9	58.6	58.0	56.6
Total	**0.0**	**63.4**	**63.7**	**66.7**	**116.1**	**117.2**	**131.0**	**217.0**	**223.4**	**246.6**
Cumulative Retirements	**0.0**	**25.7**	**25.4**	**24.4**	**34.9**	**35.2**	**40.0**	**37.3**	**39.3**	**44.3**
Generation by Fuel (billion kilowatthours)										
Coal	1749	1792	1769	1763	2002	2016	1990	2083	2107	2179
Petroleum	36	37	38	38	40	40	41	42	42	42
Natural Gas	841	838	858	861	822	820	840	1035	1033	983
Nuclear Power	799	839	839	839	877	877	877	874	874	874
Renewable Sources/Pumped Storage	386	491	493	493	550	544	541	581	572	565
Distributed Generation	0	0	1	2	1	3	8	4	5	14
Combined Heat and Power[1]	167	255	255	255	381	381	377	537	533	526
Total	**3978**	**4253**	**4253**	**4252**	**4674**	**4682**	**4675**	**5155**	**5167**	**5183**
Fuel Consumption by the Electric Power Sector (quadrillion Btu)[2]										
Coal	18.30	18.21	17.99	17.92	20.44	20.61	20.33	21.35	21.64	22.11
Petroleum	0.40	0.43	0.43	0.44	0.45	0.45	0.46	0.47	0.47	0.48
Natural Gas	7.06	6.99	7.15	7.18	6.84	6.82	6.92	8.11	8.07	7.69
Nuclear Power	8.35	8.77	8.77	8.77	9.17	9.17	9.17	9.14	9.14	9.14
Renewable Sources	3.89	5.03	5.08	5.06	5.87	5.84	5.76	6.52	6.47	6.20
Total	**38.19**	**39.63**	**39.62**	**39.57**	**42.97**	**43.09**	**42.84**	**45.79**	**45.99**	**45.82**
Carbon Dioxide Emissions by the Electric Power Sector (million metric tons)[2]										
Coal	1742	1734	1714	1706	1935	1951	1925	2023	2049	2096
Petroleum	34	33	33	34	35	35	36	37	37	37
Natural Gas	373	371	379	381	363	362	367	430	428	408
Other[3]	12	12	12	12	12	12	12	12	12	12
Total	**2160**	**2150**	**2138**	**2133**	**2345**	**2360**	**2340**	**2502**	**2526**	**2553**

[1]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors. Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
[2]Includes electricity-only and combined heat and power plants whose primary business to sell electricity, or electricity and heat, to the public.
[3]Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs HCFOSS11.D020911A, REF2011.D020911A, and LCFOSS11.D020911A.

Table D12. Key results for electric power sector capital cost cases
(gigawatts, unless otherwise noted)

Net Summer Capacity, Generation Consumption, and Emissions	2009	2015			2025			2035		
		Frozen Plant Capital Costs	Reference	Decreasing Plant Capital Costs	Frozen Plant Capital Costs	Reference	Decreasing Plant Capital Costs	Frozen Plant Capital Costs	Reference	Decreasing Plant Capital Costs
Capacity										
Pulverized Coal	312.9	316.4	316.4	316.7	314.5	315.0	315.4	314.5	315.3	320.5
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	2.6	2.6	2.6	2.6	2.6	2.6
Conventional Natural Gas Combined-Cycle	197.2	203.2	203.2	203.2	203.7	203.9	204.1	205.2	205.0	204.4
Advanced Natural Gas Combined-Cycle	0.0	0.4	0.3	0.2	4.5	6.0	14.4	53.1	54.6	52.3
Conventional Combustion Turbine	137.5	136.5	136.7	138.6	135.6	135.8	137.8	135.6	135.8	137.2
Advanced Combustion Turbine	0.0	3.9	3.9	3.4	18.6	19.5	17.1	44.0	45.8	32.4
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	101.0	105.7	105.7	105.7	110.5	110.5	110.5	110.5	110.5	117.0
Oil and Natural Gas Steam	114.4	100.3	99.9	100.5	91.6	92.8	88.4	90.2	88.7	87.3
Renewable Sources/Pumped Storage	138.8	157.8	158.0	162.4	161.8	163.4	168.8	166.2	170.2	202.9
Distributed Generation	0.0	0.3	0.5	1.1	1.0	1.3	6.7	2.1	3.1	24.3
Combined Heat and Power[1]	31.5	50.0	50.0	49.7	68.3	68.1	67.0	90.4	89.5	86.7
Total	**1033.4**	**1075.2**	**1075.0**	**1082.2**	**1112.7**	**1118.9**	**1132.7**	**1214.4**	**1221.0**	**1267.6**
Cumulative Additions										
Pulverized Coal	0.0	10.9	10.9	10.9	12.9	12.9	12.9	12.9	13.2	18.1
Coal Gasification Combined-Cycle	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Conventional Natural Gas Combined-Cycle	0.0	6.4	6.4	6.4	6.8	7.0	7.3	8.4	8.1	7.5
Advanced Natural Gas Combined-Cycle	0.0	0.4	0.3	0.2	4.5	6.0	14.4	53.1	54.6	52.3
Conventional Combustion Turbine	0.0	2.0	2.1	4.0	2.0	2.1	4.0	2.0	2.1	4.0
Advanced Combustion Turbine	0.0	3.9	3.9	3.4	18.6	19.5	17.1	44.0	45.8	32.4
Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	0.0	1.1	1.1	1.1	6.3	6.3	6.3	6.3	6.3	12.9
Oil and Natural Gas Steam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renewable Sources	0.0	19.2	19.4	23.9	23.2	24.8	30.2	27.6	31.6	64.3
Distributed Generation	0.0	0.3	0.5	1.1	1.0	1.3	6.7	2.1	3.1	24.3
Combined Heat and Power[1]	0.0	18.5	18.5	18.2	36.8	36.6	35.5	58.9	58.0	55.2
Total	**0.0**	**63.4**	**63.7**	**69.9**	**112.8**	**117.2**	**135.1**	**215.9**	**223.4**	**271.7**
Cumulative Retirements	**0.0**	**24.9**	**25.4**	**24.4**	**37.0**	**35.2**	**39.3**	**38.5**	**39.3**	**41.0**
Generation by Fuel (billion kilowatthours)										
Coal	1749	1754	1769	1794	2008	2016	2060	2089	2107	2153
Petroleum	36	38	38	38	41	40	40	42	42	42
Natural Gas	841	871	858	827	821	820	796	1043	1033	919
Nuclear Power	799	839	839	839	877	877	877	874	874	925
Renewable Sources/Pumped Storage	386	492	493	507	542	544	551	566	572	656
Distributed Generation	0	0	1	1	2	3	3	5	5	10
Combined Heat and Power[1]	167	255	255	253	382	381	374	539	533	515
Total	**3978**	**4251**	**4253**	**4259**	**4674**	**4682**	**4702**	**5159**	**5167**	**5220**
Fuel Consumption by the Electric Power Sector (quadrillion Btu)[2]										
Coal	18.30	17.83	17.99	18.28	20.53	20.61	21.11	21.44	21.64	22.07
Petroleum	0.40	0.43	0.43	0.43	0.46	0.45	0.46	0.48	0.47	0.48
Natural Gas	7.06	7.25	7.15	6.92	6.84	6.82	6.58	8.14	8.07	7.32
Nuclear Power	8.35	8.77	8.77	8.77	9.17	9.17	9.17	9.14	9.14	9.67
Renewable Sources	3.89	5.04	5.08	5.22	5.79	5.84	5.87	6.39	6.47	7.12
Total	**38.19**	**39.53**	**39.62**	**39.82**	**42.99**	**43.09**	**43.39**	**45.79**	**45.99**	**46.86**
Carbon Dioxide Emissions by the Electric Power Sector (million metric tons)[2]										
Coal	1742	1698	1714	1741	1945	1951	1999	2032	2049	2090
Petroleum	34	34	33	33	36	35	36	37	37	37
Natural Gas	373	385	379	367	363	362	349	432	428	388
Other[3]	12	12	12	12	12	12	12	12	12	12
Total	**2160**	**2128**	**2138**	**2153**	**2355**	**2360**	**2395**	**2514**	**2526**	**2527**

[1]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors. Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
[2]Includes electricity-only and combined heat and power plants whose primary business to sell electricity, or electricity and heat, to the public.
[3]Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs FRZCST11.D020911A, REF2011.D020911A, and DECCST11.D020911A.

Table D13. Key results for electric power sector renewable technology cost cases

Capacity, Generation, and Emissions	2009	2015			2025			2035		
		High Renewable Technology Cost	Reference	Low Renewable Technology Cost	High Renewable Technology Cost	Reference	Low Renewable Technology Cost	High Renewable Technology Cost	Reference	Low Renewable Technology Cost
Net Summer Capacity (gigawatts)										
Electric Power Sector[1]										
Conventional Hydropower	76.87	77.60	77.52	77.74	78.23	78.59	79.66	79.38	79.85	83.07
Geothermal[2]	2.42	2.66	2.75	2.57	4.01	4.21	4.41	4.80	6.42	6.81
Municipal Waste[3]	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37	3.37
Wood and Other Biomass[4]	2.19	2.19	2.19	2.19	2.19	2.19	2.46	2.19	2.19	4.86
Solar Thermal	0.61	1.26	1.26	1.26	1.30	1.30	1.30	1.35	1.35	1.35
Solar Photovoltaic	0.07	0.15	0.15	0.15	0.32	0.32	0.33	0.46	0.52	8.25
Wind	31.45	49.10	49.10	52.04	52.88	51.76	53.82	58.89	54.83	84.27
Total	**116.98**	**136.32**	**136.33**	**139.32**	**142.30**	**141.75**	**145.35**	**150.45**	**148.53**	**191.98**
End-Use Sector[5]										
Conventional Hydropower	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Municipal Waste[6]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Wood and Other Biomass	4.86	7.12	7.26	7.64	11.06	15.14	17.31	16.97	18.06	23.18
Solar Photovoltaic	1.50	7.15	7.73	8.10	8.35	9.51	10.72	8.73	10.68	14.40
Wind	0.18	1.37	1.45	1.61	1.53	1.70	1.90	1.57	1.83	2.14
Total	**7.55**	**16.65**	**17.46**	**18.35**	**21.95**	**27.36**	**30.94**	**28.28**	**31.58**	**40.72**
Generation (billion kilowatthours)										
Electric Power Sector[1]										
Coal	1749	1775	1769	1779	2016	2016	1999	2102	2107	2059
Petroleum	36	37	38	38	40	40	41	42	42	42
Natural Gas	841	851	858	828	815	820	795	1039	1033	912
Total Fossil	**2626**	**2663**	**2665**	**2645**	**2871**	**2876**	**2834**	**3182**	**3182**	**3013**
Conventional Hydropower	270.20	293.77	293.22	293.54	303.66	305.17	310.02	308.99	310.59	322.88
Geothermal	15.21	18.87	19.63	18.20	29.71	31.36	33.01	36.10	49.19	52.54
Municipal Waste[7]	16.39	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Wood and Other Biomass[4]	10.39	22.44	20.51	34.74	58.98	38.41	66.47	43.98	32.64	82.19
Dedicated Plants	8.73	7.34	7.06	9.93	12.13	8.54	11.61	10.15	8.15	28.46
Cofiring	1.66	15.10	13.45	24.81	46.85	29.87	54.87	33.83	24.49	53.72
Solar Thermal	0.76	2.49	2.49	2.49	2.56	2.56	2.56	2.66	2.66	2.66
Solar Photovoltaic	0.04	0.36	0.36	0.36	0.78	0.80	0.82	1.14	1.31	19.69
Wind	70.82	142.55	142.52	152.48	154.36	151.48	158.22	174.69	160.88	256.57
Total Renewable	**383.82**	**495.27**	**493.52**	**516.60**	**564.86**	**544.58**	**585.89**	**582.35**	**572.06**	**751.32**
End-Use Sector[5]										
Total Fossil	**118**	**176**	**176**	**177**	**238**	**237**	**239**	**368**	**365**	**365**
Conventional Hydropower[8]	3.34	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49
Geothermal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Municipal Waste[6]	1.96	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Wood and Other Biomass	27.88	41.74	42.60	44.81	71.86	104.98	119.01	115.84	126.57	161.27
Solar Photovoltaic	2.34	10.85	11.99	12.52	12.70	14.86	16.67	13.30	16.79	22.65
Wind	0.24	1.85	1.97	2.15	2.08	2.34	2.58	2.15	2.53	2.92
Total Renewable	**35.76**	**60.49**	**62.61**	**65.54**	**92.69**	**128.22**	**144.31**	**137.33**	**151.94**	**192.89**
Carbon Dioxide Emissions by the Electric Power Sector (million metric tons)[1]										
Coal	1742.2	1720.9	1713.6	1722.6	1954.4	1951.5	1935.5	2045.5	2049.1	2000.8
Petroleum	33.5	33.1	33.3	33.2	35.5	35.0	35.8	36.9	36.7	36.8
Natural Gas	372.6	376.6	379.4	367.3	359.6	362.0	352.6	429.1	428.3	386.2
Other[9]	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Total	**2160.3**	**2142.5**	**2138.2**	**2135.1**	**2361.4**	**2360.4**	**2335.9**	**2523.5**	**2526.1**	**2435.8**

[1] Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[2] Includes hydrothermal resources only (hot water and steam).
[3] Includes all municipal waste, landfill gas, and municipal sewage sludge. Incremental growth is assumed to be for landfill gas facilities. All municipal waste is included, although a portion of the municipal waste stream contains petroleum-derived plastics and other non-renewable sources.
[4] Includes projections for energy crops after 2010.
[5] Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
[6] Includes municipal waste, landfill gas, and municipal sewage sludge. All municipal waste is included, although a portion of the municipal waste stream contains petroleum-derived plastics and other non-renewable sources.
[7] Includes biogenic municipal waste, landfill gas, and municipal sewage sludge. Incremental growth is assumed to be for landfill gas facilities.
[8] Represents own-use industrial hydroelectric power.
[9] Includes emissions from geothermal power and nonbiogenic emissions from municipal solid waste.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs HIRENCST11.D022811B, REF2011.D020911A, and LORENCST11.D022811A.

Table D14. Key results for electric power sector emissions cases
(gigawatts, unless otherwise noted)

Net Summer Capacity, Generation, Emissions, and Fuel Prices	2009	2035								
		Reference	Transport Rule Mercury MACT 20	Transport Rule Mercury MACT 5	Retrofit Required 20	Retrofit Required 5	GHG Price	High Shale EUR	Low Gas Price Retrofit Required 20	Low Gas Price Retrofit Required 5
Capacity										
Coal Steam	312.9	317.9	313.2	308.6	307.8	282.7	191.2	310.8	286.9	253.8
Oil and Natural Gas Steam	114.4	88.7	90.3	91.0	91.1	94.3	84.4	97.2	99.5	100.7
Combined Cycle	197.2	259.5	261.2	269.0	266.8	278.0	263.3	253.7	268.2	292.5
Combustion Turbine/Diesel	137.5	181.6	179.4	175.6	179.3	180.0	149.2	187.4	186.8	190.9
Nuclear Power	101.0	110.5	110.5	110.5	110.5	110.5	133.6	108.2	108.2	110.5
Pumped Storage	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
Renewable Sources	117.0	148.5	148.2	148.5	150.0	151.3	203.9	138.0	141.1	145.4
Distributed Generation (Natural Gas)	0.0	3.1	2.9	3.5	4.1	4.4	1.3	14.1	13.6	10.6
Combined Heat and Power[1]	31.5	89.5	90.6	89.8	90.1	90.5	128.0	98.4	99.2	99.6
Total	**1033.4**	**1221.2**	**1218.1**	**1218.2**	**1221.6**	**1213.5**	**1176.8**	**1229.5**	**1225.4**	**1225.8**
Cumulative Additions										
Coal Steam	0.0	13.8	13.8	13.5	14.2	14.7	13.5	13.5	13.5	13.5
Oil and Natural Gas Steam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle	0.0	62.7	64.4	72.1	69.9	81.2	66.4	56.8	71.3	95.6
Combustion Turbine/Diesel	0.0	47.9	45.8	41.9	45.3	44.2	18.7	51.7	50.7	55.0
Nuclear Power	0.0	6.3	6.3	6.3	6.3	6.3	29.5	6.3	6.3	6.3
Renewable Sources	0.0	31.6	31.3	31.6	33.1	34.4	87.0	21.1	24.2	28.5
Distributed Generation	0.0	3.1	2.9	3.5	4.1	4.4	1.3	14.1	13.6	10.6
Combined Heat and Power[1]	0.0	58.0	59.1	58.3	58.6	59.1	96.4	66.6	67.5	67.8
Total	**0.0**	**223.4**	**223.5**	**227.2**	**231.6**	**244.2**	**312.9**	**230.1**	**247.2**	**277.5**
Cumulative Retirements	**0.0**	**39.3**	**42.5**	**46.1**	**47.2**	**67.8**	**173.4**	**38.0**	**59.2**	**89.0**
Retrofits										
Scrubber	0.0	53.6	59.7	38.1	145.0	119.3	32.4	38.2	127.3	92.8
Nitrogen Oxides Controls	0.0	51.6	44.4	43.4	40.6	35.6	34.5	50.9	34.5	26.3
SCR Post-combustion	0.0	94.7	71.9	45.5	223.5	198.4	51.7	75.2	203.0	170.3
SNCR Post-combustion	0.0	8.3	8.3	32.7	5.2	6.1	13.4	18.4	5.2	5.1
Generation by Fuel (billion kilowatthours)										
Coal	1749	2107	2051	1955	2066	1903	699	1933	1893	1689
Petroleum	36	42	41	41	46	47	37	41	45	43
Natural Gas	841	1033	1072	1150	1063	1205	1345	1214	1236	1416
Nuclear Power	799	874	874	874	874	874	1052	856	856	874
Pumped Storage	2	-0	-0	-0	-0	-0	-0	-0	-0	-0
Renewable Sources	384	572	576	583	568	567	842	551	555	553
Distributed Generation	0	5	5	4	3	3	1	45	43	30
Combined Heat and Power[1]	167	533	541	535	539	540	785	603	610	611
Total	**3978**	**5167**	**5161**	**5143**	**5159**	**5140**	**4762**	**5244**	**5238**	**5217**
Emissions by the Electric Power Sector [2]										
Carbon Dioxide (million metric tons)	2160	2526	2494	2424	2507	2390	1082	2443	2422	2265
Sulfur Dioxide (million tons)	5.72	3.93	3.38	3.37	1.99	1.84	2.26	3.83	1.79	1.65
Nitrogen Oxides (million tons)	1.99	2.03	2.19	2.20	1.44	1.37	0.93	1.99	1.39	1.30
Mercury (tons)	40.66	29.32	7.68	7.19	8.34	7.69	9.19	26.51	7.47	6.79
Prices to the Electric Power Sector[2] (2009 dollars per million Btu)										
Natural Gas	4.82	6.80	6.86	7.02	6.88	7.08	11.04	5.34	5.26	5.55
Coal	2.20	2.40	2.41	2.38	2.37	2.29	9.31	2.30	2.27	2.20

[1]Includes combined heat and power plants and electricity-only plants in commercial and industrial sectors. Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. Excludes off-grid photovoltaics and other generators not connected to the distribution or transmission systems.
[2]Includes electricity-only and combined heat and power plants whose primary business to sell electricity, or electricity and heat, to the public.
EUR = Estimated ultimate recovery.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Source: U.S. Energy Information Administration, AEO2011 National Energy Modeling System runs REF2011.D020911A, and TRMA20.D021811A, TRMA05.D021811A, BAMA20.D021811A, BAMA05.D021811A, POLMAX.D031411A, HSHLEUR.D020911A, LGBAMA20.D021811A, and LGBAMA05.D021811A.

Table D15. Liquid fuels supply and disposition, E15 availability cases
(million barrels per day, unless otherwise noted)

Supply, Disposition, and Prices	2009	2015			2025			2035		
		Low E15 Penetration	Reference	High E15 Penetration	Low E15 Penetration	Reference	High E15 Penetration	Low E15 Penetration	Reference	High E15 Penetration
Prices (2009 dollars per barrel)										
Imported Low Sulfur Light Crude Oil[1]	**61.66**	**94.58**	**94.58**	**94.12**	**117.38**	**117.54**	**117.33**	**124.91**	**124.94**	**124.71**
Imported Crude Oil[1]	**59.04**	**86.84**	**86.83**	**86.39**	**107.22**	**107.40**	**107.13**	**113.62**	**113.70**	**113.42**
Crude Oil Supply										
Domestic Crude Oil Production[2]	5.36	5.82	5.81	5.81	5.88	5.88	5.87	5.89	5.95	5.89
Alaska	0.65	0.49	0.49	0.49	0.41	0.41	0.41	0.39	0.39	0.39
Lower 48 Onshore	3.00	3.52	3.51	3.51	3.92	3.92	3.91	3.59	3.65	3.59
Lower 48 Offshore	1.71	1.81	1.81	1.81	1.55	1.55	1.55	1.91	1.91	1.91
Net Crude Oil Imports	8.97	8.71	8.70	8.58	8.27	8.25	8.19	8.21	8.25	8.14
Other Crude Oil Supply	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Crude Oil Supply	**14.33**	**14.53**	**14.52**	**14.40**	**14.15**	**14.13**	**14.06**	**14.10**	**14.20**	**14.04**
Other Petroleum Supply	**3.59**	**4.37**	**4.38**	**4.36**	**4.41**	**4.41**	**4.44**	**4.45**	**4.46**	**4.49**
Natural Gas Plant Liquids	1.91	2.22	2.23	2.22	2.67	2.68	2.68	2.94	2.94	2.95
Net Petroleum Product Imports[3]	0.75	1.14	1.14	1.11	0.81	0.81	0.83	0.66	0.64	0.67
Refinery Processing Gain[4]	0.98	1.01	1.01	1.02	0.92	0.92	0.93	0.85	0.88	0.88
Product Stock Withdrawal	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Non-petroleum Supply	**0.81**	**1.42**	**1.42**	**1.62**	**2.35**	**2.40**	**2.41**	**3.36**	**3.28**	**3.35**
From Renewable Sources[5]	0.76	1.12	1.12	1.27	1.92	1.92	1.89	2.58	2.48	2.53
Ethanol	0.73	1.01	1.03	1.18	1.60	1.60	1.58	1.86	1.83	1.80
Domestic Production	0.72	0.95	0.97	1.11	1.44	1.44	1.43	1.59	1.58	1.54
Net Imports	0.01	0.05	0.06	0.07	0.16	0.16	0.16	0.28	0.26	0.26
Biodiesel	0.02	0.09	0.08	0.07	0.12	0.12	0.13	0.13	0.13	0.13
Domestic Production	0.03	0.09	0.07	0.07	0.12	0.12	0.12	0.13	0.13	0.13
Net Imports	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Biomass-derived Liquids	0.00	0.02	0.02	0.01	0.19	0.19	0.19	0.58	0.52	0.61
Liquids from Coal	0.00	0.05	0.05	0.04	0.17	0.19	0.18	0.51	0.55	0.54
Other[6]	0.05	0.25	0.25	0.31	0.27	0.30	0.33	0.27	0.25	0.28
Total Primary Supply[7]	**18.73**	**20.31**	**20.32**	**20.38**	**20.91**	**20.94**	**20.91**	**21.91**	**21.94**	**21.88**
Refined Petroleum Products Supplied										
Liquefied Petroleum Gases	2.13	2.33	2.32	2.32	2.33	2.33	2.33	2.19	2.19	2.19
E85[8]	0.00	0.01	0.01	0.01	0.81	0.64	0.28	1.01	0.84	0.42
Motor Gasoline[9]	9.00	9.40	9.40	9.45	8.67	8.87	9.21	9.08	9.28	9.67
Jet Fuel[10]	1.39	1.55	1.55	1.55	1.68	1.68	1.68	1.75	1.75	1.75
Distillate Fuel Oil[11]	3.63	4.14	4.13	4.14	4.49	4.49	4.49	4.87	4.87	4.86
of which: Diesel	3.18	3.68	3.68	3.68	4.09	4.09	4.09	4.50	4.51	4.50
Residual Fuel Oil	0.51	0.60	0.60	0.59	0.61	0.61	0.61	0.62	0.62	0.62
Other[12]	2.15	2.44	2.43	2.42	2.38	2.38	2.37	2.39	2.38	2.36
Total	**18.81**	**20.45**	**20.44**	**20.48**	**20.97**	**20.99**	**20.95**	**21.90**	**21.93**	**21.87**
Discrepancy[13]	**-0.08**	**-0.13**	**-0.12**	**-0.10**	**-0.06**	**-0.04**	**-0.04**	**0.01**	**0.01**	**0.01**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes lease condensate.
[3]Includes net imports of finished petroleum products, unfinished oils, other hydrocarbons, alcohols, ethers, and blending components.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes ethanol (including imports), biodiesel (including imports), pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks for the production of green diesel and gasoline.
[6]Includes alcohols, ethers, domestic sources of blending components, and other hydrocarbons.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold-starting issues, the percentage of ethanol varies seasonally. The average annual ethanol content of 74 percent is used for this forecast.
[9]Includes ethanol and ethers blended into gasoline.
[10]Includes only kerosene type.
[11]Includes distillate fuel oil and kerosene from petroleum and biomass feedstocks.
[12]Includes aviation gasoline, petrochemical feedstocks, lubricants, waxes, asphalt, road oil, still gas, special naphthas, petroleum coke, crude oil product supplied, methanol, and miscellaneous petroleum products.
[13]Balancing item. Includes unaccounted for supply, losses and gains.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 product supplied data and imported crude oil price based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 imported low sulfur light crude oil price: EIA, Form EIA-856, “Monthly Foreign Crude Oil Acquisition Report.” Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs E15LOW.D030211A, REF2011.D020911A, and E15HIGH.D022811A.

Table D16. Natural gas supply and disposition, oil and gas technology progress cases
(trillion cubic feet per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	2015			2025			2035		
		Slow Technology	Reference	Rapid Technology	Slow Technology	Reference	Rapid Technology	Slow Technology	Reference	Rapid Technology
Natural Gas Prices										
(2009 dollars per million Btu)										
Henry Hub Spot Price	3.95	5.16	4.66	4.33	6.83	5.97	5.33	7.69	7.07	6.45
Average Lower 48 Wellhead Price[1]	3.62	4.57	4.13	3.83	6.04	5.29	4.72	6.81	6.26	5.71
(2009 dollars per thousand cubic feet)										
Average Lower 48 Wellhead Price[1]	3.71	4.69	4.24	3.93	6.20	5.43	4.84	6.98	6.42	5.86
Dry Gas Production[2]	**20.96**	**21.47**	**22.43**	**23.02**	**22.65**	**23.98**	**24.78**	**25.92**	**26.32**	**26.89**
Lower 48 Onshore	17.88	19.09	20.00	20.57	20.09	21.31	22.03	21.36	23.05	23.46
Associated-Dissolved	1.40	1.45	1.48	1.49	1.32	1.36	1.34	1.00	1.02	1.02
Non-Associated	16.48	17.64	18.51	19.08	18.78	19.95	20.69	20.36	22.04	22.44
Tight Gas	6.59	5.83	5.90	5.76	5.55	5.74	5.55	5.35	5.84	5.59
Shale Gas	3.28	6.32	7.20	8.00	8.66	9.69	10.69	11.14	12.25	12.92
Coalbed Methane	1.80	1.72	1.67	1.62	1.75	1.72	1.64	1.63	1.72	1.70
Other	4.80	3.77	3.74	3.69	2.82	2.81	2.80	2.24	2.23	2.23
Lower 48 Offshore	2.70	2.10	2.15	2.17	2.32	2.42	2.51	2.79	3.05	3.21
Associated-Dissolved	0.64	0.63	0.64	0.65	0.66	0.68	0.70	0.73	0.80	0.82
Non-Associated	2.05	1.47	1.51	1.52	1.66	1.74	1.81	2.07	2.26	2.39
Alaska	0.37	0.28	0.28	0.28	0.24	0.24	0.24	1.77	0.21	0.22
Supplemental Natural Gas[3]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Net Imports	**2.64**	**2.84**	**2.69**	**2.66**	**1.22**	**1.08**	**1.12**	**-0.03**	**0.18**	**0.50**
Pipeline[4]	2.23	2.46	2.33	2.32	0.84	0.74	0.82	-0.17	0.04	0.36
Liquefied Natural Gas	0.41	0.38	0.36	0.35	0.38	0.34	0.30	0.14	0.14	0.14
Total Supply	**23.66**	**24.38**	**25.18**	**25.75**	**23.94**	**25.12**	**25.97**	**25.96**	**26.57**	**27.45**
Consumption by Sector										
Residential	4.75	4.77	4.81	4.84	4.77	4.83	4.88	4.73	4.78	4.82
Commercial	3.11	3.32	3.38	3.41	3.46	3.56	3.64	3.74	3.82	3.90
Industrial[5]	6.14	7.95	8.05	8.14	7.89	8.10	8.29	7.79	8.02	8.28
Electric Power[6]	6.89	6.41	6.98	7.36	5.92	6.66	7.15	7.54	7.88	8.30
Transportation[7]	0.03	0.04	0.04	0.04	0.10	0.10	0.11	0.16	0.16	0.19
Pipeline Fuel	0.64	0.64	0.65	0.66	0.61	0.62	0.64	0.71	0.65	0.67
Lease and Plant Fuel[8]	1.16	1.17	1.20	1.23	1.14	1.19	1.22	1.26	1.25	1.28
Total	**22.71**	**24.31**	**25.11**	**25.67**	**23.88**	**25.07**	**25.92**	**25.93**	**26.55**	**27.43**
Discrepancy[9]	**0.95**	**0.07**	**0.07**	**0.07**	**0.06**	**0.05**	**0.05**	**0.03**	**0.02**	**0.02**
Lower 48 End of Year Reserves	**261.37**	**273.29**	**279.40**	**285.23**	**290.09**	**299.51**	**309.12**	**306.69**	**314.16**	**322.51**

[1]Represents lower 48 onshore and offshore supplies.
[2]Marketed production (wet) minus extraction losses.
[3]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.
[4]Includes any natural gas regasified in the Bahamas and transported via pipeline to Florida.
[5]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[6]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[7]Compressed natural gas used as a vehicle fuel.
[8]Represents natural gas used in field gathering and processing plant machinery.
[9]Balancing item. Natural gas lost as a result of converting flow data measured at varying temperatures and pressures to a standard temperature and pressure and the merger of different data reporting systems which vary in scope, format, definition, and respondent type. In addition, 2009 values include net storage injections.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 supply values: U.S. Energy Information Administration (EIA), *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 consumption based on: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs OGLTEC11.D020911A, REF2011.D020911A, and OGHTEC11.D020911A.

Table D17. Liquid fuels supply and disposition, oil and gas technology progress cases
(million barrels per day, unless otherwise noted)

Supply, Disposition, and Prices	2009	2015			2025			2035		
		Slow Technology	Reference	Rapid Technology	Slow Technology	Reference	Rapid Technology	Slow Technology	Reference	Rapid Technology
Prices (2009 dollars per barrel)										
Imported Low Sulfur Light Crude Oil[1]	**61.66**	**94.85**	**94.58**	**94.35**	**118.13**	**117.54**	**117.16**	**125.83**	**124.94**	**124.24**
Imported Crude Oil[1]	**59.04**	**87.11**	**86.83**	**86.61**	**108.18**	**107.40**	**106.93**	**114.89**	**113.70**	**112.86**
Crude Oil Supply										
Domestic Crude Oil Production[2]	5.36	5.76	5.81	5.86	5.64	5.88	5.94	5.58	5.95	6.05
Alaska	0.65	0.49	0.49	0.49	0.41	0.41	0.41	0.19	0.39	0.36
Lower 48 Onshore	3.00	3.49	3.51	3.53	3.75	3.92	3.93	3.63	3.65	3.77
Lower 48 Offshore	1.71	1.78	1.81	1.84	1.49	1.55	1.60	1.76	1.91	1.92
Net Crude Oil Imports	8.97	8.79	8.70	8.63	8.52	8.25	8.15	8.57	8.25	8.01
Other Crude Oil Supply	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Crude Oil Supply	**14.33**	**14.55**	**14.52**	**14.50**	**14.16**	**14.13**	**14.08**	**14.15**	**14.20**	**14.06**
Other Petroleum Supply	**3.59**	**4.38**	**4.38**	**4.40**	**4.29**	**4.41**	**4.48**	**4.33**	**4.46**	**4.48**
Natural Gas Plant Liquids	1.91	2.17	2.23	2.28	2.52	2.68	2.79	2.72	2.94	3.02
Net Petroleum Product Imports[3]	0.75	1.20	1.14	1.11	0.84	0.81	0.77	0.76	0.64	0.60
Refinery Processing Gain[4]	0.98	1.02	1.01	1.00	0.94	0.92	0.91	0.85	0.88	0.86
Product Stock Withdrawal	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Non-petroleum Supply	**0.81**	**1.40**	**1.42**	**1.43**	**2.40**	**2.40**	**2.41**	**3.42**	**3.28**	**3.39**
From Renewable Sources[5]	0.76	1.12	1.12	1.12	1.90	1.92	1.91	2.59	2.48	2.57
From Non-renewable Sources[6]	0.05	0.28	0.30	0.31	0.49	0.49	0.50	0.82	0.80	0.82
Total Primary Supply[7]	**18.73**	**20.33**	**20.32**	**20.33**	**20.85**	**20.94**	**20.98**	**21.89**	**21.94**	**21.93**
Refined Petroleum Products Supplied										
Residential and Commercial	1.04	0.95	0.95	0.95	0.88	0.88	0.88	0.85	0.85	0.85
Industrial[8]	4.25	5.00	4.99	4.98	4.93	4.94	4.95	4.78	4.77	4.77
Transportation	13.61	14.31	14.31	14.32	14.92	14.96	14.97	16.07	16.10	16.09
Electric Power[9]	0.18	0.20	0.19	0.19	0.21	0.20	0.20	0.22	0.21	0.21
Total	**18.81**	**20.46**	**20.44**	**20.45**	**20.94**	**20.99**	**21.01**	**21.91**	**21.93**	**21.93**
Discrepancy[10]	**-0.08**	**-0.13**	**-0.12**	**-0.12**	**-0.09**	**-0.04**	**-0.03**	**-0.02**	**0.01**	**0.01**
Lower 48 End of Year Reserves (billion barrels)[2]	**17.88**	**19.47**	**19.69**	**19.85**	**21.46**	**21.89**	**22.07**	**22.18**	**22.76**	**23.01**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes lease condensate.
[3]Includes net imports of finished petroleum products, unfinished oils, other hydrocarbons, alcohols, ethers, and blending components.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes ethanol (including imports), biodiesel (including imports), pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks for the production of green diesel and gasoline.
[6]Includes alcohols, ethers, domestic sources of blending components, other hydrocarbons, natural gas converted to liquid fuel, and coal converted to liquid fuel.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]Includes consumption for combined heat and power, which produces electricity and other useful thermal energy.
[9]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[10]Balancing item. Includes unaccounted for supply, losses and gains.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 product supplied data and imported crude oil price based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 imported low sulfur light crude oil price: EIA, Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs OGLTEC11.D020911A, REF2011.D020911A, and OGHTEC11.D020911A.

Table D18. Liquid fuels supply and disposition, enhanced oil recovery cases
(million barrels per day, unless otherwise noted)

Supply, Disposition, and Prices	2009	2025				2035			
		Low EOR	Reference	Low EOR – GHG Price	GHG Price	Low EOR	Reference	Low EOR – GHG Price	GHG Price
Prices (2009 dollars per barrel)									
Imported Low Sulfur Light Crude Oil[1]	**61.66**	**117.83**	**117.54**	**115.34**	**115.29**	**125.24**	**124.94**	**120.78**	**120.80**
Imported Crude Oil[1]	**59.04**	**107.81**	**107.40**	**104.50**	**104.41**	**114.08**	**113.70**	**108.79**	**108.77**
Crude Oil Supply									
Domestic Crude Oil Production[2]	5.36	5.76	5.88	5.88	5.90	5.81	5.95	5.95	5.98
Alaska	0.65	0.41	0.41	0.41	0.41	0.39	0.39	0.19	0.19
Lower 48 Onshore	3.00	3.80	3.92	3.92	3.94	3.52	3.65	3.86	3.89
Lower 48 Offshore	1.71	1.55	1.55	1.55	1.55	1.90	1.91	1.90	1.90
Net Crude Oil Imports	8.97	8.36	8.25	7.68	7.66	8.38	8.25	7.00	7.10
Other Crude Oil Supply	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Crude Oil Supply	**14.33**	**14.13**	**14.13**	**13.56**	**13.57**	**14.19**	**14.20**	**12.95**	**13.08**
Other Petroleum Supply	**3.59**	**4.41**	**4.41**	**4.47**	**4.47**	**4.44**	**4.46**	**4.13**	**4.05**
Natural Gas Plant Liquids	1.91	2.67	2.68	2.93	2.93	2.94	2.94	2.98	2.98
Net Petroleum Product Imports[3]	0.75	0.82	0.81	0.66	0.67	0.63	0.64	0.38	0.31
Refinery Processing Gain[4]	0.98	0.92	0.92	0.87	0.87	0.87	0.88	0.77	0.76
Product Stock Withdrawal	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Non-petroleum Supply	**0.81**	**2.40**	**2.40**	**2.62**	**2.62**	**3.32**	**3.28**	**4.35**	**4.30**
From Renewable Sources[5]	0.76	1.92	1.92	2.14	2.13	2.51	2.48	3.52	3.48
From Non-renewable Sources[6]	0.05	0.48	0.49	0.49	0.49	0.81	0.80	0.82	0.83
Total Primary Supply[7]	**18.73**	**20.94**	**20.94**	**20.65**	**20.65**	**21.94**	**21.94**	**21.43**	**21.44**
Refined Petroleum Products Supplied									
Residential and Commercial	1.04	0.88	0.88	0.87	0.87	0.85	0.85	0.83	0.83
Industrial[8]	4.25	4.93	4.94	4.82	4.82	4.77	4.77	4.58	4.58
Transportation	13.61	14.96	14.96	14.73	14.73	16.09	16.10	15.79	15.80
Electric Power[9]	0.18	0.21	0.20	0.19	0.19	0.22	0.21	0.19	0.19
Total	**18.81**	**20.98**	**20.99**	**20.61**	**20.61**	**21.93**	**21.93**	**21.39**	**21.40**
Discrepancy[10]	**-0.08**	**-0.04**	**-0.04**	**0.04**	**0.04**	**0.01**	**0.01**	**0.04**	**0.03**
Lower 48 End of Year Reserves (billion barrels)[2]	**17.88**	**21.60**	**21.89**	**21.88**	**22.06**	**22.32**	**22.76**	**22.96**	**23.19**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes lease condensate.
[3]Includes net imports of finished petroleum products, unfinished oils, other hydrocarbons, alcohols, ethers, and blending components.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes ethanol (including imports), biodiesel (including imports), pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks for the production of green diesel and gasoline.
[6]Includes alcohols, ethers, domestic sources of blending components, other hydrocarbons, natural gas converted to liquid fuel, and coal converted to liquid fuel.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]Includes consumption for combined heat and power, which produces electricity and other useful thermal energy.
[9]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[10]Balancing item. Includes unaccounted for supply, losses and gains.
EOR = Enhanced oil recovery.
GHG = Greenhouse gas.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 product supplied data and imported crude oil price based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 imported low sulfur light crude oil price: EIA, Form EIA-856, “Monthly Foreign Crude Oil Acquisition Report.” Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LOWCO2.D030711A, REF2011.D020911A, POLMAXLCO2.D032111A, and POLMAX.D031411A.

Table D19. Liquid fuels supply and disposition, Outer Continental Shelf resource cases
(million barrels per day, unless otherwise noted)

Supply, Disposition, and Prices	2009	2025				2035			
		High OCS Costs	Reduced OCS Access	Reference	High OCS Resource	High OCS Costs	Reduced OCS Access	Reference	High OCS Resource
Prices (2009 dollars per barrel)									
Imported Low Sulfur Light Crude Oil[1]	**61.66**	**117.71**	**117.51**	**117.54**	**117.12**	**125.47**	**125.93**	**124.94**	**122.04**
Imported Crude Oil[1]	**59.04**	**107.67**	**107.41**	**107.40**	**106.91**	**114.44**	**115.13**	**113.70**	**110.47**
Crude Oil Supply									
Domestic Crude Oil Production[2]	5.36	5.80	5.87	5.88	5.93	5.72	5.57	5.95	7.01
Alaska	0.65	0.41	0.41	0.41	0.47	0.19	0.19	0.39	1.11
Lower 48 Onshore	3.00	3.89	3.92	3.92	3.91	3.64	3.63	3.65	3.60
Lower 48 Offshore	1.71	1.50	1.55	1.55	1.55	1.89	1.74	1.91	2.30
Net Crude Oil Imports	8.97	8.33	8.26	8.25	8.20	8.44	8.61	8.25	7.19
Other Crude Oil Supply	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Crude Oil Supply	**14.33**	**14.13**	**14.13**	**14.13**	**14.13**	**14.16**	**14.18**	**14.20**	**14.20**
Other Petroleum Supply	**3.59**	**4.43**	**4.44**	**4.41**	**4.40**	**4.44**	**4.43**	**4.46**	**4.53**
Natural Gas Plant Liquids	1.91	2.67	2.68	2.68	2.68	2.92	2.93	2.94	2.95
Net Petroleum Product Imports[3]	0.75	0.83	0.83	0.81	0.80	0.66	0.63	0.64	0.67
Refinery Processing Gain[4]	0.98	0.93	0.93	0.92	0.92	0.87	0.86	0.88	0.91
Product Stock Withdrawal	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Non-petroleum Supply	**0.81**	**2.40**	**2.38**	**2.40**	**2.38**	**3.30**	**3.29**	**3.28**	**3.30**
From Renewable Sources[5]	0.76	1.91	1.91	1.92	1.91	2.50	2.50	2.48	2.50
From Non-renewable Sources[6]	0.05	0.48	0.47	0.49	0.47	0.80	0.79	0.80	0.79
Total Primary Supply[7]	**18.73**	**20.95**	**20.95**	**20.94**	**20.91**	**21.90**	**21.90**	**21.94**	**22.02**
Refined Petroleum Products Supplied									
Residential and Commercial	1.04	0.88	0.88	0.88	0.88	0.85	0.85	0.85	0.85
Industrial[8]	4.25	4.94	4.94	4.94	4.94	4.77	4.76	4.77	4.78
Transportation	13.61	14.97	14.96	14.96	14.95	16.07	16.07	16.10	16.13
Electric Power[9]	0.18	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.21
Total	**18.81**	**20.99**	**20.98**	**20.99**	**20.97**	**21.91**	**21.89**	**21.93**	**21.97**
Discrepancy[10]	**-0.08**	**-0.04**	**-0.03**	**-0.04**	**-0.06**	**-0.00**	**0.00**	**0.01**	**0.05**
Lower 48 End of Year Reserves (billion barrels)[2]	**17.88**	**21.79**	**21.87**	**21.89**	**21.88**	**22.67**	**22.00**	**22.76**	**23.91**

[1]Weighted average price delivered to U.S. refiners.
[2]Includes lease condensate.
[3]Includes net imports of finished petroleum products, unfinished oils, other hydrocarbons, alcohols, ethers, and blending components.
[4]The volumetric amount by which total output is greater than input due to the processing of crude oil into products which, in total, have a lower specific gravity than the crude oil processed.
[5]Includes ethanol (including imports), biodiesel (including imports), pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks for the production of green diesel and gasoline.
[6]Includes alcohols, ethers, domestic sources of blending components, other hydrocarbons, natural gas converted to liquid fuel, and coal converted to liquid fuel.
[7]Total crude supply plus natural gas plant liquids, other inputs, refinery processing gain, and net product imports.
[8]Includes consumption for combined heat and power, which produces electricity and other useful thermal energy.
[9]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[10]Balancing item. Includes unaccounted for supply, losses and gains.
OCS = Outer continental shelf.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 product supplied data and imported crude oil price based on: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). 2009 imported low sulfur light crude oil price: EIA, Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." Other 2009 data: EIA, *Petroleum Supply Annual 2009,* DOE/EIA-0340(2009)/1 (Washington, DC, July 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs OCSHCST.D031811A, OCSACCESS.D032911A, REF2011.D020911A, and OCSHRES3S.D032911A.

Table D20. Natural gas supply and disposition, shale gas recovery cases
(trillion cubic feet per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	2025					2035				
		Low Shale EUR	Low Shale Recovery	Reference	High Shale Recovery	High Shale EUR	Low Shale EUR	Low Shale Recovery	Reference	High Shale Recovery	High Shale EUR
Natural Gas Prices											
(2009 dollars per million Btu)											
Henry Hub Spot Price	3.95	8.53	7.38	5.97	5.16	4.45	9.26	8.17	7.07	6.03	5.35
Average Lower 48 Wellhead Price[1]	3.62	7.55	6.54	5.29	4.57	3.94	8.20	7.23	6.26	5.34	4.74
(2009 dollars per thousand cubic feet)											
Average Lower 48 Wellhead Price[1]	3.71	7.74	6.71	5.43	4.69	4.05	8.41	7.42	6.42	5.48	4.86
Dry Gas Production[2]	**20.96**	**20.03**	**21.46**	**23.98**	**25.81**	**27.50**	**22.43**	**24.61**	**26.32**	**28.49**	**30.11**
Lower 48 Onshore	17.88	17.07	18.71	21.31	23.23	24.98	17.17	19.62	23.05	25.51	27.24
Associated-Dissolved	1.40	1.34	1.36	1.36	1.34	1.33	1.02	1.02	1.02	1.02	1.02
Non-Associated	16.48	15.73	17.35	19.95	21.89	23.64	16.14	18.60	22.04	24.49	26.22
Tight Gas	6.59	6.54	6.27	5.74	5.56	5.43	6.35	6.20	5.84	5.48	5.26
Shale Gas	3.28	4.37	6.44	9.69	11.88	13.82	5.50	8.24	12.25	15.12	17.13
Coalbed Methane	1.80	1.99	1.85	1.72	1.63	1.62	2.06	1.91	1.72	1.65	1.62
Other	4.80	2.82	2.80	2.81	2.82	2.78	2.23	2.24	2.23	2.23	2.22
Lower 48 Offshore	2.70	2.72	2.52	2.42	2.34	2.28	3.48	3.21	3.05	2.76	2.66
Associated-Dissolved	0.64	0.73	0.69	0.68	0.67	0.66	0.84	0.80	0.80	0.72	0.70
Non-Associated	2.05	2.00	1.83	1.74	1.67	1.62	2.64	2.41	2.26	2.05	1.96
Alaska	0.37	0.24	0.24	0.24	0.24	0.24	1.78	1.78	0.21	0.21	0.21
Supplemental Natural Gas[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Net Imports	**2.64**	**2.44**	**1.89**	**1.08**	**0.59**	**0.26**	**1.66**	**0.72**	**0.18**	**-0.27**	**-0.54**
Pipeline[5]	2.23	1.97	1.48	0.74	0.30	0.01	1.52	0.58	0.04	-0.41	-0.68
Liquefied Natural Gas	0.41	0.48	0.42	0.34	0.30	0.26	0.14	0.14	0.14	0.14	0.14
Total Supply	**23.66**	**22.54**	**23.42**	**25.12**	**26.47**	**27.82**	**24.15**	**25.39**	**26.57**	**28.28**	**29.63**
Consumption by Sector											
Residential	4.75	4.66	4.73	4.83	4.90	4.96	4.63	4.70	4.78	4.85	4.91
Commercial	3.11	3.29	3.41	3.56	3.66	3.76	3.58	3.69	3.82	3.95	4.06
Industrial[6]	6.14	7.61	7.81	8.10	8.36	8.62	7.51	7.77	8.02	8.37	8.68
Electric Power[7]	6.89	5.17	5.61	6.66	7.50	8.30	6.43	7.14	7.88	8.89	9.62
Transportation[8]	0.03	0.08	0.09	0.10	0.11	0.14	0.15	0.15	0.16	0.20	0.25
Pipeline Fuel	0.64	0.61	0.61	0.62	0.64	0.67	0.69	0.69	0.65	0.68	0.70
Lease and Plant Fuel[9]	1.16	1.05	1.10	1.19	1.26	1.33	1.14	1.22	1.25	1.33	1.39
Total	**22.71**	**22.48**	**23.37**	**25.07**	**26.42**	**27.78**	**24.12**	**25.37**	**26.55**	**28.26**	**29.62**
Discrepancy[10]	**0.95**	**0.06**	**0.05**	**0.05**	**0.05**	**0.04**	**0.03**	**0.03**	**0.02**	**0.02**	**0.02**
Lower 48 End of Year Reserves	**261.37**	**278.92**	**283.19**	**299.51**	**315.25**	**322.81**	**295.54**	**299.40**	**314.16**	**331.79**	**336.03**

[1]Represents lower 48 onshore and offshore supplies.
[2]Marketed production (wet) minus extraction losses.
[3]Includes tight gas.
[4]Synthetic natural gas, propane air, coke oven gas, refinery gas, biomass gas, air injected for Btu stabilization, and manufactured gas commingled and distributed with natural gas.
[5]Includes any natural gas regasified in the Bahamas and transported via pipeline to Florida.
[6]Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes consumption of energy by electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.
[8]Compressed natural gas used as a vehicle fuel.
[9]Represents natural gas used in field gathering and processing plant machinery.
[10]Balancing item. Natural gas lost as a result of converting flow data measured at varying temperatures and pressures to a standard temperature and pressure and the merger of different data reporting systems which vary in scope, format, definition, and respondent type. In addition, 2009 values include net storage injections.
EUR = Estimated ultimate recovery.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 supply values: U.S. Energy Information Administration (EIA), *Natural Gas Monthly*, DOE/EIA-0130(2010/07) (Washington, DC, July 2010). 2009 consumption based on: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **Projections:** EIA, AEO2011 National Energy Modeling System runs LSHLEUR.D020911A, LSHLDRL.D020911A, REF2011.D020911A, HSHLDRL.D020911A, and HSHLEUR.D020911A.

Table D21. International liquids supply and disposition, world oil price cases
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	2025					2035				
		Low Oil Price	Traditional Low Oil Price	Reference	Traditional High Oil Price	High Oil Price	Low Oil Price	Traditional Low Oil Price	Reference	Traditional High Oil Price	High Oil Price
Crude Oil Prices[1]											
(2009 dollars per barrel)											
Imported Low Sulfur Light Crude Oil	61.66	51.28	51.28	117.54	185.87	185.87	50.07	50.07	124.94	199.95	199.95
Imported Crude Oil	59.04	41.36	41.36	107.40	175.09	175.09	39.66	39.66	113.70	187.79	187.79
(nominal dollars per barrel)											
Imported Low Sulfur Light Crude Oil	61.66	68.94	68.94	155.46	246.11	246.11	81.59	81.59	199.37	321.76	321.76
Imported Crude Oil	59.04	55.61	55.61	142.05	231.84	231.84	64.62	64.62	181.43	302.20	302.20
Conventional Production (Conventional)[2]											
OPEC[3]											
Middle East	22.61	31.81	37.59	28.64	23.01	27.48	34.74	45.10	33.87	22.96	30.24
North Africa	3.92	4.15	5.35	3.84	3.12	3.72	3.94	5.68	3.98	2.76	3.70
West Africa	4.06	6.54	6.52	5.10	3.93	4.90	6.81	7.21	5.31	3.37	4.86
South America	2.31	1.86	2.38	1.73	1.42	1.68	1.62	2.29	1.64	1.18	1.54
Total OPEC	**32.91**	**44.35**	**51.85**	**39.32**	**31.47**	**37.78**	**47.10**	**60.29**	**44.80**	**30.28**	**40.33**
Non-OPEC											
OECD											
United States (50 states)	8.26	9.07	9.07	9.78	10.89	10.89	8.45	8.45	9.89	10.70	10.70
Canada	1.96	1.78	1.79	1.78	1.84	1.84	1.71	1.75	1.78	1.87	1.94
Mexico	2.90	1.35	1.35	1.22	1.20	1.19	1.50	1.57	1.48	1.41	1.52
OECD Europe[4]	4.62	2.73	2.77	2.67	2.61	2.61	2.48	2.64	2.66	2.51	2.73
Japan	0.13	0.15	0.17	0.14	0.13	0.14	0.16	0.18	0.15	0.13	0.14
Australia and New Zealand	0.65	0.53	0.53	0.52	0.51	0.51	0.49	0.52	0.54	0.51	0.55
Total OECD	**18.52**	**15.62**	**15.68**	**16.13**	**17.18**	**17.18**	**14.79**	**15.11**	**16.49**	**17.13**	**17.59**
Non-OECD											
Russia	9.66	12.43	12.41	10.86	10.59	10.41	12.90	13.63	12.64	12.03	13.15
Other Europe and Eurasia[5]	3.08	4.47	4.47	3.97	3.88	3.81	4.48	4.73	4.47	4.26	4.64
China	3.93	4.10	4.12	4.02	3.93	3.89	3.83	4.08	4.22	3.99	4.40
Other Asia[6]	3.70	3.03	3.04	2.99	2.93	2.91	2.63	2.77	2.85	2.71	2.94
Middle East	1.54	1.26	1.26	1.24	1.22	1.20	0.98	1.04	1.10	1.05	1.15
Africa	2.34	2.89	2.89	2.85	2.80	2.75	2.82	2.99	3.16	3.03	3.32
Brazil	2.05	4.41	4.40	3.87	3.78	3.72	5.02	5.29	4.93	4.71	5.11
Other Central and South America	1.87	2.27	2.27	2.24	2.20	2.17	2.35	2.47	2.59	2.48	2.70
Total Non-OECD	**28.17**	**34.86**	**34.86**	**32.03**	**31.32**	**30.85**	**35.00**	**36.99**	**35.95**	**34.27**	**37.41**
Total Conventional Production	**79.60**	**94.83**	**102.39**	**87.47**	**79.97**	**85.81**	**96.89**	**112.38**	**97.24**	**81.67**	**95.33**
Unconventional Production[7]											
United States (50 states)	0.75	1.55	1.55	1.94	3.01	3.01	1.95	1.95	2.90	5.42	5.42
Other North America	1.68	2.70	2.70	3.57	5.38	5.38	3.32	3.32	5.27	7.11	7.11
OECD Europe[3]	0.22	0.11	0.11	0.26	0.29	0.29	0.18	0.18	0.28	0.33	0.33
Middle East	0.01	0.19	0.19	0.24	0.21	0.21	0.19	0.19	0.24	0.21	0.21
Africa.	0.21	0.16	0.16	0.39	0.40	0.40	0.16	0.16	0.44	0.46	0.46
Central and South America	1.14	3.28	3.28	2.61	2.98	2.98	4.70	4.70	3.17	3.60	3.60
Other	0.12	0.25	0.25	0.64	0.88	0.88	0.50	0.50	1.22	2.61	2.61
Total Unconventional Production	**4.14**	**8.23**	**8.23**	**9.66**	**13.15**	**13.15**	**11.00**	**11.00**	**13.54**	**19.72**	**19.72**
Total Production	**83.74**	**103.06**	**110.62**	**97.13**	**93.11**	**98.96**	**107.90**	**123.39**	**110.78**	**101.40**	**115.06**

Table D21. International liquids supply and disposition, world oil price cases (continued)
(million barrels per day, unless otherwise noted)

Supply and Disposition	2009	2025					2035				
		Low Oil Price	Traditional Low Oil Price	Reference	Traditional High Oil Price	High Oil Price	Low Oil Price	Traditional Low Oil Price	Reference	Traditional High Oil Price	High Oil Price
Consumption[8]											
OECD											
United States (50 states)	18.81	22.34	22.34	20.99	20.18	20.18	23.76	23.76	21.93	20.91	20.91
United States Territories	0.27	0.30	0.34	0.30	0.29	0.32	0.28	0.36	0.32	0.30	0.36
Canada	2.15	2.48	2.47	2.14	2.01	2.01	2.64	2.60	2.24	2.08	2.08
Mexico	2.13	2.57	2.60	2.30	2.18	2.20	3.02	3.03	2.63	2.47	2.51
OECD Europe[3]	14.49	14.61	14.76	12.82	12.05	12.14	14.91	15.01	12.95	12.00	12.11
Japan	4.37	4.49	4.57	3.98	3.72	3.75	4.37	4.41	3.88	3.52	3.55
South Korea	2.32	3.01	3.04	2.63	2.52	2.54	3.45	3.47	3.13	2.87	2.89
Australia and New Zealand	1.19	1.26	1.27	1.13	1.09	1.08	1.30	1.30	1.17	1.10	1.10
Total OECD	**45.73**	**51.06**	**51.38**	**46.29**	**44.03**	**44.23**	**53.72**	**53.93**	**48.25**	**45.25**	**45.51**
Non-OECD											
Russia	2.83	2.73	3.02	2.66	2.54	2.71	2.59	3.17	2.78	2.60	3.01
Other Europe and Eurasia[5]	2.16	2.41	2.78	2.25	2.12	2.36	2.33	3.03	2.48	2.22	2.70
China	8.32	15.60	17.77	14.36	14.06	15.97	16.50	21.16	19.13	16.31	20.68
India	3.06	4.80	5.41	4.54	4.28	4.82	4.96	6.31	5.64	4.93	6.12
Other Asia	6.13	8.01	9.25	7.98	7.59	8.46	8.69	11.21	9.75	8.89	10.94
Middle East	6.64	8.27	9.31	8.76	8.69	9.50	9.01	11.42	11.02	10.32	12.81
Africa	3.31	3.82	4.39	3.76	3.55	3.97	3.96	5.12	4.45	4.04	4.94
Brazil	2.46	3.10	3.60	3.20	3.06	3.42	3.16	4.20	3.79	3.57	4.40
Other Central and South America	3.09	3.27	3.72	3.33	3.19	3.52	3.00	3.86	3.51	3.28	3.94
Total Non-OECD	**38.01**	**52.00**	**59.24**	**50.84**	**49.08**	**54.73**	**54.20**	**69.48**	**62.54**	**56.15**	**69.54**
Total Consumption	**83.74**	**103.06**	**110.62**	**97.13**	**93.11**	**98.95**	**107.92**	**123.41**	**110.79**	**101.40**	**115.06**
OPEC Production[9]	33.45	47.25	54.75	40.77	33.03	39.34	50.88	64.06	46.50	32.08	42.14
Non-OPEC Production[9]	50.29	55.81	55.88	56.37	60.09	59.62	57.02	59.33	64.28	69.32	72.92
Net Eurasia Exports	9.80	16.17	15.49	13.80	13.59	12.87	17.48	17.44	16.78	16.19	17.18
OPEC Market Share (percent)	39.9	45.8	49.5	42.0	35.5	39.8	47.2	51.9	42.0	31.6	36.6

[1]Weighted average price delivered to U.S. refiners.
[2]Includes production of crude oil (including lease condensate), natural gas plant liquids, other hydrogen and hydrocarbons for refinery feedstocks, alcohol and other sources, and refinery gains.
[3]OPEC = Organization of Petroleum Exporting Countries - Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.
[4]OECD Europe = Organization for Economic Cooperation and Development - Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.
[5]Other Europe and Eurasia = Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Malta, Moldova, Montenegro, Romania, Serbia, Slovenia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
[6]Other Asia = Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia (Kampuchea), Fiji, French Polynesia, Guam, Hong Kong, Indonesia, Kiribati, Laos, Malaysia, Macau, Maldives, Mongolia, Myanmar (Burma), Nauru, Nepal, New Caledonia, Niue, North Korea, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand, Tonga, Vanuatu, and Vietnam.
[7]Includes liquids produced from energy crops, natural gas, coal, extra-heavy oil, oil sands, and shale. Includes both OPEC and non-OPEC producers in the regional breakdown.
[8]Includes both OPEC and non-OPEC consumers in the regional breakdown.
[9]Includes both conventional and unconventional liquids production.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 low sulfur light crude oil price: U.S. Energy Information Administration (EIA), Form EIA-856, "Monthly Foreign Crude Oil Acquisition Report." 2009 imported crude oil price: EIA, *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010). **2009 quantities and projections:** EIA, AEO2011 National Energy Modeling System runs LP2011LNO.D022511A, LP2011MNO.D020911A, REF2011.D020911A, HP2011MNO.D022811A, and HP2011HNO.D022511A and EIA, Generate World Oil Balance Model.

Table D22. Key results for the No Greenhouse Gas Concern case
(million short tons per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	2015		2025		2035	
		Reference	No GHG Concern	Reference	No GHG Concern	Reference	No GHG Concern
Production[1]	**1075**	**1040**	**1032**	**1188**	**1303**	**1319**	**1512**
Appalachia	343	274	277	282	293	282	297
Interior	147	156	158	166	176	177	195
West	585	610	597	739	834	860	1020
Waste Coal Supplied[2]	**12**	**14**	**14**	**14**	**15**	**14**	**17**
Net Imports[3]	**-38**	**-40**	**-40**	**-19**	**-18**	**-18**	**-16**
Total Supply[4]	**1049**	**1014**	**1006**	**1183**	**1300**	**1315**	**1513**
Consumption by Sector							
Residential and Commercial	3	3	3	3	3	3	3
Coke Plants	15	22	22	21	21	18	18
Other Industrial[5]	45	49	49	48	48	47	47
Coal-to-Liquids Heat and Power	0	6	6	23	86	66	166
Coal-to-Liquids Liquids Production	0	5	6	21	80	62	156
Electric Power[6]	937	928	919	1066	1061	1119	1124
Total Coal Use	**1000**	**1013**	**1005**	**1182**	**1300**	**1315**	**1513**
Average Minemouth Price[7]							
(2009 dollars per short ton)	33.26	32.36	32.72	33.22	33.56	33.92	34.12
(2009 dollars per million Btu)	1.67	1.62	1.63	1.68	1.71	1.73	1.76
Delivered Prices[8] (2009 dollars per short ton)							
Coke Plants	143.01	157.51	158.07	169.26	169.13	172.38	172.06
Other Industrial[5]	64.87	61.78	61.87	63.58	65.56	66.89	68.54
Coal to Liquids	- -	30.96	30.98	31.66	35.64	36.68	36.56
Electric Power[6]							
(2009 dollars per short ton)	43.48	40.94	41.24	43.33	44.69	46.36	47.87
(2009 dollars per million Btu)	2.20	2.11	2.12	2.24	2.30	2.40	2.46
Average	**46.03**	**44.40**	**44.72**	**45.97**	**46.34**	**47.87**	**47.58**
Exports[9]	101.44	123.13	123.47	136.16	137.60	133.36	131.94
Cumulative Electricity Generating Capacity Additions (gigawatts)[10]							
Coal	0.0	12.4	12.5	17.4	28.0	25.5	47.9
Conventional	0.0	10.9	10.9	10.9	10.9	11.2	17.2
Advanced without Sequestration	0.0	0.6	0.6	0.6	0.6	0.6	0.6
Advanced with Sequestration	0.0	0.0	0.0	2.0	2.0	2.0	2.0
End-Use Generators[11]	0.0	0.9	1.0	3.9	14.5	11.7	28.1
Petroleum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas	0.0	20.0	20.1	48.0	46.6	135.1	125.2
Nuclear	0.0	1.1	1.1	6.3	6.3	6.3	6.3
Renewables[12]	0.0	29.3	29.0	44.7	43.7	55.7	52.8
Other	0.0	0.8	0.8	0.8	0.8	0.8	0.8
Total	**0.0**	**63.7**	**63.6**	**117.2**	**125.5**	**223.4**	**233.0**
Liquids from Coal (million barrels per day)	0.00	0.05	0.05	0.19	0.70	0.55	1.33

[1]Includes anthracite, bituminous coal, subbituminous coal, and lignite.
[2]Includes waste coal consumed by the electric power and industrial sectors. Waste coal supplied is counted as a supply-side item to balance the same amount of waste coal included in the consumption data.
[3]Excludes imports to Puerto Rico and the U.S. Virgin Islands.
[4]Production plus waste coal supplied plus net imports.
[5]Includes consumption for combined heat and power plants, except those plants whose primary business is to sell electricity, or electricity and heat, to the public. Excludes all coal use in the coal to liquids process.
[6]Includes all electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes reported prices for both open market and captive mines.
[8]Prices weighted by consumption tonnage; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
[9]F.a.s. price at U.S. port of exit.
[10]Cumulative additions after December 31, 2009. Includes all additions of electricity only and combined heat and power plants projected for the electric power, industrial, and commercial sectors.
[11]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
[12]Includes conventional hydroelectric, geothermal, wood, wood waste, municipal waste, landfill gas, other biomass, solar, and wind power. Facilities co-firing biomass and coal are classified as coal.
- - = Not applicable.
Btu = British thermal unit.
GHG = Greenhouse gas.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 data based on: U.S. Energy Information Administration (EIA), *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010); EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010); and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. **Projections:** EIA, AEO2011 National Energy Modeling System runs REF2011.D020911A and NORSK2011.D020911A.

Table D23. Key results for coal cost cases
(million short tons per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	2020			2035			Growth Rate, 2009-2035		
		Low Coal Cost	Reference	High Coal Cost	Low Coal Cost	Reference	High Coal Cost	Low Coal Cost	Reference	High Coal Cost
Production[1]	**1075**	**1154**	**1100**	**1030**	**1435**	**1319**	**1007**	**1.1%**	**0.8%**	**-0.3%**
Appalachia	343	287	279	273	274	282	270	-0.9%	-0.8%	-0.9%
Interior	147	157	160	164	122	177	203	-0.7%	0.7%	1.3%
West	585	710	661	594	1038	860	534	2.2%	1.5%	-0.4%
Waste Coal Supplied[2]	**12**	**13**	**14**	**15**	**12**	**14**	**32**	**-0.2%**	**0.6%**	**3.7%**
Net Imports[3]	**-38**	**-40**	**-38**	**-24**	**-56**	**-18**	**15**	**1.5%**	**-2.8%**	**- -**
Total Supply[4]	**1049**	**1126**	**1076**	**1021**	**1391**	**1315**	**1054**	**1.1%**	**0.9%**	**0.0%**
Consumption by Sector										
Residential and Commercial	3	3	3	3	3	3	3	-0.2%	-0.2%	-0.2%
Coke Plants	15	22	22	22	18	18	18	0.7%	0.6%	0.5%
Other Industrial[5]	45	49	49	48	47	47	46	0.2%	0.1%	0.0%
Coal-to-Liquids Heat and Power	0	7	7	6	70	66	34	- -	- -	- -
Coal-to-Liquids Liquids Production	0	7	6	6	66	62	32	- -	- -	- -
Electric Power[6]	937	1037	989	936	1186	1119	922	0.9%	0.7%	-0.1%
Total Coal Use	**1000**	**1125**	**1076**	**1021**	**1391**	**1315**	**1054**	**1.3%**	**1.1%**	**0.2%**
Average Minemouth Price[7]										
(2009 dollars per short ton)	33.26	25.55	32.85	42.40	16.37	33.92	67.62	-2.7%	0.1%	2.8%
(2009 dollars per million Btu)	1.67	1.29	1.65	2.12	0.85	1.73	3.34	-2.6%	0.2%	2.7%
Delivered Prices[8] (2009 dollars per short ton)										
Coke Plants	143.01	140.19	165.95	189.18	119.48	172.38	253.08	-0.7%	0.7%	2.2%
Other Industrial[5]	64.87	54.01	62.45	72.80	44.43	66.89	100.64	-1.4%	0.1%	1.7%
Coal to Liquids	- -	26.63	35.63	46.32	20.25	36.68	57.03	- -	- -	- -
Electric Power[6]										
(2009 dollars per short ton)	43.48	35.14	41.57	50.96	28.09	46.36	79.12	-1.7%	0.2%	2.3%
(2009 dollars per million Btu)	2.20	1.82	2.15	2.62	1.48	2.40	3.95	-1.5%	0.3%	2.3%
Average	**46.03**	**37.94**	**45.00**	**54.91**	**29.08**	**47.87**	**81.58**	**-1.8%**	**0.2%**	**2.2%**
Exports[9]	101.44	111.44	132.67	150.29	94.32	133.36	181.30	-0.3%	1.1%	2.3%
Cumulative Electricity Generating Capacity Additions (gigawatts)[10]										
Coal	0.0	14.7	14.7	14.6	30.4	25.5	19.2	- -	- -	- -
Conventional	0.0	10.9	10.9	10.9	16.0	11.2	10.9	- -	- -	- -
Advanced without Sequestration	0.0	0.6	0.6	0.6	0.6	0.6	0.6	- -	- -	- -
Advanced with Sequestration	0.0	2.0	2.0	2.0	2.0	2.0	2.0	- -	- -	- -
End-Use Generators[11]	0.0	1.2	1.2	1.1	11.8	11.7	5.7	- -	- -	- -
Petroleum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	- -	- -	- -
Natural Gas	0.0	28.8	26.7	26.9	135.6	135.1	126.1	- -	- -	- -
Nuclear	0.0	6.3	6.3	6.3	6.3	6.3	6.3	- -	- -	- -
Renewables[12]	0.0	34.4	34.1	34.1	56.6	55.7	52.2	- -	- -	- -
Other	0.0	0.8	0.8	0.8	0.8	0.8	0.8	- -	- -	- -
Total	**0.0**	**85.1**	**82.7**	**82.8**	**229.8**	**223.4**	**204.7**	**- -**	**- -**	**- -**
Liquids from Coal (million barrels per day)	0.00	0.06	0.06	0.06	0.55	0.55	0.27	- -	- -	- -

Table D23. Key results for coal cost cases (continued)
(million short tons per year, unless otherwise noted)

Supply, Disposition, and Prices	2009	2020			2035			Growth Rate, 2009-2035		
		Low Coal Cost	Reference	High Coal Cost	Low Coal Cost	Reference	High Coal Cost	Low Coal Cost	Reference	High Coal Cost
Cost Indices										
(constant dollar index, 2009=1.000)										
Transportation Rate Multipliers										
Eastern Railroads	1.000	0.920	1.019	1.120	0.760	1.004	1.260	-1.0%	0.0%	0.9%
Western Railroads	1.000	0.890	0.983	1.090	0.790	1.058	1.320	-0.9%	0.2%	1.1%
Mine Equipment Costs										
Underground	1.000	0.909	1.005	1.111	0.782	1.005	1.289	-0.9%	0.0%	1.0%
Surface	1.000	0.895	0.989	1.093	0.769	0.989	1.269	-1.0%	-0.0%	0.9%
Other Mine Supply Costs										
East of the Mississippi: All Mines	1.000	0.904	1.000	1.105	0.778	1.000	1.282	-1.0%	0.0%	1.0%
West of the Mississippi: Underground	1.000	0.904	1.000	1.105	0.778	1.000	1.282	-1.0%	0.0%	1.0%
West of the Mississippi: Surface	1.000	0.904	1.000	1.105	0.778	1.000	1.282	-1.0%	0.0%	1.0%
Coal Mining Labor Productivity (short tons per miner per hour)	5.61	7.97	5.97	4.40	13.18	6.12	2.58	3.3%	0.3%	-2.9%
Average Coal Miner Wage (2009 dollars per hour)	26.13	23.62	26.13	28.87	20.33	26.13	33.50	-1.0%	0.0%	1.0%

[1]Includes anthracite, bituminous coal, subbituminous coal, and lignite.
[2]Includes waste coal consumed by the electric power and industrial sectors. Waste coal supplied is counted as a supply-side item to balance the same amount of waste coal included in the consumption data.
[3]Excludes imports to Puerto Rico and the U.S. Virgin Islands.
[4]Production plus waste coal supplied plus net imports.
[5]Includes consumption for combined heat and power plants, except those plants whose primary business is to sell electricity, or electricity and heat, to the public. Excludes all coal use in the coal to liquids process.
[6]Includes all electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7]Includes reported prices for both open market and captive mines.
[8]Prices weighted by consumption tonnage; weighted average excludes residential and commercial prices, and export free-alongside-ship (f.a.s.) prices.
[9]F.a.s. price at U.S. port of exit.
[10]Cumulative additions after December 31, 2009. Includes all additions of electricity only and combined heat and power plants projected for the electric power, industrial, and commercial sectors.
[11]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
[12]Includes conventional hydroelectric, geothermal, wood, wood waste, municipal waste, landfill gas, other biomass, solar, and wind power. Facilities co-firing biomass and coal are classified as coal.
- - = Not applicable.
Btu = British thermal unit.
Note: Totals may not equal sum of components due to independent rounding. Data for 2009 are model results and may differ slightly from official EIA data reports.
Sources: 2009 data based on: U.S. Energy Information Administration (EIA), *Annual Coal Report 2009*, DOE/EIA-0584(2009) (Washington, DC, October 2010); EIA, *Quarterly Coal Report, October-December 2009*, DOE/EIA-0121(2009/4Q) (Washington, DC, April 2010); U.S. Department of Labor, Bureau of Labor Statistics, Average Hourly Earnings of Production Workers: Coal Mining, Series ID : ceu1021210008; and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A. **Projections:** EIA, AEO2011 National Energy Modeling System runs LCCST11.D020911A, REF2011.D020911A, and HCCST11.D020911A.

Appendix E

NEMS overview and brief description of cases

The National Energy Modeling System

The projections in the Annual Energy Outlook 2011 (*AEO2011*) are generated from the National Energy Modeling System (NEMS) [*1*], developed and maintained by the Office of Energy Analysis (OEA), formerly known as the Office Integrated Analysis and Forecasting (OIAF), of the U.S. Energy Information Administration (EIA) [*2*]. In addition to its use in developing the *Annual Energy Outlook* (*AEO*) projections, NEMS is also used to complete analytical studies for the U.S. Congress, the Executive Office of the President, other offices within the U.S. Department of Energy (DOE), and other Federal agencies. NEMS is also used by other nongovernment groups, such as the Electric Power Research Institute, Duke University, Georgia Institute of Technology, and OnLocation, Inc. In addition, the *AEO* projections are used by analysts and planners in other government agencies and nongovernment organizations.

The projections in NEMS are developed with the use of a market-based approach to energy analysis. For each fuel and consuming sector, NEMS balances energy supply and demand, accounting for economic competition among the various energy fuels and sources. The time horizon of NEMS is the period through 2035, approximately 25 years into the future. In order to represent regional differences in energy markets, the component modules of NEMS function at the regional level: the nine Census divisions for the end-use demand modules; production regions specific to oil, natural gas, and coal supply and distribution; 22 subregions of the North American Electric Reliability Council regions and subregions for electricity [*3*]; and the 5 Petroleum Administration for Defense Districts (PADDs) for refineries.

NEMS is organized and implemented as a modular system. The modules represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. NEMS also includes delivered prices of energy to end users and the quantities consumed, by product, region, and sector. The delivered fuel prices encompass all the activities necessary to produce, import, and transport fuels to end users. The information flows also include other data on such areas as economic activity, domestic production, and international petroleum supply.

The Integrating Module controls the execution of each of the component modules. To facilitate modularity, the components do not pass information to each other directly but communicate through a central data structure. This modular design provides the capability to execute modules individually, thus allowing decentralized development of the system and independent analysis and testing of individual modules. The modular design also permits the use of the methodology and level of detail most appropriate for each energy sector. NEMS calls each supply, conversion, and end-use demand module in sequence until the delivered prices of energy and the quantities demanded have converged within tolerance, thus achieving an economic equilibrium of supply and demand in the consuming sectors. A solution is reached annually through the projection horizon. Other variables, such as petroleum product imports, crude oil imports, and several macroeconomic indicators, also are evaluated for convergence.

Each NEMS component represents the impacts and costs of legislation and environmental regulations that affect that sector. NEMS accounts for all combustion-related carbon dioxide (CO_2) emissions, as well as emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury from the electricity generation sector.

The version of NEMS used for *AEO2011* represents current legislation and environmental regulations as of January 31, 2011, such as: the October 13, 2010, U.S. Environmental Protection Agency (EPA) waiver that allows the use of E15 in light-duty vehicles (LDVs) built in 2007 or later; EPA guidelines regarding compliance of surface coal mining operations in Appalachia, issued on April 1, 2010; the American Recovery and Reinvestment Act (ARRA), which was enacted in mid-February 2009; the Energy Improvement and Extension Act of 2008 (EIEA2008), signed into law on October 3, 2008; the Food, Conservation, and Energy Act of 2008; and the Energy Independence and Security Act of 2007 (EISA2007), signed into law on December 19, 2007. The *AEO2011* models do not represent the Clean Air Mercury Rule, which was vacated and remanded by the D.C. Circuit Court of the U.S. Court of Appeals on February 8, 2008, but it does represent State requirements for reduction of mercury emissions.

The *AEO2011* Reference case reflects the temporary reinstatement of the NO_x and SO_2 cap-and-trade programs included in the Clean Air Interstate Rule (CAIR) as a result of the ruling issued by the United States Court of Appeals for the District of Columbia on December 23, 2008. The potential impacts of proposed Federal and State legislation, regulations, or standards—or of sections of legislation that have been enacted but require funds or implementing regulations that have not been provided or specified—are not reflected in NEMS. However, many pending provisions are examined in alternatives cases included in *AEO2011* or in other analyses completed by EIA.

In general, the historical data used for the *AEO2011* projections are based on EIA's *Annual Energy Review 2009*, published in August 2010 [*4*]; however, data were taken from multiple sources. In some cases, only partial or preliminary data were available for 2009. CO_2 emissions were calculated by using CO_2 coefficients from the EIA report, *Emissions of Greenhouse Gases in the United States 2009*, published in April 2011 [*5*]. Historical numbers are presented for comparison only and may be estimates. Source documents should be consulted for the official data values. Footnotes to the *AEO2011* appendix tables indicate the definitions and sources of historical data.

The *AEO2011* projections for 2010 and 2011 incorporate short-term projections from EIA's October 2010 *Short-Term Energy Outlook (STEO)*. For short-term energy projections, readers are referred to monthly updates of the *STEO* [6].

Component modules

The component modules of NEMS represent the individual supply, demand, and conversion sectors of domestic energy markets and also include international and macroeconomic modules. In general, the modules interact through values representing prices or expenditures for energy delivered to the consuming sectors and the quantities of end-use energy consumption.

Macroeconomic Activity Module

The Macroeconomic Activity Module (MAM) provides a set of macroeconomic drivers to the energy modules and receives energy-related indicators from the NEMS energy components as part of the macroeconomic feedback mechanism within NEMS. Key macroeconomic variables used in the energy modules include gross domestic product (GDP), disposable income, value of industrial shipments, new housing starts, sales of new LDVs, interest rates, and employment. Key energy indicators fed back to the MAM include aggregate energy prices and costs. The MAM uses the following models from IHS Global Insight: Macroeconomic Model of the U.S. Economy, National Industry Model, and National Employment Model. In addition, EIA has constructed a Regional Economic and Industry Model to project regional economic drivers, and a Commercial Floorspace Model to project 13 floorspace types in 9 Census divisions. The accounting framework for industrial value of shipments uses the North American Industry Classification System (NAICS).

International Energy Module

The International Energy Module (IEM) uses assumptions of economic growth and expectations of future U.S. and world petroleum liquids production and consumption, by year, to project the interaction of U.S. and international liquids markets. The IEM computes world oil prices, provides a world crude-like liquids supply curve, generates a worldwide oil supply/demand balance for each year of the projection period, and computes initial estimates of crude oil and light and heavy petroleum product imports to the United States by PADD regions. The supply-curve calculations are based on historical market data and a world oil supply/demand balance, which is developed from reduced-form models of international liquids supply and demand, current investment trends in exploration and development, and long-term resource economics for 221 countries and territories. The oil production estimates include both conventional and unconventional supply recovery technologies.

In interacting with the rest of NEMS, the IEM changes the world oil price—which is defined as the price of foreign light, low-sulfur crude oil delivered to Cushing, Oklahoma (Petroleum Allocation Defense District 2)—in response to changes in expected production and consumption of crude oil and product liquids in the United States.

Residential and Commercial Demand Modules

The Residential Demand Module projects energy consumption in the residential sector by housing type and end use, based on delivered energy prices, the menu of equipment available, the availability and cost of renewable sources of energy, and housing starts. The Commercial Demand Module projects energy consumption in the commercial sector by building type and non-building uses of energy and by category of end use, based on delivered prices of energy, availability of renewable sources of energy, and macroeconomic variables representing interest rates and floorspace construction.

Both modules estimate the equipment stock for the major end-use services, incorporating assessments of advanced technologies, including representations of renewable energy technologies, and the effects of both building shell and appliance standards, including the recent consensus agreement reached between manufacturers and environmental interest groups. The Commercial Demand Module incorporates combined heat and power (CHP) technology. The modules also include projections of distributed generation. Both modules incorporate changes to "normal" heating and cooling degree-days by Census division, based on a 10-year average and on State-level population projections. The Residential Demand Module projects an increase in the average square footage of both new construction and existing structures, based on trends in new construction and remodeling.

Industrial Demand Module

The Industrial Demand Module (IDM) projects the consumption of energy for heat and power, feedstocks, and raw materials in each of 21 industries, subject to the delivered prices of energy and the values of macroeconomic variables representing employment and the value of shipments for each industry. As noted in the description of the MAM, the value of shipments is based on NAICS. The industries are classified into three groups—energy-intensive manufacturing, non-energy-intensive manufacturing, and nonmanufacturing. Of the eight energy-intensive industries, seven are modeled in the IDM, with energy-consuming components for boiler/steam/cogeneration, buildings, and process/assembly use of energy. The use of energy for petroleum refining is modeled in the Petroleum Market Module (PMM), as described below, and the projected consumption is included in the industrial totals.

A generalized representation of cogeneration and a recycling component also are included. A new economic calculation for CHP systems was implemented for *AEO2011*. The evaluation of CHP systems now uses a discount rate, which depends on the 10-year Treasury bill rate plus a risk premium, replacing the previous calculation that used simple payback. Also, the base year of the IDM was updated to 2006 in keeping with an update to EIA's 2006 Manufacturing Energy Consumption Survey [7].

Transportation Demand Module

The Transportation Demand Module projects consumption of fuels in the transportation sector, including petroleum products, electricity, methanol, ethanol, compressed natural gas, and hydrogen, by transportation mode, vehicle vintage, and size class, subject to delivered prices of energy fuels and macroeconomic variables representing disposable personal income, GDP, population, interest rates, and industrial shipments. Fleet vehicles are represented separately to allow analysis of other legislation and legislative proposals specific to those market segments. The Transportation Demand Module also includes a component to assess the penetration of alternative-fuel vehicles. The Energy Policy Act of 2005 (EPACT2005) and EIEA2008 are reflected in the assessment of impacts of tax credits on the purchase of hybrid gas-electric, alternative-fuel, and fuel-cell vehicles. Representations of corporate average fuel economy (CAFE) standards and of biofuel consumption in the module reflect standards enacted by the National Highway Traffic Safety Administration (NHTSA) and EPA, and provisions in EISA2007.

The air transportation component of the Transportation Demand Module explicitly represents air travel in domestic and foreign markets and includes the industry practice of parking aircraft in both domestic and international markets to reduce operating costs, as well as the movement of aging aircraft from passenger to cargo markets. For passenger travel and air freight shipments, the module represents regional fuel use in regional, narrow-body, and wide-body aircraft. An infrastructure constraint, which is also modeled, can potentially limit overall growth in passenger and freight air travel to levels commensurate with industry-projected infrastructure expansion and capacity growth.

Electricity Market Module

There are three primary submodules of the Electricity Market Module—capacity planning, fuel dispatching, and finance and pricing. The capacity expansion submodule uses the stock of existing generation capacity; the menu, cost, and performance of future generation capacity; expected fuel prices; expected financial parameters; expected electricity demand; and expected environmental regulations to project the optimal mix of new generation capacity that should be added in future years. The fuel dispatching submodule uses the existing stock of generation equipment types, their operation and maintenance costs and performance, fuel prices to the electricity sector, electricity demand, and all applicable environmental regulations to determine the least-cost way to meet that demand. The submodule also determines transmission and pricing of electricity. The finance and pricing submodule uses capital costs, fuel costs, macroeconomic parameters, environmental regulations, and load shapes to estimate generation costs for each technology.

All specifically identified options promulgated by the EPA for compliance with the Clean Air Act Amendments of 1990 (CAAA90) are explicitly represented in the capacity expansion and dispatch decisions; those that have not been promulgated (e.g., fine particulate proposals) are not incorporated. All financial incentives for power generation expansion and dispatch specifically identified in EPACT2005 have been implemented. Several States, primarily in the Northeast, have recently enacted air emission regulations for CO_2 that affect the electricity generation sector, and those regulations are represented in *AEO2011*. The *AEO2011* Reference case reflects the temporary reinstatement of the NO_x and SO_2 cap-and-trade programs included in CAIR due to the ruling issued by the United States Court of Appeals for the District of Columbia on December 23, 2008. State regulations on mercury also are reflected in *AEO2011*.

Although currently there is no Federal legislation in place that restricts greenhouse gas (GHG) emissions, regulators and the investment community have continued to push energy companies to invest in technologies that are less GHG-intensive. The trend is captured in the *AEO2011* Reference case through a 3-percentage-point increase in the cost of capital when evaluating investments in new coal-fired power plants and new coal-to-liquids (CTL) plants without carbon capture and storage (CCS).

Renewable Fuels Module

The Renewable Fuels Module (RFM) includes submodules representing renewable resource supply and technology input information for central-station, grid-connected electricity generation technologies, including conventional hydroelectricity, biomass (dedicated biomass plants and co-firing in existing coal plants), geothermal, landfill gas, solar thermal electricity, solar photovoltaics (PV), and wind energy. The RFM contains renewable resource supply estimates representing the regional opportunities for renewable energy development. Investment tax credits (ITCs) for renewable fuels are incorporated, as currently enacted, including a permanent 10-percent ITC for business investment in solar energy (thermal nonpower uses as well as power uses) and geothermal power (available only to those projects not accepting the production tax credit [PTC] for geothermal power). In addition, the module reflects the increase in the ITC to 30 percent for solar energy systems installed before January 1, 2017, and the extension of the credit to individual homeowners under EIEA2008.

PTCs for wind, geothermal, landfill gas, and some types of hydroelectric and biomass-fueled plants also are represented. They provide a credit of up to 2.1 cents per kilowatthour for electricity produced in the first 10 years of plant operation. For *AEO2011*, new wind plants coming on line before January 1, 2013, are eligible to receive the PTC; other eligible plants must be in service before January 1, 2014. As part of the ARRA, plants eligible for the PTC may instead elect to receive a 30-percent ITC or an equivalent direct grant. *AEO2011* also accounts for new renewable energy capacity resulting from State renewable portfolio standard (RPS) programs, mandates, and goals, as described in *Assumptions to the Annual Energy Outlook 2011* [*8*].

Oil and Gas Supply Module

The Oil and Gas Supply Module represents domestic crude oil and natural gas supply within an integrated framework that captures the interrelationships among the various sources of supply—onshore, offshore, and Alaska—by all production techniques, including natural gas recovery from coalbeds and low-permeability formations of sandstone and shale. The framework analyzes cash flow and profitability to compute investment and drilling for each of the supply sources, based on the prices for crude oil and natural gas, the domestic recoverable resource base, and the state of technology. Oil and natural gas production activities are modeled for 12 supply regions, including 6 onshore, 3 offshore, and 3 Alaskan regions.

The Onshore Lower 48 Oil and Gas Supply Submodule evaluates the economics of future exploration and development projects for crude oil and natural gas at the play level. Crude oil resources are divided into known plays and undiscovered plays, including highly fractured continuous zones, such as the Austin chalk and Bakken shale formations. Production potential from advanced secondary recovery techniques (such as infill drilling, horizontal continuity, and horizontal profile) and enhanced oil recovery (such as CO_2 flooding, steam flooding, polymer flooding, and profile modification) are explicitly represented. Natural gas resources are divided into known producing plays, known developing plays, and undiscovered plays in high-permeability carbonate and sandstone, tight gas, shale gas, and coalbed methane.

Domestic crude oil production quantities are used as inputs to the PMM in NEMS for conversion and blending into refined petroleum products. Supply curves for natural gas are used as inputs to the Natural Gas Transmission and Distribution Module (NGTDM) for determining natural gas wellhead prices and domestic production.

Natural Gas Transmission and Distribution Module

The NGTDM represents the transmission, distribution, and pricing of natural gas, subject to end-use demand for natural gas and the availability of domestic natural gas and natural gas traded on the international market. The module tracks the flows of natural gas and determines the associated capacity expansion requirements in an aggregate pipeline network, connecting the domestic and foreign supply regions with 12 U.S. lower 48 demand regions. The 12 regions align with the 9 Census divisions, with three subdivided and Alaska handled separately. The flow of natural gas is determined for both a peak and off-peak period in the year, assuming a historically based seasonal distribution of natural gas demand. Key components of pipeline and distributor tariffs are included in separate pricing algorithms. An algorithm is included to project the addition of compressed natural gas retail fueling capability. The module also accounts for foreign sources of natural gas, including pipeline imports and exports to Canada and Mexico, as well as liquefied natural gas (LNG) imports and exports.

Petroleum Market Module

The PMM projects prices of petroleum products, crude oil and product import activity, and domestic refinery operations, subject to demand for petroleum products, availability and price of imported petroleum, and domestic production of crude oil, natural gas liquids, and biofuels—ethanol, biodiesel, biomass-to-liquids (BTL), CTL, and gas-to-liquids (GTL). Costs, performance, and first dates of commercial availability for the advanced alternative liquids technologies [*9*] are reviewed and updated annually.

The module represents refining activities in the five PADDs, as well as a less detailed representation of refining activities in the rest of the world. It models the costs of automotive fuels, such as conventional and reformulated gasoline, and includes production of biofuels for blending in gasoline and diesel. Fuel ethanol and biodiesel are included in the PMM, because they are commonly blended into petroleum products. The module allows ethanol blending into gasoline at 10 percent or less by volume (E10), 15 percent by volume (E15) in States that lack explicit language capping ethanol volume or oxygen content, and up to 85 percent by volume (E85) for use in flex-fuel vehicles.

The PMM includes representation of the Renewable Fuels Standard (RFS) included in EISA2007, which mandates the use of 36 billion gallons of renewable fuel by 2022. Both domestic and imported ethanol count toward the RFS. Domestic ethanol production is modeled for three feedstock categories: corn, cellulosic plant materials, and advanced feedstock materials. Corn-based ethanol plants are numerous (more than 180 are now in operation, with a total operating production capacity of more than 13 billion gallons annually), and they are based on a well-known technology that converts starch and sugar into ethanol. Ethanol from cellulosic sources is a new technology with only a few small pilot plants in operation.

Fuels produced by gasification and Fischer-Tropsch synthesis and through a pyrolysis process are also modeled in the PMM, based on their economics relative to competing feedstocks and products. The five processes modeled are CTL, GTL, BTL, coal- and biomass-to-liquids, and pyrolysis.

Coal Market Module

The Coal Market Module (CMM) simulates mining, transportation, and pricing of coal, subject to end-use demand for coal differentiated by heat and sulfur content. U.S. coal production is represented in the CMM by 41 separate supply curves—differentiated by region, mine type, coal rank, and sulfur content. The coal supply curves respond to capacity utilization of mines, mining capacity, labor productivity, and factor input costs (mining equipment, mining labor, and fuel requirements). Projections of U.S. coal distribution are determined by minimizing the cost of coal supplied, given coal demands by region and sector, environmental restrictions, and accounting for minemouth prices, transportation costs, and coal supply contracts. Over the projection horizon, coal transportation costs in the CMM vary in response to changes in the cost of rail investments.

The CMM produces projections of U.S. steam and metallurgical coal exports and imports in the context of world coal trade, determining the pattern of world coal trade flows that minimizes production and transportation costs while meeting a specified set of regional world coal import demands, subject to constraints on export capacities and trade flows. The international coal market component of the module computes trade in 3 types of coal for 17 export regions and 20 import regions. U.S. coal production and distribution are computed for 14 supply regions and 16 demand regions.

Annual Energy Outlook 2011 cases

Table E1 provides a summary of the cases produced as part of *AEO2011*. For each case, the table gives the name used in *AEO2011*, a brief description of the major assumptions underlying the projections, the mode in which the case was run in NEMS (either fully integrated, partially integrated, or standalone), and a reference to the pages in the body of the report and in this appendix where the case is discussed. The text sections following Table E1 describe the various cases. The Reference case assumptions for each sector are described in *Assumptions to the Annual Energy Outlook 2011* [*10*]. Regional results and other details of the projections are available at website www.eia.gov/oiaf/aeo/supplement.

Macroeconomic growth cases

In addition to the *AEO2011* Reference case, *Low Economic Growth* and *High Economic Growth cases* were developed to reflect the uncertainty in projections of economic growth. The alternative cases are intended to show the effects of alternative growth assumptions on energy market projections. The cases are described as follows:

- In the *Reference case*, population grows by 0.9 percent per year, nonfarm employment by 1.0 percent per year, and labor productivity by 2.0 percent per year from 2009 to 2035. Economic output as measured by real GDP increases by 2.7 percent per year from 2009 through 2035, and growth in real disposable income per capita averages 1.6 percent per year.
- The *Low Economic Growth case* assumes lower growth rates for population (0.6 percent per year) and labor productivity (1.6 percent per year), resulting in lower nonfarm employment (0.7 percent per year), higher prices and interest rates, and lower growth in industrial output. In the Low Economic Growth case, economic output as measured by real GDP increases by 2.1 percent per year from 2009 through 2035, and growth in real disposable income per capita averages 1.5 percent per year.
- The *High Economic Growth case* assumes higher growth rates for population (1.2 percent per year) and labor productivity (2.4 percent per year), resulting in higher nonfarm employment (1.4 percent per year). With higher productivity gains and employment growth, inflation and interest rates are lower than in the Reference case, and consequently economic output grows at a higher rate (3.2 percent per year) than in the Reference case (2.7 percent). Disposable income per capita grows by 1.63 percent per year, compared with 1.57 percent in the Reference case.

Oil price cases

The world oil price in *AEO2011* is defined as the average price of light, low-sulfur crude oil delivered in Cushing, Oklahoma, and is similar to the price for light, sweet crude oil traded on the New York Mercantile Exchange. *AEO2011* also includes a projection of the U.S. annual average refiners' acquisition cost of imported crude oil, which is more representative of the average cost of all crude oils used by domestic refiners.

The historical record shows substantial variability in world oil prices, and there is arguably even more uncertainty about future prices in the long term. *AEO2011* considers five oil price cases (Reference, Low Oil Price, Traditional Low Oil Price, High Oil Price, and Traditional High Oil Price) to allow an assessment of alternative views on the course of future oil prices. The Low Oil Price case and Traditional Low Oil Price case use the same price path, as do the High Oil Price case and Traditional High Oil Price.

The Low and High Oil Price cases reflect a wide range of potential price paths, resulting from variation in demand for countries outside the Organization for Economic Cooperation and Development (OECD) for liquid fuels due to different levels of economic growth. The Traditional Low and Traditional High Oil Price cases define the same wide range of potential price paths, but they also reflect different assumptions about decisions by members of the Organization of the Petroleum Exporting Countries (OPEC) regarding the preferred rate of oil production and about the future finding and development costs and accessibility of conventional oil resources outside the United States. Because the Low, Traditional Low, High, and Traditional High Oil Price cases are not fully integrated with a world economic model, the impact of world oil prices on international economies is not accounted for directly.

- In the *Reference case*, real world oil prices rise from a low of $78 per barrel (2009 dollars) in 2010 to $95 per barrel in 2015, then increase more slowly to $125 per barrel in 2035. The Reference case represents EIA's current judgment regarding exploration and development costs and accessibility of oil resources outside the United States. It also assumes that OPEC producers will choose to maintain their share of the market and will schedule investments in incremental production capacity so that OPEC's conventional oil production will represent about 42 percent of the world's total liquids production.
- In the *Low Oil Price case*, world crude oil prices are only $50 per barrel (2009 dollars) in 2035, compared with $125 per barrel in the Reference case. In the Low Oil Price case, the low price results from lower demand for liquid fuels in the non-OECD nations. Lower demand is derived from lower economic growth relative to the Reference case. In this case, GDP growth in the non-OECD is reduced by 1.5 percentage points in each projection year beginning in 2015 relative to Reference case. The OECD projections are only affected by the price impact.

Table E1. Summary of the *AEO2011* cases

Case name	Description	Integration mode	Reference in text	Reference in Appendix E
Reference	Baseline economic growth (2.7 percent per year from 2009 through 2035), world oil price, and technology assumptions. Complete projection tables in Appendix A. World light, sweet crude oil prices rise to about $125 per barrel (2009 dollars) in 2035. Assumes RFS target to be met as soon as possible.	Fully integrated	--	--
Low Economic Growth	Real GDP grows at an average annual rate of 2.1 percent from 2009 to 2035. Other energy market assumptions are the same as in the Reference case. Partial projection tables in Appendix B.	Fully integrated	p. 58	p. 213
High Economic Growth	Real GDP grows at an average annual rate of 3.2 percent from 2009 to 2035. Other energy market assumptions are the same as in the Reference case. Partial projection tables in Appendix B.	Fully integrated	p. 58	p. 213
Low Oil Price (primary low price case)	Low prices result from low demand for liquid fuels in the non-OECD nations. Lower demand is measured by lower economic growth relative to the Reference case. In this case, GDP growth in the non-OECD region is reduced by 1.5 percentage points in each projection year relative to Reference case assumptions from 2015 to 2035. World light, sweet crude oil prices fall to about $50 per barrel in 2035, compared with $125 per barrel in the Reference case (2009 dollars). Other assumptions are the same as in the Reference case. Partial projection tables in Appendix C.	Fully integrated	p. 23	p. 213
Traditional Low Oil Price	More optimistic assumptions for economic access to non-OPEC resources and OPEC behavior than in the Reference case. Prices are the same as those used in the Low Oil Price case. Partial projection tables in Appendix C.	Fully integrated	p. 24	p. 218
High Oil Price (primary high price case)	High prices result from high demand for liquid fuels in the non-OECD nations. Higher demand is measured by higher economic growth relative to the Reference case. In this case, GDP growth in the non-OECD region is raised by 1.0 percentage points in each projection year relative to Reference case assumptions from 2015 to 2035. World light, sweet crude oil prices rise to about $200 per barrel (2009 dollars) in 2035. Other assumptions are the same as in the Reference case. Partial projection tables in Appendix C.	Fully integrated	p. 23	p. 218
Traditional High Oil Price	More pessimistic assumptions for economic access to non-OPEC resources and OPEC behavior than in the Reference case. Prices are the same as those used in the High Oil Price case. Partial projection tables in Appendix C.	Fully integrated	p. 24	p. 218
No Sunset	Begins with the Reference case and assumes extension of all existing energy policies and legislation that contain sunset provisions, except those requiring additional funding (e.g., loan guarantee programs) and those that involve extensive regulatory analysis, such as CAFE improvements and periodic efficiency standard updates. Partial projection tables in Appendix D	Fully integrated	p. 18	p. 223
Extended Policies	Begins with the No Sunset case but excludes extension of blender and other biofuel tax credits that were included in No Sunset case. Assumes expansion of the maximum industrial ITC and CHP credits and extension of the program. Includes assumptions of the "Expanded Standards and Codes case" described below. Assumes new LDV CAFE standards (to 46 miles per gallon by 2025) and tailpipe emissions proposal consistent with the CAFE 3% Growth case described below. Partial projection tables in Appendix D.	Fully Integrated	p. 18	p. 223
Expanded Standards	Begins with Reference case assumptions for standards. Adds additional rounds of efficiency standards for currently covered products as well as new standards for products not yet covered. Efficiency levels assume improvement similar to those in ENERGY STAR or Federal Energy Management Plan (FEMP) guidelines. Partial projection tables in Appendix D.	Residential and commercial only	p. 32	p. 219

Table E1. Summary of the *AEO2011* cases (continued)

Case name	Description	Integration mode	Reference in text	Reference in Appendix E
Expanded Standards and Codes	Begins with Expanded Standards case and adds multiple rounds of national building codes by 2026. Partial projection tables in Appendix D.	Residential and commercial only	p. 32	p. 219
Residential: 2010 Technology	Future equipment purchases based on equipment available in 2010. New and existing building shell efficiencies fixed at 2010 levels. Partial projection tables in Appendix D.	With commercial	p. 64	p. 218
Residential: High Technology	Earlier availability, lower costs, and higher efficiencies assumed for more advanced equipment. Building shell efficiencies for new construction meet ENERGY STAR requirements after 2015. Consumers evaluate efficiency investments at a 7-percent real discount rate. Partial projection tables in Appendix D.	With commercial	p. 64	p. 218
Residential: Best Available Technology	Future equipment purchases and new building shells based on most efficient technologies available by fuel. Building shell efficiencies for new construction meet the criteria for most efficient components after 2010. Partial projection tables in Appendix D.	With commercial	p. 64	p. 218
Commercial: 2010 Technology	Future equipment purchases based on equipment available in 2010. Building shell efficiencies fixed at 2010 levels. Partial projection tables in Appendix D.	With residential	p. 66	p. 218
Commercial: High Technology	Earlier availability, lower costs, and higher efficiencies for more advanced equipment. Energy efficiency investments evaluated at a 7-percent real discount rate. Building shell efficiencies for new and existing buildings increase by 17.4 and 7.5 percent, respectively, from 2003 values by 2035. Partial projection tables in Appendix D.	With residential	p. 66	p. 218
Commercial: Best Available Technology	Future equipment purchases based on most efficient technologies available by fuel. Building shell efficiencies for new and existing buildings increase by 20.8 and 9.0 percent, respectively, from 2003 values by 2035. Partial projection tables in Appendix D.	With residential	p. 66	p. 218
Industrial: 2010 Technology	Efficiencies of plant and equipment fixed at 2010 levels. Partial projection tables in Appendix D.	Standalone	p. 184	p. 219
Industrial: High Technology	Earlier availability, lower costs, and higher efficiencies for more advanced equipment. Partial projection tables in Appendix D.	Standalone	p. 184	p. 219
Transportation: Low Technology	Advanced technologies are more costly and less efficient than in the Reference case. Partial projection tables in Appendix D.	Standalone	p. 71	p. 219
Transportation: High Technology	Advanced technologies are less costly and more efficient than in the Reference case. Partial projection tables in Appendix D.	Standalone	p. 71	p. 219
Transportation: CAFE 3% Growth	Implements a 3-percent annual increase in fuel economy standards for LDVs from 2017 to 2025, with CAFE standard reaching 46 miles per gallon in 2025. Standards are held constant after 2025. Partial projection tables in Appendix D.	Fully integrated	p. 25	p. 220
Transportation: CAFE 6% Growth	Implements a 6-percent annual increase in fuel economy standards for LDVs from 2017 to 2025, with CAFE standard reaching 59 miles per gallon in 2025. Standards are held constant after 2025. Partial projection tables in Appendix D.	Fully integrated	p. 25	p. 220
Transportation: Heavy-Duty Vehicle Fuel Economy Standards	Implements increased fuel economy standards for heavy-duty vehicles for model years 2014 through 2018. Standards are held constant after 2018. Partial projection tables in Appendix D.	Fully integrated	p. 29	p. 220
Electricity: Low Fossil Technology Cost	Capital and operating costs for all new fossil-fired generating technologies start 20 percent below the Reference case level and decline to 40 percent below the Reference case in 2035. Partial projection tables in Appendix D.	Fully integrated	p. 41	p. 220
Electricity: High Fossil Technology Cost	Costs for all new fossil-fired generating technologies do not improve due to learning from 2011 levels in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 193	p. 220

Table E1. Summary of the *AEO2011* cases (continued)

Case name	Description	Integration mode	Reference in text	Reference in Appendix E
Electricity: Low Nuclear Cost	Capital and operating costs for new nuclear capacity start 20 percent lower than in the Reference case and fall to 40 percent lower in 2035. Partial projection tables in Appendix D.	Fully integrated	p. 41	p. 220
Electricity: High Nuclear Cost	Costs for new nuclear technology do not improve due to learning from 2011 levels in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 192	p. 220
Electricity: Frozen Plant Capital Costs	Base overnight costs for all new electricity generating technologies are frozen at 2015 levels. Costs decline due to learning, but do not decline due to commodity price changes. Partial projection tables in Appendix D.	Fully integrated	p. 41	p. 221
Electricity: Decreasing Plant Capital Costs	Base overnight costs for all new electric generating technologies fall more rapidly than in the Reference case, starting 20 percent below the Reference case costs in 2011 and falling to 40 percent below in 2035. Partial projection tables in Appendix D.	Fully integrated	p. 41	p. 221
Electricity: Transport Rule Mercury MACT 5	Assumes that the Transport Rule limits on SO2 and NOx and 90-percent mercury MACT are enacted. A 5-year capital recovery period is assumed for the retrofits. Partial projection tables in Appendix D.	Fully integrated	p. 48	p. 221
Electricity: Transport Rule Mercury MACT 20	Same environmental rules as above, but assuming a 20-year capital recovery period for retrofits. Partial projection tables in Appendix D.	Fully integrated	p. 48	p. 221
Electricity: Retrofit Required 5	Assumes that all coal-fired plants are required to install flue gas desulfurization (FGD) scrubbers by 2020 to comply with acid gas reduction requirements and that all plants install selective catalytic reduction (SCR) in order to meet future NOx and ozone requirements. Assumes a 5-year capital recovery period for retrofits. Partial projection tables in Appendix D.	Fully integrated	p. 49	p. 221
Electricity: Retrofit Required 20	Same requirements on environmental controls as above, but assuming a 20-year capital recovery period for retrofits. Partial projection tables in Appendix D.	Fully integrated	p. 48	p. 221
Electricity: Low Gas Price Retrofit Required 5	Same assumptions as the Retrofit Required 5 case, plus assumption of increased domestic shale gas availability and utilization rate as in the High Shale EUR case described below. Partial projection tables in Appendix D.	Fully integrated	p. 49	p. 221
Electricity: Low Gas Price Retrofit Required 20	Same assumptions as the Retrofit Required 20 case, plus assumption of increased domestic shale gas availability and utilization rate as in the High Shale Estimated Ultimate Recovery (EUR) case described below. Partial projection tables in Appendix D.	Fully integrated	p. 49	p. 221
Renewable Fuels: Low Renewable Technology Cost	Costs for new nonhydropower renewable generating technologies start 20 percent lower in 2011 and decline to 40 percent lower than Reference case levels in 2035. Capital costs of renewable liquid fuel technologies start 20 percent lower in 2011 and decline to approximately 40 percent lower than Reference case levels in 2035. Partial projection tables in Appendix D.	Fully integrated	p. 195	p. 219
Renewable Fuels: High Renewable Technology Cost	Costs for new nonhydropower renewable generating technologies do not improve from 2011 levels over the projection. Capital costs of renewable liquid fuel technologies do not improve from 2011 levels over the projection. Partial projection tables in Appendix D.	Fully integrated	p. 195	p. 219
Oil and Gas: Slow Technology	Improvements in exploration and development costs, production rates, and success rates due to technological advancement are 50 percent lower than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 78	p. 221
Oil and Gas: Rapid Technology	Improvements in exploration and development costs, production rates, and success rates due to technological advancement are 50 percent higher than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 78	p. 222

Table E1. Summary of the *AEO2011* cases (continued)

Case name	Description	Integration mode	Reference in text	Reference in Appendix E
Oil and Gas: Reduced OCS Access	No lease sales occur in the Eastern Gulf of Mexico, Pacific, Atlantic, and Alaska Outer Continental Shelf (OCS) through 2035. Partial projection tables in Appendix D.	Fully integrated	p. 35	p. 222
Oil and Gas: High OCS Resource	Oil and natural gas resources in the Pacific, Eastern Gulf of Mexico, Atlantic, and Alaska OCS are assumed to be three times higher than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 35	p. 222
Oil and Gas: High OCS Costs	Costs for exploration and development of oil and natural gas resources in the OCS are assumed to be 30 percent higher than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 35	p. 222
Oil and Gas: Low Shale EUR	EUR per shale gas well is assumed to be 50 percent lower than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 38	p. 222
Oil and Gas: High Shale EUR	EUR per shale gas well is assumed to be 50 percent higher than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 38	p. 222
Oil and Gas: Low Shale Recovery	Estimated undeveloped technically recoverable shale gas resource base is 50 percent lower than in the Reference case, with recovery rate per well unchanged from the Reference case, resulting in fewer wells needed to fully recover the resource. Partial projection tables in Appendix D.	Fully integrated	p. 38	p. 222
Oil and Gas: High Shale Recovery	Estimated undeveloped technically recoverable shale gas resource base is 50 percent higher than in the Reference case, with recovery rate per well unchanged from the Reference case, resulting in more wells needed to fully recover the resource. Partial projection tables in Appendix D.	Fully integrated	p. 38	p. 222
Oil and Gas: Low E15 Penetration	Consumers and retailers adopt E15 at a minimal rate in States that do not prohibit E15 blends. Partial projection tables in Appendix D.	Fully Integrated	p. 197	p. 224
Oil and Gas: High E15 Penetration	All States that currently limit or prohibit E15 remove the restrictions by 2015. Consumers and retailers adopt widespread E15 blending. Partial projection tables in Appendix D.	Fully Integrated	p. 197	p. 224
Coal: Low Coal Cost	Regional productivity growth rates for coal mining are approximately 2.7 percent per year higher than in the Reference case, and coal mining wages, mine equipment, and coal transportation rates are between 22 and 25 percent lower by 2035 than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 85	p. 222
Coal: High Coal Cost	Regional productivity growth rates for coal mining are approximately 2.7 percent per year lower than in the Reference case, and coal mining wages, mine equipment, and coal transportation rates are between 25 and 28 percent by higher by 2035 than in the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 85	p. 222
Integrated 2010 Technology	Combination of the Residential, Commercial, and Industrial 2010 Technology cases and the Electricity High Fossil Technology Cost, High Renewable Technology Cost, and High Nuclear Cost cases. Partial projection tables in Appendix D.	Fully integrated	p. 78	p. 223
Integrated High Technology	Combination of the Residential, Commercial, Industrial, and Transportation High Technology cases and the Electricity Low Fossil Technology Cost, Low Renewable Technology Cost, and Low Nuclear Cost cases. Partial projection tables in Appendix D.	Fully integrated	p. 78	p. 223
No GHG Concern	No GHG emissions reduction policy is enacted, and market investment decisions are not altered in anticipation of such a policy. Partial projection tables in Appendix D.	Fully integrated	p. 87	p. 223
GHG Price Economywide	Applies a price for CO_2 emissions throughout the economy. The CO_2 price assumed starts at $25 per ton beginning in 2013 and increases to $75 per ton in 2035. Partial projection tables in Appendix D.	Fully integrated	p. 49	p. 223

Table E1. Summary of the *AEO2011* cases (continued)

Case name	Description	Integration mode	Reference in text	Reference in Appendix E
Low EOR	The quantity of CO_2 available for CO_2-enhanced oil recovery (EOR) from industrial sources with high-purity CO_2 emissions is reduced from the Reference case. All other assumptions are the same as the Reference case. Partial projection tables in Appendix D.	Fully integrated	p. 45	p. 223
Low EOR/GHG Price Economywide	Same as the Low EOR case but with the same carbon price as in the GHG Price Economywide case. Partial projection tables in Appendix D.	Fully integrated	p. 45	p. 223

- In the *Traditional Low Oil Price case*, the OPEC countries increase their conventional oil production to obtain a 52-percent share of total world liquids production, and oil resources outside the U.S. are more accessible and/or less costly to produce (as a result of technology advances, more attractive fiscal regimes, or both) than in the Reference case. With these assumptions, conventional oil production outside the United States is higher in the Traditional Low Oil Price case than in the Reference case. Prices are the same as in the Low Oil Price case.
- In the *High Oil Price case*, world oil prices reach about $200 per barrel (2009 dollars) in 2035. In the High Oil Price case, the high prices result from higher demand for liquid fuels in the non-OECD nations. Higher demand is measured by higher economic growth relative to the Reference case. In this case, GDP growth in the non-OECD region is raised by 1.0 percentage points relative to Reference case in each projection year, starting in 2015. The OECD projections are only affected by the price impact.
- In the *Traditional High Oil Price case*, OPEC countries are assumed to reduce their production from the current rate, sacrificing market share, and oil resources outside the United States are assumed to be less accessible and/or more costly to produce than in the Reference case. Prices are the same as in the High Oil Price case.

Buildings sector cases

In addition to the *AEO2011* Reference case, three standalone technology-focused cases using the Residential and Commercial Demand Modules of NEMS were developed to examine the effects of changes in equipment and building shell efficiencies. Residential and commercial sector assumptions for the 2010 Technology case and the High Technology case are also used in the appropriate Integrated Technology cases.

Residential sector assumptions for the three technology-focused cases are as follows:

- The *2010 Technology case* assumes that all future equipment purchases are based only on the range of equipment available in 2010. Existing building shell efficiencies are assumed to be fixed at 2010 levels (no further improvements). For new construction, building shell technology options are constrained to those available in 2010.
- The *High Technology case* assumes earlier availability, lower costs, and higher efficiencies for more advanced equipment [*11*]. For new construction, building shell efficiencies are assumed to meet ENERGY STAR requirements after 2015. Consumers evaluate investments in energy efficiency at a 7-percent real discount rate.
- The *Best Available Technology case* assumes that all future equipment purchases are made from a menu of technologies that includes only the most efficient models available in a particular year for each fuel, regardless of cost. For new construction, building shell efficiencies are assumed to meet the criteria for the most efficient components after 2010.

Commercial sector assumptions for the three technology-focused cases are as follows:

- The *2010 Technology case* assumes that all future equipment purchases are based only on the range of equipment available in 2010. Building shell efficiencies are assumed to be fixed at 2010 levels.
- The *High Technology case* assumes earlier availability, lower costs, and/or higher efficiencies for more advanced equipment than in the Reference case [*12*]. Energy efficiency investments are evaluated at a 7-percent real discount rate. Building shell efficiencies for new and existing buildings in 2035 are assumed to be 17.4 percent and 7.5 percent higher, respectively, than their 2003 levels—a 25-percent improvement relative to the Reference case.
- The *Best Available Technology case* assumes that all future equipment purchases are made from a menu of technologies that includes only the most efficient models available in a particular year for each fuel, regardless of cost. Building shell efficiencies for new and existing buildings in 2035 are assumed to be 20.8 percent and 9.0 percent higher, respectively, than their 2003 values—a 50-percent improvement relative to the Reference case.

The Residential and Commercial Demand Modules of NEMS were also used to complete the High and Low Renewable Technology Cost cases, which are discussed in more detail below, in the renewable fuels cases section. In combination with assumptions for electricity generation from renewable fuels in the electric power sector and industrial sector, these sensitivity cases analyze the impacts of changes in generating technologies that use renewable fuels and in the availability of renewable energy sources. For the Residential and Commercial Demand Modules:

- The *Low Renewable Technology Cost case* assumes greater improvements in residential and commercial PV and wind systems than in the Reference case. The assumptions result in capital cost estimates that are 20 percent below Reference case assumptions in 2011 and decline to at least 40 percent lower than Reference case costs in 2035.
- The *High Renewable Technology Cost case* assumes that costs and performance levels for residential and commercial PV and wind systems remain constant at 2010 levels through 2035.

The No Sunset and Extended Policies cases described below in the cross-cutting integrated cases discussion also include assumptions in the Residential and Commercial Demand Modules of NEMS. The Extended Policies case builds on the No Sunset case and adds multiple rounds of appliance standards and building codes. In the two cases described below, those standards and codes are examined on their own. Essentially, these cases are similar to the Extended Policies case, but without the tax-credit extension assumptions of the No Sunset case.

- The *Expanded Standards case* includes updates to appliance standards, as prescribed by the timeline in DOE's multiyear plan, and introduces new standards for products currently not covered by DOE. Efficiency levels for the updated residential appliance standards are based on current ENERGY STAR guidelines. Efficiency levels for updated commercial equipment standards are based on the technology menu from the *AEO2011* Reference case and FEMP-designated purchasing specifications for Federal agencies.
- The *Expanded Standards and Codes case* begins with the Expanded Standards case and adds national building codes to reach 30-percent improvement relative to the IECC 2006 for residential households and ASHRAE 90.1-2004 for commercial buildings by 2020, with additional rounds of improved codes in 2023 and 2026.

Industrial sector cases

In addition to the *AEO2011* Reference case, two standalone cases using the IDM of NEMS were developed to examine the effects of less rapid and more rapid technology change and adoption. Because they are standalone cases, the energy intensity changes discussed in this section exclude the refining industry. Energy use in the refining industry is estimated as part of the PMM in NEMS. Different assumptions for the IDM were also used as part of the Integrated Low and High Renewable Technology Cost cases, Integrated Technology cases, No Sunset case, and Extended Policies case. For the industrial sector:

- The *2010 Technology case* holds the energy efficiency of new plant and equipment constant at the 2010 level over the projection period. Changes in aggregate energy intensity may result both from changing equipment and production efficiency and from changing composition of output within an individual industry. Because the level and composition of overall industrial output are assumed to be the same as in the Reference, 2010 Technology, and High Technology cases, the change in energy intensity in the two technology side cases is attributable to process and efficiency changes and increased use of CHP.
- The *High Technology case* assumes earlier availability, lower costs, and higher efficiency for more advanced equipment [*13*] and a more rapid rate of improvement in the recovery of biomass byproducts from industrial processes (0.7 percent per year, as compared with 0.4 percent per year in the Reference case). The same assumption is incorporated in the integrated Low Renewable Technology Cost case, which focuses on electricity generation. Although the choice of the 0.7-percent annual rate of improvement in byproduct recovery is an assumption in the High Technology case, it is based on the expectation of higher recovery rates and substantially increased use of CHP in that case.

The 2010 Technology and High Technology cases were run with only the IDM, rather than in fully integrated NEMS runs. Consequently, no potential feedback effects from energy market interactions are captured, and energy consumption and production in the refining industry, which are modeled in the PMM, are excluded.

- The *No Sunset and Extended Policies cases* include an assumption for CHP that extends the existing industrial CHP ITC through the end of the forecast. Additionally, the Extended Policies case includes expansion of the ITC for all industrial CHP capacities and raises the maximum credit that can be claimed. These assumptions are based on the current proposals in S. 1639 and H.R. 4751.

Transportation sector cases

In addition to the *AEO2011* Reference case, two standalone cases using the NEMS Transportation Demand Module were developed to examine the effects of advanced technology costs and efficiency improvement on technology adoption and vehicle fuel economy [*14*]. For the transportation sector:

- In the *Low Technology case*, the characteristics of conventional technologies, advanced technologies, and alternative-fuel LDVs, heavy-duty vehicles, and aircraft reflect more pessimistic assumptions about cost and efficiency improvements achieved over the projection. More pessimistic assumptions for fuel efficiency improvement are also reflected in the rail and shipping sectors.
- In the *High Technology case*, the characteristics of conventional and alternative-fuel LDVs reflect more optimistic assumptions about incremental improvements in fuel economy and costs. In the freight truck sector, the High Technology case assumes more

rapid incremental improvement in fuel efficiency for engine and emissions control technologies. More optimistic assumptions for fuel efficiency improvements are also made for the air, rail, and shipping sectors.

The Low and High Technology cases were run with only the Transportation Demand Module rather than as fully integrated NEMS runs. Consequently, no potential macroeconomic feedback related to vehicles costs or travel demand was captured, nor were changes in fuel prices incorporated.

Three additional integrated cases were developed to examine the potential energy impacts associated with the implementation of stricter fuel economy standards for LDVs and heavy-duty trucks, including:

- A *CAFE 3% Growth case* that examines the impact of increasing fuel economy standards by 3 percent annually for model years 2017 through 2025, reaching a combined standard of 46 miles per gallon for new LDVs by 2025. The standards are held constant beyond model year 2025.
- A *CAFE 6% Growth case* that examines the impact of increasing fuel economy standards by 6 percent annually for model years 2017 through 2025, reaching a combined standard of 59 miles per gallon for new LDVs by 2025. The standards are held constant beyond model year 2025.
- A *Heavy-Duty Vehicle Fuel Economy Standards case* that simulates the expected fuel economy impact of the fuel economy standards for heavy-duty vehicles (Class 2b through Class 8) for model years 2014 through 2018 proposed by the EPA and NHTSA.

Electricity sector cases

In addition to the Reference case, several integrated cases with alternative electric power assumptions were developed to analyze uncertainties about the future costs and performance of new generating technologies. Two of the cases examine alternative assumptions for nuclear power technologies, and two examine alternative assumptions for fossil fuel technologies. Reference case values for technology characteristics are determined in consultation with industry and government specialists; however, there is always uncertainty surrounding the major component costs. The electricity cases analyze what could happen if costs of new plants were either lower or higher than assumed in the Reference case. The cases are fully integrated to allow feedback between the potential shifts in fuel consumption and fuel prices.

Nuclear technology cost cases

- The cost assumptions for the *Low Nuclear Cost case* reflect a 20-percent reduction in the capital and operating costs for advanced nuclear technology in 2011, relative to the Reference case, and fall to 40 percent below the Reference case in 2035. The Reference case projects a 35-percent reduction in the capital costs of nuclear power plants from 2011 to 2035; the Low Nuclear Cost case assumes a 51-percent reduction from 2011 to 2035.
- The *High Nuclear Cost case* assumes that capital costs for advanced nuclear technology remain fixed at the 2011 levels assumed in the *Reference case*. The capital costs are still tied to key commodity price indices, but no cost improvement from "learning-by-doing" effects is assumed.

Fossil technology cost cases

- In the *Low Fossil Technology Cost case*, capital costs and operating costs for all coal- and natural-gas-fired generating technologies are assumed to start 20 percent lower than *Reference case* levels and fall to 40 percent lower than Reference case levels in 2035. Because learning in the Reference case reduces costs with manufacturing experience, costs in the Low Fossil Technology Cost case are reduced by 43 to 58 percent between 2011 and 2035, depending on the technology.
- In the *High Fossil Technology Cost case*, capital costs for all coal- and natural-gas-fired generating technologies remain fixed at the 2011 values assumed in the Reference *case*. Costs are still adjusted year to year by the Commodity Price Index, but no learning-related cost reductions are assumed.

Additional details about annual capital costs, operating and maintenance costs, plant efficiencies, and other factors used in the Low and High Fossil Technology Cost cases are provided in *Assumptions to the Annual Energy Outlook 2011* [*15*].

Electricity plant capital cost cases

Costs to build new power plants have risen dramatically in the past few years, driven primarily by significant increases in the costs of construction-related materials, such as cement, iron, steel and copper. For the *AEO2011* Reference case, initial overnight costs for all technologies were updated to be consistent with cost estimates for 2010. A cost adjustment factor based on the projected producer price index for metals and metal products is also applied throughout the projection, allowing overnight costs to fall in the future if the index drops or to rise if the index increases. Although there is significant correlation between commodity prices and power plant costs, there may be other factors influencing future costs that increase the uncertainties surrounding the future costs of building new power plants. For *AEO2011*, two additional cost cases were run that focus on the uncertainties of future plant construction costs. These cases use exogenous assumptions for the annual adjustment factors, rather than linking to the metals price index. The cases are discussed in the Issues in focus article, "Electricity Plant Cost Uncertainties."

- In the *Frozen Plant Capital Costs case*, base overnight costs for all new electric generating technologies are assumed to be frozen at 2015 levels. Cost decreases due to learning can still occur. In this case, costs do decline slightly over the projection, but by 2035 are roughly 25 percent above Reference case costs for the same year.
- In the *Decreasing Plant Capital Costs case*, base overnight costs for all new electricity generating technologies are assumed to fall more rapidly than in the Reference case. The base overnight costs are assumed to be 20 percent below the Reference case, through a reduction in the annual cost index. Costs are also assumed to decline more rapidly, so that by 2035 the cost factor is 40 percentage points below the Reference case value.

Electricity environmental regulation cases

Over the next few years, electricity generators will have to begin steps to comply with a large number of new environmental regulations currently in various stages of promulgation. The *AEO2011* Reference case does not include regulations that are still under development. However, the Issues in focus article "Power sector environmental regulations on the horizon" discusses the status of the different rules and examines potential impacts through a number of cases.

- The *Transport Rule Mercury MACT 5 case* assumes that the Air Transport Rule limits on SO_2 and NO_x and a 90-percent mercury MACT (maximum achievable control technology) are enacted. A 5-year recovery period for investments in environmental control projects is assumed.
- The *Transport Rule Mercury MACT 20 case* assumes the same rules as above, but a 20-year recovery period for investments in environmental control projects is assumed.
- The *Retrofit Required 5 case* represents stringent requirements for reductions in airborne emissions from coal-fired power plants. It assumes that utility boilers fall under the MACT rule, which requires all plants to install FGD scrubbers by 2020 in order to comply with acid gas reduction requirements. It also requires that all plants install SCR in order to meet future NO_x and ozone emission reduction requirements. If the investment in an FGD and SCR is not economical, the plant is retired. Investments in retrofits are assumed to be recovered over a 5-year period.
- The *Retrofit Required 20 case* assumes the same requirements as above, but investments in retrofits are assumed to be recovered over a 20-year period.
- The *Low Gas Price Retrofit Required 5 case* is identical to the Retrofit Required 5 case but adds an assumption of increased availability domestic shale availability and utilization rate, as in the High Shale EUR case. Increased access to natural gas lowers the natural gas prices paid by the electric power sector.
- The *Low Gas Price Retrofit Required 20 case* is identical to the Low Gas Price Retrofit Required 5 case, but investments in retrofits are assumed to be recovered over a 20-year period.

Renewable fuels cases

In addition to the *AEO2011* Reference case, two integrated cases with alternative assumptions about renewable fuels were developed to examine the effects of less aggressive and more aggressive improvement in the cost of renewable technologies. The cases are as follows:

- In the *Low Renewable Technology Cost case*, the levelized costs of energy resources for generating technologies using renewable resources are assumed to start at 20 percent below Reference case assumptions in 2011 and decline to 40 percent below the Reference case costs for the same resources in 2035. In general, lower costs are represented by reducing the capital costs of new plant construction. Biomass fuel supplies also are assumed to be 40 percent less expensive than in the Reference case for the same resource quantities used in the Reference case. Assumptions for other generating technologies are unchanged from those in the Reference case. In the Low Renewable Technology Cost case, the rate of improvement in recovery of biomass byproducts from industrial processes is also increased.
- In the *High Renewable Technology Cost case*, capital costs, operating and maintenance costs, and performance levels for wind, solar, biomass, geothermal, and renewable liquid fuel technologies are assumed to remain constant at 2011 levels through 2035. Costs are still tied to key commodity price indexes, but no cost improvement from "learning-by-doing" effects is assumed. Although biomass prices are not changed from the Reference case, this case assumes that dedicated energy crops (also known as "closed-loop" biomass fuel supply) do not become available.

Oil and gas supply cases

The sensitivity of the *AEO2011* projections to changes in the assumed rates of technological progress in oil and natural gas supply are examined in two cases:

- In the *Slow Technology case*, parameters representing the effects of technological progress on production rates, exploration and development costs, and success rates for conventional and unconventional oil and natural gas drilling are 50 percent less optimistic than those in the Reference case. Key Canadian supply parameters also are modified to simulate the assumed impacts of slow oil and natural gas technology penetration on Canadian supply potential. All other parameters in the model are kept at the Reference case values.

- In the *Rapid Technology case*, parameters representing the effects of technological progress on production rates, exploration and development costs, and success rates for conventional and unconventional oil and natural gas drilling in the Reference case are improved by 50 percent. Key supply parameters for Canadian oil and natural gas also are modified to simulate the assumed impacts of more rapid oil and natural gas technology penetration on Canadian supply potential. All other parameters in the model are kept at Reference case values, including technology parameters for other modules, parameters affecting foreign oil supply, and assumptions about imports and exports of LNG and natural gas trade between the United States and Mexico. Specific detail by region and fuel category is provided in *Assumptions to the Annual Energy Outlook 2011* [*16*].

Seven additional cases examine key uncertainties affecting exploration and development of offshore and shale gas resources and their impacts on future domestic natural gas supply.

- In the *Reduced OCS Access case*, no new lease sales occur in the Eastern Gulf of Mexico, Pacific, Atlantic, and Alaska OCS through 2035.
- In the *High OCS Resource case*, oil and natural gas resources in undeveloped areas of the OCS (namely the Pacific, Eastern Gulf of Mexico, Atlantic, and Alaska) are assumed to be 3 times higher than in the Reference case.
- In the *High OCS Costs case*, the costs of exploration and development of oil and natural gas resources in the OCS are assumed to be 30 percent higher than in the Reference case.
- In the *Low Shale EUR case*, the estimated ultimately recovery (EUR) per shale gas well is assumed to be 50 percent lower than in the Reference case, increasing the per-unit cost of developing the resource. The total unproved technically recoverable shale gas resource is decreased to 423 trillion cubic feet.
- In the *High Shale EUR case*, the EUR per shale gas well is assumed to be 50 percent higher than in the Reference case, decreasing the per-unit cost of developing the resource. The total unproved technically recoverable shale gas resource is increased from 827 trillion cubic feet in the Reference case to 1,230 trillion cubic feet.
- In the *Low Shale Recoverability case*, the total unproved technically recoverable shale gas resource base is the same as in the Low Shale EUR case (423 trillion cubic feet), but instead of decreasing the EUR per well, the estimate of the number of wells that need to be drilled to fully recover the shale gas in each play is assumed to be 50 percent lower than in the Reference case. This means that the per-unit cost of developing the resource is the same as in the Reference case.
- In the *High Shale Recoverability case*, the total unproved technically recoverable shale gas resource base is the same as in the High Shale EUR case (1,230 trillion cubic feet), but instead of increasing the EUR per well, the estimate of the number of wells that need to be drilled to fully recover the shale gas in each play is assumed to be 50 percent higher than in the Reference case. This means that the per-unit cost of developing the resource is the same as in the Reference case.

Coal market cases

Two alternative coal cost cases examine the impacts on U.S. coal supply, demand, distribution, and prices that result from alternative assumptions about mining productivity, labor costs, mine equipment costs, and coal transportation rates. The alternative productivity and cost assumptions are applied in every year from 2011 through 2035. For the coal cost cases, adjustments to the Reference case assumptions for coal mining productivity are based on variation in the average annual productivity growth of 2.7 percent observed since 2000. Transportation rates are lowered (in the Low Coal Cost case) or raised (in the High Coal Cost case) from Reference case levels to achieve a 25-percent change in rates relative to the Reference case in 2035. The Low and High Coal Cost cases represent fully integrated NEMS runs, with feedback from the macroeconomic activity, international, supply, conversion, and end-use demand modules.

- In the *Low Coal Cost case*, the average annual growth rates for coal mining productivity are higher than those in the Reference case and are applied at the supply curve level. As an example, the average annual growth rate for Wyoming's Southern Powder River Basin supply curve is increased from -0.5 percent in the Reference case for the years 2011 through 2035 to 2.2 percent in the Low Coal Cost case. Coal mining wages, mine equipment costs, and other mine supply costs all are assumed to be about 22 percent lower in 2035 in real terms in the Low Coal Cost case than in the Reference case. Coal transportation rates, excluding the impact of fuel surcharges, are assumed to be 25 percent lower in 2035.
- In the *High Coal Cost case*, the average annual productivity growth rates for coal mining are lower than those in the Reference case and are applied as described in the Low Coal Cost case. Coal mining wages, mine equipment costs, and other mine supply costs in 2035 are assumed to be about 28 percent higher than in the Reference case, and coal transportation rates in 2035 are assumed to be 25 percent higher.

Additional details of the productivity, wage, mine equipment cost, and coal transportation rate assumptions for the Reference and alternative coal cost cases are provided in Appendix D.

Cross-cutting integrated cases

In addition to the sector-specific cases described above, a series of cross-cutting integrated cases are used in *AEO2011* to analyze specific cases with broader sectoral impacts. For example, two integrated technology progress cases combine the assumptions from the other technology progress cases to analyze the broader impacts of more rapid and slower technology improvement rates. In addition, two cases also were run with alternative assumptions about expectations of future regulation of GHG emissions.

Integrated technology cases

The *Integrated 2010 Technology case* combines the assumptions from the Residential, Commercial, and Industrial 2010 Technology cases and the Electricity High Fossil Technology Cost, High Renewable Technology Cost, and High Nuclear Cost cases. The *Integrated High Technology case* combines the assumptions from the Residential, Commercial, and Industrial High Technology cases and the Electricity Low Fossil Technology Cost, Low Renewable Technology Cost, and Low Nuclear Cost cases.

Greenhouse gas cases

Although currently no Federal cap-and-trade legislation or carbon allowance pricing for CO_2 emissions is in place in the United States, the EPA announced a proposal in September 2009 to regulate emissions under the CAAA90. Under the proposal, industrial facilities with emission over 25,000 metric tons per year would be required to obtain permits that would demonstrate they are using the best practices and technologies to minimize GHG emissions. The rule also proposes new CAAA90 thresholds for permits to new or existing industrial facilities for GHG emissions under the New Source Review (NSR) and Title V operating permits programs. As a result, regulators and the investment community are beginning to push energy companies to invest in less GHG-intensive technologies. To reflect the market reaction to potential future GHG regulation, a 3-percentage-point increase is assumed in the cost of capital for investments in new coal-fired power plants without CCS and new CTL plants without CCS in the Reference case and all other *AEO2011* cases except the No GHG Concern and GHG Price Economywide cases. Those assumptions affect cost evaluations for the construction of new capacity but not the actual operating costs when a new plant begins operation

Two alternative GHG cases are used to provide a range of other potential outcomes, from no concern about future GHG legislation to the imposition of a specific economy-wide carbon allowance price. In the *GHG Price Economywide case*, an economy-wide carbon allowance price is examined. The price begins at $25 per metric ton CO_2 in 2013 and rises to $75 per metric ton CO_2 in 2035 (2009 dollars). This trajectory is consistent with the cost containment provisions in both the Kerry-Lieberman and Waxman-Markey GHG legislation. No assumptions are made for offsets, bonus allowances for CCS, or specific allocation of allowances in these cases.

The *No GHG Concern case*, which was run without any adjustment for concern about potential GHG regulations, is similar to what was run in previous *AEO*s (without the 3-percentage-point increase). In the No GHG Concern case, the same cost of capital is used to evaluate all new capacity builds, regardless of type.

CO_2 availability cases

Two alternative CO_2 availability cases are used to provide sensitivity analysis of oil production from CO_2-EOR, depending on the availability of relatively inexpensive CO_2 both with a carbon price and without one. The *Low EOR case* assumes that industrial CO_2 available from CTL and BTL plants is reduced by 50 percent from the Reference case. The *Low EOR/GHG Price Economywide case* assumes that the CO_2 availability is reduced and a carbon price exists that provides incentives for emitters to install carbon capture capabilities.

No Sunset case

In addition to the *AEO2011* Reference case, a case was run assuming that selected policies with sunset provisions like the PTC, ITC, and tax credits for energy-efficient equipment in the buildings and industrial sectors will be extended indefinitely rather than allowed to sunset as the law currently prescribes.

For the residential sector, these extensions include: (a) personal tax credits for selected end-use equipment, including furnaces, heat pumps, and central air conditioning; (b) personal tax credits for PV installations, solar water heaters, small wind turbines, and geothermal heat pumps; (c) manufacturer tax credits for refrigerators, dishwashers, and clothes washers, passed on to consumers at 100 percent of the tax credit value.

For the commercial sector, business ITCs for PV installations, solar water heaters, small wind turbines, geothermal heat pumps, and CHP are extended to the end of the projection. The business tax credit for solar technologies remains at the current 30-percent level without reverting to 10 percent as scheduled.

In the industrial sector, the existing ITC for industrial CHP, which currently ends in 2016, is extended to 2035.

For the refinery sector, blending credits are extended; the $1.00 per gallon biodiesel tax credit is extended; the $0.54 per gallon imported ethanol tariff is extended; and the $1.01 per gallon cellulosic biofuels PTC is extended.

For renewables, the PTC of 2.1 cents per kilowatthour (or 30 percent for wind, geothermal, biomass, hydroelectric, and landfill gas resources), which currently are set to expire at the end of 2012 for wind and 2013 for other eligible resources, are extended to 2035; and the 30-percent solar power ITC, which currently is scheduled to revert to 10 percent, is extended indefinitely.

Extended Policies case

Assumptions for tax credit extensions are the same as in the No Sunset case described above. Further, updates to Federal appliance efficiency standards are assumed to occur at regular intervals, and new standards for products not currently covered by DOE are introduced. Finally, proposed rules by NHTSA and the EPA for national tailpipe CO_2-equivalent emissions and fuel economy standards for LDVs, including both passenger cars and light-duty trucks, are harmonized and incorporated in this case.

Updates to appliance standards are assumed to occur as prescribed by the timeline in DOE's multiyear plan, and new standards for products currently not covered by DOE are introduced by 2019. The efficiency levels chosen for the updated residential appliance standards are based on current ENERGY STAR guidelines. The efficiency levels chosen for updated commercial equipment standards are based on the technology menu from the *AEO2011* Reference case and either FEMP-designated purchasing specifications for Federal agencies or ENERGY STAR guidelines. National building codes are added to reach 30-percent improvement relative to IECC 2006 for residential households and ASHRAE 90.1-2004 for commercial buildings by 2020, with additional rounds of improvements in 2023 and 2026.

In the industrial sector, tax credits are further extended to cover all systems sizes rather than applying only to systems under 50 megawatts, and the maximum credit (cap) is increased from $15,000 to $25,000 per system. These extensions are consistent with previously proposed legislation (S. 1639) or pending legislation (H.R. 4751).

For transportation, the Extended Policies case assumes that the standards are further increased, so that the minimum fuel economy standard achieved by LDVs increases to 45.6 miles per gallon in 2035.

E15 cases

Two alternative E15 cases were established to reflect the potential variability in consumer demand for E15, which depends on multiple factors and ultimately affects the conversion rate of gasoline stations from E10 to E15.

- In the *Low E15 Penetration case*, the infrastructure and regulatory barriers to E15 adoption are more pronounced, and penetration of E15 in all demand regions grows at a slower rate, reaching a lower maximum level than in the Reference case. E15 penetration never rises to one-third of the maximum potential penetration level in any of the U.S. Census Divisions.
- In the *High E15 Penetration case*, E15 adoption occurs at a faster rate and reaches a higher overall level than in the Reference case. Any State that currently has laws or regulations that prohibit the use of ethanol blends above 10 percent or gasoline with an oxygenate content in excess of 3.5 percent is assumed to remove those restrictions by 2015. In addition, E15 penetration rises to 99 percent of the potential maximum level in all regions by 2020, indicating that infrastructure or regulatory barriers do not inhibit the use of E15 in gasoline markets.

Endnotes for Appendix E

Links current as of April 2011

1. U.S. Energy Information Administration, The National Energy Modeling System: An Overview 2009, DOE/EIA-0581(2009) (Washington, DC: March 2009), website www.eia.gov/oiaf/aeo/overview.
2. On October 1, 2010, the U.S. Energy Information Administration was reorganized along functional lines. The new Office of Energy Analysis has been assigned all analysis responsibilities for EIA, including short- and mid-term functions as well as fuel-specific analysis. The referenced documents on the EIA website will be changed gradually over the next year to reflect the new organizational structure.
3. The disaggregation to 22 subregions for electricity planning and dispatch is new for *AEO2011*. Disaggregation of the Electricity Market Module (EMM) is intended to reduce errors that result from aggregation and averaging, to better represent environmental and regional issues, and thus to improve the projections of capacity additions and fuels consumed for generation.
4. U.S. Energy Information Administration, Annual Energy Review 2009, DOE/EIA-0384(2009) (Washington, DC: August 2010), website www.eia.gov/emeu/aer.
5. U.S. Energy Information Administration, Emissions of Greenhouse Gases in the United States 2009, DOE/EIA-0573(2009) (Washington, DC, April, 2011), website www.eia.gov/environment/emissions/ghg_report.
6. U.S. Energy Information Administration, "Short-Term Energy and Summer Fuels Outlook," website www.eia.gov/emeu/steo/pub. Portions of the preliminary information were also used to initialize the NEMS Petroleum Market Module projection.
7. U.S. Energy Information Administration, "Manufacturing Energy Consumption Survey," website www.eia.doe.gov/emeu/mecs.
8. U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook 2011*, DOE/EIA-0554(2011) (Washington, DC: April 2011), website www.eia.gov/forecasts/aeo/assumptions/.
9. Alternative liquids technologies include all biofuel technologies plus CTL and GTL.
10. U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook 2011*, DOE/EIA-0554(2011) (Washington, DC: April 2011), website www.eia.gov/forecasts/aeo/assumptions/.
11. High technology assumptions for the residential sector are based on U.S. Energy Information Administration, *EIA—Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Case Second Edition (Revised)* (Navigant Consulting, Inc., September 2007), and *EIA—Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Case: Residential and Commercial Lighting, Commercial Refrigeration, and Commercial Ventilation Technologies* (Navigant Consulting, Inc., September 2008).
12. High technology assumptions for the commercial sector are based on Energy Information Administration, *EIA—Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Case Second Edition (Revised)* (Navigant Consulting, Inc., September 2007), and *EIA—Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Case: Residential and Commercial Lighting, Commercial Refrigeration, and Commercial Ventilation Technologies* (Navigant Consulting, Inc., September 2008).
13. These assumptions are based in part on Energy Information Administration, *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model* (FOCIS Associates, October 2005).
14. U.S. Energy Information Administration, *Documentation of Technologies Included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks* (Energy and Environmental Analysis, September 2003).
15. U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook 2011*, DOE/EIA-0554(2011) (Washington, DC: April 2011), website www.eia.gov/forecasts/aeo/assumptions/.
16. U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook 2011*, DOE/EIA-0554(2011) (Washington, DC: April 2011), website www.eia.gov/forecasts/aeo/assumptions/.

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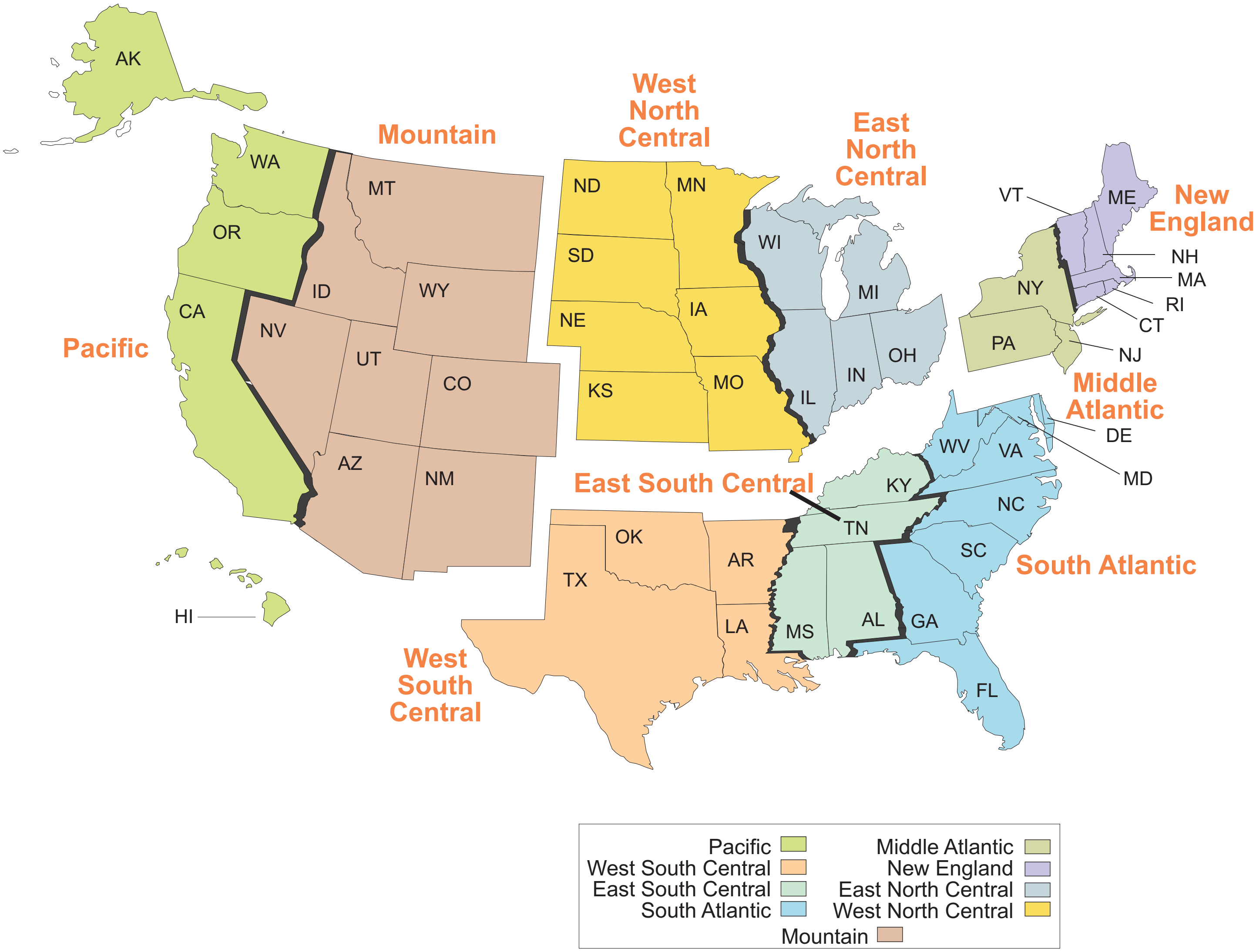
Regional Maps

Figure F1. United States Census Divisions



Source: U.S. Energy Information Administration, Office of Energy Analysis.

Figure F1. United States Census Divisions (continued)

Division 1
New England

Connecticut
Maine
Massachusetts
New Hampshire
Rhode Island
Vermont

Division 2
Middle Atlantic

New Jersey
New York
Pennsylvania

Division 3
East North Central

Illinois
Indiana
Michigan
Ohio
Wisconsin

Division 4
West North Central

Iowa
Kansas
Minnesota
Missouri
Nebraska
North Dakota
South Dakota

Division 5
South Atlantic

Delaware
District of Columbia
Florida
Georgia
Maryland
North Carolina
South Carolina
Virginia
West Virginia

Division 6
East South Central

Alabama
Kentucky
Mississippi
Tennessee

Division 7
West South Central

Arkansas
Louisiana
Oklahoma
Texas

Division 8
Mountain

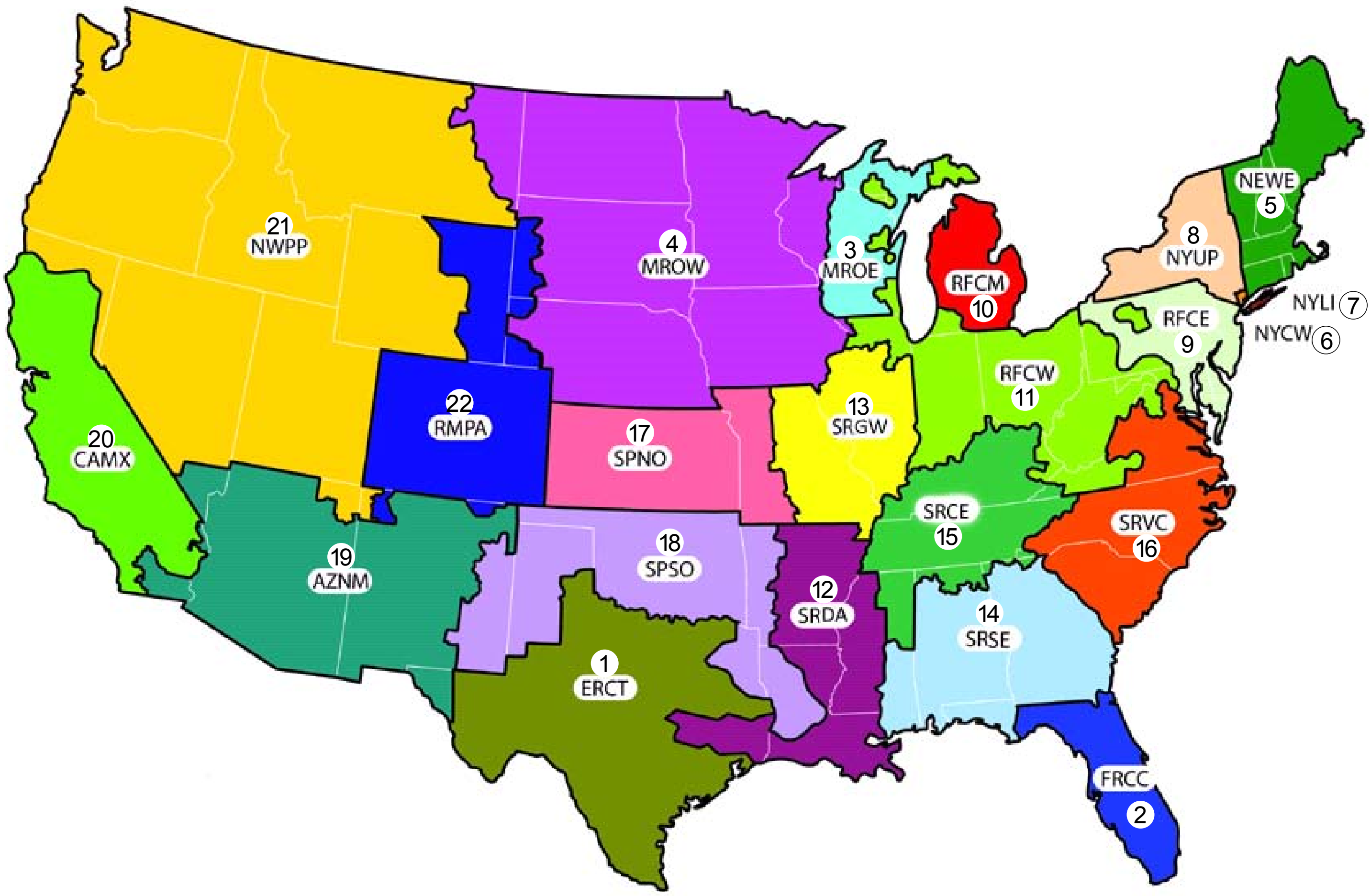
Arizona
Colorado
Idaho
Montana
Nevada
New Mexico
Utah
Wyoming

Division 9
Pacific

Alaska
California
Hawaii
Oregon
Washington

Source: U.S. Energy Information Administration, Office of Energy Analysis.

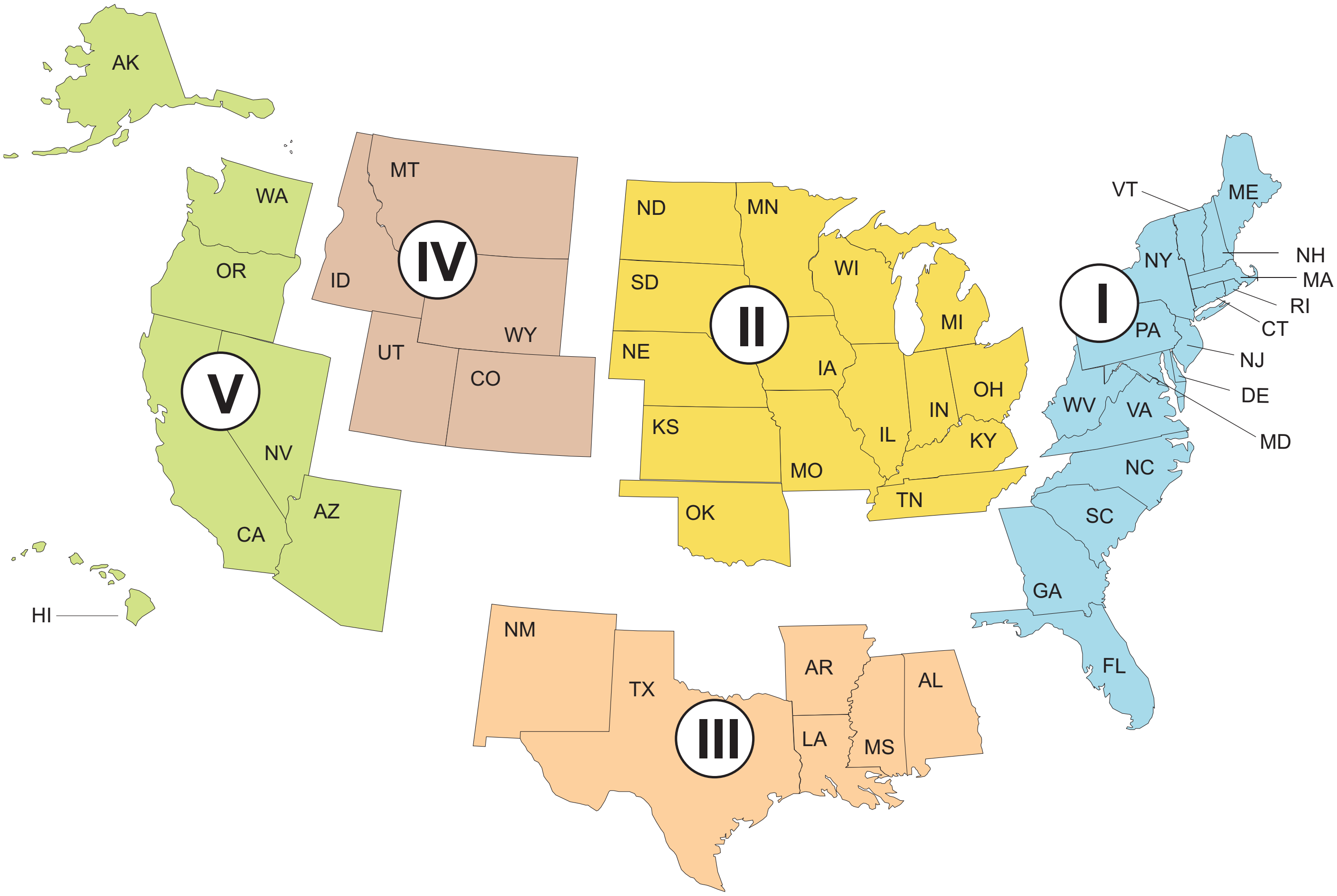
Figure F2. Electricity market module regions



1.	ERCT	ERCOT All	12.	SRDA	SERC Delta
2.	FRCC	FRCC All	13.	SRGW	SERC Gateway
3.	MROE	MRO East	14.	SRSE	SERC Southeastern
4.	MROW	MRO West	15.	SRCE	SERC Central
5.	NEWE	NPCC New England	16.	SRVC	SERC VACAR
6.	NYCW	NPCC NYC/Westchester	17.	SPNO	SPP North
7.	NYLI	NPCC Long Island	18.	SPSO	SPP South
8.	NYUP	NPCC Upstate NY	19.	AZNM	WECC Southwest
9.	RFCE	RFC East	20.	CAMX	WECC California
10.	RFCM	RFC Michigan	21.	NWPP	WECC Northwest
11.	RFCW	RFC West	22.	RMPA	WECC Rockies

Source: U.S. Energy Information Administration, Office of Energy Analysis.

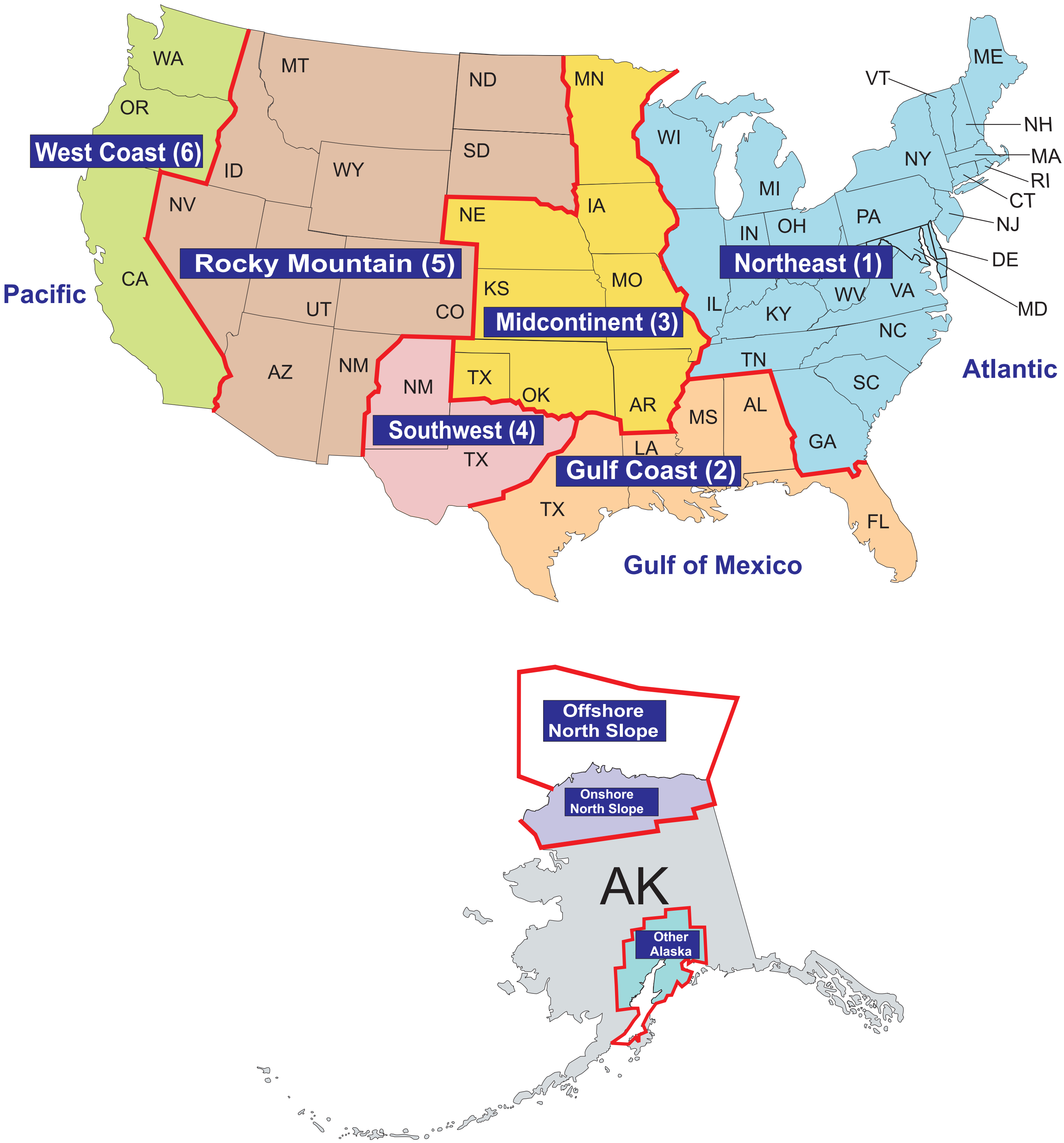
Figure F3. Petroleum Administration for Defense Districts



PAD District I -	East Coast
PAD District II -	Midwest
PAD District III -	Gulf Coast
PAD District IV -	Rocky Mountain
PAD District V -	West Coast

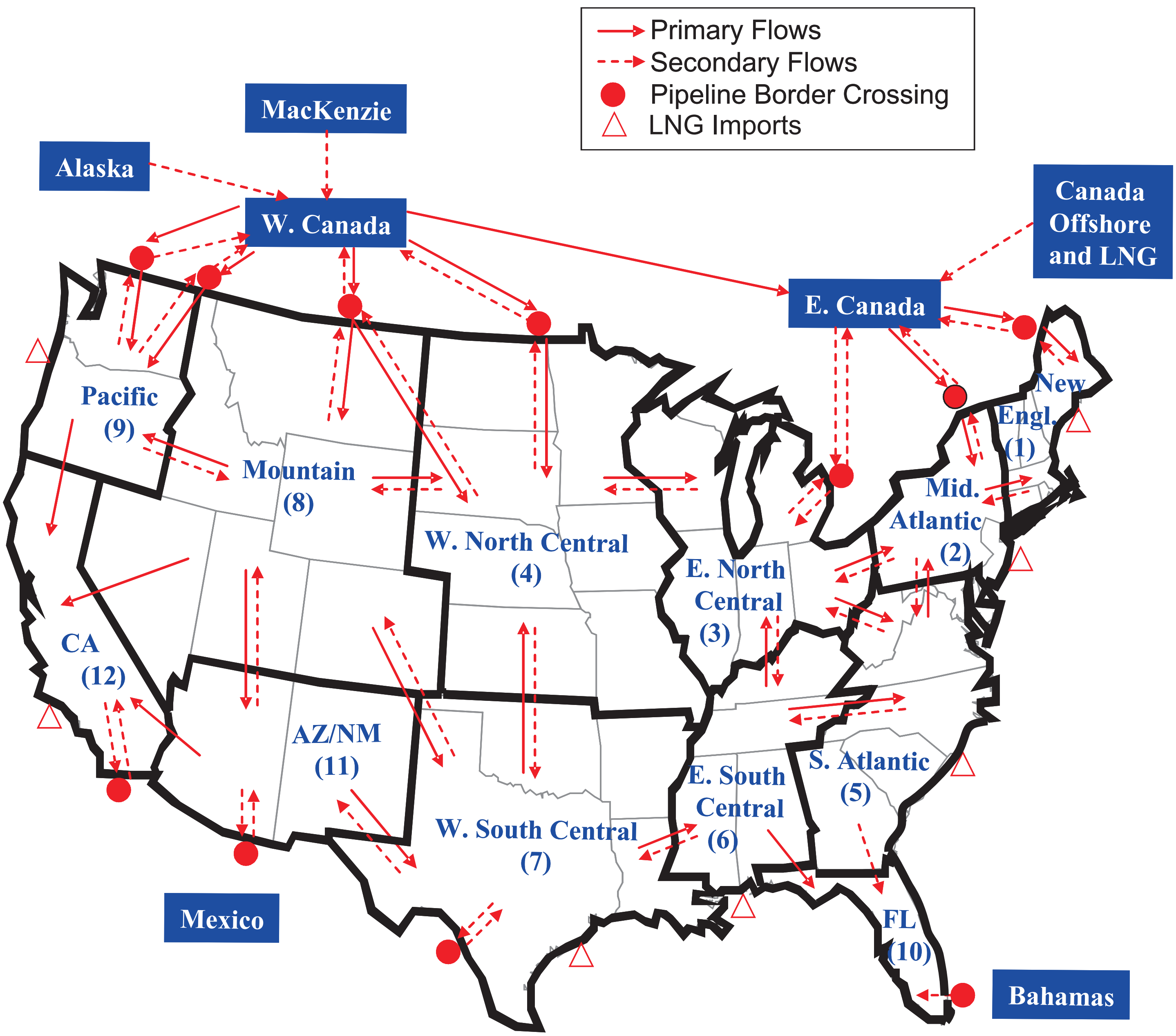
Source: U.S. Energy Information Administration, Office of Energy Analysis.

Figure F4. Oil and gas supply model regions



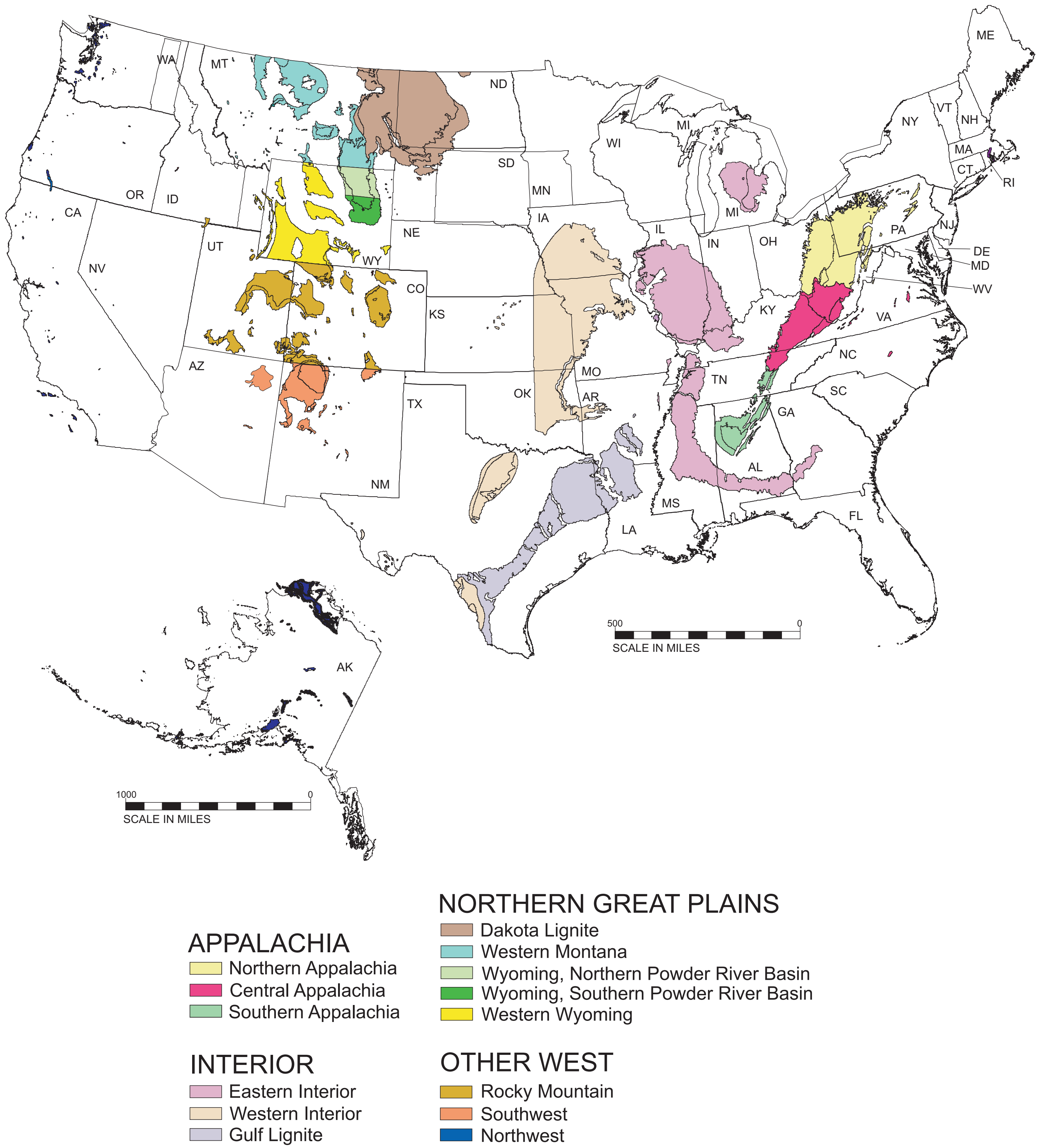
Source: U.S. Energy Information Administration, Office of Energy Analysis.

Figure F5. Natural gas transmission and distribution model regions



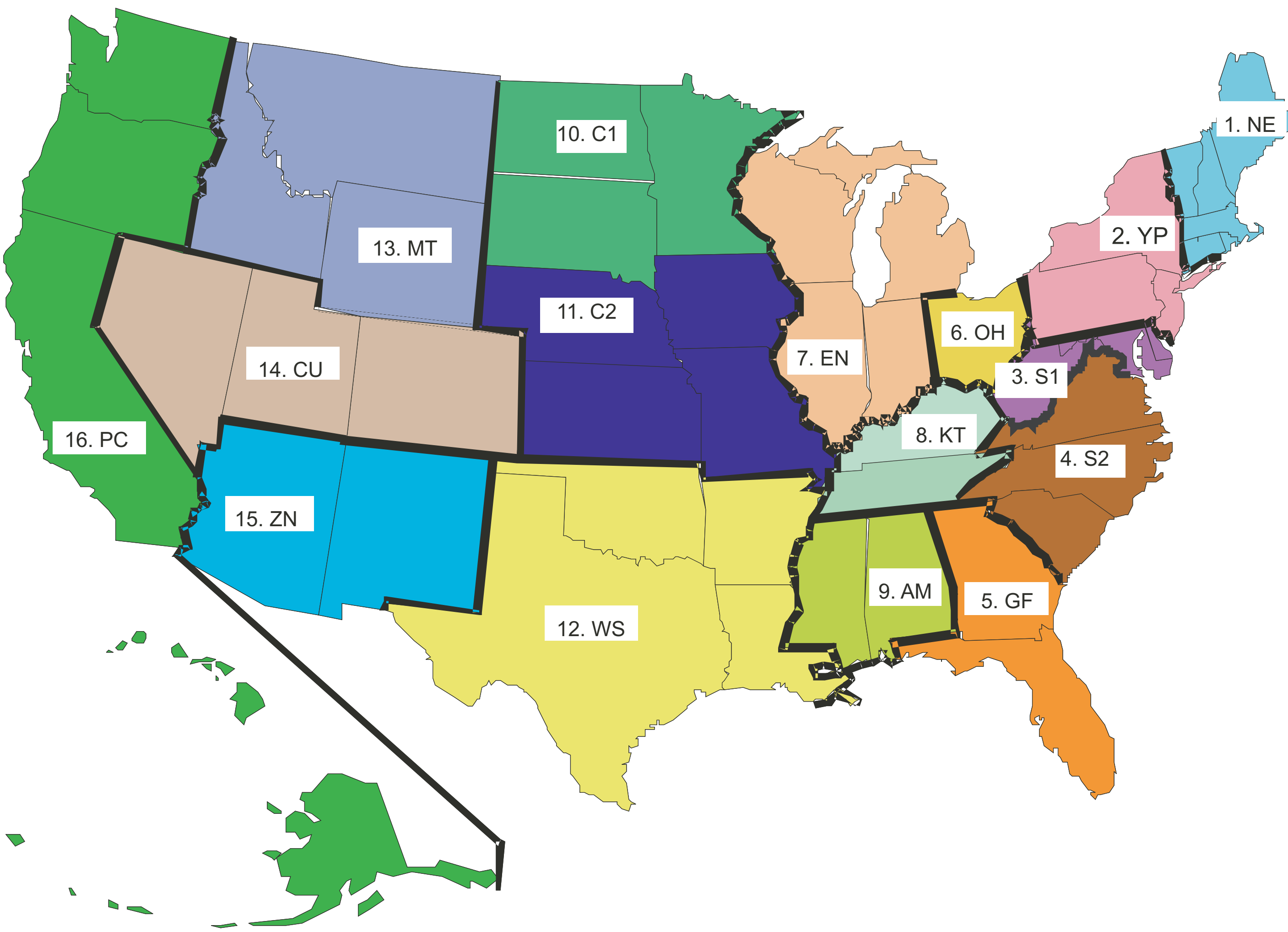
Source: U.S. Energy Information Administration, Office of Energy Analysis.

Figure F6. Coal supply regions



Source: U.S. Energy Information Administration, Office of Energy Analysis.

Figure F7. Coal demand regions



Region Code	Region Content
1. NE	CT,MA,ME,NH,RI,VT
2. YP	NY,PA,NJ
3. S1	WV,MD,DC,DE
4. S2	VA,NC,SC
5. GF	GA,FL
6. OH	OH
7. EN	IN,IL,MI,WI
8. KT	KY,TN

Region Code	Region Content
9. AM	AL,MS
10. C1	MN,ND,SD
11. C2	IA,NE,MO,KS
12. WS	TX,LA,OK,AR
13. MT	MT,WY,ID
14. CU	CO,UT,NV
15. ZN	AZ,NM
16. PC	AK,HI,WA,OR,CA

Source: U.S. Energy Information Administration, Office of Energy Analysis.

Appendix G

Conversion factors

Table G1. Heat rates

Fuel	Units	Approximate Heat Content
Coal[1]		
Production	million Btu per short ton	19.933
Consumption	million Btu per short ton	19.800
Coke Plants	million Btu per short ton	26.327
Industrial	million Btu per short ton	21.911
Residential and Commercial	million Btu per short ton	21.284
Electric Power Sector	million Btu per short ton	19.536
Imports	million Btu per short ton	24.786
Exports	million Btu per short ton	25.550
Coal Coke	million Btu per short ton	24.800
Crude Oil		
Production	million Btu per barrel	5.800
Imports[1]	million Btu per barrel	5.989
Petroleum Products and Other Liquids		
Consumption[1]	million Btu per barrel	5.261
Motor Gasoline[1]	million Btu per barrel	5.119
Jet Fuel	million Btu per barrel	5.670
Distillate Fuel Oil[1]	million Btu per barrel	5.775
Diesel Fuel[1]	million Btu per barrel	5.766
Residual Fuel Oil	million Btu per barrel	6.287
Liquefied Petroleum Gases[1]	million Btu per barrel	3.558
Kerosene	million Btu per barrel	5.670
Petrochemical Feedstocks[1]	million Btu per barrel	5.506
Unfinished Oils	million Btu per barrel	6.118
Imports[1]	million Btu per barrel	5.520
Exports[1]	million Btu per barrel	5.782
Ethanol	million Btu per barrel	3.539
Biodiesel	million Btu per barrel	5.376
Natural Gas Plant Liquids		
Production[1]	million Btu per barrel	3.692
Natural Gas[1]		
Production, Dry	Btu per cubic foot	1,026
Consumption	Btu per cubic foot	1,026
End-Use Sectors	Btu per cubic foot	1,027
Electric Power Sector	Btu per cubic foot	1,025
Imports	Btu per cubic foot	1,025
Exports	Btu per cubic foot	1,009
Electricity Consumption	Btu per kilowatthour	3,412

[1]Conversion factor varies from year to year. The value shown is for 2009.
Btu = British thermal unit.
Sources: U.S. Energy Information Administration (EIA), *Annual Energy Review 2009*, DOE/EIA-0384(2009) (Washington, DC, August 2010), and EIA, AEO2011 National Energy Modeling System run REF2011.D020911A.

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Engine Efficiency Improvements Enabled by Ethanol Fuel Blends in a GDi VVA Flex Fuel Engine

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Delphi Powertrain Systems

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ABSTRACT

Advances in engine technology including Gasoline Direct injection (GDi), Dual Independent Cam Phasing (DICP), advanced valvetrain and boosting have allowed the simultaneous reductions of fuel consumption and emissions with increased engine power density. The utilization of fuels containing ethanol provides additional improvements in power density and potential for lower emissions due to the high octane rating and evaporative cooling of ethanol in the fuel. In this paper results are presented from a flexible fuel engine capable of operating with blends from E0-E85. The increased geometric compression ratio, (from 9.2 to 11.85) can be reduced to a lower effective compression ratio using advanced valvetrain operating on an Early Intake Valve Closing (EIVC) or Late Intake Valve Closing (LIVC) strategy. DICP with a high authority intake phaser is used to enable compression ratio management. The advanced valvetrain also provides significantly reduced throttling losses by efficient control of intake air and residuals. Increased ethanol blends provide improvements in power density due to knock resistance. Knock resistance also provides a significant potential for reduced NOx since higher dilution without knock is enabled at moderate loads typical of normal driving. E85 also shows significant advantages for particulate emissions that enable broader authority in selection of optimal injection timings for improving efficiency. An increase in the ethanol content improves low end torque providing an addition opportunity for improved fuel economy by using down-speeding for more efficient vehicle operation

INTRODUCTION

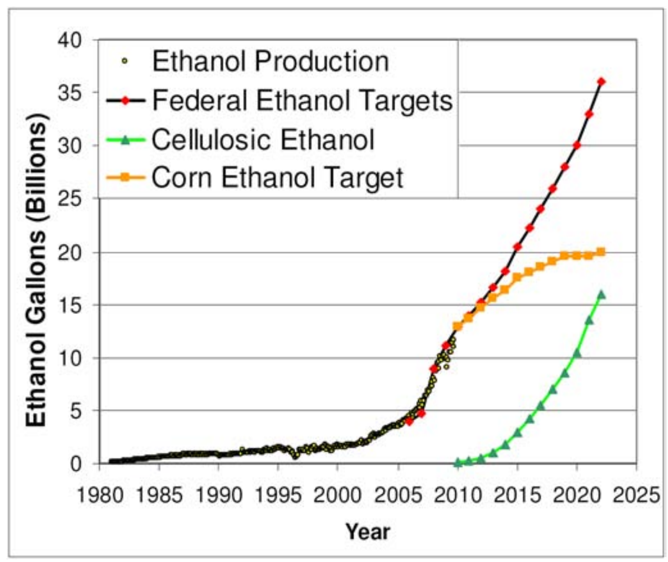

Figure 1. Ethanol production and targets as outline by the EISA.

The production of ethanol for fuel has risen dramatically in the last decade since to a level of 12 Billion gallons/year in 2009[1], as shown in figure 1. The passage of the Energy Independence and Security Act (EISA) of 2007 [2] has set a target for ethanol production of 36 billion gallons by 2022. The United States approves the use of blends up to E10, for use in all vehicles, E15 for Model year 2007 and newer vehicles and E85 for use in flex fuel vehicles. The increased production of ethanol is rapidly approaching the point where even if all the gasoline is blended to E10 the goals of the EISA can not be met. Current acceptance of E85 is hindered due to its reduced energy density relative to gasoline, which results in reduced MPG and vehicle range. The energy content is about 28% lower on a volumetric basis and 32%

lower on a mass basis. Despite its lower energy density ethanol blends offer significant benefits with respect to increased power density due to its high octane rating and latent heat of vaporization. E85 can operate more efficiently and produces lower warmed up exhaust emissions. Difficulties include cold starting, primarily at low ambient temperatures due to poor vaporization. Corrosion and compatibility with materials are also critical such that flex fuel vehicles must be specifically designed and calibrated to operate on E85 and intermediate blends. These designed modifications are well outlined in [3,4,5] and include issues of pump flow capability, injector flow capability and dynamic range, injector deposits, valve seat, ring, liner and piston durability. Ethanol usage in other markets is also driving development including E85 in Sweden and E100 in Brazil [5].

The investigation of ethanol as a fuel to leverage its ability to increase power density due to its high octane and latent heat of vaporization has been studied in various platforms. Evaluation on a CFR engine was able increase the knock limited Compression Ratio (CR) to 16.5:1 at 900 RPM with E85 [6]. Evaluation with a port injected engine with the CR increased to 13 showed demonstrated knock free operation above E50 blends but low end torque suffered with conventional gasoline and E10-20 blends[7]. Researchers investigated the effect of valvetrain modifications for improving cold start ability by using Late Intake Valve Opening (LIVO) with closing near Bottom Dead Center (BDC) to increase mixing and maximize compression heating [7,8]. These evaluations were able to reduce cold start temperatures to −35 C with a 10.5 CR port fueled engine. Ethanol blends up to E85 were evaluated in a Direct Injection (DI) Engine with Variable Valve Actuation (VVA) with compression ratios up to 12.87. E50 and E85 blends were not knock limited [9]. The electro-hydraulic VVA was used to evaluate EIVC and LIVC strategies to reduce the compression ratio when operating on gasoline or low ethanol blends. This reduced the knocking tendency but with reduced output due to lower displacement. A naturally aspirated DI Flex Fuel application with CR increased to 11.9 showed improvement in specific power, even over knock free gasoline reaching 13 Bar BMEP on E85 at 4000 RPM[3].

The use of ethanol blends with boosted engines provides significant opportunity for increased power density and efficiency. High ethanol blends such as E85 can provide knock free operation at high loads. Cooler exhaust temperatures also reduce the need for Power Enrichment (PE) to limit turbine inlet temperatures. Work to optimize for E85 and Flex fuel operation cover a spectrum of technologies including calibration optimization and algorithm development of a boosted MPFI [5] and of a boosted DI engine with DICP [10]. Research results [4,10] conclude that power density using E85 could be further increased if the engine was designed to allow peak cylinder pressures of 140-150 Bar. An evaluation to determine the relative benefits of the increased RON and the latent heat of evaporation has been documented showing the RON provides 70% of the knock resistance at 1000 RPM but only 40% at 3000 RPM [11].

Technical approaches to address the inherent power density discrepancy between E85 and gasoline operation have been investigated to develop strategies to reduce the knocking tendency with gasoline. This enables some of the power density and efficiency losses from spark retard and PE to be reduced. These include cooled EGR, [12,13] cooled EGR with hydrogen addition to improve dilution tolerance [14] and the use of an Atkinson cycle (LIVC) to reduce the effective compression ratio to limit knock [15]. Lean boosted systems have also been evaluated with E85 to improve efficiency [15]. The use of a duel fuel system with gasoline Port Fuel Injection (PFI) and DI E85 has demonstrated the ability to leverage E85 for high load efficient operation while providing increased efficiency with gasoline at low loads [4]. The 12:1 CR boosted engine uses the required quantity of E85 to limit knock as load increases effectively providing the required ethanol "blend". This application did not require exclusive E85 operation since peak cylinder pressures limits required spark retard which reduced the octane requirement. They concluded the development of engines permitting increased peak cylinder temperatures would enable increased power densities with E85 without the need for spark retard or PE.

CONCEPT DESCRIPTION

To leverage the high octane potential of ethanol a turbocharged GDi Engine with DICP was chosen. Engine simulation was carried out previously [16] to identify strategies for improved engine efficiency and allow operation as a flex fuel vehicle with gasoline to E85 blends. To improve engine efficiency the CR was increased from 9.2 to 11.85 by changing out the pistons. The valvetrain was also modified to accept a 2 step VVA system that employed both EIVC and LIVC strategies to control the effective displacement and compression ratio of the engine. The phasing authority of the intake phaser was increased to 80 crank angle degrees (cad) based on results of the engine simulation. Table 1 outlines the base engine specifications and calls out the modifications that took place.

Table 1. Engine Specifications

Base Engine Specification	GDi Turbocharged Engine with DICP
Displacement	2.0 L
Bore	86 mm
Stroke	86 mm
Compression Ratio	11.85 increased from 9.2
Intake cam phaser	80 cad increased from 50 cad
Exhaust cam phaser	50 cad
Intake valve lift / Duration (high)	10.3 mm / 277 cad @0.15mm lift
Intake valve lift / Duration (low)	5.6 mm / 132 cad @0.15mm lift
Exhaust valve lift / Duration	10.3 mm / 230 cad @0.15mm lift
Intake Valve (High) Opening / Closing	Opening -41 to 39 cad atdc Closing 136 to 56 cad abdc
Intake Valve (Low) Opening / Closing	Opening -42 to 38 cad atdc Closing 6 to 86 cad bbdc
Exhaust Valve Opening / Closing	Opening 10 to 60 cad bbdc Closing -10 to 40 cad atdc
Fuel Injector	6 hole, 16.4 g/s @10 MPa
Turbocharger	Borg Warner K04-025 *Wastegate and Compressor bypass fully open for testing*
Fuel injection pressure	10 MPa (100 Bar) for all testing

The CR of the engine was limited by valve clearance constraints to allow valve phasing. A picture of the modified piston is shown in figure 2. The design includes a small feature to aid cold starting with late stratified injection timing. The feature is smaller than desirable for stratified operation but was a compromise for increased compression ratio.

Figure 2. Modified geometry of 11.85 CR piston.

The modifications to the valvetrain include a Delphi 2-step mechanism, 3 lobe camshaft and associated oil control valves and passages. The 2-Step Roller Finger Follower (RFF), Figure 3, is designed for a type II valvetrain. The 2-step RFF operates on the trilobe camshaft, Figure 4, by operating on the outer rollers in low lift mode. A central slider integrates a loss motion spring to retain contact on the center high lift profile. The high lift is activated by increasing oil pressure through the Hydraulic Lash Adjuster (HLA) to engage a locking pin, via an oil control valve to the HLA passages. Development of this system is documented in reference [17].

Figure 3. Delphi 2-step Roller Finger follower

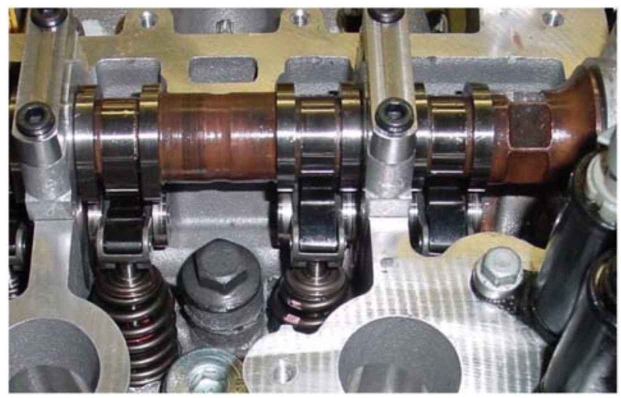

Figure 4. Tri-lobe camshaft installed with 2-step RFF

The use of EIVC has been documented [9, 18,19,20,21] to improve fuel efficiency at low load by a reduction of pumping losses. Typical challenges involve reduced in-cylinder charge motion from reduced valve lift and more time for turbulence dissipation. An alternative is to use LIVC [9, 22] which has better charge motion but is slightly less efficient than EIVC at low loads. The cam profiles selected for this engine allow both of these strategies to be utilized to provide a variable displacement system controlled by valve closing time. The relative cam positions, valve lift and phasing authority is shown in figure 5. The dashed lines indicate the cam positions in the park condition at cold start, since oil pressure is required to provide valve phasing. The engine starts in low lift at the condition of the dashed low lift cam and dashed exhaust cam. This start configuration provides low overlap for minimal internal EGR and Late Intake Valve Opening (LIVO) which has been documented to aid cold starting due to high intake velocities and high effective compression at low speeds, [8].

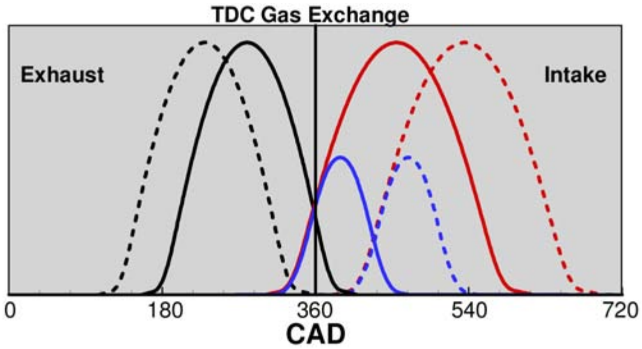

Figure 5. Cam profiles and cam phasing authority.

INSTRUMENTATION

The modified engine was installed on an engine dynamometer. Table 2 lists instrumentation and sampling locations on the engine.

Table 2. Instrumentation Description

In-cylinder Pressure Transducers	Kistler 6117BCD36
Shaft Encoder	Kistler 2614A @ 0.5 cad
Combustion Analysis	A and D Redline II
UEGO Sensor	Post Turbo before converter
Emission analyzer	AVL GEM 110 HC, CO, NOx, O2, CO2
Emission Sample tap	Exhaust plenum prior to TC
Particulate	AVL 415S
Particulate sample	Post converter
Fuel Measurement	AVL 735
Fuel Conditioner	AVL 753 (20 C)
Intake Temperature TC	Inlet port Cyl. 1-4
Exhaust Temperature TC	Exhaust runners Cyl. 1-4, Turbine inlet 1+3,2+4, Converter inlet, 25 mm bed
Manifold Pressure	Intake manifold
Exhaust Backpressure	Turbocharger inlet

FUELS

A variety of fuels were evaluated during testing, and with the exception of the section evaluating fuel blends, the test fuels consisted of 91 RON E0 and a commercial grade E85 designated as E85C. Tables 3 and 4 show the measured and calculated fuel properties. The intermediate blends E10-E50 were prepared by splash blending the E0 and E85 to the targeted concentration E100 was not evaluated. The data is only shown for reference from the stock used for making the E85 blend.

Table 3. Test Fuel Properties (Measured)

Fuel Blend	Vol. % Ethanol	LHV KJ/g	Density g/cc	Wt.% Water	RON
ASTM	D5501	D240	D4052	E203	D2699
E0*	0	43.397	.7426	0.013	90.8
EEE#	0	42.890	.742	0	96.8
E10	10.46	41.47	.7449	.1289	95.6
E20	21	39.53	.7512	.2373	99.7
E50	49.7	34.38	.7666	.4947	104
E85	82.2	29.2	.7854	.7653	106
E85C	82.8	29.16	.7856	.8179	(-)
E100 x	96.6	26.7	.794	0.9	(-)
* 91 RON (87 (R+M)/2) Test fuel M52642 -Gage products					
# EPA TIER II EEE – Haltermann Products					
x Ethanol feed stock includes 2% denaturant					

Table 4. Test Fuel Properties (Calculated)

Fuel Blend	Stoich. AFR	H/C	%O2 wt.	J/cc Rel E0
E0*	14.67	1.92	.012	1
EEE#	14.61	1.879	0	.994
E10	14.08	2.04	3.971	.964
E20	13.48	2.16	7.89	.927
E50	11.83	2.47	18.219	.825
E85	9.94	2.82	29.389	.716
E85C	9.89	2.82	29.613	.715
E100	8.99	3	34.78	.657

CONCEPT EVALUATION

The fundamental evaluation on the engine in this report focuses on un-boosted operation to maximize fuel consumption during loads typical of the Federal Test Procedure (FTP) city and highway drive cycles. The engine retained the OEM turbocharger configuration but all testing was completed with the waste gate fully open and the compressor bypass fully open to eliminate boost pressure. The advanced valvetrain allows the effective compression ratio to be managed to compensate for the ethanol variation in the fuel. Initial testing focused on the limit fuels of E0 91 RON gasoline and E85 fuel. The concept evaluation involved the following phases which will be reviewed:

• Engine valvetrain evaluation for load and compression ratio control

• Injection timing evaluation

• Evaluation of valve deactivation

• Valvetrain cam timing optimization for efficiency

• Evaluation of Ethanol Blends E0, E10, E20, E50 and E85

• Fuel consumption optimization of E85

• GT power simulation using speed-load maps optimized for fuel efficiency on E85

Valvetrain Evaluation

A primary feature of this engine concept is its ability to modify the effective displacement and hence compression ratio of the engine using valve timing. It still retains its full geometric expansion ratio of 11.85 independent of the effective compression ratio. The effective displacement is controlled by the intake phaser. By adjusting the intake valve closing time the trapped air mass is controlled as shown in figure 6. The system provides a smooth transition between cams by matching airflow at the switch point. The system is limited at low displacements by poor combustion stability due to increased residual fraction and slow combustion. At high loads, tuning allows volumetric efficiency to exceed 100% this providing increased effective displacement.

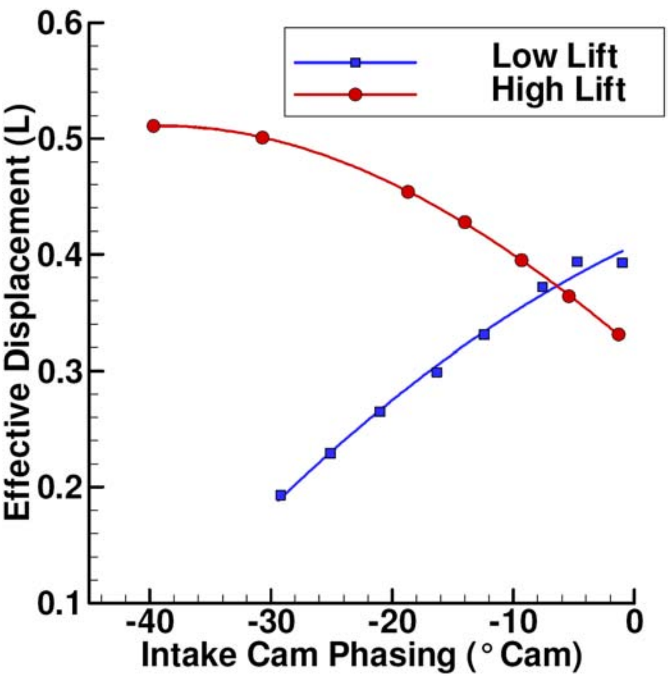

Figure 6. Effective displacement of engine controlled by lift selection and intake cam phasing, 2000 RPM, un-throttled operation, E85C fuel.

Cylinder pressure analysis is used to define the effective displacement and compression ratio. When operating on EIVC the valve closes prior to Bottom Dead Center (BDC) and the gas is expanded and recompressed in a nearly isentropic process. Conventional pegging of cylinder pressure is not possible at bottom dead center since the cylinder pressure is different than intake pressure. To resolve this issue alternative times were evaluated in the cycle both earlier in the intake stroke for intake pegging and late in the exhaust stroke with exhaust pegging. A third technique was also developed which involved adjustment to maximize linearity of the polytropic recompression process. Depending on the cam phasing, at higher speeds and loads, the intake and exhaust pegging were not always reliable due to transient flows across the valves. In these cases the polytropic technique was used. The definition of effective displacement and CR is illustrated in Figure 7 which shows an un-throttled EIVC condition. To define the effective displacement the volume where the cylinder pressure crosses MAP during polytropic compression is used as a definition. This effective volume can then be used to calculate the effective CR. The effective displacement is calculated by correcting for the geometric clearance volume. For the LIVC strategy the polytropic compression is extrapolated to MAP to define effective CR.

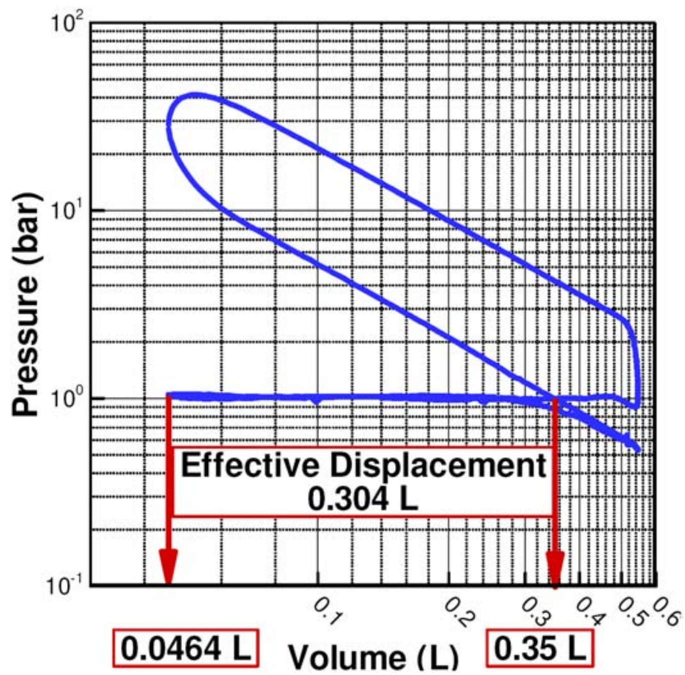

Figure 7. Definition of effective displacement, effective CR=7.6

The range of load control enabled by the EIVC/LIVC strategy is shown in figure 8. The low lift cam is speed limited to 4000 RPM but testing was limited to 3500 RPM due to deterioration of combustion stability. Operation of the EIVC strategy in an un-throttled condition revealed problems with long burn durations at poor combustion stability as the speed was increased, see figure 9. The increase in burn duration indicates poor turbulent mixing and near laminar flame propagation during initial flame development as shown in the 0-10 burn durations. Conversely when operating with an LIVC strategy the burn duration in crank angle degrees did not deteriorate significantly with speed maintaining short burn durations and good combustion stability.

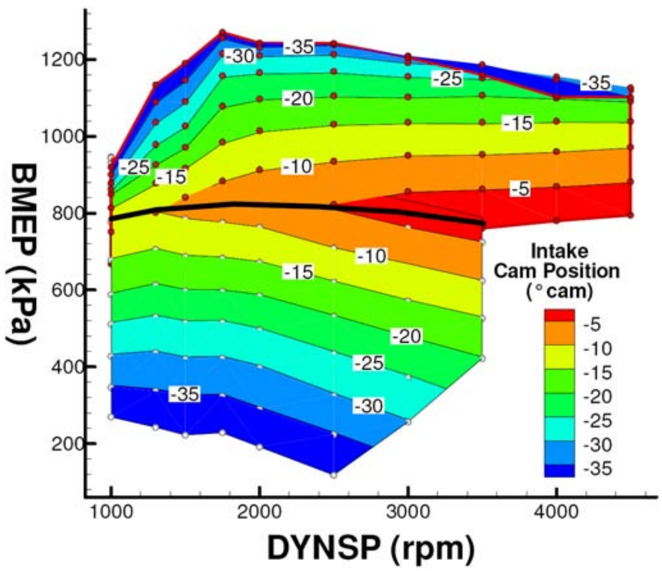

Figure 8. Un-throttled load control domain, contours indicate cam phasing location, 0=park, 40 =max phasing in cam degrees, Black Line Switch point

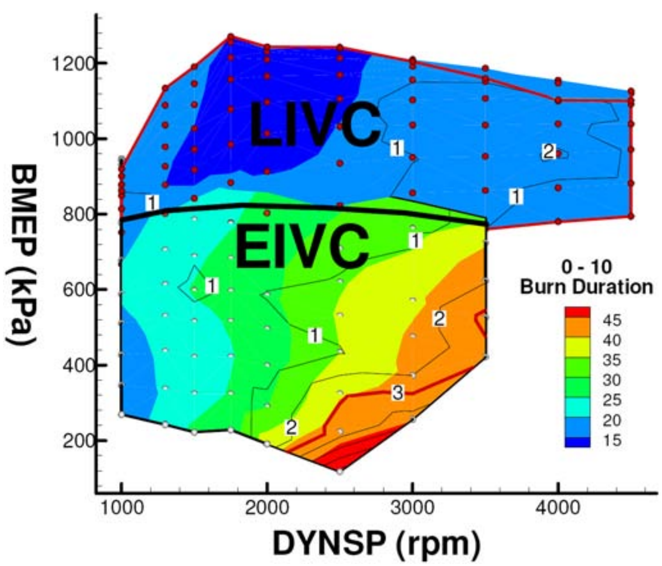

Figure 9. 0-10 cad burn duration (colors) with %COV contour lines for EIVC and LIVC

Injection Timing Evaluation

Another issue that was identified was a region prone to producing smoke at high loads and at speeds below 2000 RPM. This was only apparent when testing with the 91 RON E0 gasoline and not observed with E85 due to its resistance to particulate formation. This difficulty actually arises with all of the fuel blends tested other than E85 as will be discussed in the fuel blend section. To illustrate the issue a stoichiometric injection timing sweep at 1500 RPM, 8 bar BMEP, on gasoline is shown in figure 10. Of notice is the plateau in smoke level near 0.4 Filter Smoke Number (FSN) regardless of the injection timing. The FSN tends to trend sharply higher if injection is too early due to development of fuel films on the piston likely producing diffusion flames. The FSN also tends to increase for timings later than 280 cad bTDC likely the result of fuel on the cylinder liner which has not fully evaporated and mixed. An accompanying increase in HC is also shown for the later injection timings. During engine mapping injection timing optimization was conducted with the primary goal of minimizing fuel consumption, subject to acceptable combustion stability and FSN. The minimum fuel consumption was not limited by combustion stability since both are related, however at some conditions injection timing from minimum BSFC needed to be retarded due to high soot.

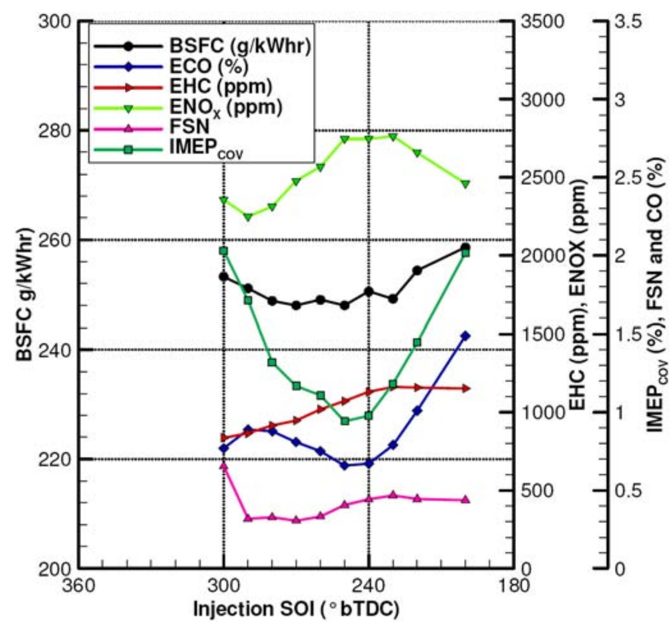

Figure 10. Injection timing sweep at 1500 RPM, 8 bar BMEP 91 RON E0 Gasoline. (2 Valves)

Valve Deactivation Evaluation

To address the issues identified with combustion stability with EIVC and particulates at high load valve deactivation was evaluated. By deactivating a single intake valve swirl is significantly increased and the measured tumble index approximately doubles. Valve deactivation to address these issues with improved charge motion with EIVC and LIVC has been effective. [23] Charge motion enhances the increased in-cylinder charge motion which can minimize liquid impingement that produces wall films that can lead to inhomogenieties and diffusion flames. Work by other researchers [24, 25] also shows similar findings for 2-3 mm lift valves. Bulk cylinder motion is significantly enhanced. Figure 11 shows flow bench results quantifying in-cylinder swirl and tumble at the peak lifts of the 2 cams for this application. The base engine is swirl neutral but does include a tumble feature in the intake port. To evaluate the effects on engine performance the valvetrain was reconfigured to allow deactivation of one of the intake valve. Comparisons were made at a series of operating points. These points are listed in [23] showing improved combustion stability with EIVC and reduced soot at higher loads.

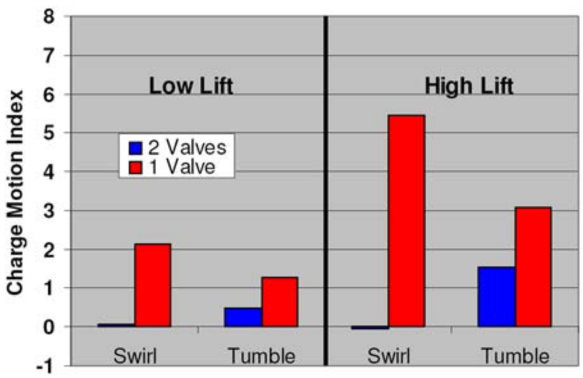

Figure 11. Swirl and tumble comparison with a 2 valve and 1 valve configuration, (single valve deactivation).

The effects of valve deactivation at high loads on the injection timing widow are shown in Figure 12, In contrast to Figure 10 the soot and hydrocarbon levels are reduced significantly at later injection timings. The best injection timing shifted earlier with a slightly reduced injection timing window.

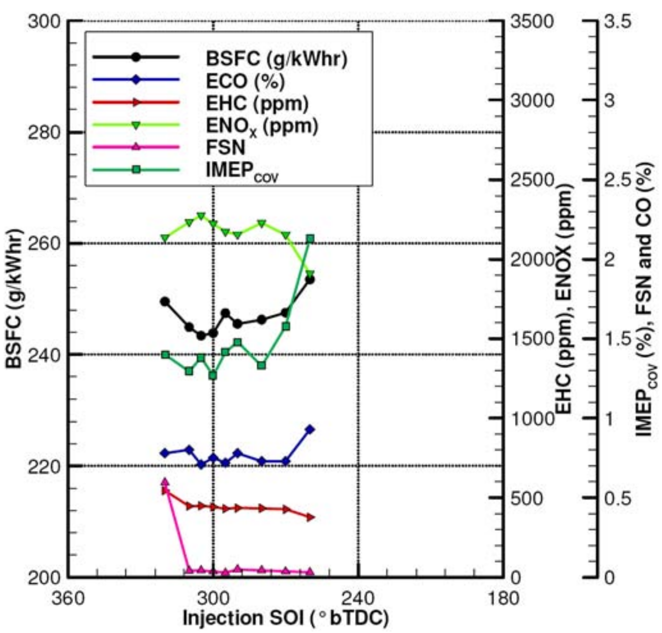

Figure 12. Injection timing sweep at 1500 RPM, 91 RON E0 Gasoline. (With valve deactivation).

The effect of valve deactivation on power density was evaluated by measuring peak torque from 1000 - 4000 RPM, Figure 13. The testing was conducted on E85 and all conditions are free of knock with MBT timing and stoichiometric fueling. Results show a shift to peak torque to slightly lower speeds and a falloff of peak torque at higher speeds. Particulate formation was primarily an issue at speeds under 2500 RPM, where engine breathing was not compromised significantly. Results when testing with E0 and E20 blends, which were knock limited, at peak torque did show an additional small reduction in peak torque due to an increased knocking tendency. [23] The increased swirl and charge motion is likely to increase the mixture temperature during the intake process thus leading to higher end gas temperatures. Additional spark retard was needed with the low ethanol fuels which compromised peak torque and reduced volumetric efficiency since these fuels are not as effective at charge cooling. Further valvetrain optimization to moderate the in-cylinder motion may provide a better compromise between volumetric efficiency and mixing, but is beyond the scope of work for this paper.

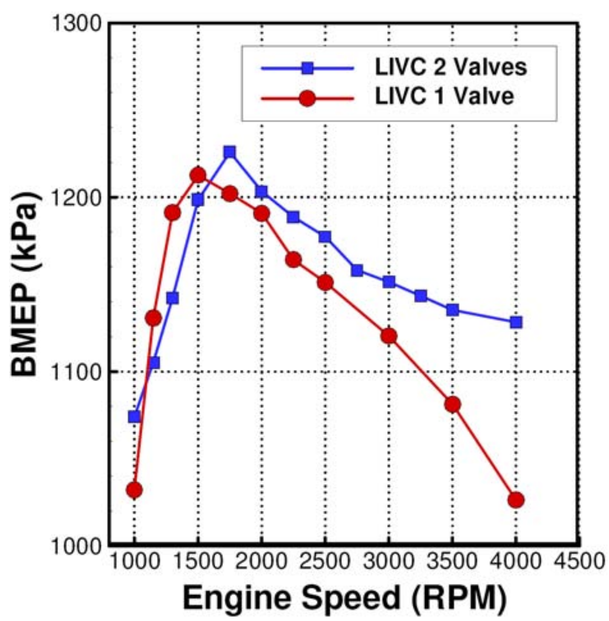

Figure 13. Peak torque curves, 2 Valve (Normal) vs. 1 Valve (valve deactivation) E85C Fuel.

Valvetrain Control Optimization

The use of DICP with the addition of the 2-step VVA system on a DI engine provides a high degree of freedom system for optimization of fuel consumption, emissions and performance. To gain a better understanding of the tradeoffs resulting from cam phasing, selected operating conditions were mapped across the allowable cam phasing domain with simultaneous optimization of injection timing for minimal BSFC. To illustrate these tradeoffs a cam optimization map is shown in Figure 14, showing the cam timing effects on fuel consumption, engine stability and MAP for a 2000 RPM, nominal 2 Bar BMEP operating condition. The testing was actually conducted with a fixed fueling rate which enabled more efficient testing. The BSFC is therefore based on the maximum performance for a given fuel quantity. The data presented is for an EIVC strategy with one valve deactivated and E0 Gasoline. When operating with valve deactivation and EIVC, combustion stability was excellent at 2 bar BMEP with the exception of small region with high valve overlap and some manifold vacuum to drive excess internal EGR. For loads above 2 bar combustion stability (COV) was typically less than 1% at all cam phasings, at lower loads the region of excessive EGR with poor COV increased. As shown in the plot MAP varies from 50 KPA to un-throttled conditions. Of interest, minimum BSFC is not under un-throttled conditions but with light throttle which enables capture of internal EGR. This also results in reduced NOx Emissions.

Cam phasing and injection timing optimization was also completed for the 2 valve EIVC configurations as well as the LIVC strategy with and without valve deactivation. A comparison between these strategies is shown in figure 15 for E85. Evaluations were also conducted with E0 showing similar trends. Data in Figure 15a (Top) shows the fuel consumption benefit resulting from the strategies evaluated. All improvements are relative to the base engine gasoline thermal efficiency. All of the strategies show an improvement near 8% at higher loads. This is a combination of benefits from the increased compression ratio and thermodynamic benefits inherent to E85. [9] When operating on gasoline the improvement is about 5% as a result of the increased compression ratio. A significant fuel consumption improvement using EIVC with valve deactivation is provided below 5 bar BMEP, resulting from reduced pumping losses. The base engine configuration and calibration already was providing very good fuel consumption by use of DICP for internal EGR management to reduce throttling. The reduction in throttling is apparent in figure 15c (Bottom) where at loads above 2 Bar BMEP the MAP was above 90 KPA for the EIVC with deactivation strategy. Figure 15b (Mid) shows the NOx emissions. With E85 it was possible to introduce significant internal EGR without EGR induced knock at higher loads. The LIVC strategy, with high overlap, provides minimal NOX emissions with E85. High residual levels can be introduced and excellent charge motion and combustion stability is maintained. This benefit is limited with gasoline or low ethanol blends since high internal EGR results in knock requiring spark retard which leads to deteriorating combustion stability and efficiency. This will be discussed further in the section on ethanol blend testing.

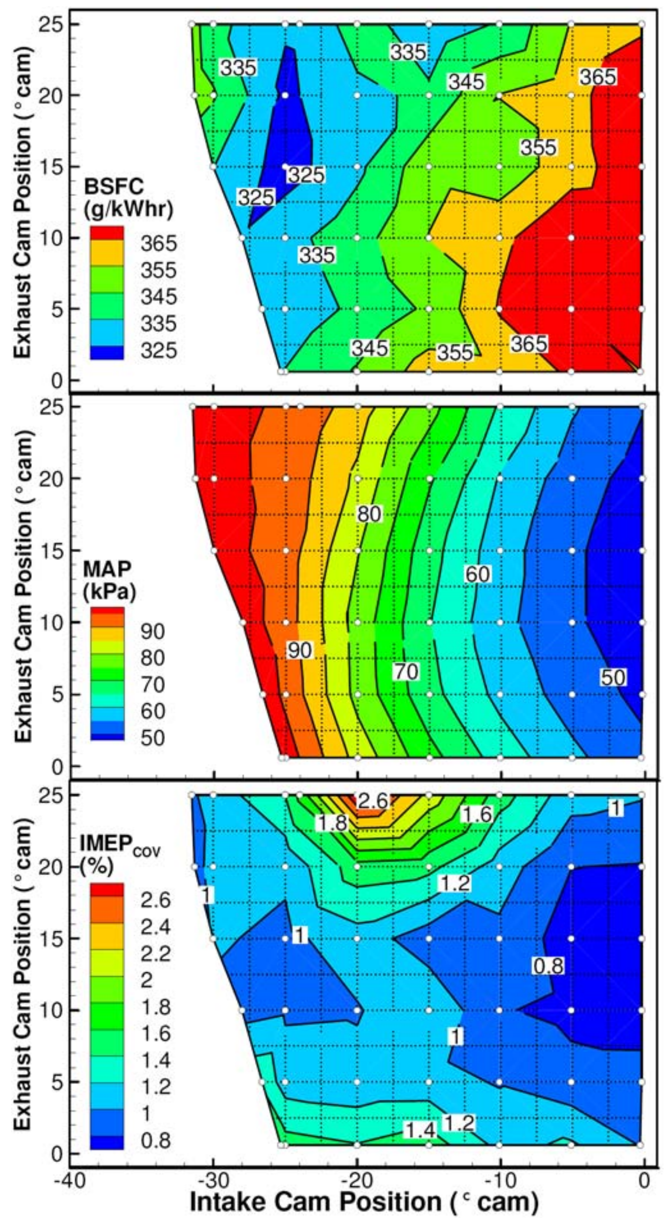

Figure 14. Cam phasing optimization map with EIVC with valve deactivation, 2000 RPM, Fixed fuel 9,95 mg/cyl, Nominal load 2 Bar BMEP, 91 RON E0 gasoline

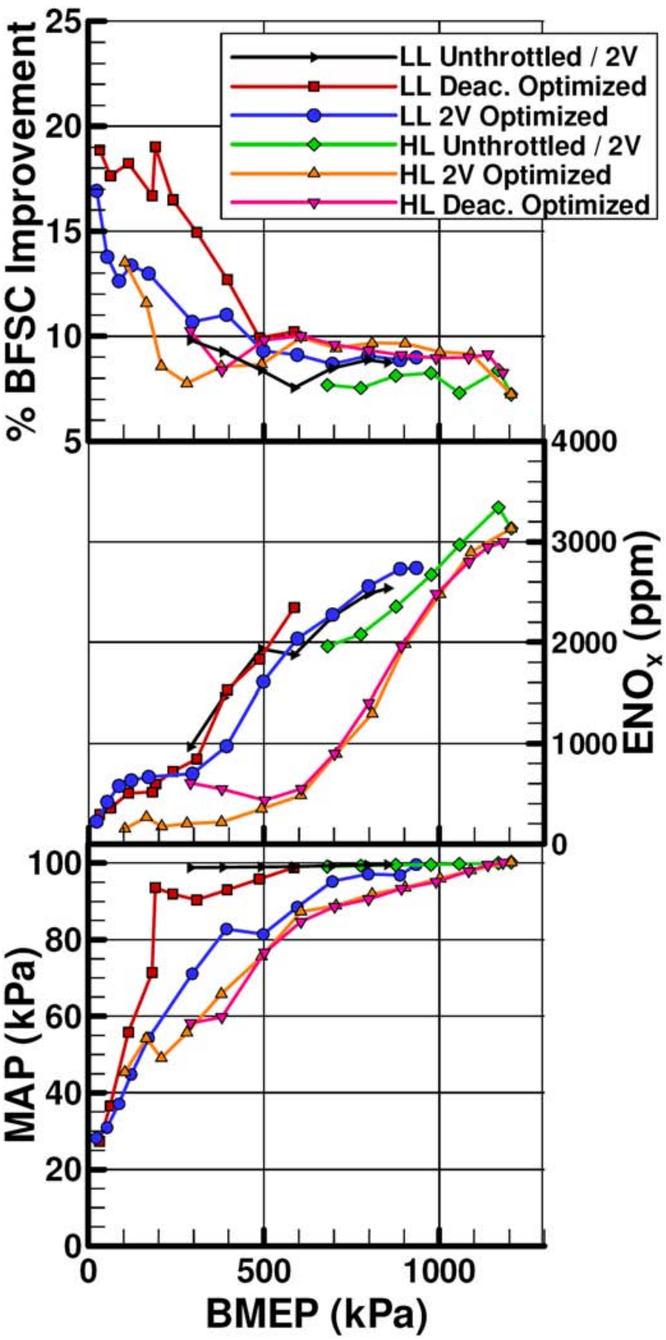

Figure 15. 2000 RPM load sweeps, E85C Fuel, Evaluation of valvetrain control strategies. (a) Improvement in fuel consumption (thermal efficiency) over base engine, (b) NOx Emissions, (c) Map showing reduced throttling.

FUEL BLEND EVALUATION

Fuel blends from E0 gasoline to E85 were evaluated; fuel properties are shown in Tables 3 and 4. A 97 RON E0 Gasoline was also tested for reference. A series of test were conducted to evaluate the benefit of ethanol content for knock control and soot reduction, which were the primary benefits observed in the previous phases of work.

The test consisted of the following evaluations:

• Start of Injection (SOI) timing sweeps (EIVC and LIVC) 2250 RPM, 6 Bar BMEP

• EGR tolerance evaluation LIVC, 2000 RPM, 6 Bar BMEP

• Load sweeps to identify knock limited load and compression ratio LIVC, 1500 RPM, 2000RPM

• Knock limited torque vs. speed LIVC, 1000-4000 RPM

EIVC 2250 RPM SOI Evaluation

The primary interest in evaluating injection timing windows was to determine if the ethanol content significantly changed the allowable injection window or optimal timing with the EIVC and LIVC strategies. Testing with E0 and E85 had demonstrated a significant difference resulting from the E85 blends resistance to soot. When evaluating the EIVC strategy a small acceptable injection timing window was typical. Narrow injection windows with EIVC has also been documented in another evaluation.[25] E85 provided a wider window resulting from elimination of the soot constraint there was no significant benefit identified from the intermediate blends tested. Soot levels were generally lower for later injection timings with increasing ethanol content. Figure 16a. The combustion stability limited timing was not changed for any of the blends evaluated, Figure 16b. Optimal timing to minimize fuel consumption was limited by these two constraints and was similar for all of the fuel blends, Figure 16c. Hydrocarbons and NOx emissions did tend to trend lower with increasing ethanol content, Figures 17 a,b. This was also typical for all of the blend testing. Lower NOx, should result from reduced combustion temperatures due to charge cooling and a lower adiabatic flame temperature. Hydrocarbon reductions likely result from the reduced fraction of higher molecular weight components in the fuel blend. The effect of ethanol concentration on aldehydes was not measured in this study but has been shown [27] to increase with increasing ethanol content

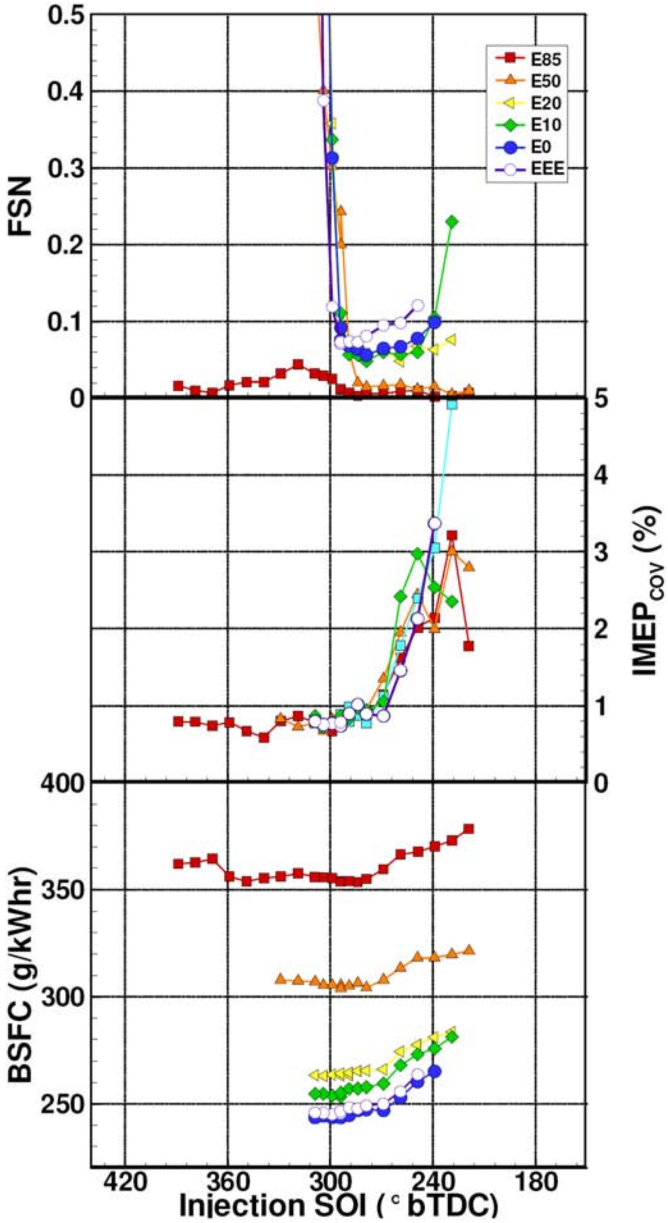

Figure 16. (a) Soot (FSN), (b) Combustion stability (COV%), (c) Fuel consumption (BSFC g/KW Hr), 2250 RPM, 6 Bar BMEP, EIVC cam

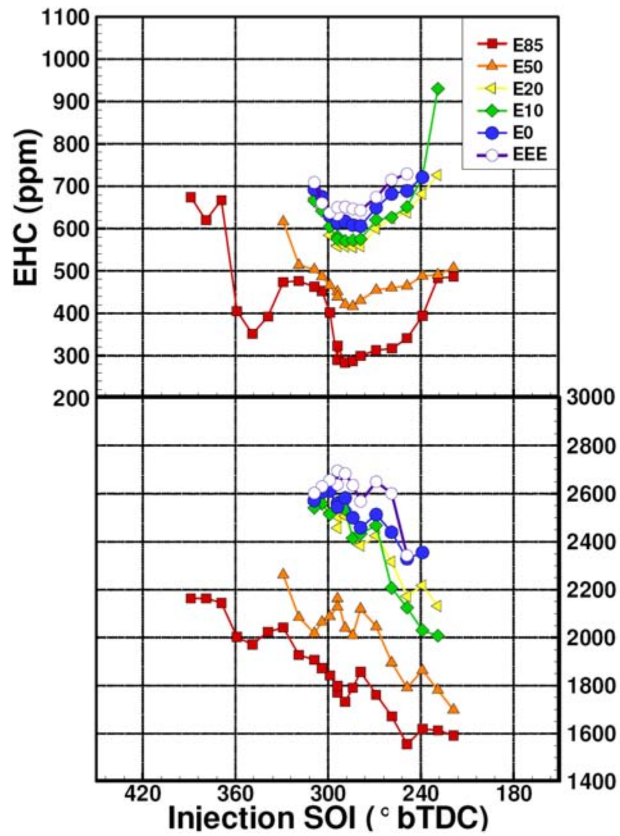

Figure 17. (a) Engine out Hydrocarbons (ppm), (b) Engine out NOx (ppm), 2250 RPM 6 Bar BMEP, EIVC cam

LIVC 2250 RPM 6 Bar Evaluation

Evaluation of injection timing with the LIVC strategy provided similar results to the EIVC strategy but combustion stability was better allowing later timings, Figure 18 a (FSN), b (%COV of IMEP). Optimal injection timings were similar between the blends and emission trends also trended lower with ethanol content.

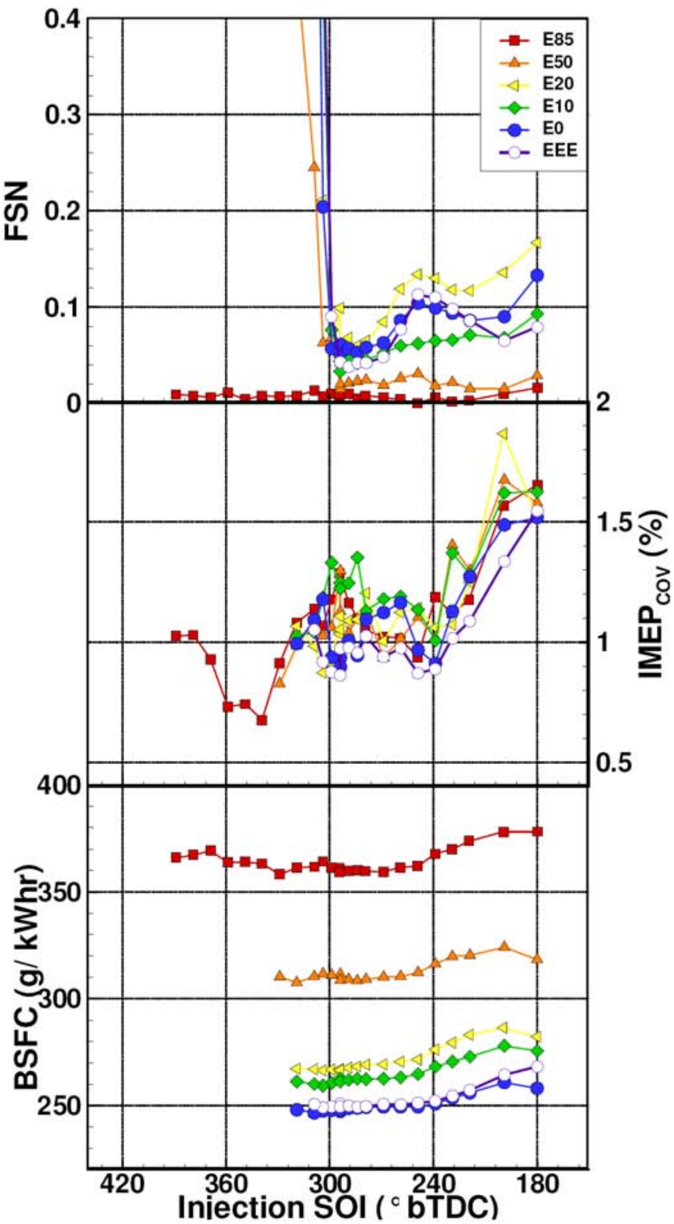

Figure 18. (a) Soot (FSN), (b) Combustion stability (COV%), (c) BSFC (g/kWhr), 2250 RPM 6 Bar BMEP, LIVC cam

Internal EGR Tolerance

E85 showed high resistance to EGR-induced-knock at high loads allowing internal EGR optimization up to peak torque. During E85 cam optimization it was determined that a small operating window existed that allowed high levels of internal EGR, high compression and high MAP where E85 was susceptible to EGR induced trace knock. Slight retard (2-3 cad) to eliminate knock was required for E85. To evaluate the effect of ethanol content this test condition was repeated for the fuel blends to determine the relative knock resistance of the test fuels. The test was conducted as an intake cam phasing sweep which produced an increase in the effective CR and an increase in valve overlap to allow more internal EGR. The condition of 0 degrees of cam phasing corresponds to nearly unthrottled operation with very low residual. All conditions are stoichiometric fueling and MBT or knock limited spark. The effect on NOX and BSFC is presented in terms of intake cam phasing Figure 19 (a) and (b) respectively. Once the onset of knock was detected spark retard was used to keep knock at an acceptable level. The use of spark retard also results in a reduction in NOx, but both combustion stability (COV) and BSFC deteriorate. Figure 20 (a) and (b) show the required retard in combustion phasing of the 50% burn duration (CA50) and the combustion stability. For this test condition, E50 and E85 ethanol blends enable a significant reduction of NOx with a reduction in fuel consumption. For gasoline and lower ethanol blends there is a tradeoff because of the reduced knock resistance. The fuel consumption reduction is also partially the result of a reduction of manifold vacuum as overlap is increased resulting in reduced pumping work for cam phasings over 20 degrees, Figure 21 (a). The effect of ethanol content on burn duration was small under low EGR conditions Figure 21 (b) but difficult to distinguish at higher EGR levels as the effect of spark retard confounds the results. Adjusting for the variation in energy content of the fuels highlights the advantage of higher ethanol blends to improve thermal efficiency by allowing higher internal residual before knock is induced.

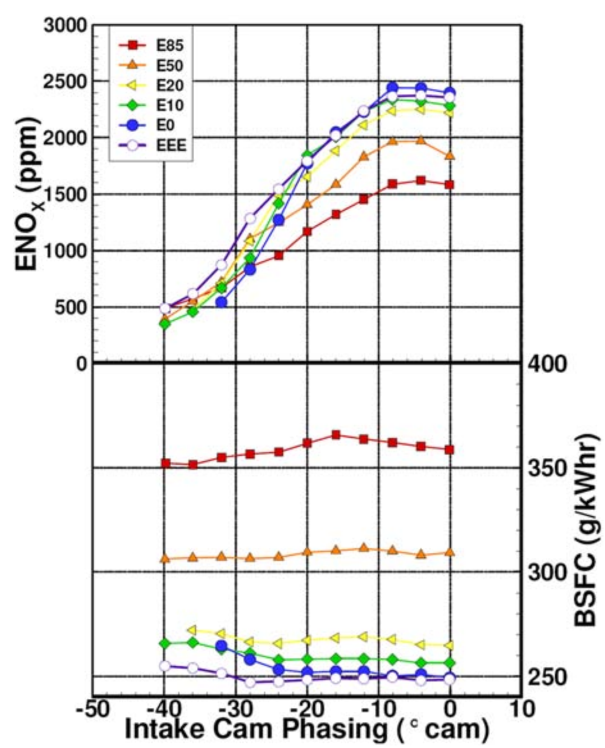

Figure 19. (a) Engine out NOx (ppm) (b) Fuel Consumption BSFC (g/KW Hr), 2000 RPM 6 bar BMEP, LIVC cam

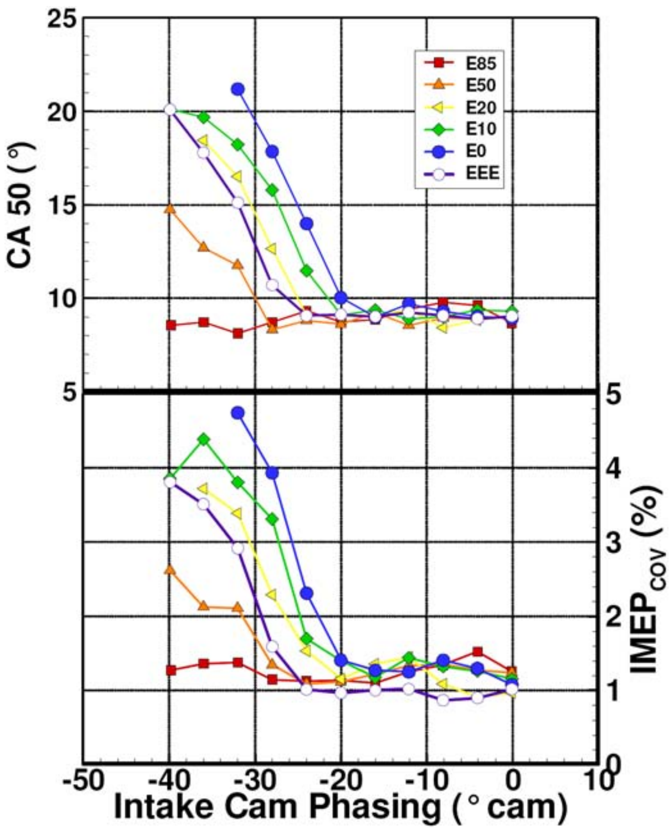

Figure 20. (a) Combustion phasing CA50 (cad aTDC) (b) Combustion Stability (COV%), 2000 RPM 6 bar BMEP, LIVC cam

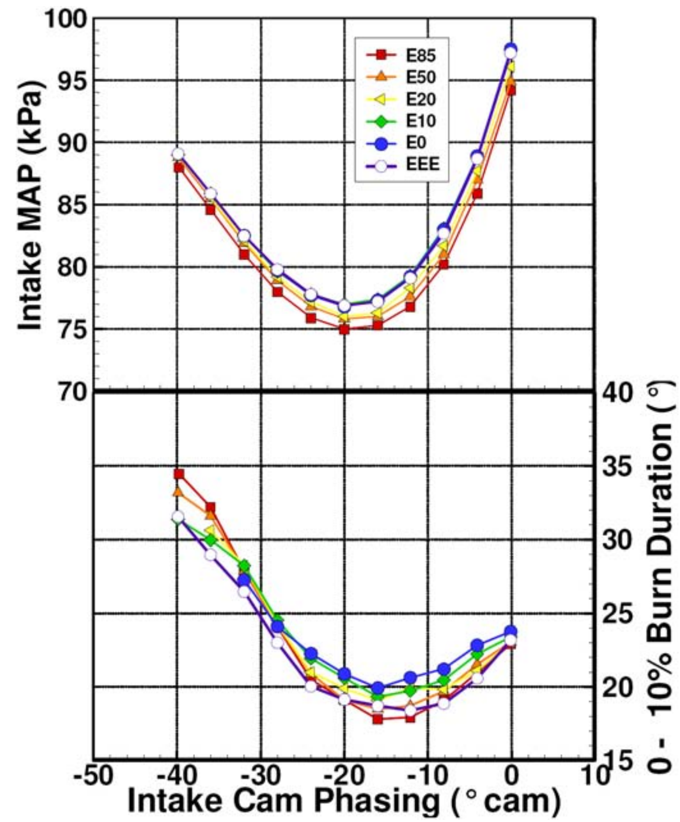

Figure 21. (a) MAP (KPa), (b) 0-10% burn durations (cad), 2000 RPM 6 bar BMEP, LIVC cam

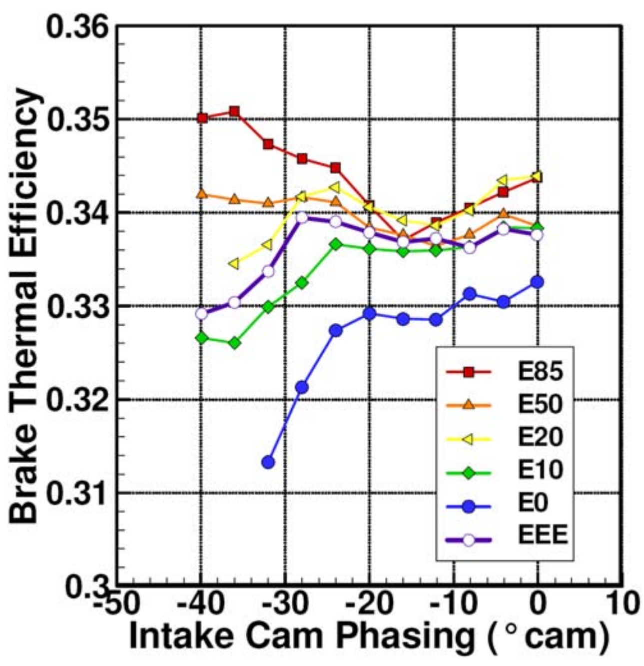

Figure 22. Brake thermal efficiency, 2000 RPM 6 Bar BMEP, LIVC cam

Load - Effective Compression Ratio Sweep (2000 RPM)

To determine the effectiveness of ethanol content for suppressing knock an effective compression ratio sweep of the engine was run at 1500 and 2000 RPM. By adjusting the intake valve closing time the effective compression ratio can be varied from 8-12. The exhaust cam phasing and injection timing were fixed for all cases, to focus on the fuel effects. Injection timing was chosen to avoid the FSN increase resulting from injections being too early. The valvetrain allows the engine to maintain MBT spark without knock for all of the fuels including the E0 91 RON gasoline. As the compression ratio is increased the trace knock limit at MBT or knock limited spark was identified for each fuel. Figure 23(a) shows ignition timing as a function of load. To provide CR specific data the MBT or knock limited combustion phasing with respect to effective compression ratio is shown in figure 24. Of interest is the similar performance of the E10 / 91 RON blend to the 97 RON EEE gasoline, showing the benefits of small quantities of ethanol for increased knock performance. As the ethanol content increased higher effective CR was possible, for the E50 and E85 blend no significant spark retard or performance penalty was apparent. E0 gasoline provides minimal fuel consumption up to 9 bar BMEP while E20 provides minimum fuel consumption at peak power, Figure 23 (b). The effect of increasing load via effective compression ratio resulted in an increase in hydrocarbons, NOx and FSN. The emissions were however strongly related to the ethanol content with higher ethanol blends reducing emissions for all 3 constituents, Figure 25 (,a,b,c) As compression ratio and load is increased the maximum pressure rise rate increases, which may be undesirable from the standpoint of combustion noise. For reference this information is provided in Figure 26. Spark retard can be used to limit combustion noise independent of knock, the reduction of pressure rise rate with low ethanol fuels is the result of spark retard for knock control.

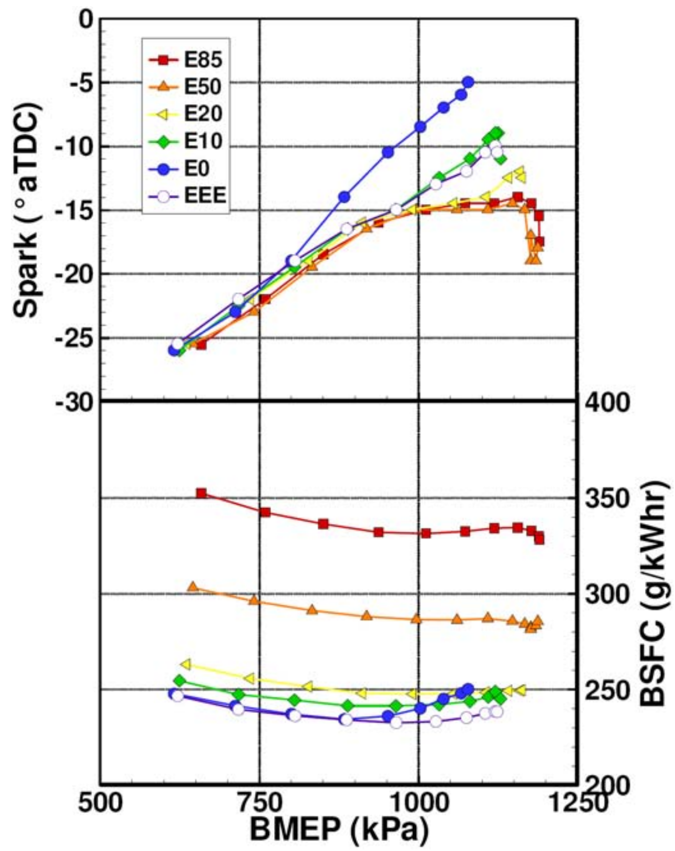

Figure 23. (a) Knock limited load and spark timing, (b) Fuel consumption BSFC (g/KW Hr), 2000 RPM Un-throttled LIVC

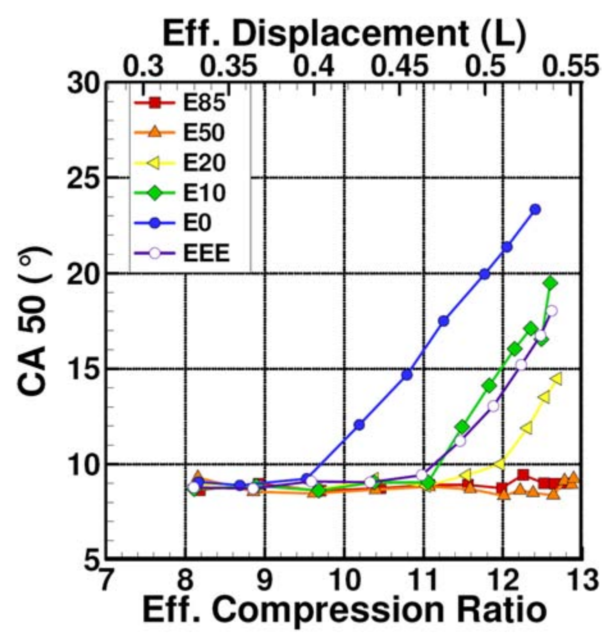

Figure 24. Knock limited CR and combustion phasing (CA50, cad aTDC), 2000 RPM un-throttled LIVC.

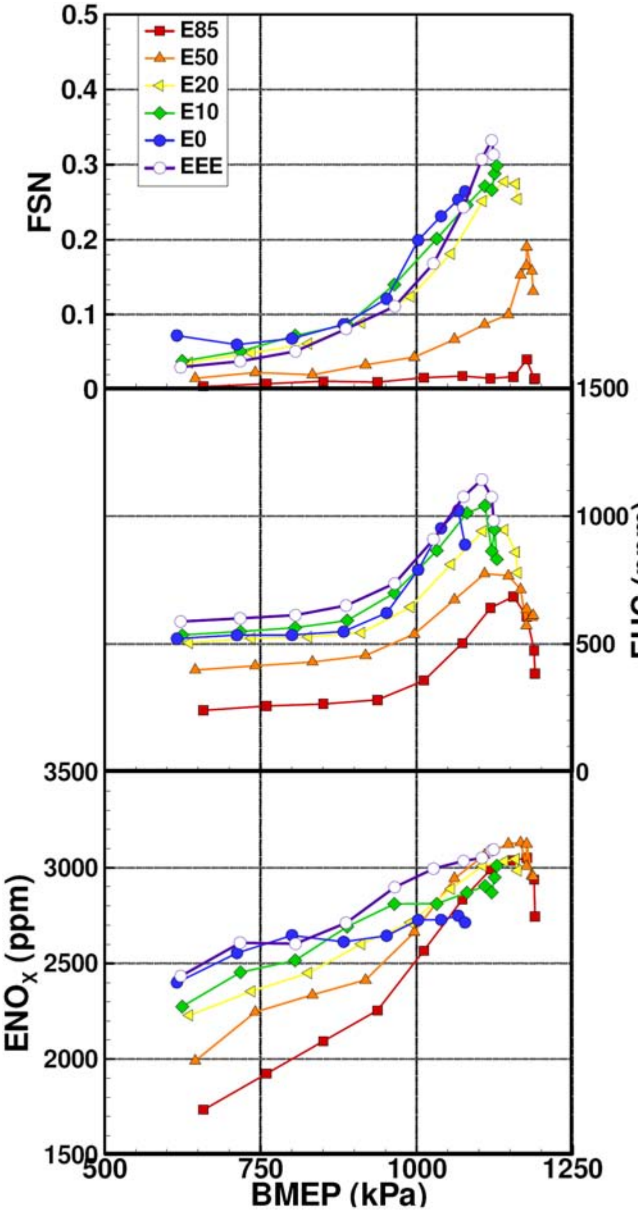

Figure 25. (a) Soot (FSN), (b) Engine out Hydrocarbons (ppm), (c) Engine out NOx (ppm), 2000 RPM un-throttled LIVC.

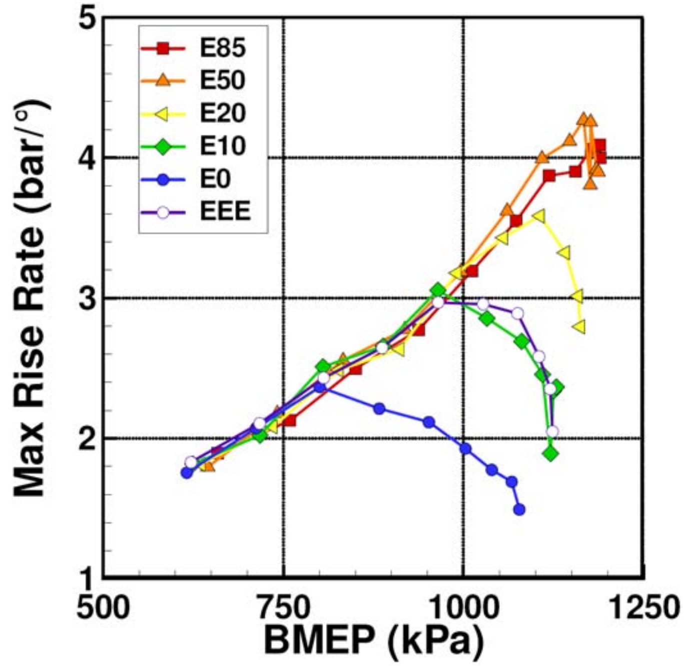

Figure 26. Maximum pressure rise rate (Bar/deg) for ethanol blends, 2000 RPM un-throttled LIVC.

Load - Effective Compression Ratio Sweep (1500 RPM)

Evaluation of the knock limited load and compression ratio was also conducted at 1500 providing a more knock sensitive condition. The testing was conducted at stoichiometric conditions and MBT or knock limited spark. The fuels are more knock prone requiring another 10% ethanol for similar knock resistance compared to 2000 RPM, Figures 27 (a). 1500 RPM is near the peak torque with E85, which results from tuning producing some scavenging. Due to the scavenging an increase in BSFC results as load is increased. Even though the net air fuel ratio is stoichiometric if air is scavenged into the exhaust the in-cylinder charge will be rich, producing additional torque and increasing fuel consumption, Figure 27 (b). This explanation is also supported by an increase in engine out CO and O2 at peak load, which would result when a rich in-cylinder mixture is mixed with air that was over scavenged. Figure 28 shows the required combustion phasing retard to limit knock as the effective compression ratio is increased. The knock limited compression ratio is increased about 1 point for each 10% increase in ethanol up to E20.

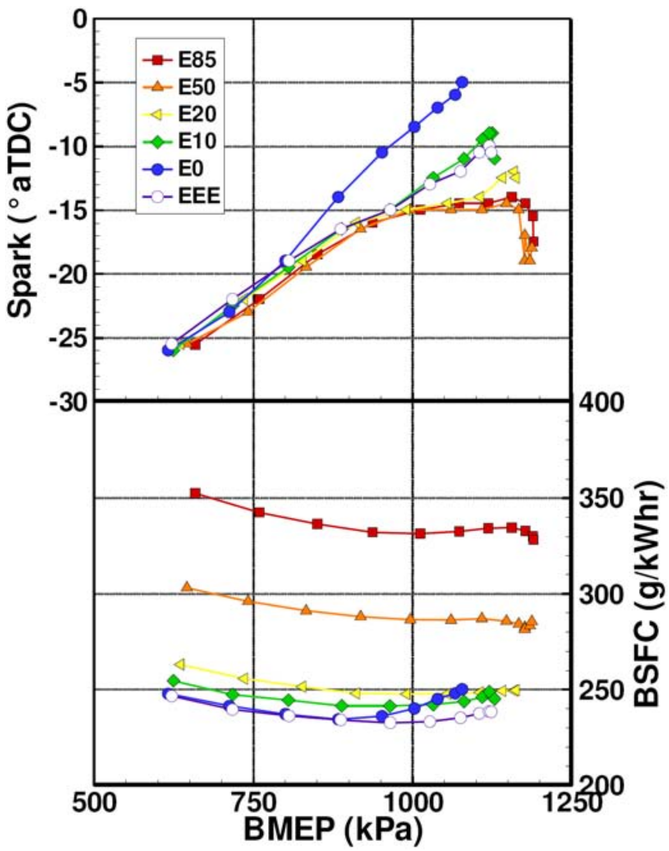

Figure 27. (a) Knock limited load and spark timing (b) Fuel consumption BSFC (g/KW Hr), 1500 RPM Un-throttled LIVC

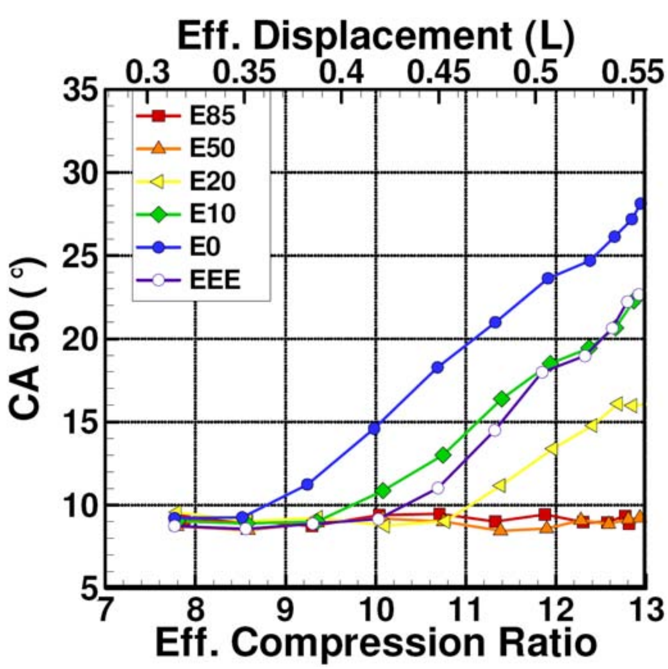

Figure 28.) Knock limited CR and combustion phasing (CA50, cad aTDC), 1500 RPM un-throttled LIVC

Knock Limited Torque - RPM Sweep

Testing was done over the speed range of 1000- 4000 RPM to identify the knock limited load and compression ratio. Testing was done in a similar fashion to the 2000 and 1500 RPM load sweeps by increasing the effective compression ratio until trace knock was detected. Data was taken with an MBT combustion phasing (CA50; 8-10 cad aTDC). Figure 29 (a,b,c) shows the knock limited BMEP, Combustion phasing and effective compression ratio over the speed range. There is a significant difference in the knock limited CR and associated MBT torque for the ethanol blends. Knock limited torque at MBT is limited to an effective CR of 7.6 at 1000 RPM to 10.5 at 4000 RPM. Increasing the ethanol content shows a consistent effect of allowing a 1 point increase per 10% ethanol addition until the geometric compression ratio of the engine is reached.

For fuel blends that were knock limited, spark retard was used to retard combustion phasing until maximum torque was achieved. As the effective compression ratio was increased spark retard allowed knock free operation. For the low ethanol blends the effective displacement and CR was limited at low speeds since excessive spark retard was needed as the CR increased. The peak CR was limited to a point in which further increases resulted in a loss of torque. Figure 30 (a,b,c) shows the knock limited BMEP, combustion phasing and effective compression ratio over the speed range. The use of spark retard allowed the effective CR to be increased about 2.5 points before the efficiency penalties associated with spark retard were more significant than the increased displacement. This level of spark retard was typically at a combustion phasing near 24 cad aTDC. Unlike a fixed cam system the use of VVA with LIVC allows cam phasing selection to limit the efficiency loss that results from very late combustion phasing which produces lower torque with increased fuel consumption. For fuel blends above E20 the maximum torque curve was not significantly limited. E20 can provide 97% of the peak torque of E85.

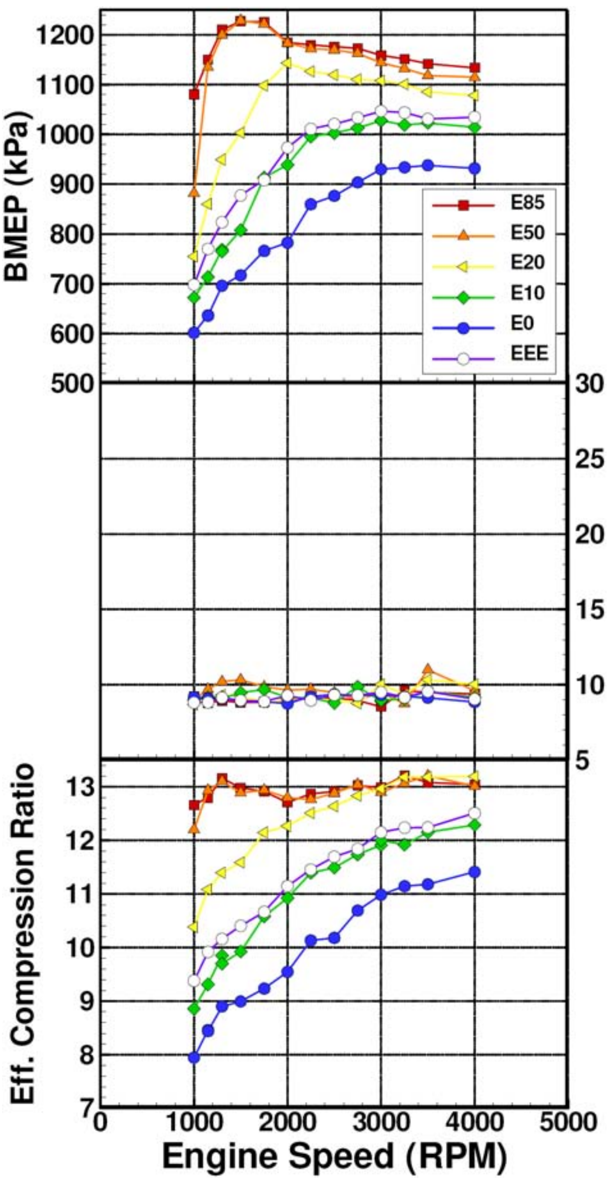

Figure 29. (a) Knock limited load,(b) Combustion phasing(CA50), (c) CR, 1000-4000 RPM LIVC Cam

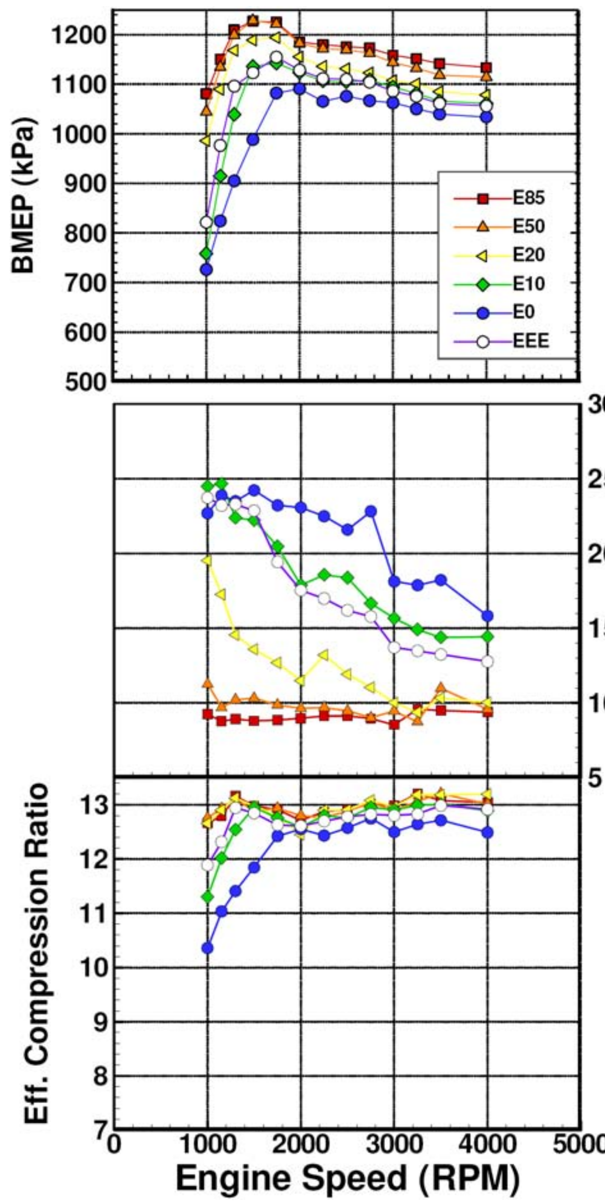

Figure 30. (a) Peak Torque, (b) CA50, (c) CR of peak torque vs RPM, MBT or knock limited torque, Stoichiometric operation. 1000-4000 RPM, LIVC Cam

ENGINE - VEHICLE OPTIMIZATION

To optimize vehicle fuel economy, improvements in both the base engine performance and how the engine is efficiently utilized in the vehicle are important. The improvements made to the base engine resulted in improvements in engine efficiency from 5% at high loads to over 20% at low loads. This is over and above the base engine which had already taken advantage of GDi technology with DICP to produce a very competitive baseline. The relative improvement in efficiency is shown in Figure 31 for E85. Peak thermal efficiency on E85 reached 38% at 2250 RPM, 11.9 bar BMEP. The use of boost will allow an increase in power density and a further increase in peak efficiency. However for typical drive cycles the range of engine operation focused on in this study is sufficient.

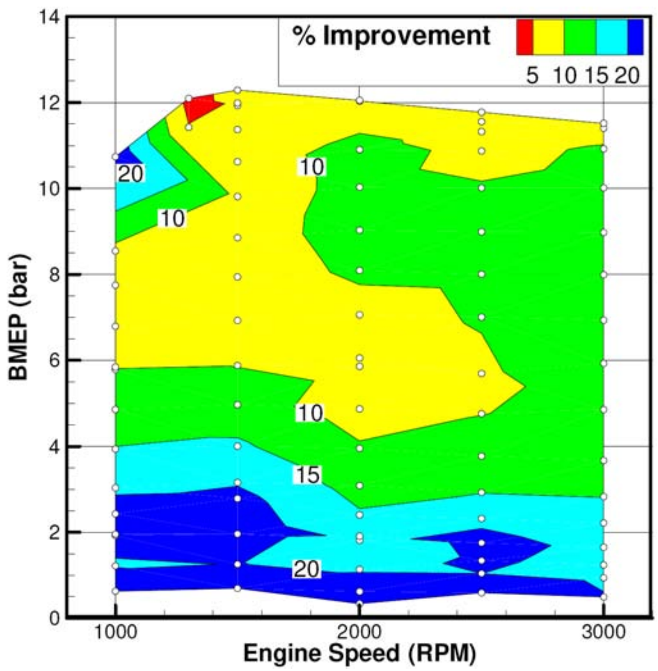

Figure 31. E85 Speed load map showing relative thermal efficiency improvement over base engine data.

Fuel Consumption Optimization

The intention of this work is to identify opportunities to improve overall vehicle efficiency when operating on E85. A significant part of this involves identifying operating conditions that allow more efficient operation of the engine. During many operating conditions with mild acceleration and moderate vehicle speeds the engine power requirements are significantly less than the engine's capacity. The Federal Test Procedure (FTP) city and highway cycle are examples of operating modes that place the engine under inefficient operating conditions. With the development of improved transmissions with 5, 6 or more speeds a significant potential exists to down-speed the engine to significantly improve performance. To analyze this potential Figure 32 is introduced. In addition to showing the BSFC curves an analysis of preferred operation conditions is presented. With the ability to select between different gear ratios, it would be desirable to operate the engine in the most efficient operating point for the desired power to supply the power demanded by the driver. To evaluate this, a line of constant power is shown by the blue dashed line, in this case 10KW. If we compare the locus of points the most efficient operating condition would be to operate at a low speed and high load. This point is shown by the Yellow line which is the locus of points of most efficient operation as a function of power. While it may not be possible due to transmission capability or even desirable to operate at this load due to Noise, Vibration and Harshness (NVH) issues it is useful as a reference. For comparison the lines with the red labels show the relative fuel economy penalty by operating at different conditions for the same power. For example at the demanded power of 10 KW this can be achieved at 1500 RPM, 4 Bar BMEP which suffers a 5% penalty, 2000 RPM 3 Bar which has a 17% penalty or 3000 RPM 2 Bar which suffers a significant 45% penalty. Figure 32 thus provides a useful tool to identify regions that proper selection of the transmission gear and shift schedules can significantly aid vehicle fuel economy. This must be balanced with needs for good drivability; however the combination of good low end torque and improved transmissions offers the potential for both good fuel economy and performance. To leverage this potential, shift strategies to minimize the amount of time at high speed low load conditions with high fuel penalties were evaluated in vehicle drive simulations.

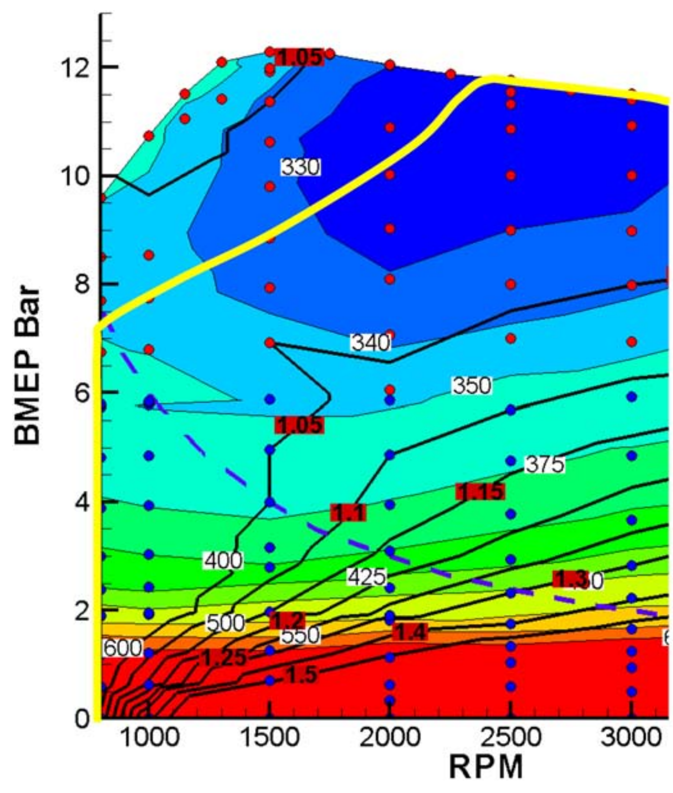

Figure 32. Speed Load map of E85 BSFC (Contours) showing relative fuel consumption (Red Labels) at equivalent power (Blue Dashed Line), Yellow line indicates most efficient path. Red Points LIVC, Blue Points EIVC (Deac).

Vehicle Simulation

A vehicle simulation using GT Drive was conducted to evaluate the potential for fuel consumption reduction from engine improvements, hardware selection and transmission calibration. A production Chevrolet Cobalt with the base engine was used as a reference. Baseline fuel consumption data was adjusted for the lower energy content of E85. This produced an E85 baseline with equivalent thermal efficiency to the base engine over the speed load domain. The system was then evaluated incrementally to determine the relative benefit of engine improvements, more aggressive shift schedules, improved transmission range and reduced final drive ratio. To reflect the engine modifications the measured fuel consumption for the E85 optimized engine was used. A shift schedule was developed which stayed within the unboosted operating window and avoided higher speed low load conditions that could be more efficiently provided by upshifting to more favorable conditions. The final drive ratio was reduced from 3.73 to 3.23 to provide additional down-speeding potential. Integration of a 6 speed transmission to offset the loss of launch torque with the lower axle ratio was also included in the evaluation, see table 5 for a tabulation of gear ratios.

Table 5. Transmission gear ratios

Gear	5 speed	6 speed
1	3.75	4.48
2	2.26	2.87
3	1.51	1.84
4	1	1.41
5	0.73	1
6		0.74

The operating points on the FTP city cycle for the base case and the final case are presented in Figure 33. A significant reduction in the amount of time spent below 4 bar BMEP above 2000 RPM is apparent. This is the result of the upshift strategy.

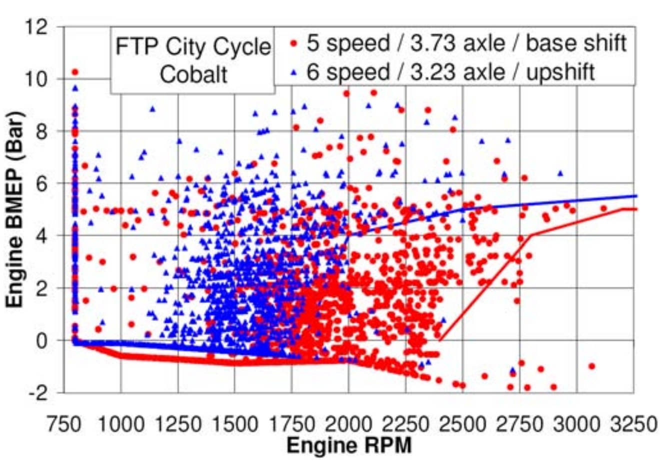

Figure 33. FTP City cycle showing operating points with base and proposed transmission, axel and shift schedule. Up-shift line, Red (Baseline) Blue (up-shifted)

Results of the drive cycle evaluation are shown in Figure 34. The benefit of the improved strategies for reducing the disparity between fuel consumption with gasoline and E85 is almost entirely offset on the FTP city cycle but is less effective as the demands of the driving conditions increase. At highway cruise speeds the shift schedule has no effect since the vehicle is in overdrive in all cases, only the benefits of the lower final drive ratio and the engine modifications are evident. The 6 speed transmission's final drive ratio is similar to the 5 speed so its advantage will primarily show up in launch performance not fuel economy.

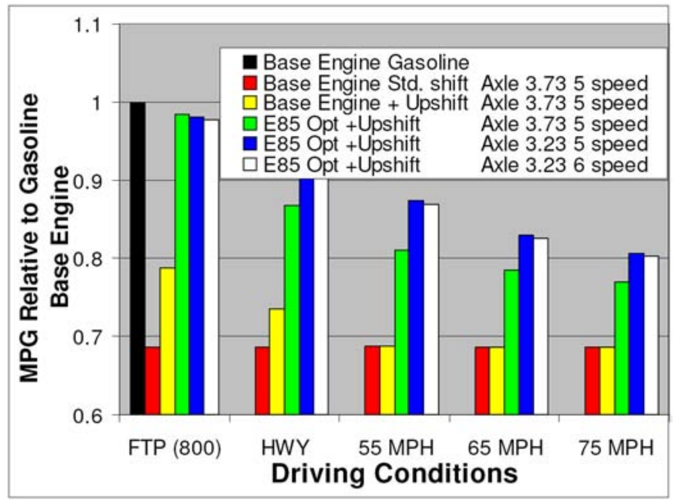

Figure 34. Relative fuel economy to base engine operating on E85 for various operating modes and effect of transmission axel ratio and shift strategy.

It is also important to consider that many of the techniques used to improve performance on E85 would also improve fuel consumption with gasoline or lower ethanol blends. Differences will show up more in performance and may need a shift schedule dependent on the ethanol blends torque capability. Ethanol blends from near E20 provide a good compromise, enabling most of the performance of an E85 blend with a significantly reduced energy density penalty. Blends in this range would likely be able to offset the fuel density penalties with improved efficiency while providing superior performance to gasoline.

Fuel Blend Variation Issues

To utilize ethanol blends effectively relies on consistent fuel properties of the E85 gasoline blend stock to produce reliable intermediate blends. A fuel specification for E85 for use in ethanol blend pumps would allow the benefits of ethanol to be consistently leveraged. If ethanol is instead used to upgrade a low quality gasoline fuel stock these benefits may be limited. A survey of the reported RON, [3, 7, 9, 10, 11, 12, 14, 26,28] of ethanol blends is shown in Figure 35. The large degree of reported variation in RON is partially the result of different gasoline blend stocks but may also indicate variation in testing with ethanol fuels or a high degree of sensitivity to fuel composition. The influence of ethanol content on RON has been shown to blend in nearly a linear response to the mole fraction of ethanol [28], this is in contrast to the non-linear response on a volumetric blend ratio

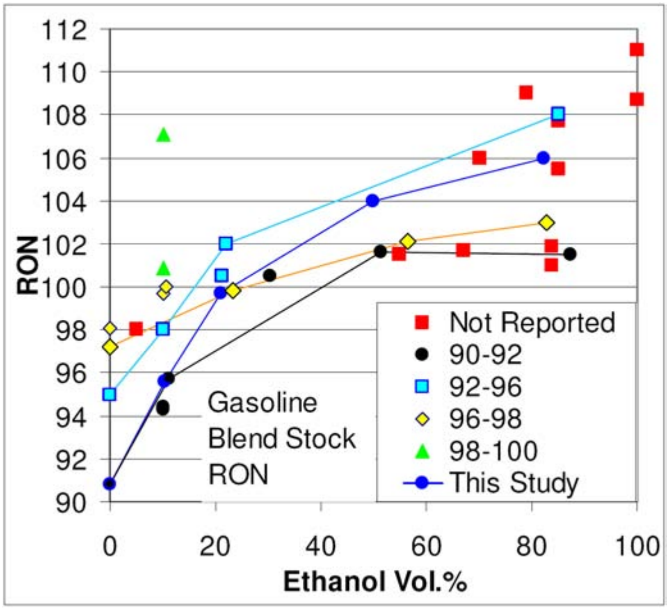

Figure 35. Variation of RON for ethanol blends

SUMMARY

A 2.0 L GDi Engine with DICP was modified for flex fuel operation with increased compression ratio and 2 step VVA to control effective CR and load with valvetrain phasing.

Effective CR could be controlled allowing MBT spark with cam phasing with an LIVC strategy for 91 RON gasoline E0-E85 fuels. Increased load could be achieved with spark retard. Excessive retard could be limited with valve phasing control.

Valve deactivation was used to improve combustion stability at low loads

Cam phasing and injection timing were optimized for E85 to minimize fuel consumption and emissions

Gasoline ethanol blends E0, E10, E20, E50 and E85 were evaluated at selected operating conditions where E0 and E85 differed significantly to understand the blending response.

Vehicle level simulation was carried out to leverage the improved low end torque with E85 to improve fuel economy by down-speeding the engine.

Future work will include evaluation of E30 and E40 blends. The engine will also be operated with boost for E0-E85 fuel blends.

CONCLUSIONS

High low end torque, (11-12 bar BMEP) under 2000 RPM could be achieved without knock for E50 and E85 blends.

Load could be managed efficiently down to 2 bar BMEP with an EIVC strategy providing improved fuel economy. The use of valve deactivation significantly improved performance.

Lightly throttled performance for internal residual control was more efficient than unthrottled operation.

Valve deactivation at high loads under 2500 RPM was effective at reducing soot.

Valve deactivation did not significantly affect peak torque under 2500 RPM with E85.

Intermediate fuel blends up to E50 were still prone to soot formation with early injection timing.

Engine out HC, NOx and soot emissions were reduced with increasing ethanol content.

Resistance to EGR induced knock enabled reduced NOx emissions for higher ethanol blends, using high valve overlap for internal EGR.

The improvement in low end torque with E20 -E85 blends should enable better launch performance and give an opportunity to operate more efficiently with down-speeding.

For the FTP city cycle much of the energy density gain from the base configuration can be made up with a down-speeding strategy and hardware leveraging the benefits of E85.

Intermediate blends near E20 can provide the majority of the performance benefit of E85 and enable strategies that offset their lower energy penalty.

REFERENCES

1. United States Energy Information Association, Official ethanol consumption statistics. URL: http://tonto.eia.doe.gov/dnav/pet/pet_pnp_oxy_dc_nus_mbbl_a.htm.

2. One Hundred Tenth Congress of the United States of America. Energy Independence and Security Act. 2007. URL: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf.

3. Marriott, C., Wiles, M., Gwidt, J., and Parrish, S., "Development of a Naturally Aspirated Spark Ignition Direct-Injection Flex-Fuel Engine," *SAE Int. J. Engines* **1**(1): 267-295, 2009, doi:10.4271/2008-01-0319.

4. Stein, R., House, C., and Leone, T., "Optimal Use of E85 in a Turbocharged Direct Injection Engine," *SAE Int. J. Fuels Lubr.* **2**(1):670-682, 2009, doi:10.4271/2009-01-1490.

5. Bergström, K., Melin, S.A., Jones, D.C., "The new ECOTEC Turbo Biopower Engine from GM Powertrain-Utilizing the Power of Nature's Resources," Internationales Wiener Motorensymposium, 2007.

6. Caton, P., Hamilton, L., and Cowart, J., "An Experimental and Modeling Investigation into the Comparative Knock and Performance Characteristics of E85, Gasohol [E10] and Regular Unleaded Gasoline [87 (R+M)/2]," SAE Technical Paper 2007-01-0473, 2007, doi:10.4271/2007-01-0473.

7. Nakata, K., Utsumi, S., Ota, A., Kawatake, K. et al., "The Effect of Ethanol Fuel on a Spark Ignition Engine," SAE Technical Paper 2006-01-3380, 2006, doi: 10.4271/2006-01-3380.

8. Tsunooka, T., Hosokawa, Y., Utsumi, S., Kawai, T. et al., "High Concentration Ethanol Effect on SI Engine Cold Startability," SAE Technical Paper 2007-01-2036, 2007, doi: 10.4271/2007-01-2036.

9. Szybist, J., Foster, M., Moore, W., Confer, K. et al., "Investigation of Knock Limited Compression Ratio of Ethanol Gasoline Blends," SAE Technical Paper 2010-01-0619, 2010, doi:10.4271/2010-01-0619.

10. Christie, M., Fortino, N., and Yilmaz, H., "Parameter Optimization of a Turbo Charged Direct Injection Flex Fuel SI Engine," *SAE Int. J. Engines* **2**(1):123-133, 2009, doi: 10.4271/2009-01-0238.

11. Milpied, J., Jeuland, N., Plassat, G., Guichaous, S. et al., "Impact of Fuel Properties on the Performances and Knock Behaviour of a Downsized Turbocharged DI SI Engine - Focus on Octane Numbers and Latent Heat of Vaporization," *SAE Int. J. Fuels Lubr.* **2**(1):118-126, 2009, doi: 10.4271/2009-01-0324.

12. Cairns, A., Stansfield, P., Fraser, N., Blaxill, H. et al., "A Study of Gasoline-Alcohol Blended Fuels in an Advanced Turbocharged DISI Engine," *SAE Int. J. Fuels Lubr.* **2**(1): 41-57, 2009, doi:10.4271/2009-01-0138.

13. Cruff, L., Kaiser, M., Krause, S., Harris, R. et al., "EBDI® - Application of a Fully Flexible High BMEP Downsized Spark Ignited Engine," SAE Technical Paper 2010-01-0587, 2010, doi:10.4271/2010-01-0587.

14. Gingrich, J., Alger, T., and Sullivan, B., "Ethanol Flex-fuel Engine Improvements with Exhaust Gas Recirculation and Hydrogen Enrichment," *SAE Int. J. Fuels Lubr.* **2**(1): 58-65, 2009, doi:10.4271/2009-01-0140.

15. Nakata, K., Uchida, D., Ota, A., Utsumi, S. et al., "The Impact of RON on SI Engine Thermal Efficiency," SAE Technical Paper 2007-01-2007, 2007, doi: 10.4271/2007-01-2007.

16. Hoyer, K., Moore, W., and Confer, K., "A Simulation Method to Guide DISI Engine Redesign for Increased Efficiency using Alcohol Fuel Blends," *SAE Int. J. Engines* **3**(1):889-902, 2010, doi:10.4271/2010-01-1203.

17. Hendriksma, N., Kunz, T., and Greene, C., "Design and Development of a 2-Step Rocker Arm," SAE Technical Paper 2007-01-1285, 2007, doi:10.4271/2007-01-1285.

18. Sellnau, M., Kunz, T., Sinnamon, J., and Burkhard, J., "2-step Variable Valve Actuation: System Optimization and Integration on an SI Engine," SAE Technical Paper 2006-01-0040, 2006, doi:10.4271/2006-01-0040.

19. Sellnau, M. and Rask, E., "Two-Step Variable Valve Actuation for Fuel Economy, Emissions, and Performance," SAE Technical Paper 2003-01-0029, 2003, doi: 10.4271/2003-01-0029.

20. Cleary, D. and Silvas, G., "Unthrottled Engine Operation with Variable Intake Valve Lift, Duration, and Timing," SAE Technical Paper 2007-01-1282, 2007, doi: 10.4271/2007-01-1282.

21. Sugiyama, T., Hiyoshi, R., Takemura, S., and Aoyama, S., "Technology for Improving Engine Performance using Variable Mechanisms," SAE Technical Paper 2007-01-1290, 2007, doi:10.4271/2007-01-1290.

22. Haugen, D., Blackshear, P., Pipho, M., and Esler, W., "Modifications of a Quad 4 Engine to Permit Late Intake Valve Closure," SAE Technical Paper 921663, 1992, doi: 10.4271/921663.

23. Moore, W., Foster, M., Lai, M., Xie, X. et al., "Charge Motion Benefits of Valve Deactivation to Reduce Fuel Consumption and Emissions in an GDi, VVA Engine," SAE Technical Paper 2011-01-1221, 2011, doi: 10.4271/2011-01-1221.

24. Stansfield, P., Wigley, G., Garner, C., Patel, R. et al., "Unthrottled Engine Operation using Variable Valve Actuation: The Impact on the Flow Field, Mixing and Combustion," SAE Technical Paper 2007-01-1414, 2007, doi:10.4271/2007-01-1414.

25. Patel, R., Ladommatos, N., Stansfield, P., Wigley, G. et al., "Comparison between Unthrottled, Single and Two-valve Induction Strategies Utilising Direct Gasoline Injection: Emissions, Heat-release and Fuel Consumption Analysis," SAE Technical Paper 2008-01-1626, 2008, doi: 10.4271/2008-01-1626.

26. Alleman, T.L., Wright, K., Hogan, D., "National Report of E85 Quality", CRC Report NO. E85, 2009. URL: http://www.crcao.com/reports/recentstudies2009/E-85/E-85%20Final%20Report%20_120609_.pdf

27. Graham, L.A., Belisle, S.L., Baas, C.-L., "Emissions from Light Duty Gasoline Vehicles Operating on Low Blend Ethanol Gasoline and E85", Atmospheric Environment 42 (19), 4498-4516, 2008.

28. Anderson, J.E., Kramer, U., Meuller, S.A., Wallington, T.J., "Octane Numbers of Ethanol-and Methanol-Gasoline Blends Estimated from Molar Concentrations", Energy and

Fuels 2010, 24,6576-6585, 2010 URL: http://pubs.acs.org/doi/abs/10.1021/ef101125c

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DEFINITIONS/ABBREVIATIONS

abdc
: **after bottom dead center**

ASTM
: **American Society for Testing and Materials**

atdc
: **after top dead center**

BDC
: **Bottom Dead Center**

bbdc
: **before bottom dead center**

BMEP
: **Brake Mean Effective Pressure (KPa)**

BSFC
: **Brake Specific Fuel Consumption (g/KW Hr)**

btdc
: **before top dead center**

cad
: **crank angle degrees**

CA50
: **Crank Angle of 50% Burn duration**

CFR
: **Cooperative Fuels Research**

COV
: **Coefficient of Variation (IMEP)**

CR
: **Compression Ratio**

DI
: **Direct Injection**

DICP
: **Dual Independent Cam Phasing**

EA
: **Engine Averaged**

ECO
: **Engine out Carbon Monoxide (%)**

EGR
: **Exhaust Gas Recirculation**

EHC
: **Engine out Hydrocarbons (ppm)**

EIVC
: **Early Intake Valve Closing**

ENOx
: **Engine out Nitrogen Oxide (ppm)**

E02
: **Engine out Oxygen (%)**

FMEP
: **Friction Mean Effective Pressure (KPa)**

FSN
: **Filter Smoke Number**

FTP
: **Federal Test Procedure**

GDi
Gasoline Direct Injection

HLA
Hydraulic Lash Adjuster

IMEP
Indicated Mean Effective pressure (KPa)

LHV
Lower Heating Value (KJ/g)

LIVC
Late Intake Valve Closing

LIVO
Late Intake Valve Opening

MAP
Manifold Absolute Pressure (KPa)

MBT
Minimum spark advance for Best Torque

MPFI
Multi -Port (Point) Fuel Injection

MPG
Miles Per Gallon

NMEP
Net Mean Effective Pressure (KPa)

NVH
Noise, Vibration, Harshness

PE
Power Enrichment

PFI
Port Fuel Injection

RFF
Roller Finger Follower

RON
Research Octane Number

SOI
Start of Injection

SI
Spark Ignited

TDC
Top Dead Center

VVA
Variable Valve Actuation

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A Comparison of Total Mass, Particle Size Distribution and Particle Number Emissions of Light-Duty Vehicles Tested at Haagen-Smit Laboratory from 2009 to 2010

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California Environmental Protection Agency
Air Resources Board

Introduction

- Recent interest in ultrafine particles in particulate matter (PM) emissions from mobile sources has increased due to concerns of health effects.

- There are special health concerns from nano-particles.

- HSL has collected particle size, distribution, number data in addition to PM mass for various projects.

- Data are used to compare total mass, particle size distribution and particle number emissions of light-duty vehicles.

Outline

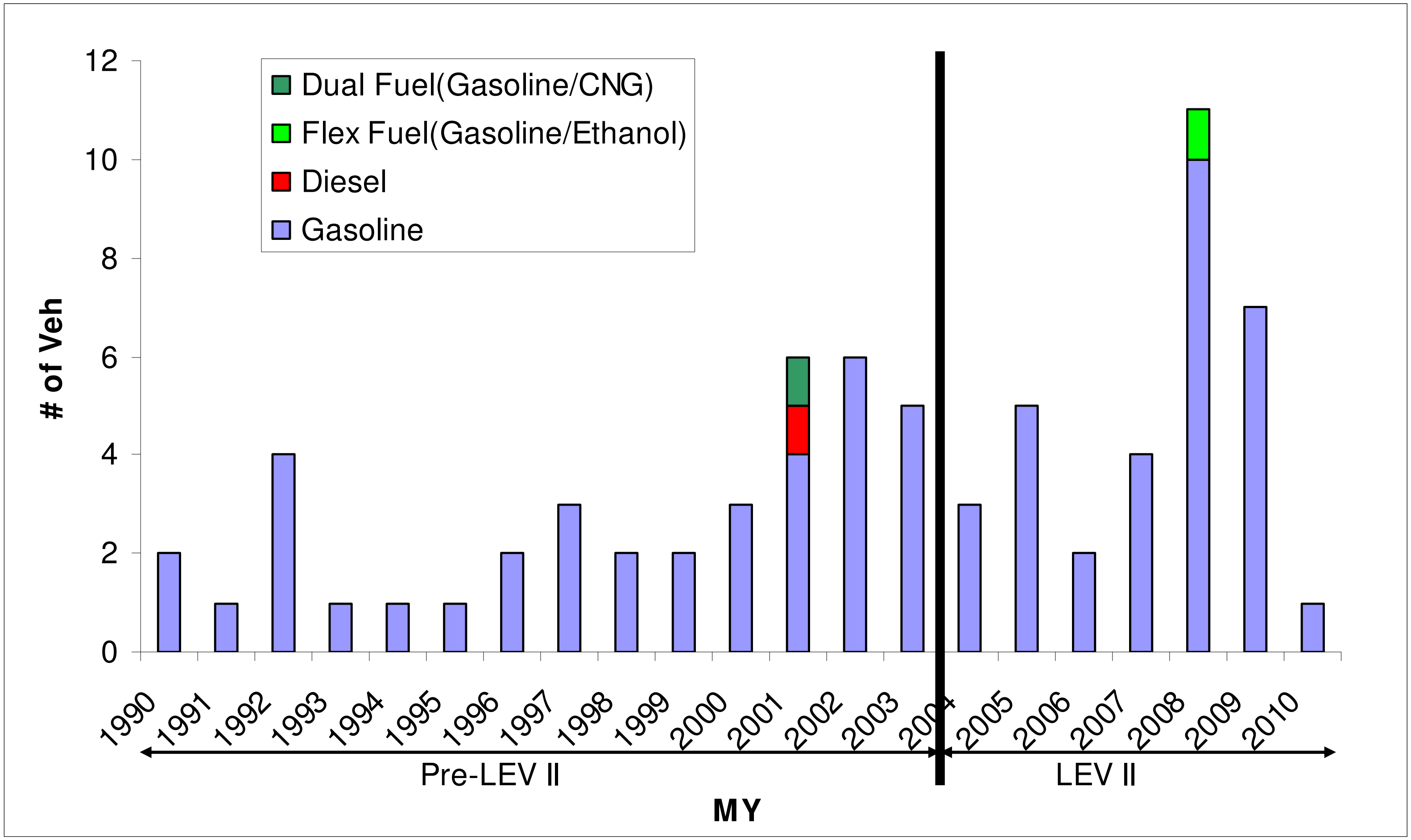
- PM measurement: mass, particle size distribution and number
- Limited data for PM measured at different temperatures
- Limited data for PM measured with different fuels

Data Sources

- Compilation of PM data from various projects between 2009 and 2010
- FTP and UC (cold and hot start) tests
- Phase and/or composite data
- Test fuels
  – California Summer/Winter, CNG, California Ultra-Low Sulfur Diesel, Ethanol blends (E6, E35, E65, E85)
- Some PM data were measured at different ambient temperatures

Test Vehicles

Total Vehicles 72



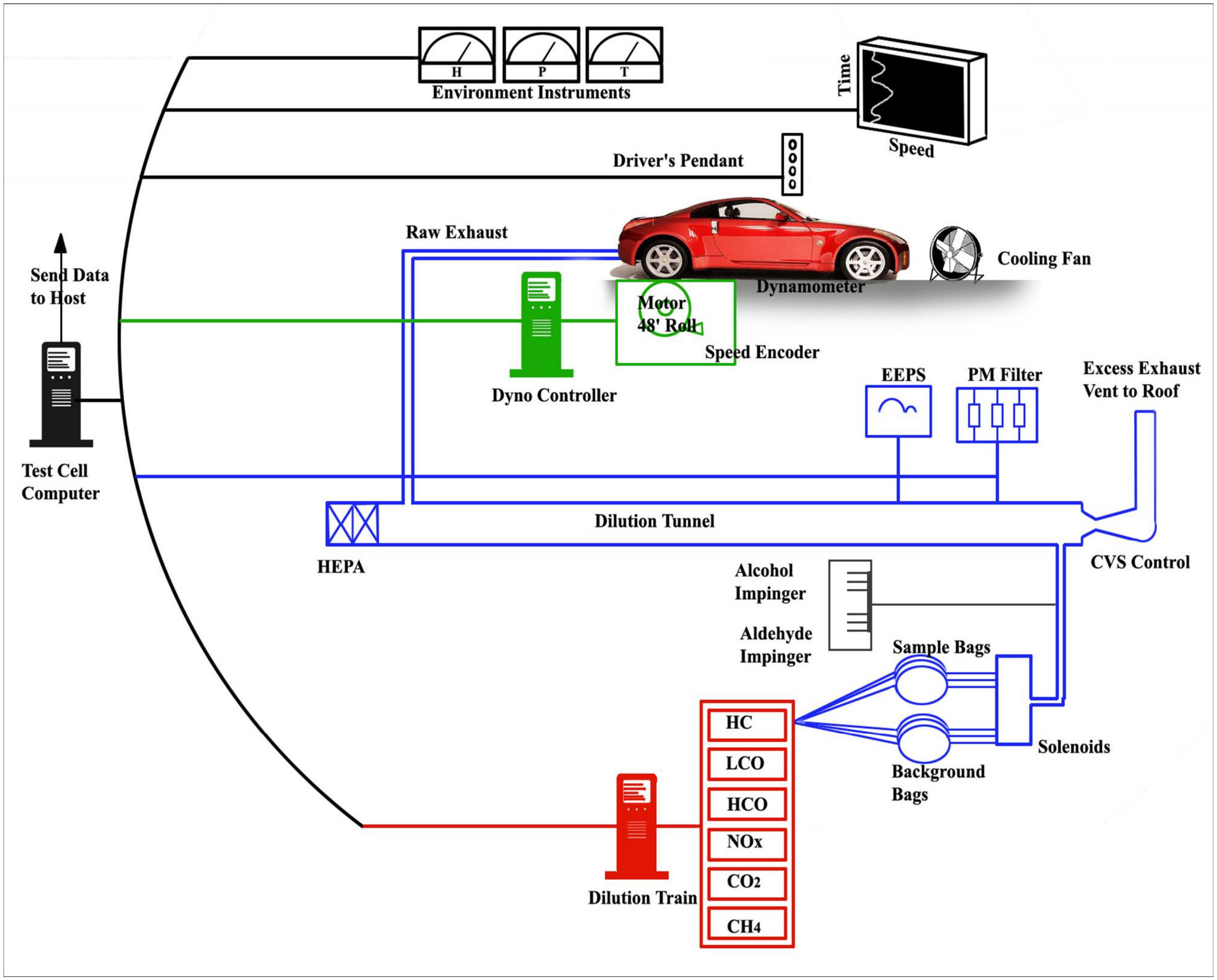
Measurement Method

- Direct sampling from CVS dilution tunnel without secondary dilution

- Particulate Mass (PM2.5):
  - Gravimetric, Teflon filter, “CFR 1065”

- Particle Number (PN):
  - TSI Engine Exhaust Particle Sizer Model 3090
  - Size range: 5.6 nm - 560 nm
  - Size distribution
  - Total particle number concentration

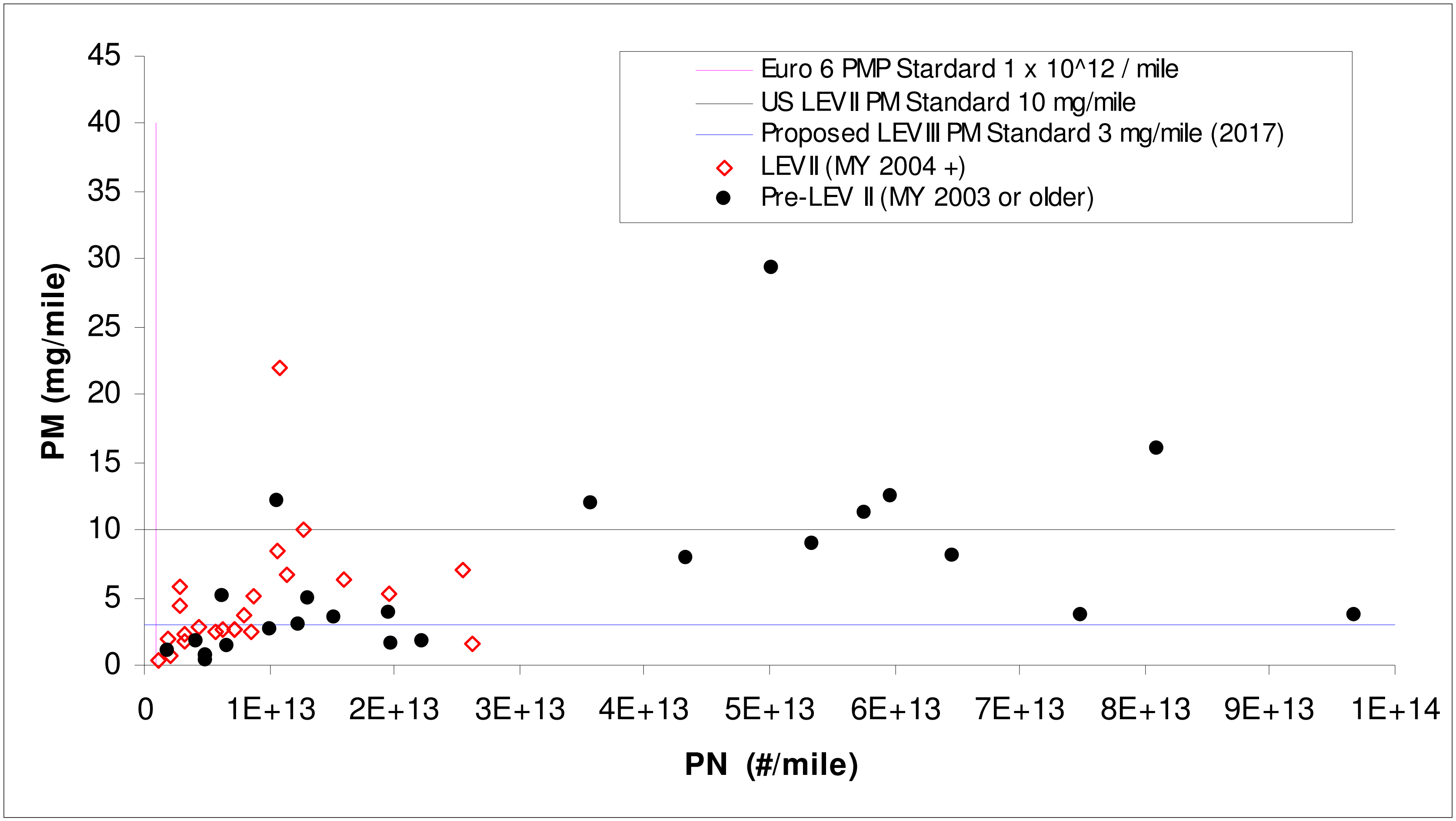
HSL Test Cells 2&3 Setup



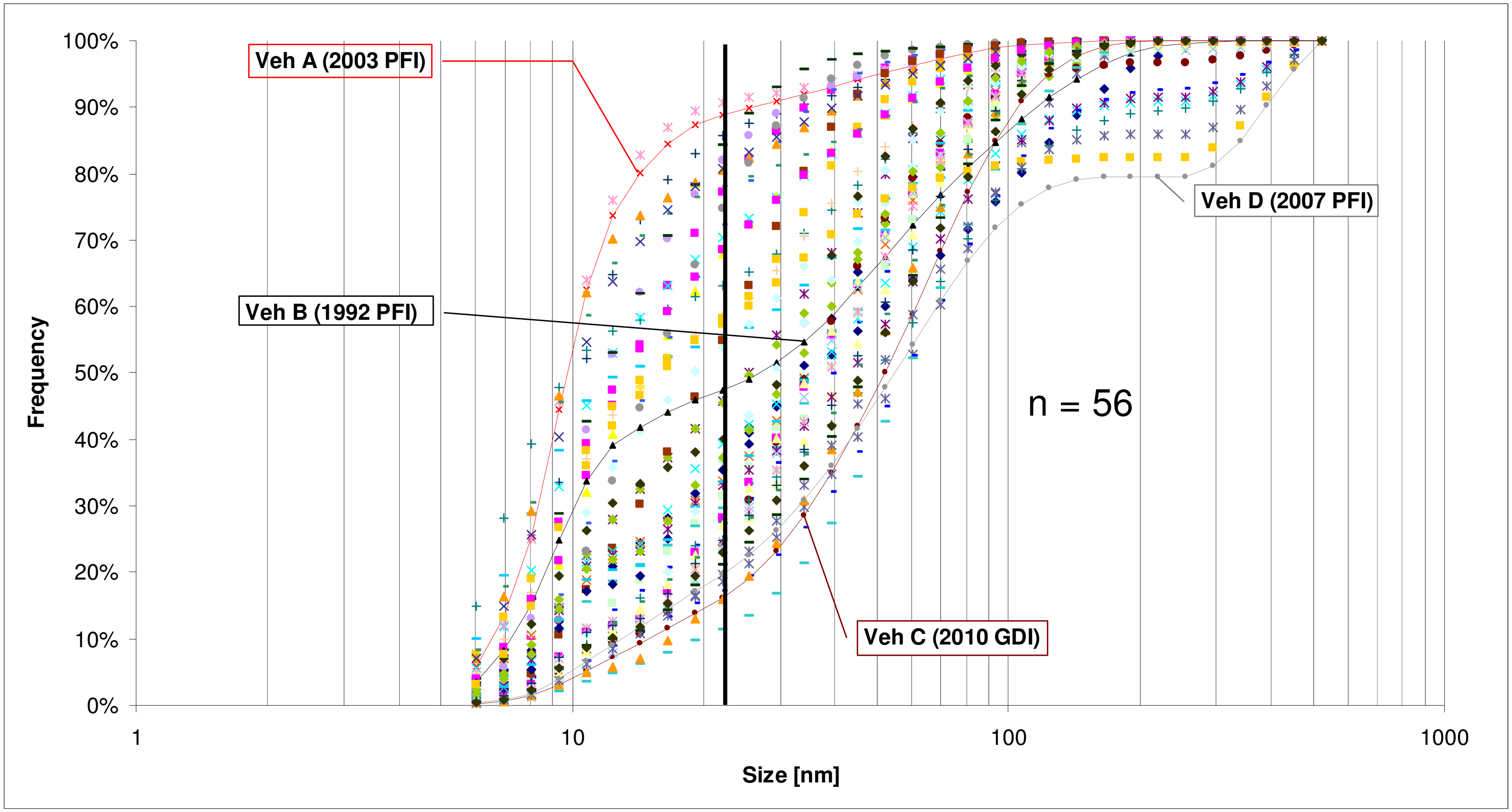
PM Mass vs Total PN

Cold start UC - 3 phase composite sampling

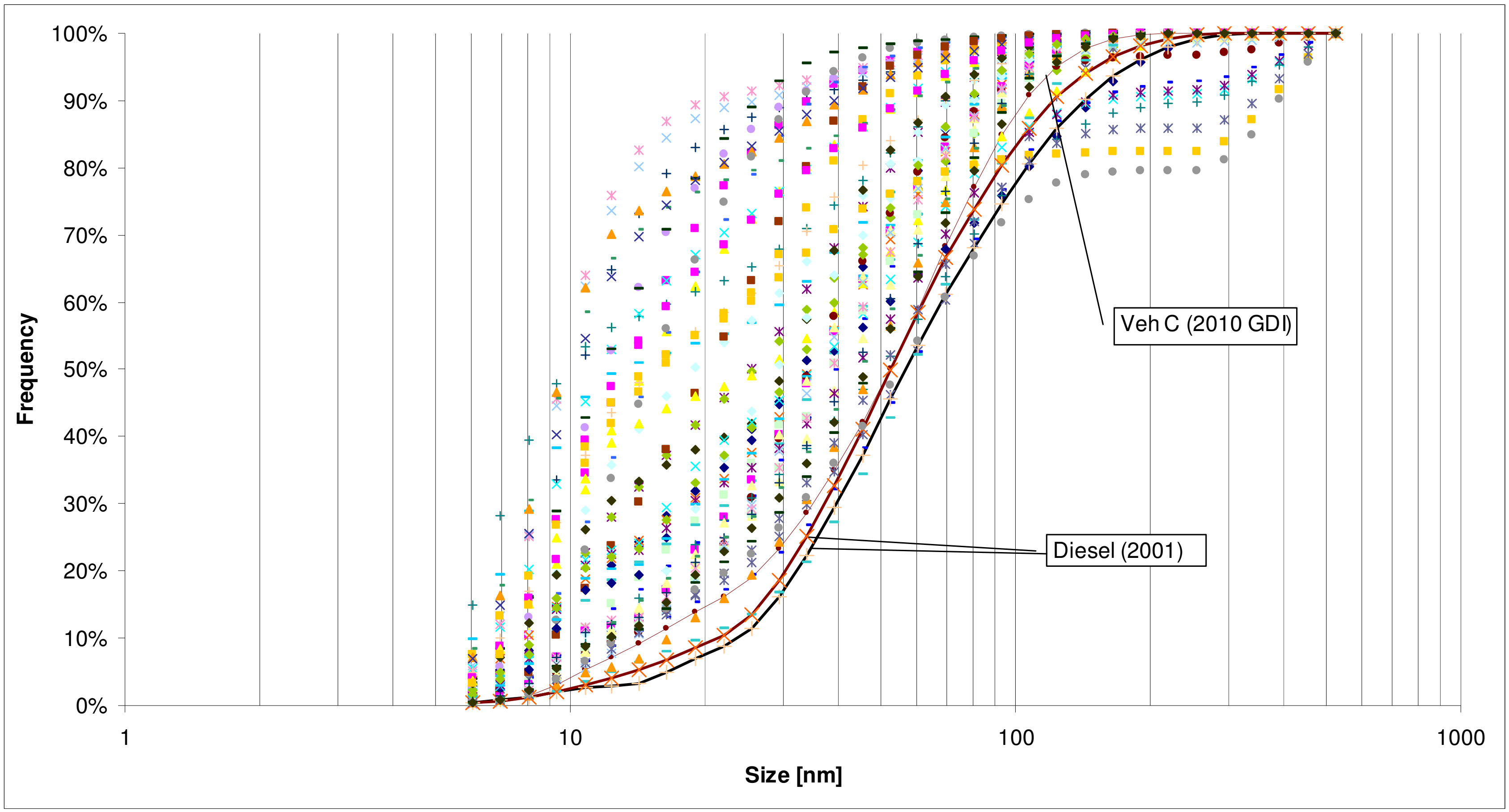
n=53



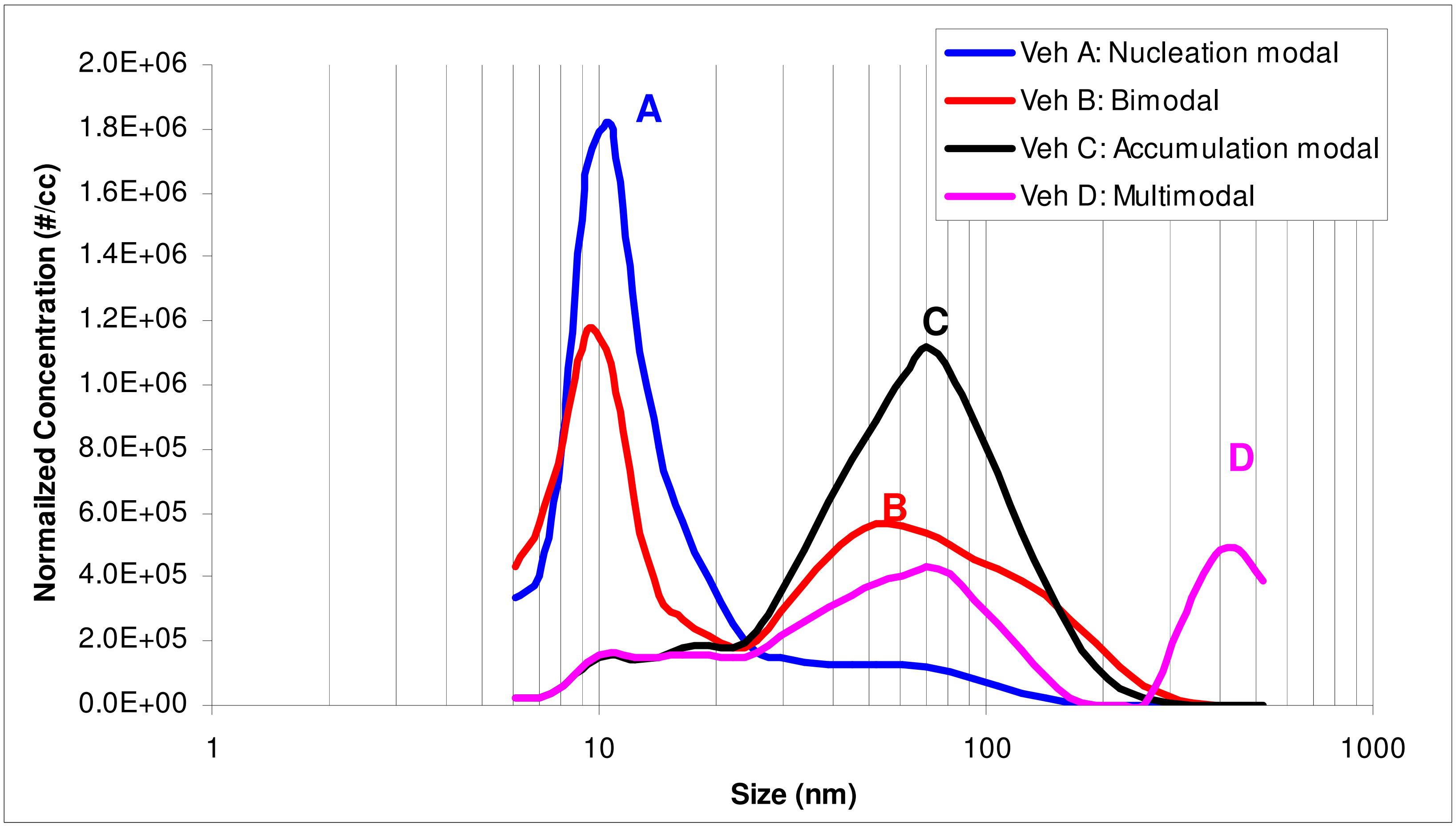
Cumulative Distribution of Gasoline PN



Cumulative Distribution of Diesel and GDI PN Compared to Gasoline



PN Profiles of Selected Gasoline Vehicles



Comparison of PN Profiles and PM Mass of Selected Gasoline Vehicles

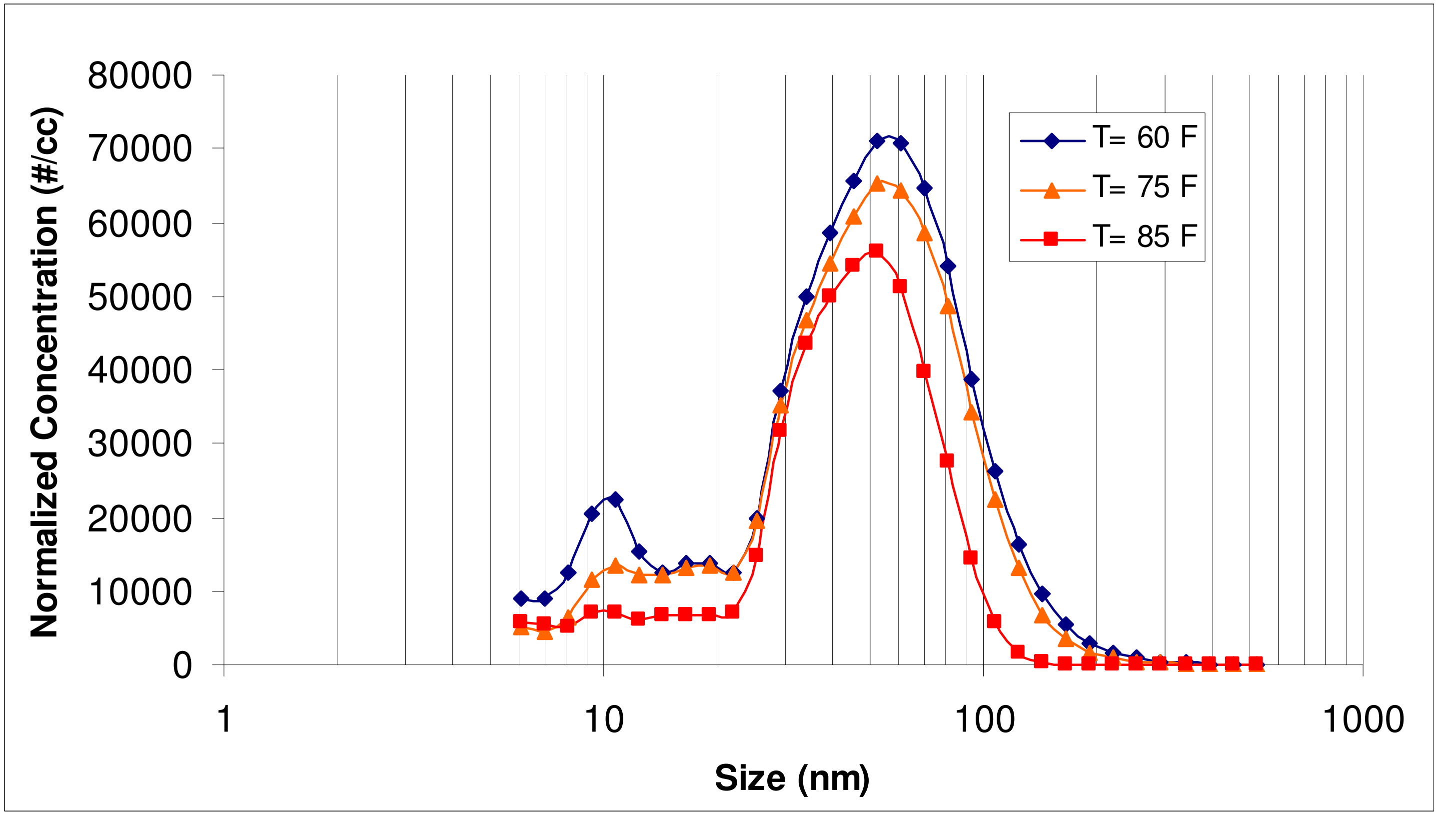
Mode	Veh	Size <23 nm	Size >23 nm	PM mg/mile	PN 10^{12} #/mile
Nucleation	Veh A	86%	14%	3.7	46.4
Bimodal	Veh B	47%	53%	1.7	18.7
Accumulation	Veh C	11%	89%	6.7	16.6
Multimodal	Veh D	20%	80%	2.5	7.0

Cold UC Composite

PM Measured at Different Ambient Temperatures

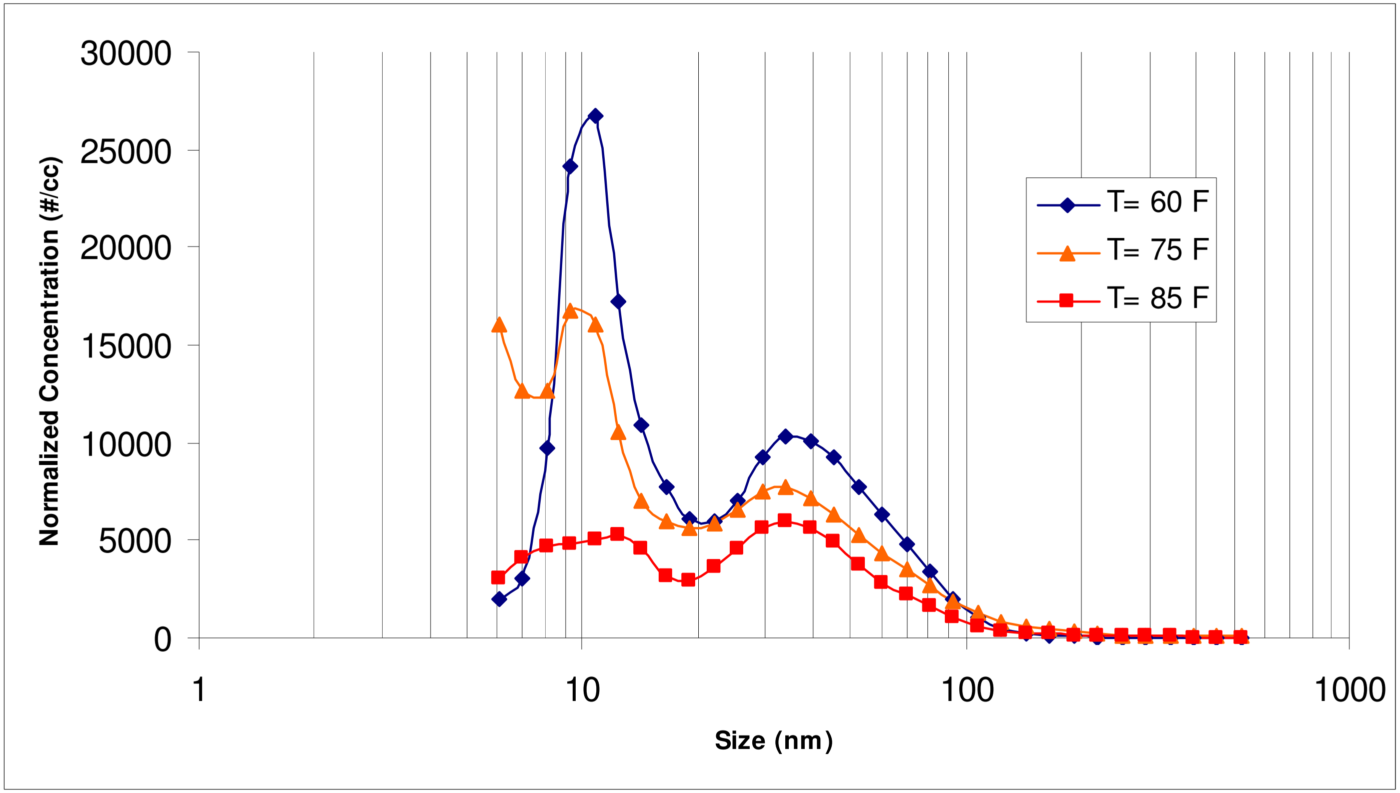
- 3 vehicles, 9 tests.
- Hot start Unified Cycle
- Composite sample of phases 1 and 2
- Triplicate tests at each temperature
- Ambient temperature at 60, 75, 85F

2008 MY – Gasoline PFI



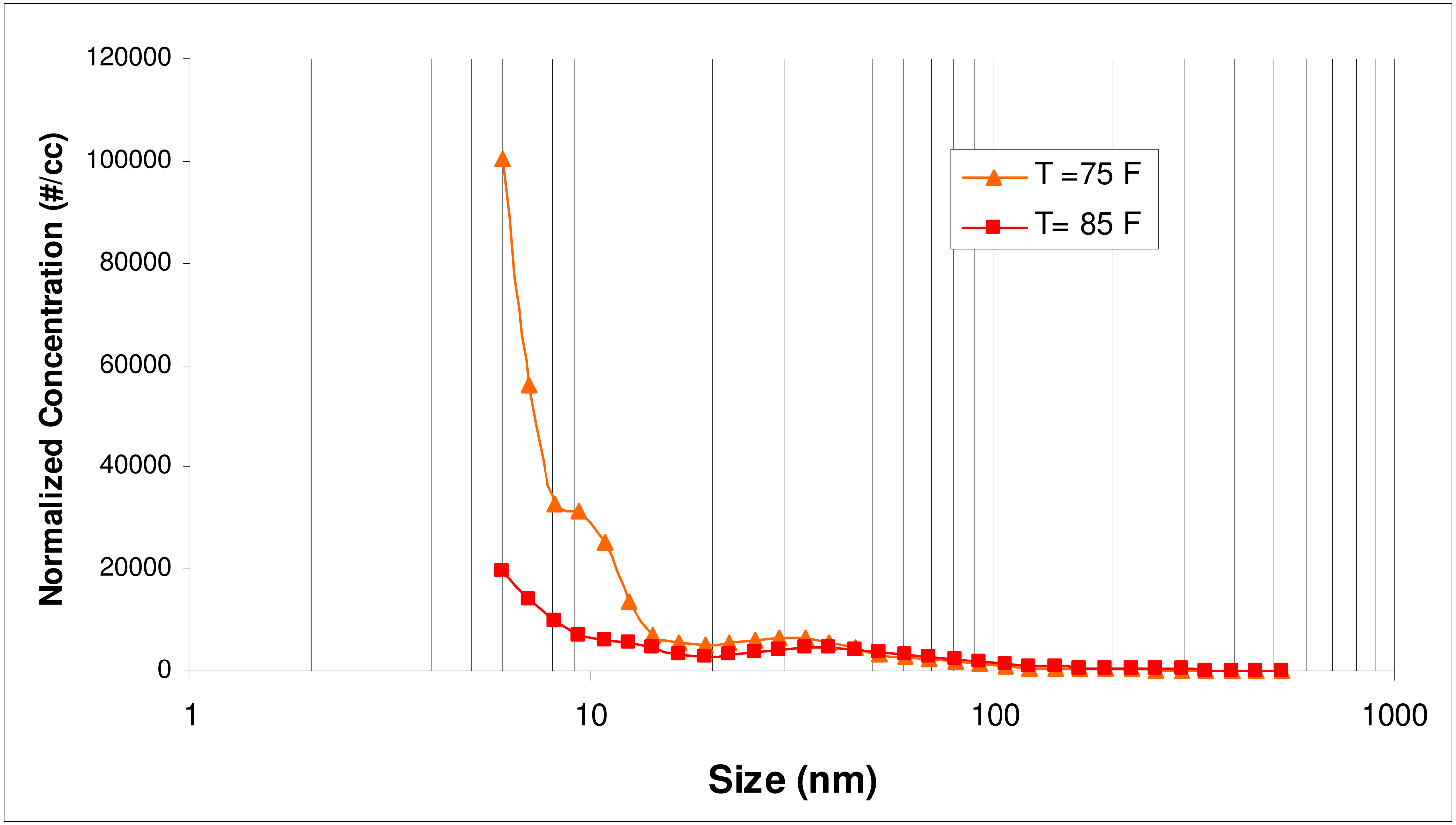
Temperature °F	PM mg/mile	PN 10^{12} #/mile
60	0.89	1.99
75	0.57	1.62
85	0.51	1.20

2001 MY Dual Fuel - Gasoline



Temperature °F	PM mg/mile	PN 10^{12} #/mile
60	0.72	0.50
75	0.30	0.44
85	0.37	0.21

2001 MY Dual Fuel - CNG



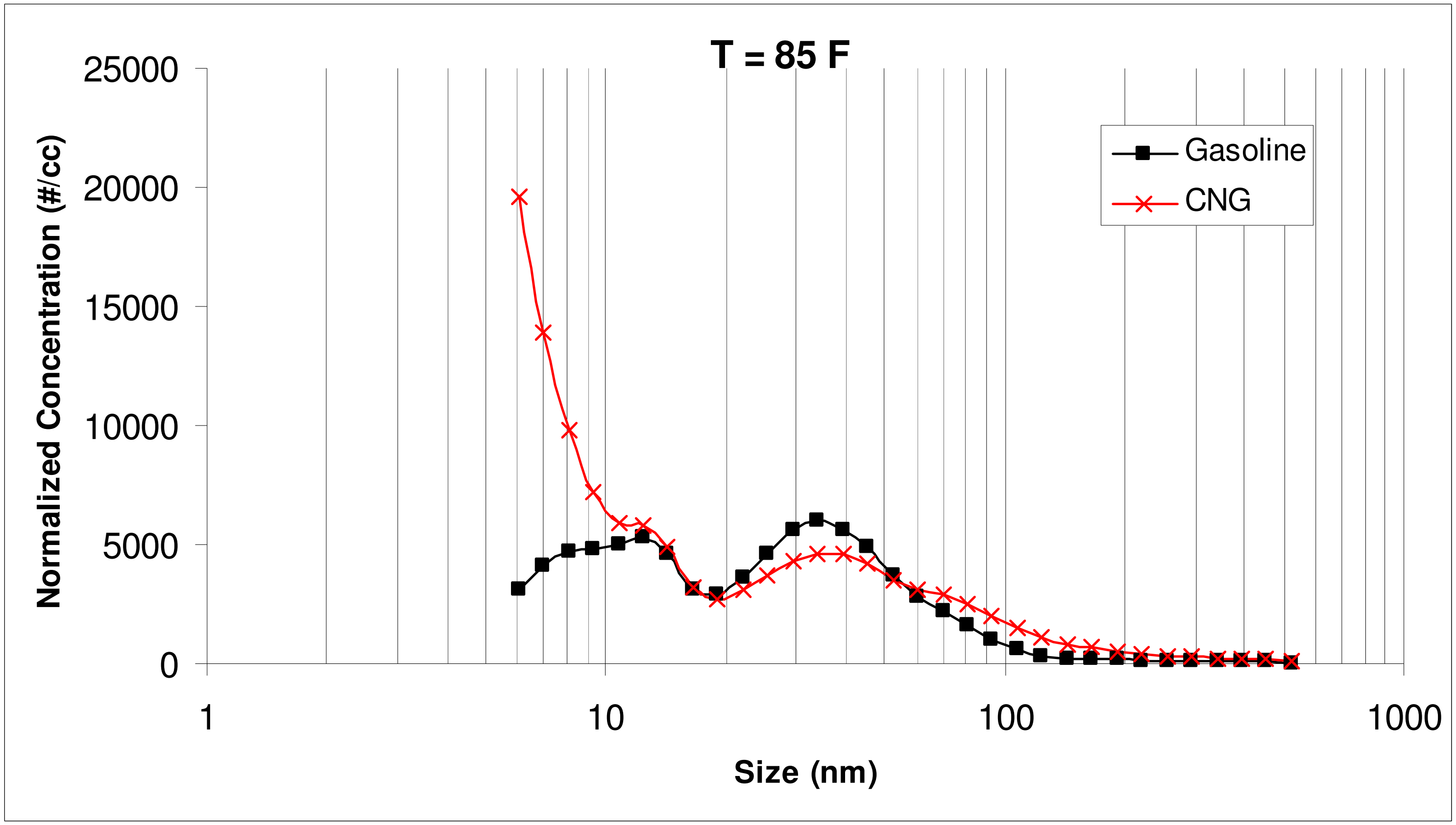
Temperature °F	PM mg/mile	PN 10^{12} #/mile
60	0.26	N/A
75	N/A	0.86
85	0.27	0.31

PM Measured with Different Fuels

- Hot start Unified Cycle
  - 2 vehicles, 6 tests
  - Composite sample of phases 1 and 2
  - CNG, Ethanol blends
- FTP tests
  - 1 vehicle, 2 tests
  - California Summer and Winter fuels

2001 MY - Dual Fuel

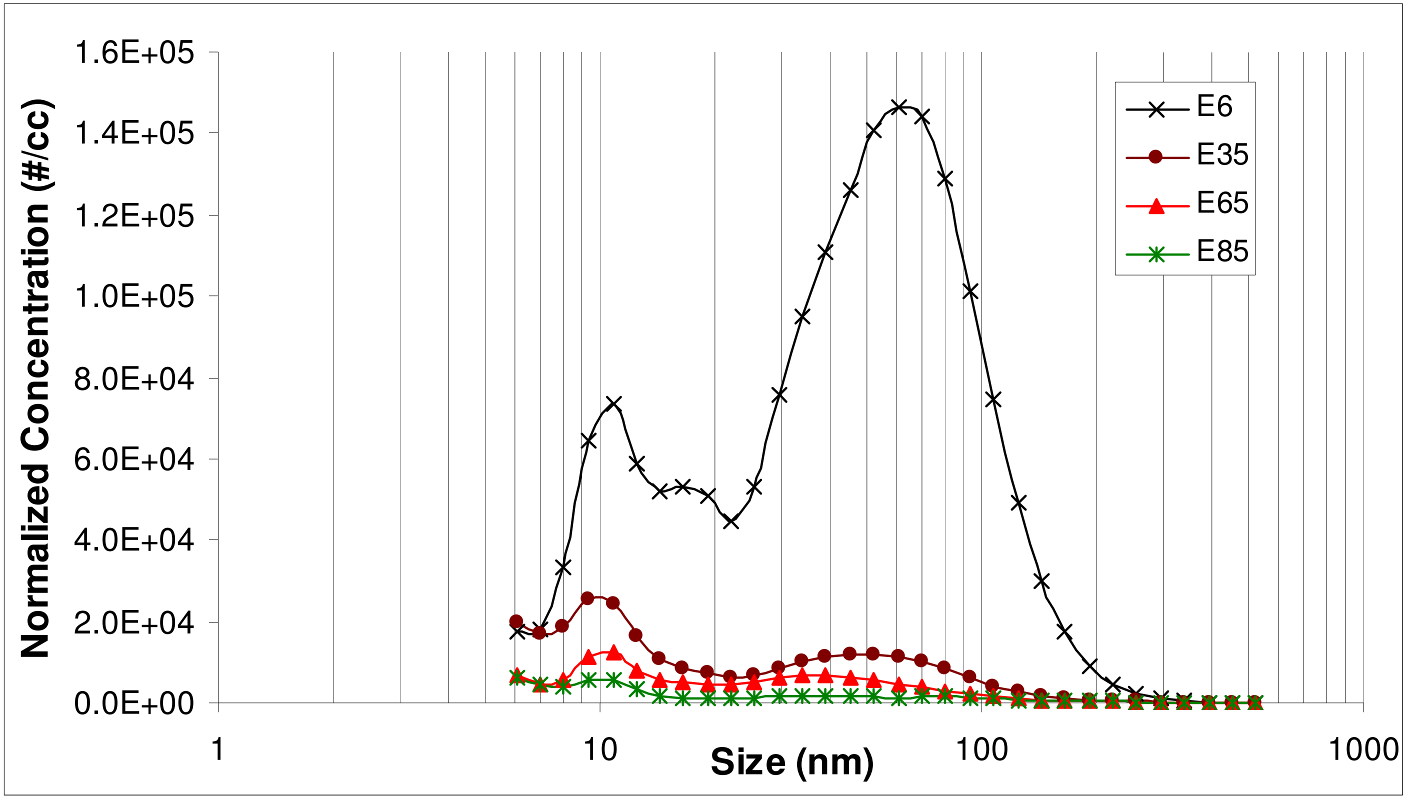
Hot UC – composite phase 1 and 2



Fuel Type	PM mg/mile	PN 10^{12} #/mile
Gasoline	0.37	0.21
CNG	0.27	0.31

2008 MY - Flex Fuel

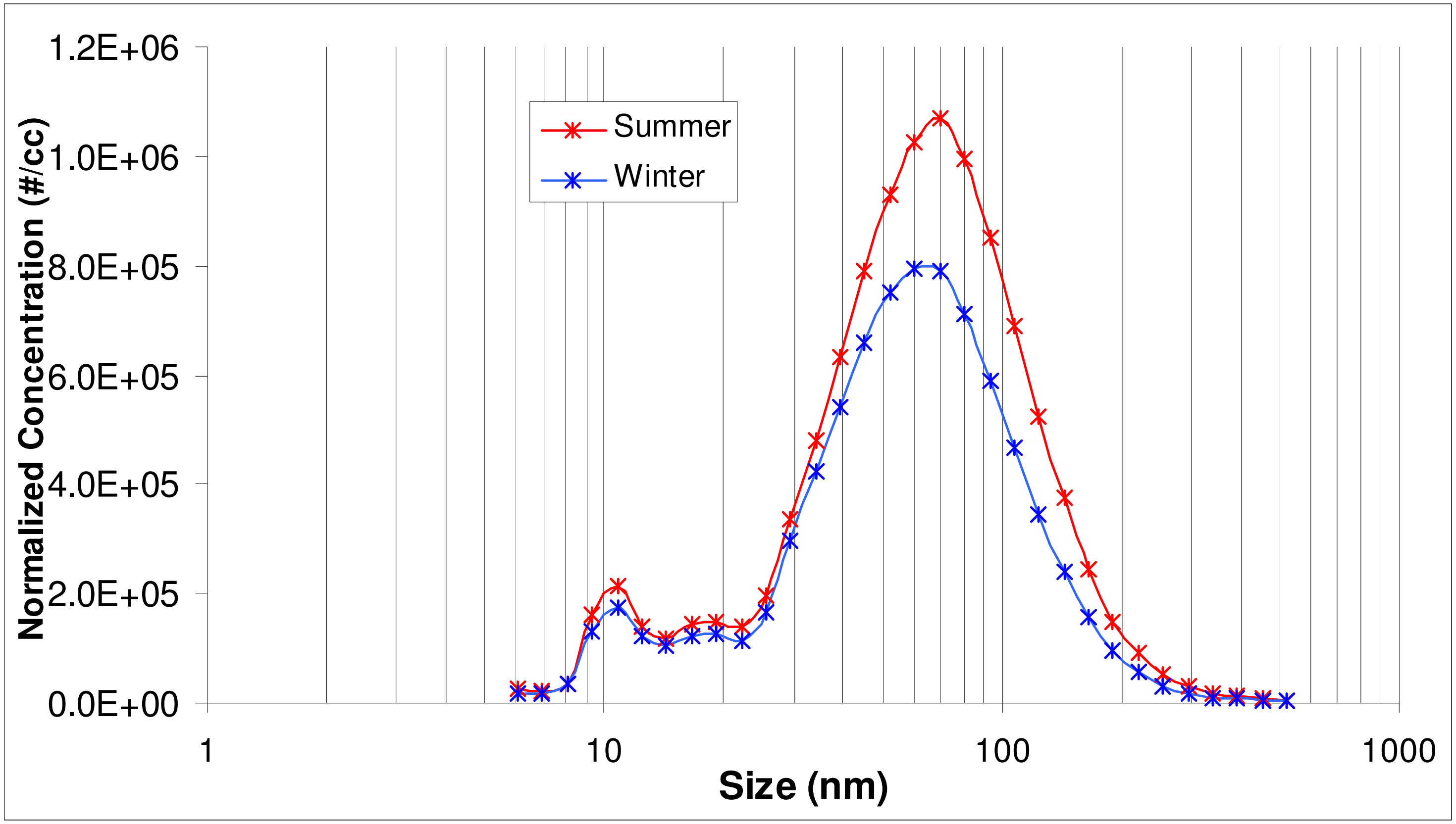
Hot UC – composite phase 1 and 2



Ethanol Fuel	PM mg/mile	PN 10^{12} #/mile
E6	1.60	4.70
E35	N/A	0.70
E65	0.60	0.30
E85	0.27	0.14

2009 MY

FTP Cycle



Fuel Type	PM mg/mile	PN 10^{12} #/mile
Summer	8.41	15.3
Winter	5.07	11.5

Fuel Properties

	Summer	Winter
Aromatics (vol %)	23.8	16.1
Benzene (vol %)	0.56	0.64
Olefin (vol %)	5.2	3.4
Ethanol (wt %)	6.08	5.73
Oxygen (wt%)	2.11	1.99
Sulfur (ppm)	8.8	7
RVP (psi)	6.8	8.96

Summary

- PM mass and PN data exhibited a poor correlation
- Test fleet showed wide range of particle size distribution
- PM mass and PN increased with lower dilution air temperature

Summary (cont'd)

- PM mass and PN decreased with higher ethanol content
- PM mass and PN were higher for California summer fuel than winter fuel
- PM mass was higher for gasoline compared to CNG while PN was lower for gasoline compared to CNG on the same vehicle

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Ethanol Blends and Engine Operating Strategy Effects on Light-Duty Spark-Ignition Engine Particle Emissions

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ABSTRACT: Spark-ignition (SI) engines with direct-injection (DI) fueling can improve fuel economy and vehicle power beyond that of port fuel injection (PFI). Despite this distinct advantage, DI fueling often increases particle number emissions, such that SI exhaust may be subject to future particle emissions regulations. In this study, ethanol blends and engine operating strategy are evaluated for their effectiveness in reducing particle emissions in DI engines. The investigated fuels include a baseline emissions certification gasoline, a blend of 20 vol % ethanol with gasoline (E20), and a blend of 85 vol % ethanol with gasoline (E85). The operating strategies investigated reflect the versatility of emerging cam-based variable valve actuation technology capable of unthrottled operation with either early or late intake valve closing (EIVC or LIVC). Particle emissions are characterized in this study by the particle number size distribution as measured with a scanning mobility particle sizer (SMPS) and by the filter smoke number (FSN). Particle emissions for PFI fueling are very low and comparable for all fuels and breathing conditions. When DI fueling is used for gasoline and E20, the particle number emissions are increased by 1−2 orders of magnitude compared to PFI fueling, depending upon the fuel injection timing. In contrast, when DI fueling is used with E85, the particle number emissions remain low and comparable to PFI fueling. Thus, by using E85, the efficiency and power advantages of DI fueling can be gained without generating the increase in particle emissions observed with gasoline and E20.

INTRODUCTION

The Energy Independence and Security Act of 2007 (EISA) requires a fuel economy improvement from the 2007 current corporate average fuel economy (CAFE) of 24.1 miles per gallon (mpg) to a CAFE of 35 mpg in the year 2020.[1] In response to a presidential memorandum, the United States Environmental Protection Agency (U.S. EPA) and the National Highway Traffic Safety Administration (NHTSA) have accelerated the timeline by requiring a combined car and light truck fleet average CO_2 emissions of 250 g/mile by 2016,[2] which is approximately equivalent to a combined fleet fuel economy 35.5 mpg. With these regulations as the impetus, technologies designed to improve fuel economy have begun to be incorporated into production vehicles. These technologies include hybrid electric technology, cylinder deactivation, variable valve actuation, and gasoline direct-injection (DI) fueling.

DI fueling for gasoline engines is an enabling technology for the development of vehicles with better fuel economy. In combination with turbocharging, gasoline DI fueling significantly improves engine power, which allows the engine displacement volume to be reduced for a given application (downsizing), even while the engine performance improves.[3] When the engine is downsized, the engine friction is reduced and the engine operates at higher engine loads for a larger fraction of the operating map, as quantified by the brake mean effective pressure (BMEP), which results in more efficient operation. In addition, gasoline DI fueling reduces the tendency of a fuel to knock because of enhanced charge cooling, allowing the compression ratio to be increased for higher efficiency. As a result, fuel economy can be increased for vehicles with DI fueling compared to engines with port fuel injection (PFI) technology.

DI gasoline engines are being rapidly incorporated into new vehicles in the United States. PFI technology has been nearly ubiquitous in light-duty vehicles over the past 2 decades, accounting for over 99% of all light-duty vehicles sold in the United States each year between 1996 and 2007.[4] Since that time, gasoline DI fueling has begun to emerge, accounting for 2.3% of light-duty gasoline vehicles in 2008 and rising to 8.5% in 2010.[4] The percentage of vehicles with gasoline DI technology in the United States is expected to continue increasing rapidly, with a projection of 60% of all new vehicles by 2016.[5]

While gasoline DI technology is beneficial for fuel economy, it produces an increase in particulate matter emissions in comparison to PFI engines. Aakko and Nylund[6] reported that the particle mass emissions for a gasoline DI vehicle were an order of magnitude higher than for a PFI vehicle for the European 70/220/EEC drive cycle. Similarly, the particle number emissions reported by Aikawa et al.[7] were roughly a factor of 5 higher for the DI vehicle than for the PFI vehicle, although direct comparison of these is difficult because different vehicle drive cycles were used. A report issued by the California Air Quality Board[5] estimates that, on average, particle mass emissions are increased somewhere between 2 and 20 times for gasoline DI engines compared to PFI.

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Reductions in particle emissions from DI engines are being pursued with a number of different strategies. Moore et al.[8] show that increased charge motion achieved through deactivation of one of the intake valves is effective in reducing soot emissions, as quantified by the filter smoke number (FSN). Hedge et al.[9] show that exhaust gas recirculation (EGR) is effective at reducing particle emissions at part-load operation while simultaneously improving fuel consumption, likely through a reduction in throttling losses. Additionally, Iyer and Yi[10] showed that improvements can be made in the targeting of the fuel spray to reduce soot emissions. With DI fueling strategies being relatively new to production engines, further improvements to fuel injection hardware and engine operating strategies may allow for further reductions in particle emissions.

However, solving the issue of increased particle emissions from gasoline DI engines may be complicated by the fact that the fuel diversity in the marketplace is increasing. The same EISA legislation that requires improved fuel economy also requires that the amount of bio-derived fuels increase more than 7-fold from their 2007 levels by 2020.[1] Although there will be a variety of different fuel types that contribute, ethanol is expected to comprise the overwhelming majority of the bio-derived fuel.

A number of investigations have examined the effect of ethanol content on particle emissions in vehicles. Storey et al.[11] found that blends of 10 and 20% ethanol in gasoline (E10 and E20) decreased particle number emissions during vehicle drive cycles, with the 20% blend decreasing particles by about 40% during the high-load US06 vehicle drive cycle. In comparison to gasoline, He et al.[12] found a 20% reduction in particle emissions with E20 but no change with E10. Khalek and Bougher[13] showed that E10 increased particle emissions compared to two different gasoline formulations, both with higher volatility than the E10. This work showed the importance of the hydrocarbon fraction of the E10 blend and suggests that the heavier hydrocarbons used to control vapor pressure of E10 may also increase particulate emissions. Aakko and Nylund[6] found that the particle mass emissions from 85% ethanol (E85) were comparable to those with gasoline in a PFI vehicle but that DI fueling with gasoline produced particle emissions that were an order of magnitude higher.

The previous studies investigating the effect of ethanol fuels on particle emissions have operated production engines in their original equipment manufacturer (OEM) configurations and calibrations. There have also been a number of additional recent research efforts to optimize engine efficiency for high concentrations of ethanol to reduce the fuel economy penalty associated with the lower energy density of ethanol.[14−18] In addition to the use of DI fueling, each of these research efforts represents departures from how spark-ignition (SI) engines are conventionally operated, particularly in regard to engine breathing strategies and compression ratio. The purpose of this investigation is to elucidate the effects of fuel type, fueling strategy, and engine breathing strategy on particle emissions in a flexible SI engine that was designed for optimization with ethanol.

EXPERIMENTAL METHODOLOGIES

Engine Platform and Experimental Procedure. The engine used in this study has been developed specifically for high-efficiency operation with ethanol. The base engine is a four-cylinder GM gasoline DI engine with turbocharging and dual independent cam phasing, and the engine has undergone a number of modifications. The detailed description of the unique engine hardware and operating strategy, including cam profiles, have been described in previous publications by Hoyer et al.[19] and Moore et al.[20] and are summarized here. The engine is equipped with custom-designed pistons that increase the compression ratio from 9.2 to 11.85 to leverage the high octane potential of ethanol fuels. The valvetrain has also been modified from its OEM configuration to increase the cam phasing authority to 80 crank angle degrees (CAD) and to accept a two-step VVA system that employs both early and late intake valve closing (EIVC and LIVC) strategies to control the effective displacement and effective compression ratio and to reduce pumping work compared to throttled operation. Pumping work is reduced because intake air flow is controlled through intake valve closing angle rather than throttling, as illustrated in the $P-V$ diagrams in Figure 1. The engine geometry and specifications are given in Table 1. Previous investigations have demonstrated efficiency benefits with both EIVC and LIVC operation.[20−22]

The engine is designed with a DI fueling system, and a PFI system has been added to allow for a direct comparison of fueling strategy. Engine management is performed with a DRIVVEN engine controller, allowing full access to all engine control parameters, including fuel injection timing, fuel injection duration, fuel injection pressure, spark timing, high or low lift cam profile, cam phasing, and throttle position. The engine is equipped with a turbocharger, but all conditions in this study are performed under naturally aspirated conditions by maintaining an open position on the turbocharger waste gate.

Table 1. Engine Geometry and Specifications

displacement (L)	2.0
bore (mm)	86
stroke (mm)	86
compression ratio	11.85
fueling	DI and PFI
DI pressure (bar)	100

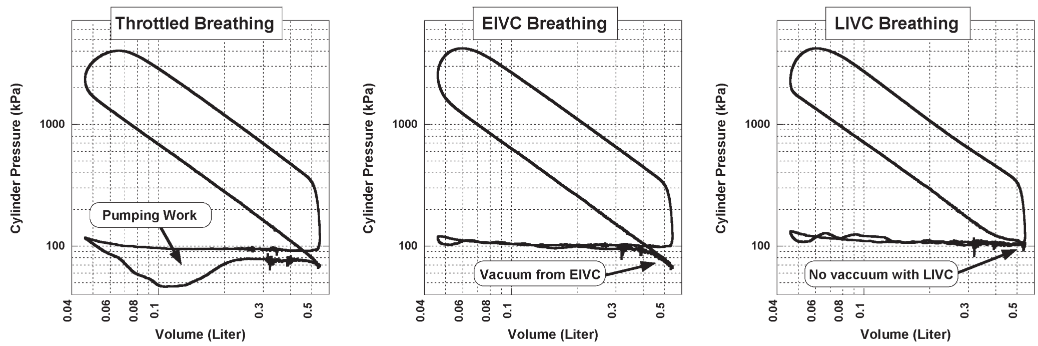

Figure 1. $P-V$ diagrams for the three different engine breathing strategies for gasoline.

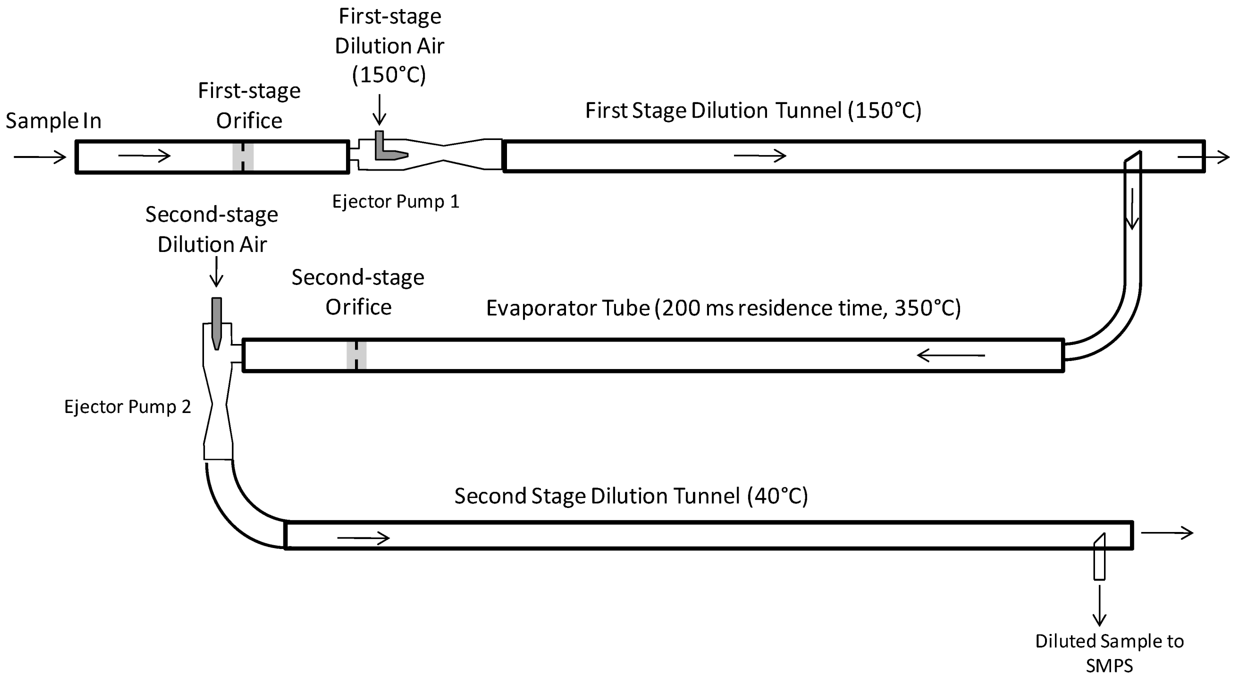

Figure 2. Schematic of the two-stage dilution system with an evaporator tube.

Cylinder pressure and fuel injection command signals are acquired at the shaft encoder resolution of 0.2 CAD. The cylinder pressure is recorded from each of the four cylinders using piezoelectric pressure transducers side-mounted in the engine block. The signals are acquired using National Instruments data acquisition hardware and analyzed using the DRIVVEN combustion analysis toolkit (microDCAT).

Gaseous engine emissions are measured using a standard emissions bench. NO_x and hydrocarbon (HC) emissions are measured directly from the hot exhaust using a chemiluminescence analyzer and a flame ionization detector (FID), respectively. Exhaust gas is chilled to condense water in the exhaust prior to measurements of CO and CO_2 using infrared analyzers and for oxygen using a paramagnetic analyzer.

Particulate emissions from the engine are measured using an AVL FSN instrument as well as a scanning mobility particle sizer (SMPS). FSN is an industry standard that has long been used to provide rapid and repeatable measurements of smoke emissions for diesel engine research and development. The measurement principle is based on a change in filter paper reflectivity and is intended to be proportional to particulate mass collected on the paper.[23] The sensitivity of the FSN instrument is limited at the lowest particle emission levels with both PFI and DI fueling, but it has proven to be a useful measure at many engine conditions for previous gasoline engine studies with DI fueling in the past.[8,24] FSN is measured from the raw exhaust downstream of the three-way catalyst.

For the particle number size distribution measurements with the SMPS, a two-stage microtunnel dilution system with an evaporator tube is used to condition the exhaust. Number size distributions from 9 to 500 nm diameter particles are measured by a SMPS (model 3936, TSI, Inc.) equipped with the differential mobility analyzer (DMA, model 3085, TSI, Inc.) and condensation particle counter (model 3025, TSI, Inc.). Each SMPS measurement is the average of three SMPS scans, resulting in a total sampling time of about 9 min. The dilution system is based on an ejector pump dilution design by Abdul-Khalek et al.[25] The probe for the SMPS measurements is located in the pre-catalyst position in the exhaust system.

The dilution system is located in close proximity to the engine exhaust, requiring only a short section of insulated stainless-steel tubing (40 cm) to connect the exhaust to the first-stage orifice. The two-stage microdilution system is designed to vaporize the liquid-phase particles, leaving only the solid particles to be measured by the SMPS, as performed previously by the European Particle Measurement Programme (PMP) systems[26] and as in proposed legislation by the California Air Resource Board.[5] In an effort to accomplish this, (1) the air for the first-stage dilution is heated to 150 °C, and the first-stage dilution tunnel is maintained at 150 °C. (2) The second-stage ejector pump draws the sample from the first-stage dilution tunnel, through an evaporator tube, and into the second-stage dilution tunnel. The evaporator tube is maintained at a temperature of 350 °C for a residence time of approximately 200 ms in an effort to vaporize condensed-phase liquid droplets. (3) The air for the second-stage dilution is not heated, and the second-stage dilution tunnel is maintained at a temperature of 40 °C. The lower temperature of the second-stage dilution system is due to the inlet temperature limitation of the SMPS system. The first-stage dilution ratio is 5:1, and the second-stage dilution ratio is 6:1, producing an overall dilution ratio of approximately 30:1. The design of the system is somewhat similar to that of the PMP,[26] but we used a lower dilution ratio to provide a greater number of particles for statistically significant SMPS number size distributions. A schematic of the two-stage dilution system is shown in Figure 2.

Fuels. Three fuels differing in ethanol concentration are investigated in this study, including a baseline gasoline, E20, and E85. The full specifications for the fuels are given in Table 2. The baseline gasoline has a high anti-knock index [$(R + M)/2 = 92.9$], and as a result, it is not necessary to retard spark timing from the maximum brake torque timing for knock mitigation in this investigation. The fuel properties show the expected trends, with specific gravity, research octane number (RON), anti-knock index, and octane sensitivity all increasing with ethanol content. The maximum Reid vapor pressure occurs for the E20 fuel blend because of the well-established azeotrope phenomenon.[27]

Engine Operating Conditions. All data for this investigation is collected at an engine speed of 1500 rpm and a load of 8 bar BMEP, with the air/fuel ratio maintained at stoichiometric conditions throughout the investigation to maintain compatibility with three-way catalyst technology.

Table 2. Fuel Properties

		gasoline	E20	E85
specific gravity	ASTM D4052	0.7437	0.7545	0.7865
Reid vapor pressure (psi)	ASTM D5191	8.49	9.32	4.82
net heat of combustion (kJ/kg)	ASTM D240	43225	39747	29168
research octane number	ASTM D2699	97.1	102	106
motor octane number	ASTM D2700	88.7	90.3	88.7
anti-knock index [$(R + M)/2$]		92.9	96.2	97.4
octane sensitivity		8.4	11.7	17.3
aromatics (vol %)	ASTM D1319	31.2	27.16	3.75
olefins (vol %)	ASTM D1319	0.7	0.48	0.25
saturates (vol %)	ASTM D1319	68.1	53.19	8.99
ethanol (vol %)	ASTM D5599		19.17	87.01
sulfur (wt %)	ASTM D2622	0.0034	0.0023	<0.001
carbon (wt %)	ASTM D5291	86.59	79.4	57.01
hydrogen (wt %)	ASTM D5291	13.44	13.26	13.01
oxygen (by difference)[a] (wt %)			7.34	29.98
oxygen (wt %)	ASTM D5599		7	30.48
water content (ppm mass)	ASTM D6304		2203	3377

[a] Oxygen (by difference) = 100 − carbon (wt %) − hydrogen (wt %).

In the past, it has been particularly challenging to achieve low particle emission levels at this engine condition.[8] For each of the three fuels, the engine is operated at the desired engine speed and load using three engine breathing conditions: conventional throttled operation, unthrottled with EIVC, and unthrottled with LIVC. For each fuel and breathing condition, the engine is operated with three different fueling strategies: single injection DI (sDI), multiple injection DI (mDI), and PFI. For the sDI and mDI fueling strategies, a start of injection timing sweep is performed, whereas only a single point is performed for the PFI strategy.

Gaseous emissions, FSN, and engine performance metrics are recorded at each engine operating point. Particle number size distribution measurements with the SMPS are collected at each of the PFI conditions but collected only at three fuel injection timings during the sDI and mDI timing sweeps.

■ RESULTS

Fuel and Operating Strategy Effects on Gaseous Emissions and Efficiency. Efficiency and gaseous emissions differences between the engine breathing strategies, fueling strategies, and fuel type follow established trends, as illustrated in Figure 3. To summarize, EIVC and LIVC operation result in increased efficiency as well as a reduction of NO_x emissions for a given fuel. The reduction in NO_x emissions is attributed to a reduction in the effective compression ratio and, thus, a lower in-cylinder temperature at the end of compression. Efficiency and emissions are also functions of fuel injection timing with the sDI and mDI fuel injection strategies. When injection timing is retarded from the maximum efficiency point, a decrease in efficiency is accompanied by increases in CO and HC emissions because of a reduction in available mixing time. When injection timing is advanced from the maximum efficiency point, the efficiency decrease is accompanied by an increase in HC emissions, likely because of fuel impingement on combustion chamber surfaces. The trends with injection timing are consistent with the study performed by Moore et al.[8]

Efficiency and gaseous emissions for PFI fueling with gasoline are illustrated by the dashed lines in Figure 3. In all cases, gaseous emissions and efficiency for PFI fueling are comparable to the

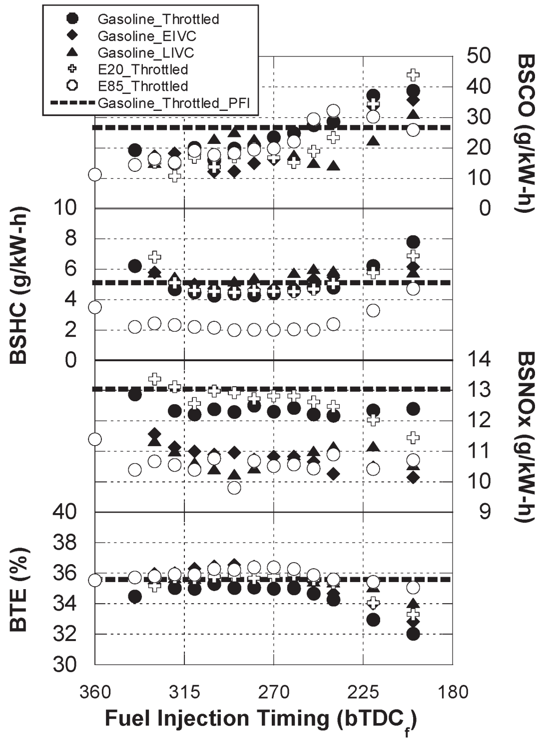

Figure 3. Efficiency and gaseous emissions for sDI gasoline operation under the throttled, EIVC and LIVC breathing strategies, throttled sDI operation with E20 and E85, and throttled PFI operation with gasoline.

sDI fueling strategy. This result is expected given that DI fueling strategies allow for higher power, downsizing, and higher compression ratio, but the efficiency remains approximately the same at a specific engine operating point. Gaseous emissions and efficiency from the mDI injection strategy (not shown) do not differ substantially from the sDI fueling strategy.

The effect of ethanol content shown in Figure 3 is consistent with established trends reported previously. HC and NO_x emissions are comparable for gasoline and E20 but are reduced for E85, similar to the findings by Moore et al.[20] Also, brake efficiency is observed to increase with an increasing ethanol content. Higher thermal efficiency with E85 has been reported in previous literature for both engine dynamometer studies[21,28,29] and vehicle studies.[30,31]

Thus, the effects of engine breathing strategy, fueling strategy, and fuel type on engine efficiency and emissions follow trends that have been previously reported in the literature. The EIVC and LIVC breathing strategies both serve to increase engine efficiency and reduce NO_x emissions. For the DI fueling strategies, there is a fuel injection timing for maximum efficiency because of trade-offs between fuel spray impingement and fuel−air mixing time. In comparison to gasoline, E85 reduces NO_x and HC emissions in addition to producing an increase in efficiency.

Gasoline Particle Emissions. FSN emissions are given as a function of fuel injection timing and breathing strategy in Figure 4. The dependence of FSN emissions upon fuel injection timing is similar for all three breathing strategies, with advanced timing producing the highest FSN emissions and intermediate timing having little effect. For the most retarded injection timing, a slight rise in FSN emissions is produced for the throttled condition but not for the other breathing strategies.

This response of FSN to fuel injection timing agrees with the well-established trends in published literature. For a similar engine architecture, Worlding et al.[24] reported FSN greater than 1.0 at advanced injection timing of 320 CAD BTDC$_f$ for a wide open throttle condition at 2000 rpm and lower FSN of approximately 0.3 as injection timing is retarded to 300 CAD BTDC$_f$. Similar trends are reported by Moore et al.,[8] where the minimum and maximum FSN measurements as functions of injection timing are highly dependent upon the speed and load condition of the engine.

The particle size distributions for gasoline for the three different breathing strategies are shown at three different fuel injection timings in Figure 5. Note that the ordinate scale for Figure 5a is larger than for panels b and c of Figure 5. The SMPS results qualitatively agree with the FSN results (Figure 4), with the highest particle emissions occurring for the early injection timing and the lowest particle emissions occurring for the later injection timings. It can also be seen that the LIVC breathing strategy produces the highest particle emissions. The higher particle emissions for the LIVC breathing strategy are likely the result of a difference in the fuel and air mixing process compared to the throttled and EIVC cases or possibly fuel spray impingement on the intake valve.

Multiple Direct Fuel Injections. In this section, we investigate whether using a multiple injection fueling strategy can be effective in reducing particle emissions. We hypothesize that, by introducing the fuel in two separate injection events, the liquid penetration length can be shortened. This can reduce the amount of fuel that impinges on the piston and ultimately lower particle emissions.

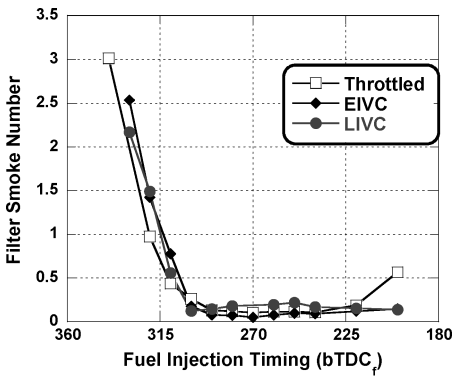

Figure 4. FSN as a function of fuel injection timing for gasoline using the sDI fuel injection strategy.

The fuel injection command for the sDI and mDI operating strategies are illustrated in Figure 6 at a commanded injection timing of 280 CAD BTDC for both injection strategies. For the mDI strategy, the two pulses are of equal duration and the time from the end of the first pulse to the start of the second pulse is held constant at 1 ms (9 CAD at 1500 rpm). As a result of the split injection process, the end of injection occurs later for the mDI strategy. Figure 6 shows that the cylinder pressure traces for the two operating strategies are nearly identical with no notable differences in performance. Although the results are not presented here, this mDI strategy does not cause any significant changes in engine emissions or efficiency.

Notable differences in FSN emissions can be seen for the two fueling strategies in Figure 7. At the most advanced fuel injection timing, the mDI strategy produces lower FSN emissions than the sDI strategy, with a FSN reduction of more than 50% at a fuel injection timing of 320 CAD BTDC$_f$. A similar trend is shown for the particle distributions at this injection timing in Figure 8a, where the peak particle concentration is also reduced by approximately 50% for the mDI strategy. This successful reduction in FSN and particle emissions with mDI fueling at advanced injection timing is likely a result of reduced fuel impingement on the piston because of reduced liquid penetration length.

While the mDI strategy enables particle emissions to be reduced at the most advanced timing (Figure 8a), it causes an increase in particle emissions at more retarded fuel injection timing. The increase in particle emissions occurs for injection timing more retarded than 300 CAD BTDC$_f$, as shown in the particle size distributions in panels b and c of Figure 8. This suggests that, while multiple injections reduce fuel spray impingement, it can be detrimental to other aspects of the fuel−air mixing process. As a result, the mDI fueling strategy employed in

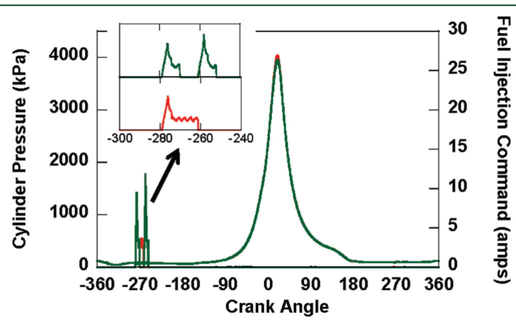

Figure 6. Cylinder pressure and fuel injector current for the sDI (red) and mDI (green) fuel injection strategies.

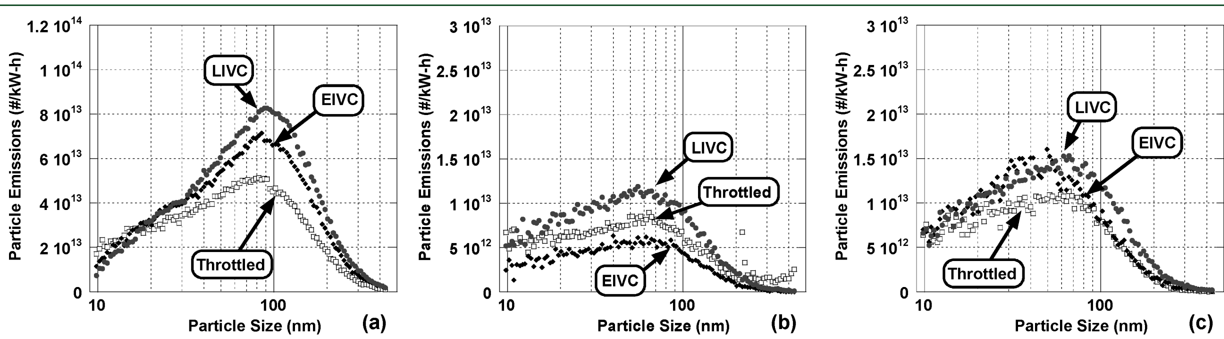

Figure 5. Particle emission number size distributions for gasoline at each breathing strategy and sDI fuel injection timing of (a) 320 CAD BTDC$_f$, (b) 280 CAD BTDC$_f$, and (c) 240 CAD BTDC$_f$.

this study is less beneficial than optimized timing with the sDI fueling strategy.

Ethanol Effects on Particle Emissions. The FSN measurements for E20 and E85 are shown in Figure 9. The E20 FSN emissions have the same trend as gasoline (Figure 5), with the early injection timing leading to the highest emissions. The most notable difference is that, under the LIVC breathing strategy, E20 produces a higher FSN than is produced for gasoline at injection timing later than 300 CA $BTDC_f$. In contrast, the FSN for E85 remains very low, near the detection limit, at all injection timing conditions. The particle size distributions for E20 and E85 are shown in Figure 10 and agree favorably with FSN results. E20 produces particle emissions that are comparable to gasoline in Figure 5 and in some cases higher. Consistent with gasoline, particle emissions for E20 are highest for the LIVC breathing strategy, indicating that both fuels are being adversely affected by the same mixing or fuel spray impingement process.

The reduction in particle emissions with E85 is seen at all injection timings in Figure 10, but significant concentrations of particle emissions can be formed under certain conditions. Specifically, particle formation is observed for E85 with the LIVC breathing condition at the most advanced injection timing and to a lesser degree at the most retarded timing condition. Particle emissions with E85 have a lower number concentration and a smaller size with a geometric mean diameter of 20−30 nm, instead of 70−100 nm for gasoline and E20. At an injection timing of 280 CAD $BTDC_f$, the injection timing that produces the lowest particle emissions for all fuels, particle emissions of E85 are very low and show no dependence upon the breathing strategy.

Thus, the ethanol content can be a very significant factor in influencing particle emissions. The particle emissions produced by gasoline and E20 are similar in magnitude, but E85 is highly effective in reducing particle emissions. Because of the lower total particle number emissions, the particle emissions with E85 are less dependent upon the breathing strategy and fuel injection timing than gasoline and E20.

PFI Fueling. We have established that E85 provides a substantial reduction in particle emissions under sDI fueling conditions relative to gasoline. In this section, we compare E85 particle emissions to that for PFI fueling. PFI vehicle particle emissions are relevant because over 99% of light-duty vehicles sold in the United States between 1996 and 2007 are equipped with PFI fueling technology.[4]

PFI fueling has comparable gaseous emissions and efficiency to sDI fueling at this operating condition, as shown in Figure 3. Further, FSN measurements for PFI fueling are found to be low at all breathing conditions for all fuels, with no value exceeding 0.05. The effect of engine breathing on PFI particle emissions is shown in Figure 11. Unlike the sDI and mDI fueling strategies for which the LIVC breathing strategy produces the highest levels of particle emissions, the differences in particle emissions between the breathing strategies is negligible for PFI fueling. It should also be noted that, unlike the previous figures in this study, the ordinate is scaled logarithmically for Figure 11 to compare E20 emissions with the sDI fueling strategy. It can be seen that, relative to PFI fueling, the sDI strategy produces particle emissions that are 1 order of magnitude higher at an injection timing of 280 CAD $BTDC_f$ and 2 orders of magnitude higher at an injection timing of 320 CAD $BTDC_f$.

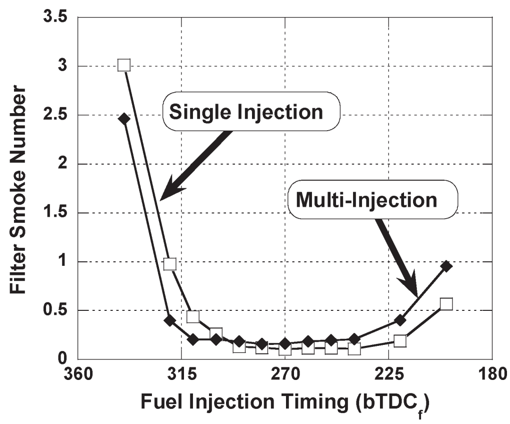

Figure 7. FSN as a function of the start of injection timing for the sDI and mDI fueling under throttled conditions.

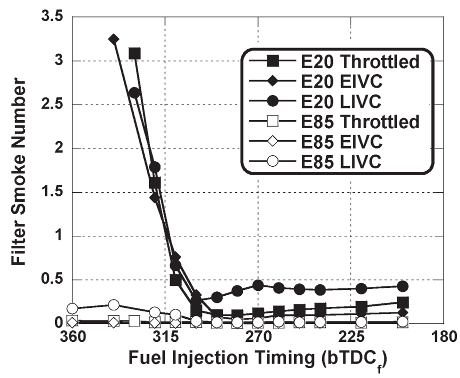

Figure 9. FSN as a function of fuel injection timing for E20 and E85 using the sDI fuel injection strategy.

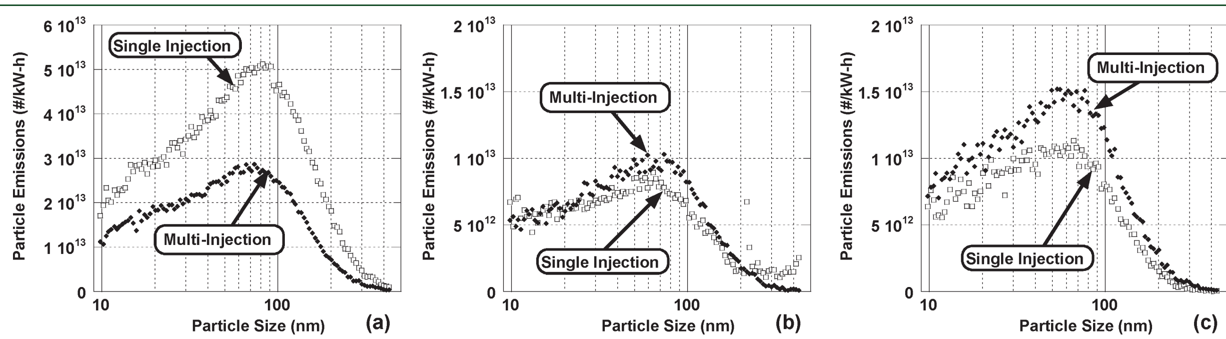

Figure 8. Particle number size distributions for fueling with sDI and mDI for gasoline under throttled conditions at an injection timing of (a) 320 CAD $BTDC_f$, (b) 280 CAD $BTDC_f$, and (c) 240 CAD $BTDC_f$.

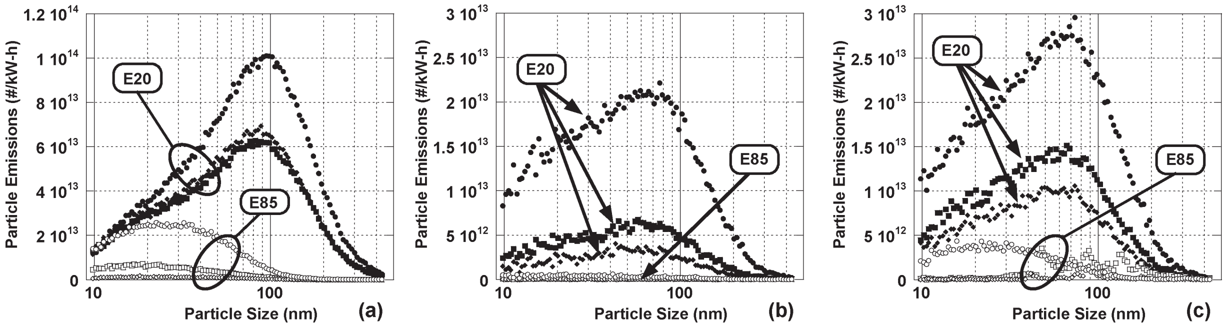

Figure 10. Particle size distribution for E20 (closed symbols) and E85 (open symbols) for (■) throttled operation, (◆) EIVC, and (●) LIVC using sDI fuel injection timing of (a) 320 CAD BTDC$_f$, (b) 280 CAD BTDC$_f$, and (c) 240 CAD BTDC$_f$.

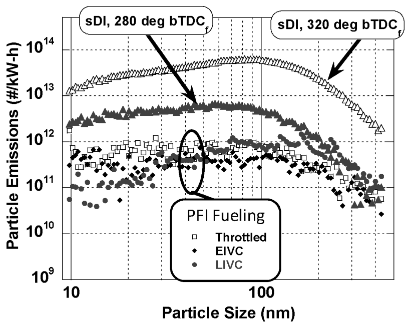

Figure 11. Particle emissions for PFI fueling with E20 for the three different breathing strategies in comparison to throttled sDI fueling at two injection timings for E20.

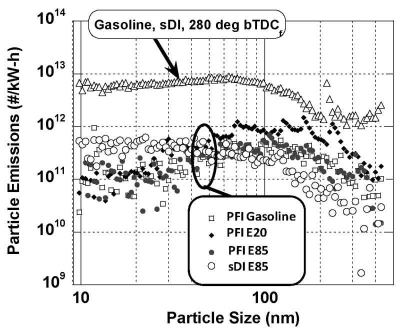

Figure 12. Particle size distributions for sDI fueling with gasoline and E85 and for PFI fueling with gasoline, E20, and E85.

The effect of fuel type on particle emissions for PFI fueling is shown in Figure 12. It can be seen that gasoline, E20, and E85 all produce similar particle emissions. This result stands in sharp contrast to the sDI and mDI fueling strategies, where gasoline and E20 produce particle emissions that are higher than E85 at all injection timing conditions. Also shown in Figure 12 are particle emissions from the sDI fueling strategy for gasoline and E85 under the LIVC breathing strategy at an injection timing of 280 CAD BTDC$_f$. While the gasoline sDI particle emissions are an order of magnitude higher than the PFI particles, particles from E85 with the sDI fueling strategy are similar to PFI fueling.

In contrast to fueling with the sDI and mDI injection strategies, neither engine breathing strategy nor fuel type substantially affects particle emissions with PFI fueling. Particle emissions for PFI fueling are low under all conditions, 1−2 orders of magnitude lower than for sDI and mDI with gasoline and E20. We also see that fueling with E85 under sDI does not produce an increase in particle emissions compared to PFI fueling. As a result, DI operation with E85 produces particle emissions that are similar to PFI with all fuels, whereas DI operation with gasoline or E20 leads to a particle emission increase.

■ DISCUSSION

Particle Formation Mechanism. A number of previous investigators have studied particle formation mechanisms in DI engines through both optical techniques and modeling. Moore et al.[8] show that, at advanced injection timing, liquid fuel spray impinges on the piston and the corresponding computational fluid dynamics (CFD) modeling illustrates that liquid fuel accumulation on the piston remains well after the injection event is completed. Sabathil et al.[32] used an optically instrumented spark plug to spatially resolve the regions of soot luminosity in-cylinder. It was found that the regions of soot luminosity correspond to the bowl feature on the piston, agreeing with the findings of liquid fuel accumulation by Moore et al.[8] Thus, fuel spray impinging on the piston during the intake stroke remains in liquid form through the compression stroke and into the combustion event, where fuel-rich pool fires can form particle emissions.

For liquid fuel to survive on the piston post-injection until combustion, the heat transfer to the liquid fuel, in either droplet or liquid film form, is insufficient to fully vaporize the fuel. The heat-transfer requirement is highly dependent upon the ethanol content of the fuel. In comparison to gasoline, both E20 and E85 require greater injected fuel mass because of the lower energy density of the fuel and higher latent heat requirement per mass of fuel. The average fuel mass injected per cycle is shown in Figure 13a, illustrating an increase in injected fuel from 25 mg/stroke for conventional gasoline to 37 mg/stroke for E85. Figure 13b shows latent heat of vaporization values for the injected fuel based on Heywood.[33] The heat required to vaporize E20 is a factor of 1.5 higher than gasoline and a factor of 4 higher for E85.

As a result, the liquid fuel mass remaining on the piston is expected to increase considerably with the ethanol content. Further, if the sooting tendency of all of the fuels is the same, it is expected that E20 and E85 will produce higher levels of particle emissions based on the increased liquid mass. The results show the opposite trend, a large reduction in particle emissions with E85. This indicates that the sooting tendency of ethanol is considerably lower than that of gasoline. This is consistent with

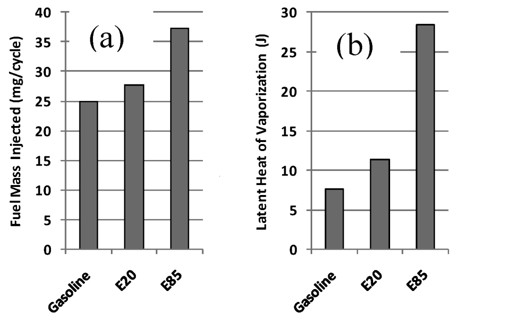

Figure 13. (a) Fuel mass injected and (b) latent heat of vaporization.

the a large body of previous work, showing that the combustion of oxygenated fuels produces lower levels of soot and/or particle emissions in diesel engines, for example, see Graboski and McCormick[34] for biodiesel effects on soot emissions and Chapman et al.[35] for dimethyl ether effects on soot formation. Results also show that particle emissions for E20 can increase compared to gasoline, indicating that there may be a trade-off between the reduced sooting tendency of the fuel and the increase in heat of vaporization with ethanol.

Regulation Compliance with E85. The findings in this study illustrate that particle emissions for PFI-fueled vehicles have little dependence upon fuel type and DI fueling with gasoline or low-level ethanol blends produces particle emissions up to 2 orders of magnitude greater than PFI. This investigation focuses on a single operating point, 1500 rpm and 8 bar BMEP, a condition for which it is challenging to achieve low particle emissions compared to other selected operating points in the engine map.[8] Over the course of a normal drive cycle, it is expected that DI fueling will increase particle emissions compared to PFI fueling but that the increase will be less substantial than was observed in this investigation.

The current particulate matter emission regulation for light-duty diesel vehicles in the state of California is 0.010 g/mile, and a typical emission rate for a gasoline vehicle with PFI fueling is 0.001 g/mile.[5] Thus, SI engines equipped with DI fueling technology can increase particle mass emissions approximately 1 order of magnitude compared to the PFI baseline and maintain compliance with current regulations. Given the historic trend of increasingly stringent emission regulations, however, it is possible that this emission standard could be subject to future reductions. Currently, light-duty vehicles account for 2% of PM10 emissions and 3% of PM2.5 emissions,[5] and if DI fueling significantly increases the contribution from light-duty vehicles, future reduction in particle emission standards becomes more likely.

In light of this, it is significant that sDI fueling with E85 not only reduces particle emissions relative to gasoline and E20 but also does not increase particle emissions beyond that of PFI with gasoline. In addition, because of advantageous fuel properties, an engine optimized for E85 can have greater efficiency and power than an engine optimized for gasoline.[14−18] Thus, performance advantages, particle emissions reduction benefits, and requirements of increased renewable fuel use given by EISA legislation make an engine optimized for efficiency with E85 an attractive option.

■ CONCLUSION

In this study, we examine the effect of fuel type, engine breathing strategy, and fueling strategy on particle emissions from a naturally aspirated SI engine. Three fuels, gasoline, E20, and E85, are used to assess the effect of the ethanol content on particle emissions. The engine breathing strategies include conventional throttled operation, EIVC, and LIVC, and the fueling strategies are sDI, mDI, and conventional PFI.

The main finding of the study is that use of E85 results in 1−2 orders of magnitude reduction in particle emissions relative to sDI fueling with gasoline and E20. Furthermore, sDI particle emissions with E85 are similar to that for PFI fueling with gasoline. Thus, an increase in particle emissions beyond that of PFI engines can be prevented while gaining the efficiency of DI engines using E85.

Additional conclusions are as follows: (1) Fuel injection timing is the engine parameter that has the most influence on particle emissions with DI fueling. Overly advanced fuel injection timing results in very high particle emissions because of fuel spray impingement on the piston, whereas overly retarded injection timing results in insufficient time for the fuel and air to mix. (2) Although it has advantages for engine efficiency, the LIVC breathing strategy used in this study increases particle emissions. This is likely due to the fuel and air mixing process or fuel spray impingement with an intake valve. It is thought that this increase is specific to the experimental system used in this study and not universally applicable to all LIVC breathing strategies. (3) While the mDI fueling strategy employed here is effective in reducing particles at overly advanced injection timing, this strategy results in higher particle emissions than the sDI strategy at more optimal injection timing conditions. (4) The PFI fueling strategy produces very low levels of particle emissions at 1500 rpm and 8 bar BMEP. Particle emissions for PFI fueling are found to be similar for all fuels and breathing strategies investigated.

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■ REFERENCES

(1) One Hundred Tenth Congress of the United States of America. *Energy Independence and Security Act of 2007*; One Hundred Tenth Congress of the United States of America: Washington, D.C., 2007; H.R. 6.

(2) United States Environmental Protection Agency (U.S. EPA). *Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule*; U.S. EPA: Washington, D. C., 2010; EPA-HQ-OAR-2009-0472, FRL-9134-6, NHTSA-2009-0059.

(3) Yi, J.; Wooldridge, S.; Coulson, G.; Hilditch, J.; Iyer, C. O.; Moilanen, P.; Papaioannou, G.; Reiche, D.; Shelby, M.; VanDerWege, B.; Weaver, C.; Xu, Z.; Davis, G.; Hinds, B.; Schamel, A. Development and optimization of the Ford 3.5L V6 EcoBoost combustion system. *SAE Int. J. Engines* **2009**, 2 (1), 20.

(4) United States Environmental Protection Agency (U.S. EPA). *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010*; U.S. EPA: Washington, D.C., 2010; EPA-420-R-10-023.

(5) State of California Air Resources Board. *Preliminary Discussion Paper—Proposed Amendments to California's Low-Emission Vehicle Regulations—Particulate Matter Mass, Ultrafine Solid Particle Number, and Black Carbon Emissions*; State of California Air Resources Board: Sacramento, CA, 2010; http://www.arb.ca.gov/msprog/levprog/leviii/meetings/051810/pm_disc_paper-v6.pdf.

(6) Aakko, P.; Nylund, N.-O. Particle emissions at moderate and cold temperatures using different fuels. *SAE [Tech. Pap.]* **2003**, DOI: 10.4271/2003-01-3285.

(7) Aikawa, K.; Sakurai, T.; Jetter, J. J. Development of a predictive model for gasoline vehicle particulate matter emissions. *SAE [Tech. Pap.]* **2010**, DOI: 10.4271/2010-01-2115.

(8) Moore, W.; Foster, M.; Lai, M.-C.; Xie, X.-B.; Zheng, Y.; Matsumoto, A. Charge motion benefits of valve deactivation to reduce fuel consumption and emissions in a GDi, VVA engine. *SAE [Tech. Pap.]* **2011**, DOI: 10.4271/2011-01-1221.

(9) Hedge, M.; Weber, P.; Gingrich, J.; Alger, T.; Khalek, I. A. Effect of EGR on particle emissions from a GDI engine. *SAE [Tech. Pap.]* **2011**, DOI: 10.4271/2011-01-0636.

(10) Iyer, C. O.; Yi, J. Spray pattern optimization for the Duratec 3.5L EcoBoost engine. *SAE [Tech. Pap.]* **2009**, DOI: 10.4271/2009-01-1916.

(11) Storey, J.; Barone, T.; Norman, K.; Lewis, S. Ethanol blend effects on direct-injection spark-ignition gasoline vehicle particulate matter emissions. *SAE Int. J. Engines* **2010**, 3 (2), 650–659.

(12) He, X.; Ireland, J. C.; Zigler, B. T.; Ratcliff, M. A.; Knoll, K. E.; Alleman, T. L.; Tester, J. T. The impacts of mid-level biofuel content in gasoline on SIDI engine-out and tailpipe particulate matter emissions. *SAE [Tech. Pap.]* **2010**, DOI: 10.4271/2010-01-2125.

(13) Khalek, I. A.; Bougher, T. Particle emissions from a 2009 gasoline direct injection engine using different commercially available fuels. *SAE [Tech. Pap.]* **2010**, DOI: 10.4271/2010-01-2117.

(14) Wu, K.-J. *The Use of Exhaust Gas Recirculation to Optimize Fuel Economy and Minimize Emissions in Engines Operating on E85 Fuel*; U.S. Department of Energy: Washington, D.C., 2009; Vehicle Technologies Annual Merit Review, Fuels Technologies Review FT-10.

(15) Kilmurray, P. *DoE Optimally Controlled Flexible Fuel Powertrain System*; U.S. Department of Energy: Washington, D.C., 2009; Vehicle Technologies Annual Merit Review, Fuels Technologies Review FT-11.

(16) Yilmaz, H. *DOE Merit Review—Flex Fuel Vehicle Systems*; U.S. Department of Energy: Washington, D.C., 2009; Vehicle Technologies Annual Merit Review, Fuels Technologies Review FT-13.

(17) Moore, W.; Confer, K.; Lai, M.-C. *E85 Optimized Engine through Boosting, Spray Optimized GDi, VCR and Variable Valvetrain*; U.S. Department of Energy: Washington, D.C., 2009; Vehicle Technologies Annual Merit Review, Fuels Technologies Review FT-14.

(18) Agarwal, A.; Whitaker, P. *E85 Optimized Engine*; U.S. Department of Energy: Washington, D.C., 2009; Vehicle Technologies Annual Merit Review, Fuels Technologies Review FT-12.

(19) Hoyer, K.; Moore, W.; Confer, K. A simulation method to guide DISI engine redesign for increased efficiency using alcohol fuel blends. *SAE [Tech. Pap.]* **2010**, DOI: 10.4271/2010-01-1203.

(20) Moore, W.; Foster, M.; Hoyer, K. Engine efficiency improvements enabled by ethanol fuel blends in a GDi VVA flex fuel engine. *SAE [Tech. Pap.]* **2011**, DOI: 10.4271/2011-01-0900.

(21) Szybist, J.; Youngquist, A.; Wagner, R.; Foster, M.; Moore, W.; Confer, K. Investigation of knock limited compression ratio of ethanol gasoline blends. *SAE [Tech. Pap.]* **2010**, DOI: 10.4271/2010-01-0619.

(22) Cleary, D.; Silvas, G. Unthrottled engine operation with variable intake valve lift, duration, and timing. *SAE [Tech. Pap.]* **2007**, DOI: 10.4271/2007-01-1282.

(23) AVL List GmbH. *AVL 415S Variable Smoke Meter Operating Manual, AT1240E, Rev. 05*; AVL List GmbH: Graz, Austria, 2005.

(24) Woldring, D.; Landenfeld, T.; Christiem, M. J. DI boost: Application of a high performance gasoline direct injection concept. *SAE [Tech. Pap.]* **2007**, DOI: 10.4271/2007-01-1410.

(25) Abdul-Khalek, I. S.; Kittleson, D. B.; Graskow, B. R.; Wei, Q. Diesel exhaust particle size: Measurement issues and trends. *SAE [Tech. Pap.]* **1998**, DOI: 10.4271/980525.

(26) Giechaskiel, B.; Dilara, P.; Sandbach, E.; Andersson, J. Particle measurement programme (PMP) light-duty inter-laboratory exercise: Comparison of different particle number measurement systems. *Meas. Sci. Technol.* **2008**, *19*, 9.

(27) Bechtold, R.; Thomas, J. F.; Huff, S. P.; Szybist, J.; Theiss, T.; West, B.; Goodman, M.; Timbario, T. A. *Technical Issues Associated with the Use of Intermediate Ethanol Blends (>E10) in the U.S. Legacy Fleet: Assessment of Prior Studies*; Oak Ridge National Laboratory: Knoxville, TN, 2007; ORNL/TM-2007/37, https://portal.ornl.gov/sites/apps/PTS/PtsDocs/Publication%207767.pdf.

(28) Nakama, K.; Kusaka, J.; Daisho, Y. Effect of ethanol on knock in spark ignition gasoline engines. *SAE [Tech. Pap.]* **2008**, DOI: 10.4271/2008-32-0200.

(29) Nakata, K.; Utsumi, S.; Ota, A.; Kawatake, K.; Kawai, T.; Tsunooka, T. The effect of ethanol fuel on a spark ignition engine. *SAE [Tech. Pap.]* **2006**, DOI: 10.4271/2006-01-3380.

(30) West, B.; Lopez, A.; Theiss, T.; Graves, R.; Storey, J.; Lewis, S. Fuel economy and emissions of the ethanol-optimized Saab 9-5 biopower. *SAE [Tech. Pap.]* **2007**, DOI: 10.4271/2007-01-3994.

(31) Datta, R.; Maher, M.; Jones, C.; Brinker, R. Ethanol—The primary renewable liquid fuel. *J. Chem. Technol. Biotechnol.* **2011**, *86*, 473–480.

(32) Sabathil, D.; Koenigstein, A.; Schaffner, P.; Fritzsche, J.; Doehler, A. The influence of DISI engine operating parameters on particle number emissions. *SAE [Tech. Pap.]* **2011**, DOI: 10.4271/2011-01-0143.

(33) Heywood, J. B. *Internal Combustion Engine Fundamentals*; McGraw-Hill Book Company: New York, 1988; p 930.

(34) Graboski, M. S.; McCormick, R. L. Combustion of fat and vegetable oil derived fuels in diesel engines. *Prog. Energy Combust. Sci.* **1998**, *24*, 125–164.

(35) Chapman, E. M.; Boehman, A. L.; Tijm, P.; Waller, F. Emissions characteristics of a Navistar 7.3L turbodiesel fueled with blends of dimethyl ether and diesel fuel. *SAE [Tech. Pap.]* **2001**, DOI: 10.4271/2001-01-3626.

CRC Report No. E-65-3

FUEL PERMEATION FROM AUTOMOTIVE SYSTEMS: E0, E6, E10, E20 AND E85

Final Report

December, 2006

COORDINATING RESEARCH COUNCIL, INC.
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022

FUEL PERMEATION FROM AUTOMOTIVE SYSTEMS: E0, E6, E10, E20 and E85

Final Report
CRC Project No. E-65-3

December, 2006

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Fuel Permeation from Automotive Systems
E0, E6, E10, E20 and E85

A. Background and Introduction

CRC Project E-65 investigated the effects of three different fuels on the permeation rates of the fuel systems from 10 different California vehicles, covering model years from 1978 to 2001. Results from this study were published in the report "Fuel Permeation from Automotive Systems" in September 2004, and are available on the websites of the Coordinating Research Council (CRC) and California Air Resources Board (CARB). Permeation is one of the three mechanisms identified as responsible for "evaporative emissions." The other two are leaks (liquid and vapor) and fuel tank venting (canister losses).

The original study vehicles were selected to represent a cross-section of the California in-use fleet as it existed in calendar year 2001, where pre-1983 model year (MY) vehicles were 10% of the registered fleet. The fuels tested in the original study included two oxygenated fuels: one with 11% MTBE and the other with 5.7% ethanol, and a non-oxygenated fuel for comparison. All the fuels had properties typical of California summer gasoline. The two oxygenated fuels contained 2.0 weight percent oxygen, the minimum oxygen content required by then-existing regulations for federal reformulated gasoline. Permeation increased in all vehicles when evaluated with the ethanol fuel.

Based on the previous work, four issues were identified for further study in CRC Project E-65-3:

1. Investigate the permeation characteristics of "near zero" evaporative emission control systems scheduled for California in MY 2004 and later.
2. Determine if changes in ethanol content affect permeation levels.
3. Establish the permeation effects of E85 (85 Volume% ethanol fuel) in a flexible fuel vehicle.
4. Determine if permeation rates are sensitive to changes in aromatics content of the fuel.

Harold Haskew & Associates, Inc. was selected as the prime contractor, with Automotive Testing Laboratories, Inc, in Mesa, AZ serving as the testing laboratory. It was agreed to re-commission Rigs 1 and 2, the 2000 and 2001 MY systems from the E-65 project, and build three new test rigs, one representing a MY 2004 California "Near Zero" evap control vehicle, another representing the California "Zero Evap" control technology, and finally, a "Flexible-Fuel" vehicle, capable of operating on E85 or gasoline.

Six test fuels were blended for this project:

1. E0 – Non-oxygenated base fuel
2. E6 – 5.7 Volume% ethanol fuel (2 Weight% oxygen)
3. E6Hi – 5.7 Volume % ethanol fuel with increased aromatics content
4. E10 – 10 Volume% ethanol fuel
5. E20 – 20 Volume% ethanol fuel, and
6. E85 – 85 Volume% ethanol fuel

The testing for this project commenced in January of 2005, and continued through early August 2006. An Interim Report was made available in August of 2006 with the results from the E0, E6, E6Hi, E10, and E85 fuel testing results. This final report adds the results from the tests with the E20, or 20 volume percentage, ethanol fuel, as well as additional test results on the E0 fuel.

These data represent a limited number of samples; care should be taken in extending these results to the fleet.

B. Conclusions and Findings

Conclusions:

1. The low-level ethanol blends (E6, E6Hi, E10 and E20) increased permeation in all the vehicle systems and technologies tested, compared to the non-ethanol fuel (E0). These increases were statistically significant.
2. The advanced technology LEV II and PZEV[1] systems (2004 MY) had much lower permeation emissions than the MY 2000-2001 enhanced evaporative systems. The zero evaporative emissions system (PZEV) had the smallest increase due to ethanol of all the vehicles tested.
3. The high-level ethanol blend (E85) tested in the flexible fuel vehicle system had lower permeation emissions than the non-ethanol (E0) fuel.
4. Diurnal permeation rates do not appear to increase between E6 and E10, but do appear to increase between E6 and E20; however, this increase is not statistically significant.
5. The highest diurnal permeation rate for three of the five rigs (1, 2, and 12) tested was measured when these rigs were tested on the E20 fuel. The highest diurnal permeation rate for Rig 11 was recorded on the E6 fuel, while the highest diurnal permeation rate for Rig 14 was measured on the E10 fuel.
6. Diurnal permeation emissions were lower on all four rigs tested with the higher-level aromatics fuel (E6Hi) versus the lower aromatics fuel (E6); however, this decrease was not statistically significant.
7. Permeation rates with the E0 fuel at the start and the end of the test program were not significantly different on all five rigs, indicating that there was no shift in the permeation performance during the program.
8. The average specific reactivities of the permeates from the low-level ethanol blends were significantly lower than those measured with the non-ethanol fuel (E0). There was no significant difference in the average specific reactivities within the low-level ethanol blends.

Findings:

1. The average diurnal permeation rate increased 347 mg/day (from 177 to 524 mg/day) when the E6 fuel was substituted for the base non-ethanol E0 fuel.
2. The average diurnal permeation rate increased 253 mg/day (from 177 to 430 mg/day) when the E6Hi fuel was substituted for the base non-ethanol E0 fuel.
3. The average diurnal permeation rate increased 307 mg/day (from 177 to 484 mg/day) when the E10 fuel was substituted for the base non-ethanol E0 fuel.
4. The average diurnal permeation rate increased 385 mg/day (from 177 to 562 mg/day) when the E20 fuel was substituted for the base non-ethanol E0 fuel.

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[1] Partial Zero Emission Vehicle – a vehicle with Super Ultra Low Exhaust Emission Levels (SULEV), and Zero Fuel Evaporative Emissions, certified to 150,000 mile and 15 year performance levels for the state of California

5. On the “Flexible Fuel” Rig 14, the diurnal permeation rate increased 205 mg/day (from 261 to 466 mg/day) from the base non-ethanol fuel (E0) rate when the E10 fuel was evaluated, increased 99 mg/day (from 261 to 360 mg/day) from the base fuel rate when the E20 fuel was evaluated, but decreased 133 mg/day (from 261 to 128 mg/day) from the base fuel rate when the E85 fuel was evaluated.
6. Relative to Rigs 1, 2 and 11, the “Zero Fuel Evaporative Emission” system (Rig 12) had a lower increase in permeation rate when the ethanol-containing fuels were evaluated. A 14 mg/day (from 36 to 50) increase was measured with fuel E6, a 9 mg/day (from 36 to 45 mg/day) increase with fuel E6Hi, a 28 mg/day (from 36 to 64 mg/day) increase with fuel E10, and a 39 mg/day (from 36 to 75 mg/day) increase with fuel E20.
7. The average specific reactivity of the base E0 fuel permeate was 3.99, the highest of the five fuels evaluated.
8. Average specific reactivity of the E6 fuel permeate was 3.00.
9. Average specific reactivity of the E6Hi fuel permeate was 3.17.
10. Average specific reactivity of the E10 fuel permeate was 2.94.
11. Average specific reactivity of the E20 fuel permeate was 3.04.
12. Average specific reactivity of the E85 fuel permeate was 2.73.
13. Rig 11 permeate had the lowest specific reactivity of all the rigs on all the fuels tested.

C. General Discussion

I. Test Program Overview

The objective of this test program was to measure the permeation emissions of the newer (MY 2000 to 2005) California vehicles with gasolines containing ethanol at various volume percent concentrations: 0, 6[2], 10, 20 and, on one system, 85. At the 6% ethanol level, two fuels were blended to meet different targets of total aromatics (designated as “E6” and “E6Hi”) in order to evaluate the effect of this latter parameter on permeation.

Five vehicle fuel systems were included in this project. Two California Enhanced Evap vehicles were carried over from the previous CRC E-65 project (the newest, Rigs 1 and 2). Three new rigs were constructed for this evaluation: a California LEV-II “near-zero” passenger car, a California PZEV Zero Evaporative Emission car, and a “Flexible-Fuel” vehicle capable of operation on gasoline, 85% ethanol, or any mixture in between.

Stabilization - Once qualified as ready for test, each test rig was filled (100% of rated capacity) with the appropriate test fuel and stored in a room (“soak room”) at 105°F and periodically tested in a SHED[3] until the results indicated that stabilization of the permeation emissions was achieved. During this stabilization period, the fuel in each rig was circulated twice a week. Every seventh week all of the fuel in each rig was drained and replaced with fresh fuel. Once a week, each rig was removed from the soak room and

---

[2] The federal minimum requirement for “reformulated” fuel was 2.0 weight percent oxygen. That correlates to 5.7 volume percent ethanol. For purposes of this report, we will refer to the 5.7 Volume% specification in its rounded off value of 6, as in E6.

[3] SHED – Sealed Housing for Evaporative Determination

placed in a hot soak SHED at a temperature of 105°F for three to five hours to estimate the current permeation rate.

The constant-temperature tests to determine stabilization were performed in a 105°F hot-soak SHED for a three-hour test period, with the emissions measured during the last two hours (later tests on the lower permeation rigs were increased to a five hour period). All fixed-temperature (105°F) testing was performed in ATL's SHED 14. Variable-temperature diurnal (65° to 105° to 65°F) testing was performed in ATL SHEDs 13 and 15. These three SHEDs are variable volume/variable temperature (VV/VT) equipment that can be operated in fixed or variable-temperature modes, and are referred to as VT-SHEDs. All the SHED's and equipment used for this program were the same as were utilized for the original E-65 program.

Diurnal Evaluation - After the steady-state permeation rate of a rig was stabilized at 105°F, and approved by the CRC E-65-3 Steering Committee, it was evaluated for diurnal permeation performance using the California "Real-Time" 24-hour diurnal (65 to 105 to 65°F) emission test procedures. The fuel was drained from the rig, and a 40% fresh fill of the appropriate test fuel added. The rig was then placed in a VT-SHED, and the California diurnal procedure was performed over a period of 24 hours. Samples of the ambient air in the VT-SHED were taken at the start of the diurnal and at the end of the 24-hour test period for later hydrocarbon speciation analysis. The fuel tanks and the canisters were vented to the outside of the SHED to eliminate the possibility of the tank venting emissions being counted as permeation. Emission rates were calculated using the 2001 California certification test procedure, with the appropriate corrections for the ethanol in the permeate.

Testing Chronology - Figure 1 on the following page shows the testing chronology to illustrate when the various rigs were being tested with the different fuels. Testing started on January 11, 2005, and the last diurnal test on Rig 2 was finished on August 10, 2006. The solid bar indicates the time interval for the steady-state and the diurnal evaluations. The interval between the solid bars indicates the decision period where the Steering Committee was considering approval of the data and authorizing the move to the next test fuel.

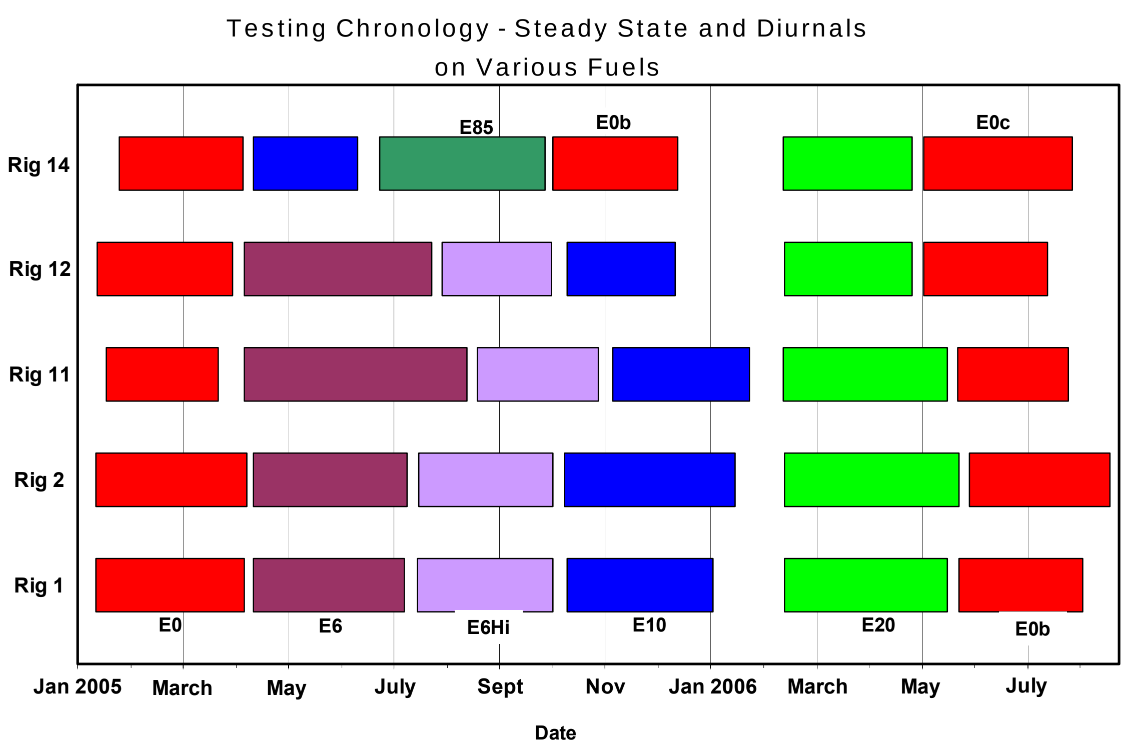

Figure 1

II. Project Scope – Fuel System Technology and Rig Construction

Fuel System Technology

Two enhanced evap rigs were carried over from the original E-65 project (Rigs 1 and 2), and three new rigs were added. The technologies are described in Tables 1 and 2.

Table 1

Technology Groups and Corresponding Rig	
Enhanced Evaporative Emissions	Rigs 1 & 2
California Near-Zero (LEV II)	Rig 11
California PZEV (Zero Fuel Evaporative Emission)	Rig 12
Flexible Fuel Vehicle (FFV)	Rig 14

Table 2

Vehicle Information for the Test Rigs

Rig No.	MY	Make	Model	Odo (miles)	Evap Family	Tank Size (Gal)	Tank Material	VIN
1	2001	Toyota	Tacoma	15,460	1TYXE0095AE0	15.8	Metal	5TENL42N01Z718176
2	2000	Honda	Odyssey	119,495	YHNXE0130AAE	20	Plastic	2HKRL1852YH518467
11	2004	Ford	Taurus	29,973	4FMXR015GAK	18	Metal	1FAFP55S54G142635
12	2004	Chrysler	Sebring	6434	4CRXR0130GZA	16	Metal	1C3EL46J74N363042
14	2005	Chevrolet	Tahoe	4054	5GMXR0176820	26	Plastic	1GCEK13U85X7313EX

The California Enhanced Evaporative Emission Control regulations were the first to require "real-time" diurnal emission measurements (three 24-hour day diurnals) and were phased in during the 1995 – 1998 model year period. The pre-enhanced evap emission standard was 2.0 g/test, but the test consisted of a one hour simulated diurnal day, with the fuel tank locally heated from 60° to 84°F. Only one hour's worth of vehicle evaporative emissions was measured during the diurnal, and that was with the vehicle at room temperature in a SHED, typically 72°F. The hot soak was measured in a SHED following an 11 mile drive at room temperature. The enhanced evap procedure measured the emissions from the vehicle in a variable-temperature SHED (VT-SHED), and the SHED ambient temperature was varied from 65° to 105°F, exposing the entire vehicle and the fuel system component to the ambient temperature. The one hour hot soak was performed as before but after the running loss test, a one hour drive at 105°F.

These regulations incorporated significant changes to the emissions certification test requirements, and produced corresponding changes in the vehicle materials and hardware used by the automobile manufacturers. The emission control system useful life and warranty period were extended to 10 years or 100,000 miles. Two-day and three-day diurnal tests were required, as was the measurement of "running-loss" emissions. The allowable limits for the highest one day of diurnal emissions for the three-day test, plus the one hour of hot soak following the drive are 2.0 g/test, or 2.5 g/test for vehicles with fuel tanks rated at 30 or more gallons. Light-duty trucks are allowed slightly higher limits.

California's Near Zero (LEV II) requirements dropped the allowable limits for passenger cars by 75% to 0.5 g/test for the three-day diurnal, and to 0.65 g/test for the two-day test. Phase-in started with 40% of production in model year 2004, 80% in 2005, and 100% in 2006. Significant improvements in permeation performance and tank vapor control (carbon canister design) were required.

California's PZEV vehicles are developed and certified to have "Zero" fuel evaporative emissions where zero is defined as less than 0.0 grams per test when measured on California's evaporative emission test procedures. This is agreed to be less than 54 milligrams per test (highest of the 3 diurnal days + one hour high temperature hot soak). This standard requires the highest level of emission control in every aspect of the vehicle's fuel and vapor control system, both in performance and durability.

Flexible Fuel Vehicle is a vehicle capable of performing on gasoline or a high percentage of ethanol (85%), or any mixture of the two. The evaporative emission standards are the enhanced emission standards with certain test procedure modifications. Sensors (or in later versions, software) are used to detect the mixture in the fuel system and make the appropriate adjustments for the engine and emission control system. This is performed automatically, and no action is required by the vehicle operator. Flexible fuel vehicles are certified to meet the evaporative emission performance limits on gasoline, or the worst combination of the ethanol/gasoline mixture (currently thought to be 10% ethanol).

Test Rig Construction

Fuel system test "rigs" are used in the automotive development process to isolate the fuel system's contribution to the emissions. Since tires, adhesives, paint and vinyl trim can also emit hydrocarbons, they need to be removed to provide a better chance of properly identifying the fuel-related emissions. Isolating the fuel system components on a "rig" is the appropriate choice.

Refueling vapor controls are commonly developed in the automotive industry using rigs, or "test bucks", but they feature only the tank and canister system, with the carbon canister located close to the tank. This project included the fuel and vapor lines, and their chassis-to-engine connection hoses at the front of the vehicle. All the fuel system components (with the exception of the engine mounted injectors and hoses[4]) that could contribute to permeation losses were kept in the original spatial relationship. This meant that the rigs were almost as long as the vehicles. For system integrity, all components were removed and remounted on the rigs without any fuel or vapor line disconnections.

In the original E-65 project, the vehicle was sacrificed to remove the fuel system components, and the remaining body parts and pieces sold as scrap. Our previous experience indicated that the fuel system on the newer vehicles (mid-90s and later) could be removed from the vehicle without catastrophic surgery.

The test rig frame was constructed of 1.5" square aluminum tube, with metal caster wheels at the four corners. A photo of Rig 12 appears in Figure 2 to show a typical configuration. There is a lot of empty space required to keep all of the fuel system components in their x, y, and z orientation as present in the vehicle.

[4] It was decided in the original E-65 project to eliminate the engine-mounted fuel system components (including carburetors and injectors) to avoid the compromising contributions of leaks and vapor losses. The investigators wanted to identify the contribution of permeation, not leaks. The fuel supply lines and hoses, and the return components, if fitted, are present on the rigs, with terminations where the engine connections are made. This practice was continued for the current project.

Figure 2 - Overall View - Rig 12

Enhanced Evaporative Emissions Technology – Rigs 1 & 2

Rigs 1 and 2 were carry-over systems from the previous CRC fuel permeation project reported in September of 2004, and photos of the fuel tank end of the rigs are shown here

Figure 3 - Rig 1 Fuel Tank

Figure 4 - Rig 2 Fuel Tank

Rig 1 was fabricated to evaluate the permeation performance of the metal fuel tank system from a 2001 MY Toyota Tacoma pick-up truck, and is shown in Figure 3 above. The metal tank was coated with a black anti-rust paint with a short metal fill-pipe that ran to the side of the truck body. The carbon canister and purge control solenoid for this pre-ORVR[5] system was located in the left front side of the engine compartment.

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[5] ORVR – On-board Refueling Vapor Recovery, an emission control configuration with components and function to capture the refueling vapors and store them for later combustion. The Toyota pick-up was not required by the California regulatory roll-out requirements to have such a system until MY 2003.

Rig 2's (2002 MY Honda Odyssey, a light-duty passenger van) fuel system features a large (20 gallon capacity) plastic fuel tank of multi-layer blow-molded construction for a high degree of permeation control (Figure 4). The carbon canister for this pre-ORVR system is located in the vehicle's under-body close to the position of the driver's seat.

Both of these rigs were certified to the California enhanced evaporative emission standard of 2.0 grams per test for the three-day diurnal + hot soak, and 2.5 grams per test for the two-day diurnal + hot soak.

Rig 11 (Figure 5) was created from the fuel system components of a 2004 MY Ford Taurus sedan. The vehicle was purchased from a California dealer and driven to the laboratory in Mesa AZ, where after inspection and approval, the fuel system was removed and mounted in the aluminum frame to become a "rig." The fuel tank was of steel construction and had a rated capacity of 18 gallons. The fuel tank was located near the rear seat position on the vehicle, and the on-board refueling vapor recovery (ORVR) canister was positioned further aft, as shown in Figure 5.

Figure 5 - Rig 11 Fuel Tank and Canister

Rig 12 (Figures 6 & 7) was fabricated using the fuel system components from a 2005 MY Chrysler Sebring sedan. It also featured a steel fuel tank and a carbon canister mounted adjacent to the tank. It was certified as an on-board refueling vapor recovery system (ORVR).

Figure 6 - Rig 12 Fuel Tank

Figure 7 - Rig 12 Fuel Tank and Canister

Rig 14 (Figure 8) featured the fuel system components from a 2005 MY Chevrolet Tahoe SUV. It was certified to be a “Flexible-Fuel” system, which means it can operate on gasoline or E85, or any mixture of the two. The Tahoe has a 26 gallon multi-layer “plastic” fuel tank, and a close-mounted carbon canister for tank vapor control. It is also an ORVR design system.

Figure 8 - Rig 14 Fuel Tank and Canister

III. The Project and Procedures

Fuels

Six test fuels were blended for the CRC E-65-3 follow-up project. All of the low-level ethanol blends (i.e., E0-E20) were made from California blending components and were targeted at California summer fuel characteristics with vapor pressures targeted at 7.0 psi. The gasoline used to blend the E85 fuel was a high vapor pressure conventional gasoline, but butane still had to be added to the blend to approach the target 7.0 psi vapor pressure. These fuels were:

Tag	Description
E0	Non-oxygenated base fuel
E6	5.7 Volume% ethanol fuel (2 Weight% oxygen)
E6Hi	5.7 Volume% ethanol fuel with increased aromatics content
E10	10 Volume% ethanol fuel
E20	20 Volume% ethanol fuel
E85	85 Volume% ethanol fuel

The basic inspections of the six test fuels are shown in Table 3.

Table 3
Test Fuel Inspections

Inspection	Units	E0	E6	E6Hi	E10	E20	E85
API Gravity	°API	61.4	58.8	52.3	58.3	55.4	48.6
Relative Density	60/60°F	0.7334	0.7434	0.7699	0.7455	0.7572	0.7855
DVPE	psi	7.00	7.25	7.19	7.17	7.06	6.80
Oxygenates--D 4815							
MTBE	vol %	0.01	0.00	0.00	0.00	0.00	0.00
ETBE	vol %	0.00	0.00	0.00	0.00	0.12	0.00
EtOH	vol %	0.00	6.02	6.28	10.29	19.82	84.69
MeOH	vol %	0.00	0.00	0.00	0.00	0.00	0.83
O2	wt %	0.00	2.23	2.25	3.81	7.23	29.73
FIAM Corrected--D 1319							
Aromatics	vol%	22.57	26.79	41.47	26.03	26.18	3.86
Olefins	vol%	10.70	4.91	3.32	4.77	4.85	1.57
Saturates	vol%	66.73	62.24	50.45	58.83	49.23	9.82
Oxygenates	vol%	0.00	6.02	6.28	10.31	19.94	85.21
Aromatics--D 5580							
Benzene	vol%	0.41	0.55	0.43	0.51	0.70	0.17
Toluene	vol%	5.26	6.84	5.25	6.50	8.31	0.67
Ethylbenzene	vol%	1.08	1.46	1.13	1.39	1.71	0.15
p/m-Xylene	vol%	4.67	5.38	4.21	5.13	6.01	0.59
o-Xylene	vol%	1.67	1.98	1.81	1.89	2.14	0.22
C9+	vol%	8.86	10.01	25.71	9.52	7.55	2.02
Total	vol%	21.96	26.22	38.55	24.93	26.42	3.82

Table 3 (Continued)

Test Fuel Inspections

Inspection		Units	E0	E6	E6Hi	E10	E20	E85
D 86 Distillation								
	IBP	°F	101.1	108.9	98.0	107.7	112.1	116.8
	5% Evaporated	°F	123.2	125.8	124.8	127.2	130.6	153.5
	10% Evaporated	°F	134.5	130.7	132.1	132.1	135.8	164.0
	20% Evaporated	°F	148.5	136.8	142.4	138.2	143.4	168.7
	30% Evaporated	°F	165.0	144.8	159.0	144.7	149.7	170.4
	40% Evaporated	°F	186.2	175.8	206.3	150.8	155.1	171.2
	50% Evaporated	°F	209.5	202.0	241.9	182.6	159.6	171.5
	60% Evaporated	°F	231.1	225.6	274.0	221.8	165.9	171.8
	70% Evaporated	°F	251.2	249.3	302.8	246.0	234.6	172.0
	80% Evaporated	°F	273.4	275.7	324.5	273.3	257.9	172.4
	90% Evaporated	°F	305.6	309.9	345.3	309.4	291.1	173.1
	95% Evaporated	°F	330.6	335.9	363.2	335.7	312.4	174.1
	EP	°F	389.9	380.4	411.4	378.3	352.0	297.4
	Recovery	vol %	97.7	97.6	97.2	98.0	97.3	97.1
	Residue	vol %	1.0	1.0	1.2	1.1	1.0	1.9
	Loss	vol %	1.3	1.4	1.5	0.8	1.7	1.0
Karl Fischer Water		wt %	-	-	-	-	-	0.42

Additional Inspections

Fuel		Units	E0	E6	E6Hi	E10	E20	E85
Gum								
	Unwashed	mg/100ml	20	16	18	17	19	9
	Washed	mg/100ml	1	1	0	0	0	0
Peroxide Number		ppm	<1	<1	<1	1.0	<1	4.4
Induction Period		Hr	24	24	24	24	24	24
Potential Gum								
	Unwashed	mg/100ml	22	22	24	20	19	7
	Washed	mg/100ml	0	0	0	0	0	2
Research ON			90.5	92.1	96.2	94.5	98.7	105.8
Motor ON			83.2	84.2	86.2	86.4	86.6	89.2
(R+M)/2			86.9	88.2	91.2	90.5	92.7	97.5

Complete speciation analyses of the fuels were also furnished, and the files are available with the following names:

Tag	File Name
E0	E0-FR41677-LDR
E6	E6-FR41678-LDR
E6Hi	E6High-FR41785-LDR
E10	E10-FR41681-LDR
E20	E20-FR43560-LD
E85	E85-FR42011-LDR

Compositions of the E0 and low level ethanol blends are presented by hydrocarbon type and carbon number in Tables 4, 5 and 6 below.

Table 4
Test Fuel Composition Comparison - Paraffins

					Paraffins by Volume %					
Fuel	**C3-**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12+**
E0		0.419	18.789	10.322	6.783	14.017	4.341	1.618	0.502	0.068
E6		0.163	14.938	17.492	8.016	9.732	3.613	0.919	0.442	0.031
E6Hi		1.609	10.58	13.061	6.091	7.394	2.808	1.343	0.424	0.126
E10		0.150	14.22	16.649	7.753	9.15	3.412	0.865	0.417	0.027
E20		0.876	9.202	12.752	8.295	9.066	1.585	0.446	0.049	0.007

Table 5
Test Fuel Composition Comparison - Olefins

					Olefins by Volume %					
Fuel	**C3-**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12+**
E0	0.029	0.101	2.025	5.126	0.579	0.514	0.013			
E6		0.013	0.914	1.613	0.771	0.347	0.007			
E6Hi		0.008	0.66	1.197	0.595	0.273	0.007			
E10		0.011	0.876	1.509	0.727	0.324	0.007			
E20	0.016	0.004	0.669	2.040	0.873	0.448				

Table 6
Test Fuel Composition Comparison – Aromatics

				Aromatics by Volume %						
Fuel	**C3-**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12+**
E0				0.448	5.286	7.971	6.443	2.696	0.594	0.087
E6				0.6	6.875	9.249	7.055	2.928	0.568	0.048
E6Hi				0.454	5.25	7.603	16.538	9.101	1.724	0.216
E10				0.569	6.502	8.715	6.650	2.753	0.523	0.045
E20				0.693	8.250	9.878	5.978	1.505	0.146	0.042

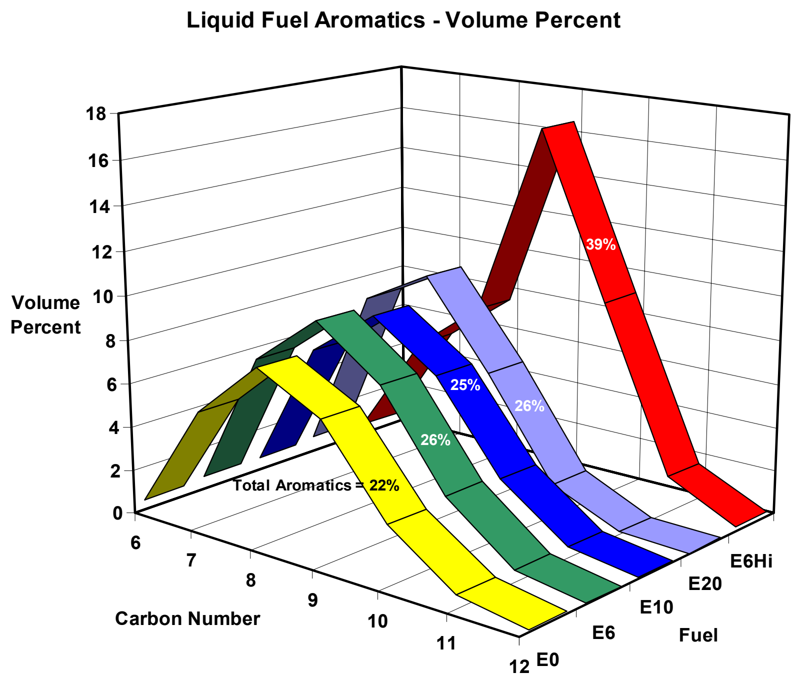

Figure 9

Figure 9 illustrates the distribution of the aromatics content in the base non-ethanol fuel and the four low-ethanol concentration fuels. The aromatics total and the distribution of the aromatics by carbon number are similar for fuels E0, E6, E10 and E20. The high aromatics fuel (E6Hi) has 39% aromatics compared to the 22-26% for the other three, and the concentration of the higher carbon number molecules (C9-C11) is much higher.

Procedures for Measuring Steady-State Permeation and Determining Stabilization

Permeation is a molecular migration of the fuel through the elastomeric materials of the vehicle fuel system. The test plan anticipated that time would be required for stabilization to occur after a new fuel composition was introduced. This would be possibly six to twelve weeks at the 105°F stabilization temperature. The vehicle fuel tank was filled to 100% of its rated capacity for stabilization, and the contents circulated through the liquid and vapor system twice a week for a 20 minute period to keep the liquid and vapor in the hoses "fresh." The canister was purged by drawing ambient air through the canister bed for a period of 20 minutes, twice a week, using a vacuum pump.

The rigs were kept in a constant-temperature test cell at 105°F during the stabilization period. A photo of the cell occupied by various rigs is shown in Figure 10.

Once each week the rig was moved from the "soak room" to the SHED for the permeation determination. The steady-state test involved placing the rig in the pre-heated 105°F SHED, connecting the tank and canister vent hoses to a bulk-head fitting in the SHED wall so that any tank or canister venting losses would not be measured as permeation, closing the door and allowing the SHED to come back to a to a stabilized temperature.

Figure 10 - Constant-Temperature Test Cell

Either a three- or five-hour test was conducted to measure permeation. The three-hour test was used for the three higher permeation level rigs, 1, 2 and 14. The five-hour test was used for rigs 11 and 12 for tests starting in June 2005 on fuels E6 and later.

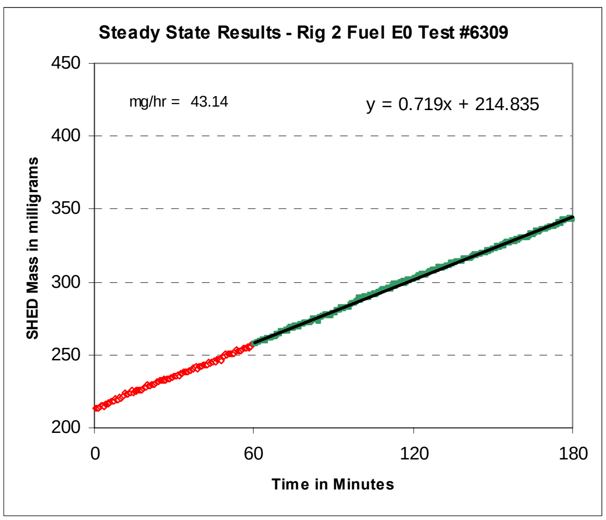

Figure 11

A sample plot of the steady-state test results is shown in Figure 11. The horizontal axis is time, in minutes, and the vertical axis is the mass (in milligrams) as measured in the SHED using the conventional SHED test procedure and equipment. The mass was calculated every 30 seconds and the results are plotted in Figure 11. The first hour of the test is shown in the red dots, and the last two hours in green. The trendline function in Microsoft EXCEL® was used to calculate the rate of change in the SHED mass over the second and third hours (the green data). This slope became the estimate of the steady-state permeation rate in mg/hour.

The five-hour test adopted for the E6 stabilization tests during June of 2005 was an attempt to improve the precision of the measurement on these really low permeation rigs (e.g., 3 mg per hour). The five-hour test used the last four hours of the five-hour test for the permeation measurement. An example of the five-hour test results is shown in Figure 12.

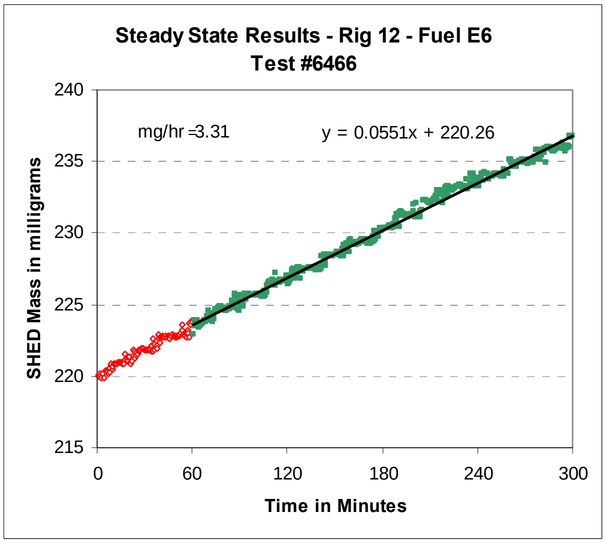

Figure 12

This plot illustrates the conditions that are created when one tries to measure 3 mg/hour in a 2100 ft3 enclosure. The SHED concentration, as determined by the FID went from 7.105 ppm at 60 minutes to 7.551 ppm at the 300 minute mark, an increase of one half of a part per million (ppm) carbon in the enclosure over the four hour period. The mass in the SHED rose from 223 mg to 237 mg during the four hour period. That the SHED can measure these differences, and identify them with the precision and resolution shown in Figure 12, would have been thought impossible just a few years ago. A smaller SHED volume (a mini-SHED) would increase the concentration change, and help with the precision, but these rigs were almost the same length as the vehicles they represented – a significantly smaller SHED was not possible.

The plot format used here was also an excellent quality check on the data, and could point out leaks and test irregularities. The mass as measured by the FID had to be corrected for the misidentification of the ethanol (if ethanol was present).

Stabilization was established when the four-week average of the permeation rate reversed in trend, i.e., when the average rate either increased or decreased over the previous trend's rate. A recommendation was made by the program administrator in a weekly status report, and the Steering Committee approved (or disapproved) the recommendation. The time required for stabilization ranged from five weeks (Rig 14, Fuel E0) to 13 weeks for Rig 12, Fuel E6. Once declared stable, the rig was drained and prepped for the diurnal measurement.

IV. Results

This section of the report begins with the details of the diurnal and steady-state test results. Following that, the hydrocarbon speciation of the diurnal measurements is addressed and the average specific reactivities of the permeates are calculated for the various technologies on the various fuels.

Diurnal[6] performance measurements are emphasized in this permeation study because the ultimate use of this information is to improve the ability of emissions inventory models to estimate the contribution of motor vehicles to air pollution. A portion of this report is also devoted to the steady-state results, as it is hoped that the steady-state (constant temperature) results can one day be used to predict the diurnal emission performance.

[6] "Diurnal", occurring daily, or having a daily cycle

Diurnal Performance – Technology

The diurnal permeation performance of the different emission technologies tested in this study is summarized in Figure 13. These results were obtained when the rigs were tested with the base fuel, E0. On the left are the two vertical bars representing the diurnal permeation performance for the two enhanced evap Rigs 1 and 2.

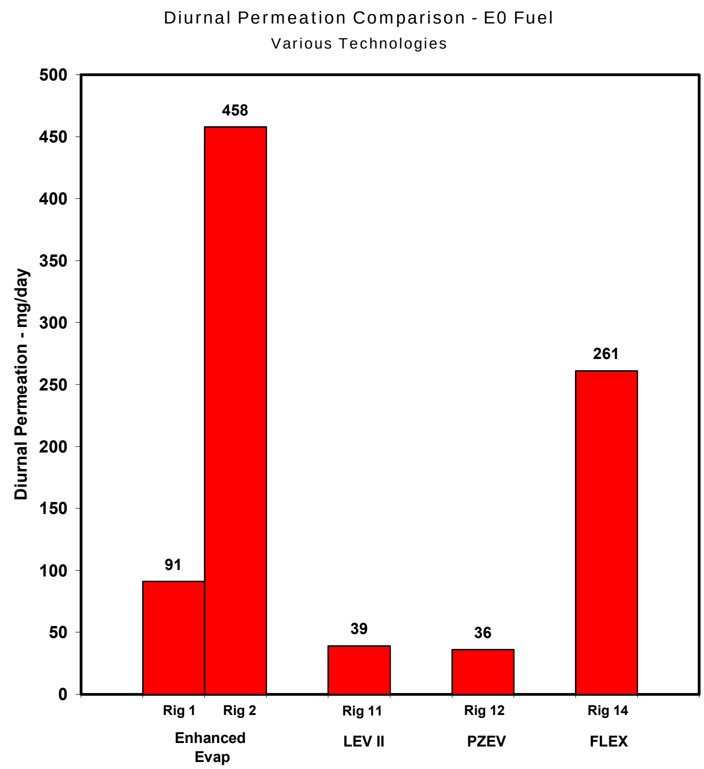

Figure 13

The third bar from the left shows the 39 mg/day level of Rig 11, the LEV II, or California Near-Zero vehicle fuel system. The fourth bar is the 36 mg/day performance of the California "Zero Fuel Emission" vehicle. To qualify as a Zero Fuel Evaporative Emission system, this vehicle is certified to have less than 54 mg/day evaporative emissions, including the canister loss and a one hour hot soak. Finally, the last bar is the permeation performance of the "flexible fuel" Chevrolet Tahoe.

While the 458 mg/day permeation result on fuel E0 on Rig 2 seems high compared to the 91 mg/day from Rig 1, it is lower than previously measured with the plastic tank systems on the non-ethanol fuel in the E-65 project, one of which measured over 11,000 mg/day. The expanded plot shown in Figure 14 includes some of the technologies from the previous CRC E-65 report[7] "Fuel Permeation from Automotive Systems." The blue bars on the left (Rigs 1-6) are the permeation results on the non-oxygenated fuel, "Fuel C" measured in the previous program. The red oval highlights the performance level of Rigs 1 and 2 on Fuel C and the current program's Fuel E0.

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[7] Coordinating Research Council (CRC) web site, http://www.crcao.org

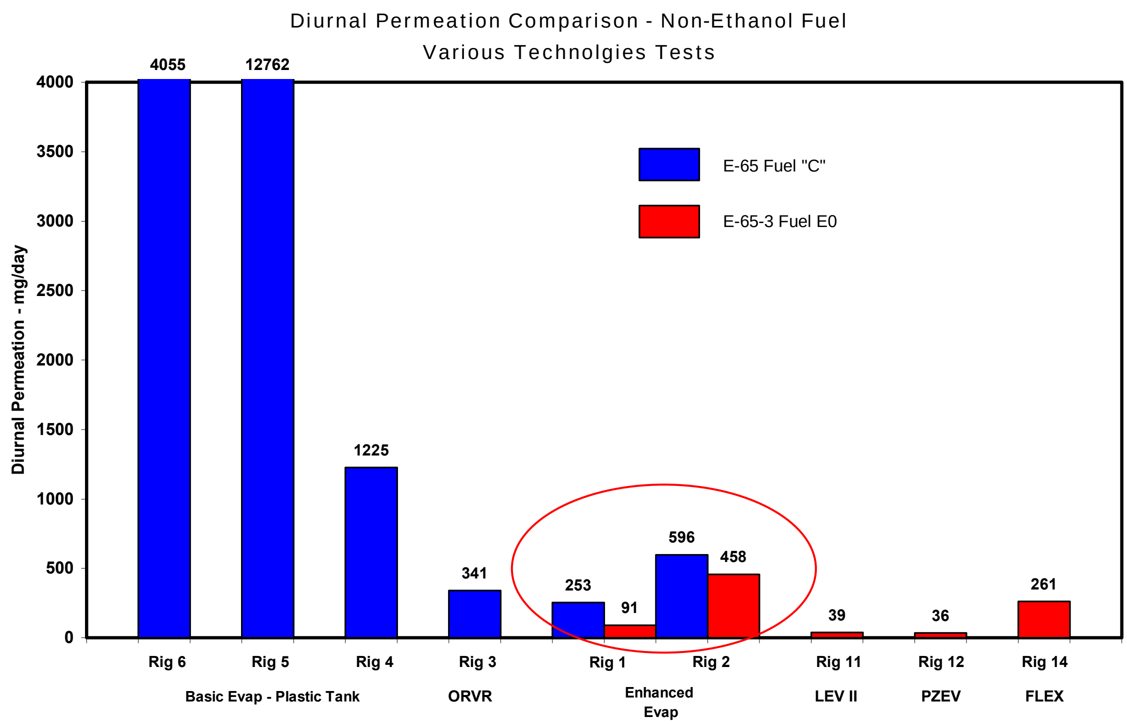


Figure 14

A plot showing the diurnal results for the five test rigs on the fuels tested in this program is shown in Figure 15**.**

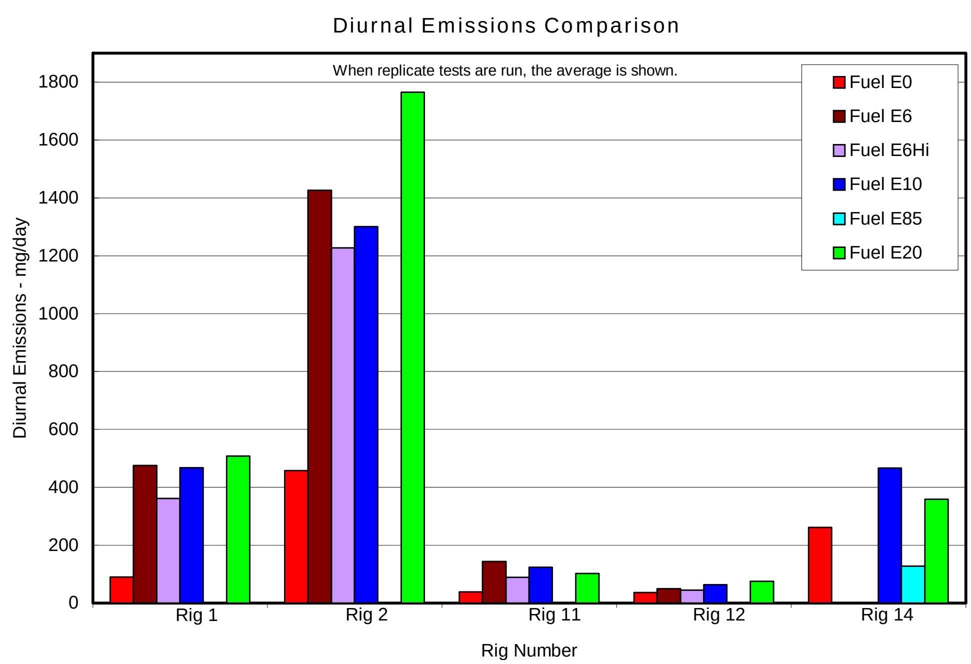


Figure 15

Diurnal Performance - Fuels

Rig 1 - The diurnal emissions measured for Rig 1, the MY 2001 enhanced evap system, ranged from 91 mg/day on the base fuel (E0) to 508 mg/day on the E20 fuel. Figure 16 compares the results for the five fuels tested. Where multiple tests were run, such as those for the E0 and E6 fuels, the average results are presented. (Table 7 at the end of this section details the actual tests used.) The component on the top of each bar illustrates the ethanol fraction of the total emissions. For example, the E6 test total of 475 mg/day had 149 mg/day of ethanol. A very small amount of the E0 test (1 mg/day) was ethanol, even though there was no ethanol in the fuel, apparently a "hang-up" from the rig's previous experience on ethanol fuel. The issue of the "hang-up" and the concerns thereof is discussed in the appendix of this report.

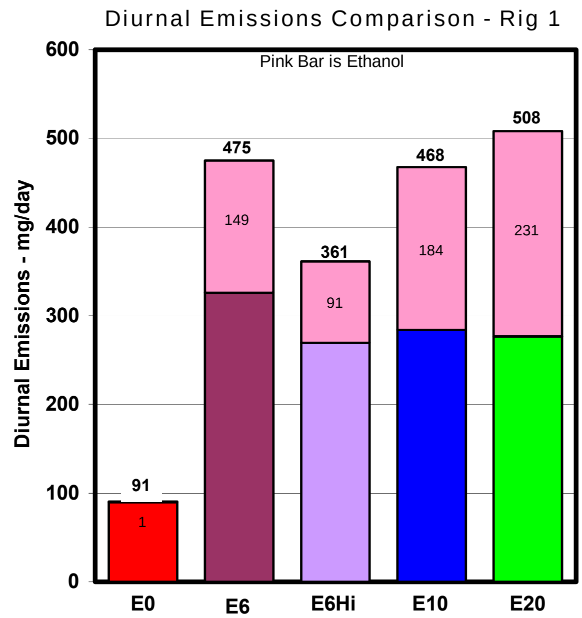


Figure 16

The diurnal permeation emissions with the E6 fuel increased by 384 mg/day compared to E0. The diurnal results with the E6Hi (high aromatics) fuel were 114 mg/day lower than the E6 fuel, with lower (91 mg/day compared to 149 mg/day) ethanol in the permeate. The permeation with the E10 fuel was almost identical compared to the E6 fuel (7 mg/day lower), but with higher ethanol in the results. The E20 permeation was the highest measured on this rig.

Rig 2 - Rig 2, another enhanced evap system (2000 MY), also had substantial increases in permeation when tested with the ethanol-containing fuels, as shown in Figure 17. The permeation increased from 458 mg/day with the base (E0) fuel to 1765 mg/day with the E20 fuel. The ethanol fraction was about 400 to 600 mg/day for the four ethanol blends evaluated. The permeation for the E10 fuel was 125 mg/day lower than for the E6 fuel. The higher aromatics fuel, E6Hi, showed a 199 mg/day lower permeation than the E6 fuel. The E20 permeation was also the highest measured on this rig.

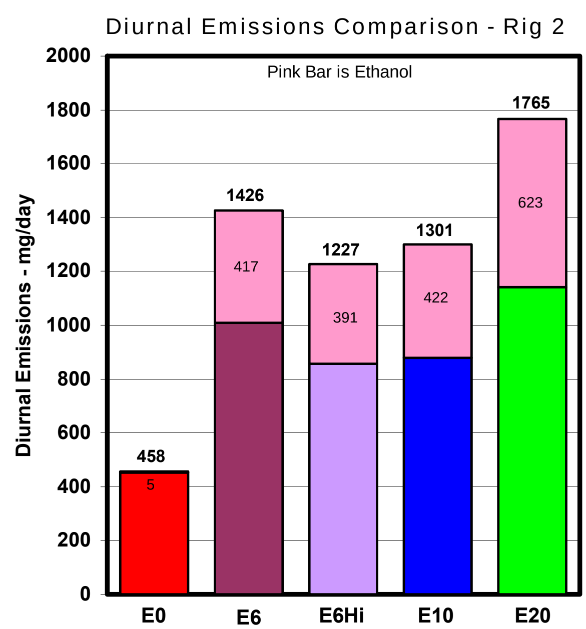


Figure 17

Rig 11 - The results for Rig 11, shown in Figure 18, indicate that all the ethanol blends increased the permeation rate compared to the base (E0) fuel. The permeation rate for the E6 fuel was 105 mg/day higher than for the E0 fuel. The higher aromatics fuel, E6Hi, had 55 mg/day lower permeation than the E6 fuel. The E10 fuel had 21 mg/day lower permeation than the E6 fuel, and the E20 fuel was 42 mg/day lower than the E6 fuel.

This rig and Rig 14 were different in their ethanol response than Rigs 1, 2 and 12, in that they had lower permeation on the E20 fuel than the E6 or E10 fuels. Rig 11 also had the lowest specific reactivity over all the fuels tested, as is described in a later section of this report on speciation and reactivity.

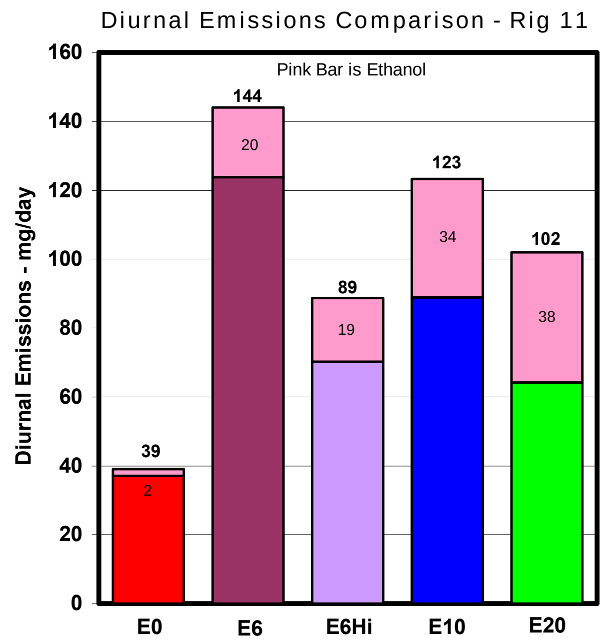


Figure 18

Rig 12 - When tested on the base (E0) non-ethanol fuel, this rig was measured at 36 mg/day. Rig 12 was found to have less than 4 mg/day ethanol "hang-up" when tested with the E0 fuel. The diurnal permeation increased when this rig was tested on any of the ethanol-containing fuels, as shown in Figure 19. The permeation for the E6 fuel was 14 mg/day greater than the E0 fuel. The permeation for the E6Hi fuel was 5 mg/day lower than the E6 fuel. This was the only rig that demonstrated a greater diurnal permeation for the E10 fuel vs. the E6 fuel, 14 mg/day higher. The highest permeation measured was on the E20 fuel, at 75 mg/day.

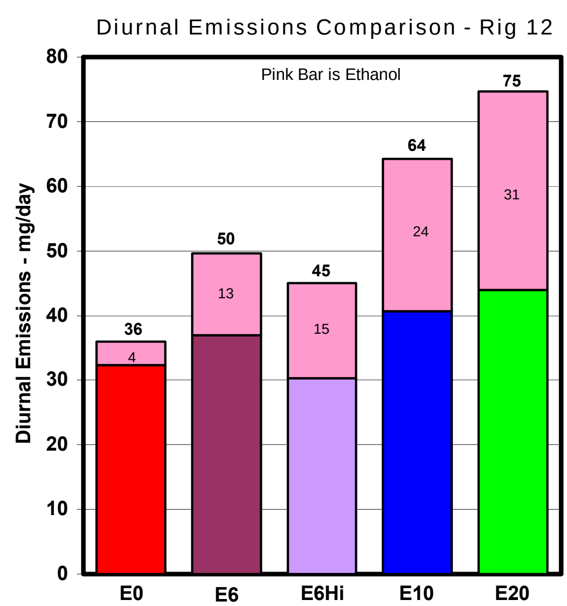


Figure 19

Rig 14 - A "FlexFuel" system evaluation was included in this project. Flexible fuel vehicles are designed and developed to perform on fuels containing just gasoline, or up to 85% ethanol fuel**,** and any combination in between.

Diurnal emissions were measured on four fuels, with the average results shown in Figure 20. The permeation emissions were nearly doubled (466 vs. 261 mg/day) with the E10 fuel, compared to the E0 fuel, but were approximately halved (128 vs. 261 mg/day) when the E85 fuel was tested. Like Rig 11, the permeation was lower on the E20 fuel compared to the E10 results. The ethanol was 139 mg/day when tested with the E10 fuel, similar in its fraction of the permeation total to the results from the other rigs evaluated. The ethanol of the E85 test results was 76 mg/day, almost 2/3rd of the total permeation. It seems reasonable that if the fuel is almost all ethanol, the permeate ought to be mostly ethanol.

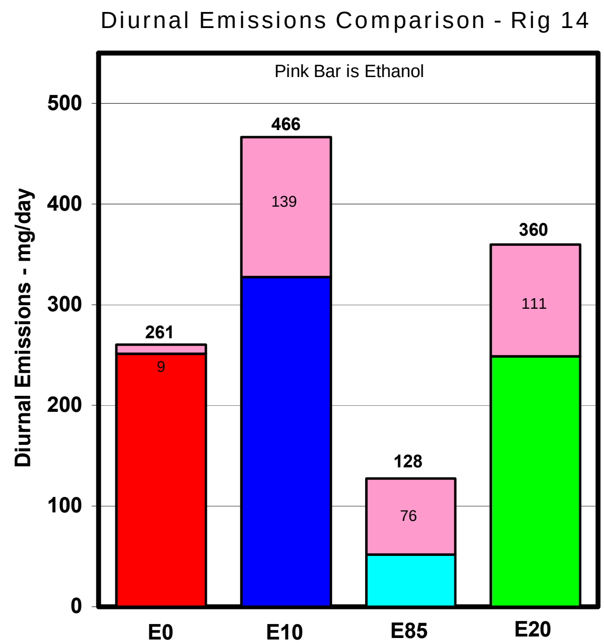


Figure 20

Data Summary

A comprehensive table, Table 7, follows with the diurnal permeation results for each vehicle and fuel, as well as the steady-state permeation results, the ratio of the diurnal result to the steady-state result, and the specific reactivity of the permeate calculated for the individual diurnal tests.

Table 7

Detailed Permeation Emission Results

Rig #1 - 2001 Toyota Tacoma					
Fuel	**4-week Avg. mg/hour**	**Diurnal Test ID**	**mg/day**	**Ratio**	**Specific Reactivity g O_3/g VOC**
E0	7.04	6389	83.9	11.9	4.31
E0b	8.57	6886	97.2	11.4	4.15
Avg. =	**7.80**		**90.6**	**11.7**	**4.23**
E6	25.6	6471	417.1	16.3	3.05
		6479	533.3	20.8	3.08
		Avg. =	**475.2**	**18.6**	**3.07**
E6Hi	29.2	6571	360.9	12.4	3.30
E10	35.2	6665	467.8	13.3	3.03
E20	43.4	6806	508.1	11.7	3.20

Rig #2 - 2000 Honda Odyssey					
Fuel	**4-week Avg. mg/hour**	**Diurnal Test ID**	**mg/day**	**Ratio**	**Specific Reactivity g O_3/g VOC**
E0	42.5	6390	463.3	10.9	4.26
E0b	33.7	6913	451.6	13.3	4.16
Avg. =	**38.1**		**457.5**	**12.1**	**4.21**
E6	97.7	6481	1426.0	14.6	3.54
E6Hi	88.9	6570	1227.0	13.8	3.66
E10	101.5	6673	1300.6	12.8	3.45
E20	148.8	6816	1765.1	11.9	3.32

Table 7 (cont)

Detailed Permeation Emission Results

Rig #11 - 2004 Ford Taurus					
Fuel	**4-week Avg. mg/hour**	**Diurnal Test ID**	**mg/day**	**Ratio**	**Specific Reactivity g O_3/g VOC**
E0	3.59	6370	48.0	13.4	2.91
E0b	2.53	6889	29.7	11.7	3.51
Avg. =	**3.06**		**38.9**	**12.6**	**3.21**
E6	11.2	6507	144.1	12.9	2.09
E6Hi	4.02	6598	88.7	20.3	2.58
E10	6.36	6675	149.3	24.1	2.23
		6676	97.3	15.7	2.43
		Avg. =	**123.3**	**19.9**	**2.33**
E20	5.42	6805	102.0	18.8	2.40

Rig #12 - 2004 Chrysler Sebring					
Fuel	**4-week Avg. mg/hour**	**Diurnal Test ID**	**mg/day**	**Ratio**	**Specific Reactivity g O_3/g VOC**
E0	3.22	6372	38.7	12.0	5.48
		6383	31.0	9.64	4.10
E0b	2.68	6874	38.3	14.3	3.73
Avg. =	**2.95**		**36.0**	**12.0**	**4.44**
E6	3.45	6492	49.6	14.4	3.30
E6Hi	3.86	6569	45.0	11.7	3.14
E10	4.65	6642	64.3	13.8	2.85
E20	5.38	6778	74.7	13.9	2.92

Table 7 (cont)

Detailed Permeation Emission Results

Rig #14 - 2005 Chevrolet Tahoe					
Fuel	**4-week Avg. mg/hour**	**Diurnal Test ID mg/day**		**Ratio**	**Specific Reactivity g O_3/g VOC**
E0	18.8	6360	250.5	13.3	3.80
		6388	248.1	13.2	3.85
E0b	18.4	6645	282.7	15.4	3.89
E0c	20.5	6892	262.8	12.8	3.91
Avg. =	**19.2**		**261.0**	**13.7**	**3.9**
E10	29.8	6454	466.3	15.6	3.05
E85	16.3	6555	142.3	8.68	2.63
		6566	112.8	6.88	2.82
		Avg. =	**127.6**	**7.78**	**2.73**
E20	27.6	6779	359.5	13.0	3.36

Rig and Fuel Type Diurnal Result Comparisons

A table was made of the diurnal emission rates for the various rigs and fuels to look for trends or relationships. Table 8 below shows the diurnal results for all of the test fuels. Rig 1 showed a large increase in permeation when any of the ethanol-containing fuels was evaluated. Rig 2 was higher in basic permeation level, and showed proportionately less of an increase from the ethanol fuels. Rig 11 had very low permeation emissions but still increased when evaluated on the ethanol fuels. Rig 12, the "Zero Fuel Evaporative Emission" system, had a different result when tested on the ethanol-containing fuels in that the increase due to the ethanol was only 9 to 39 mg/day more than the base permeation rate, a much smaller increase than seen in the other rigs.

Table 8

Diurnal Emissions Test Results
Total (Ethanol) – mg/day

	Test Fuel						**Difference from E0, mg/day**			
	E0	E6	E6Hi	E10	E20	E85	E6	E6Hi	E10	E20
Rig 1	91 (1)	475 (149)	361 (91)	468 (184)	508 (231)		384	270	377	417
Rig 2	458 (5)	1426 (417)	1227 (391)	1301 (422)	1765 (623)		968	769	843	1307
Rig 11	39 (2)	144 (20)	89 (19)	123 (34)	102 (38)		105	50	84	63
Rig 12	36 (4)	50 (13)	45 (15)	64 (24)	75 (31)		14	9	28	39
Rig 14	261 (9)	-	-	466 (139)	360 (111)	128 (76)				
Average*	177 (4)	524 (150)	430 (129)	484 (161)	562 (207)		347	253	307	385

* Averages for E0, E10 and E20 are five-rig; those for E6 and E6Hi are four-rig.

Steady-State Permeation Measurements

The plot format shown in Figures 21-25 was developed to compare the steady-state permeation rate results for each rig on the various fuels. The horizontal axis is a chronological sequence (not necessarily a linear time-scale) of the tests as they were accumulated. The red filled-box data points represent the ethanol permeation rate. The laboratory established that 1 mg/hour was the detection limit of the analytical procedure used to establish the ethanol content, and if the test level was less than 1.0 mg/hour it was reported as "below detection limit," or BDL, and counted as zero in the calculation of the total. The black diamonds are the (non-ethanol) hydrocarbon, and the blue triangles are the total of the two, or the total permeation rate in mg/hour. A horizontal blue line is drawn at the average level of the last four data points.

Rig 1 started the stabilization on fuel E0 with an initial fill on January 11, 2005 and was tested on the following day to measure the permeation rate. Permeation measurements were made each week, not necessarily on the same day of the week, although that was the normal case. The actual test dates are contained in the data record file known as "rigsum.xls," and are available on the CRC web-site.

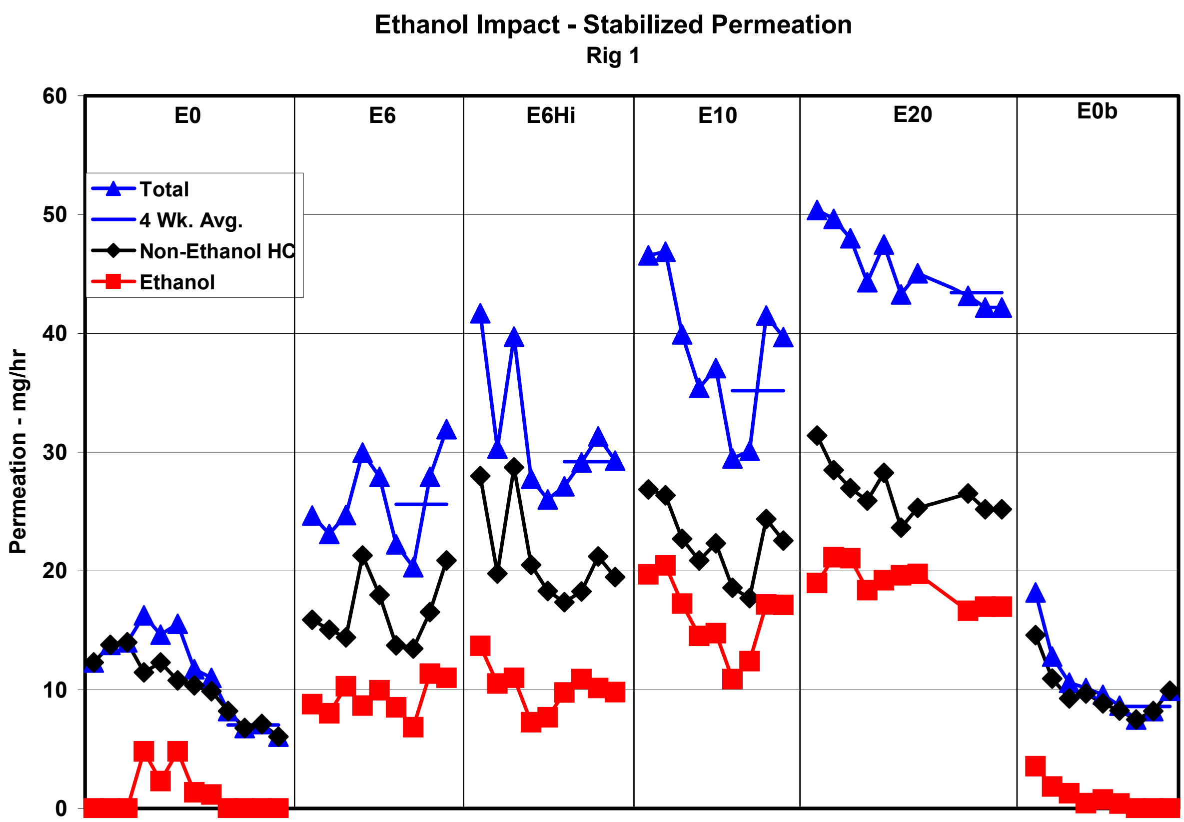


Figure 21

A concern arose when ethanol was detected in the steady-state permeation results on the E0 fuel, even though there was no ethanol in the test fuel. The first three tests on the E0 fuel reported no ethanol, but the fourth test (#6306 on February 2, 2005) reported 4.8 mg/hour as the ethanol component. A discussion arose concerning the source and authenticity of the measurement. The following week's measurement was 2.3, and then 4.8, 1.2 and 1.2 mg/hour in succeeding weeks. The test on March 9 returned to BDL for ethanol. A similar pattern arose, at the same time period, on Rig 2, as will be discussed later. Ethanol was not detected in Rigs 11, 12 or 14 during the initial steady-state permeation E0 testing. A separate discussion concerning the "ethanol hang-up" is provided in the appendix at the end of this report.

The steady-state permeation rate increased when the 5.7 Volume% ethanol fuel (E6) was introduced, as shown in Figure 21. The four-week final average permeation rate was 7.04 mg/hour on Fuel E0 and increased to 25.6 mg/hour on the 5.7 Volume% ethanol fuel. The steady-state permeation rate increased slightly on the higher aromatics E6Hi fuel, with an average of 29.2 mg/hour, and was higher yet (35.2 mg/hour) on the 10 Volume% ethanol fuel. The E20 steady-state average value was 43.4 mg/hour. The average of the original and the final steady-state permeation rate measurements on the E0 fuel (7.04 and 8.57) was 7.8 mg/hour

Rig 2 also received its initial fill of the E0 test fuel on January 11, 2005, with its first test on the following day. (The practice was later changed to not test on the day following the fuel change, but test after a week or more exposure.) It showed ethanol in the permeate on the fourth week, on February 4, of 8.8 mg/hour, and 7.9 mg/hour the following week, during the same time period as was seen on Rig 1. A check was made for any sort of a laboratory or soak room contamination problem, without finding any source of contamination or error. An expanded discussion on the ethanol "hang-up" appears in the appendix to this report.

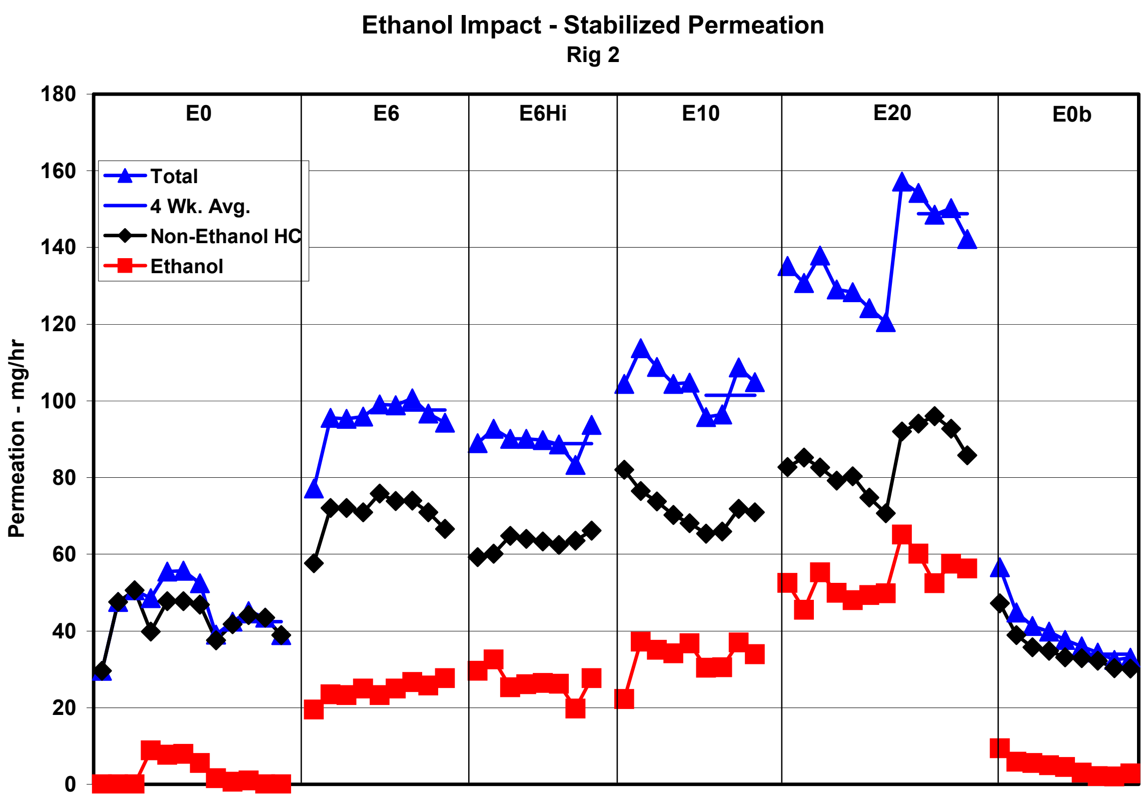


Figure 22

The following observations were made regarding the second test band in Figure 22. The first test on the E6 fuel was made after nine days of exposure. The second week's test after 17 days shows that the total permeation trend had approached the eventual stabilized level. The ethanol content, shown in the red solid squares as the lower of the three trends in the plot, appeared to be increasing slightly over the nine weeks of exposure. The permeation was declared to be stabilized after the 10th week of stabilization, and the rig was then submitted for the diurnal test.

The permeation rate decreased slightly when the higher aromatics E6Hi fuel was introduced, and then increased with the introduction of the 10 Volume% ethanol fuel (E10). The 4-week average for the tests on the E10 fuel was 101.5 mg/hour, and 148.8 mg/hour on the E20 fuel. The average of the two steady-state averages on the E0 fuel (42.5 and 33.7) was 38.1 mg/hour

The permeation rate for **Rig 11** was very low, ~ 3 mg/hour on the E0 fuel, as shown in Figure 23, which created measurement challenges. The measurement period was increased from three to five hours during the E6 fuel measurement period as was discussed earlier in this section.

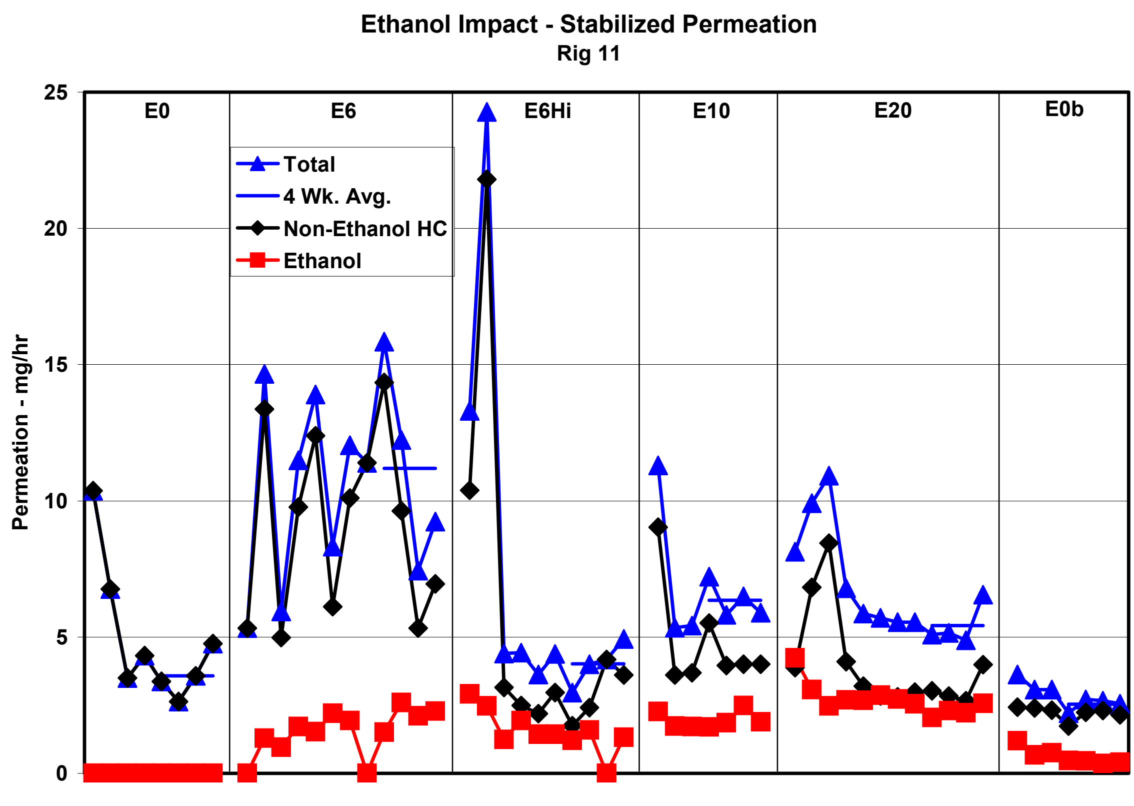


Figure 23

The permeation performance of Rig 11 was erratic on the E6 fuel. The erratic performance continued for the first two tests on the E6Hi fuel, when the permeation suddenly dropped from 24 mg/hour to ~4 mg/hour for no identified reason. This erratic condition may have also been present during the diurnal evaluation on the E6 fuel, but there is at present no basis to invalidate the data.

Rig 12 was expected to have low permeation as it was produced and certified to be a "zero fuel evaporative emission" vehicle. As anticipated, the steady-state permeation results were very low (Note the vertical scale on Figure 24). The 4-week average permeation rate on the E0 fuel was 3.2 mg/hour for the original test sequence, with any ethanol content below the detectable limit and 2.7 mg/hour on the final series, with about a 0.5 g/hour ethanol fraction. The E6 fuel increased the permeation rate slightly, mainly because the ethanol component triggered into the detectable limit of 1 mg/hour.

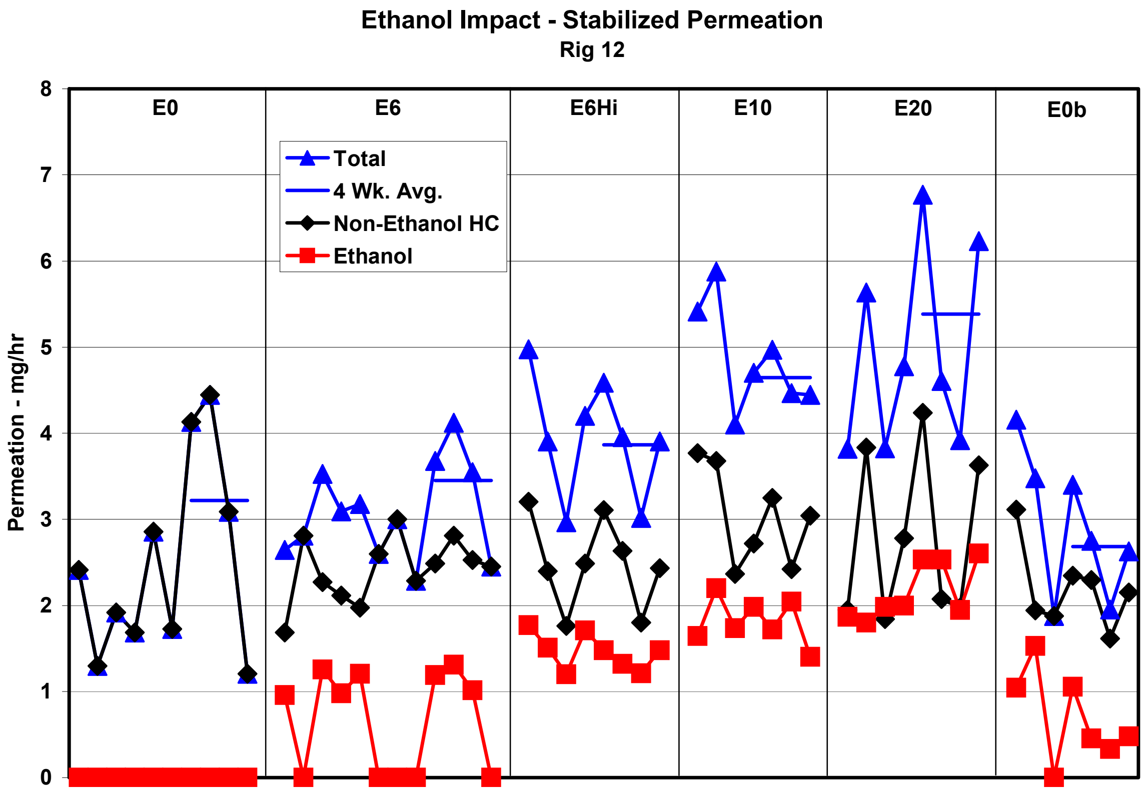


Figure 24

Unlike the other rigs, the high aromatics fuel, E6Hi, increased the permeation rate of Rig 12 over the value established for the lower aromatics E6 fuel. The 4-week average level was 3.4 mg/hour on the E6 fuel, and 3.9 mg/hour on the E6Hi fuel. The data suggests that although the non-ethanol measurement stayed about the same, there was an increase in the mass rate of the ethanol in the permeate with the higher aromatics fuel compared to the E6 fuel. The E10 steady-state average was 4.6 mg/hour, and the E20 value was 5.4 mg/hour

The final test sequence on the E0 fuel shows an ethanol content at the 0.5 mg/hour level, where the initial E0 tests were declared as below the detectable limit. This is attributed to the fact that the laboratory became more confident in declaring ethanol measurements below the level of 1 mg/hour as the program progressed.

The permeation results with the E20 fuel were the highest measured of the four test fuels, but the magnitude of the increase, when compared to the base fuel (E0), was low, less than 3 mg/hour.

Rig 14 was tested on the E0, E10, E20 and E85 fuels. The committee authorized a final test on the E0 fuel after the E85 evaluation to see if it would return to the previously measured E0 level. The results of the steady-state evaluation are shown in Figure 25. The ethanol in the permeate jumped to the 8 mg/hour level on the second test with the E10 fuel. The E10 steady-state permeation (29.8 mg/hr) was 1.6 times the E0 steady-state rate of 18.8 mg/hr, more like the results from Rigs 11 and 12, than Rigs 1 and 2. The 4-week steady-state average on the E20 test fuel was 27.6 mg/hour, close, but slightly less, than the E10 4-week average of 29.8 mg/hour.

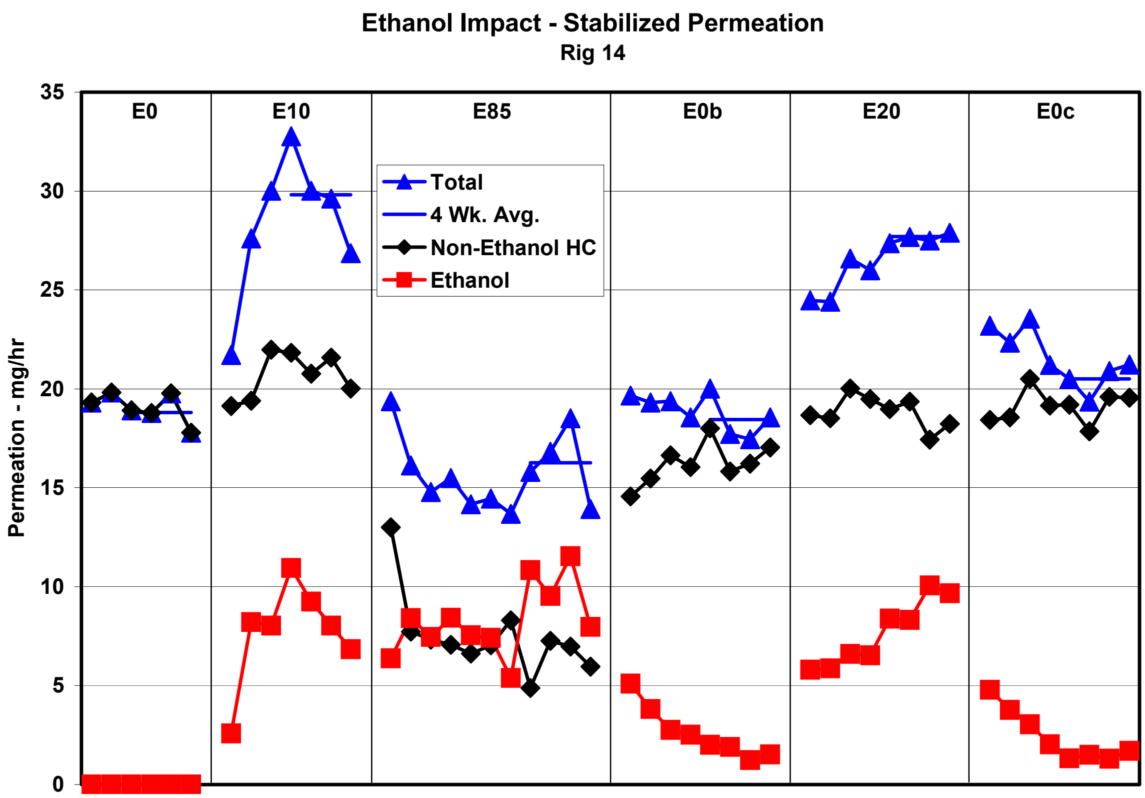


Figure 25

Steady-State Permeation Results by Rig

The steady-state tests were used to determine fuel system stability following the introduction of a new fuel and to indicate that the rig was ready for the diurnal evaluation. A three or five hour steady-state test was performed in a SHED to determine the 105°F hourly permeation rate. The 4-week average steady-state permeation rates provide another measure of the permeation performance of the various fuels on the different fuel systems, and are presented below.

Rig 1 - The bar chart in Figure 26 is used to illustrate the steady-state performance of the five test fuels on Rig 1. The hourly permeation rate is the lowest on the base fuel (E0) and increases to 43 mg/hour on fuel E20. The higher aromatic E6Hi fuel had slightly higher permeation than the E6 fuel on the steady-state measurement, a different finding than was indicated on the diurnal test.

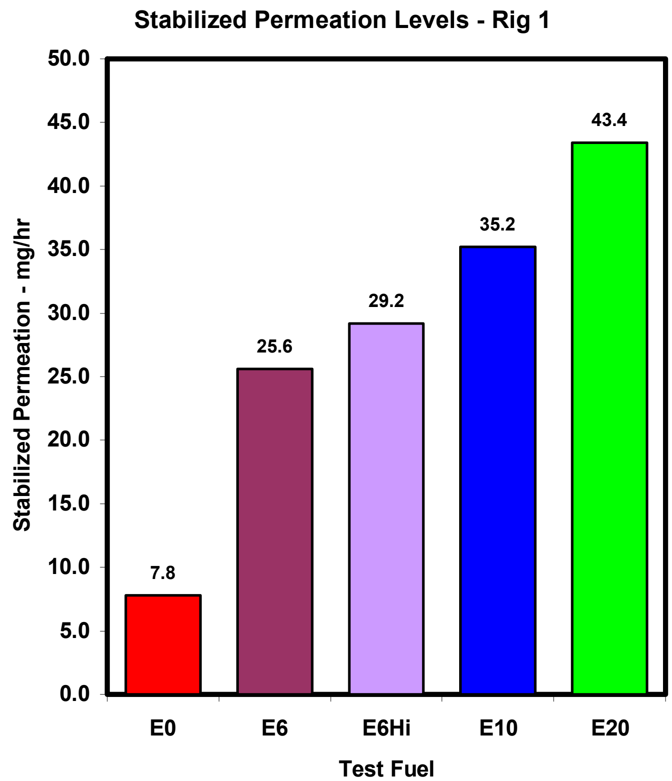


Figure 26

Rig 2 – Figure 27 shows the steady-state permeation estimate on the E6Hi fuel to be lower than the E6 fuel, more in line with the diurnal test results, while the E10 permeation is slightly higher than the E6 result, and the E20 permeation is substantially higher.

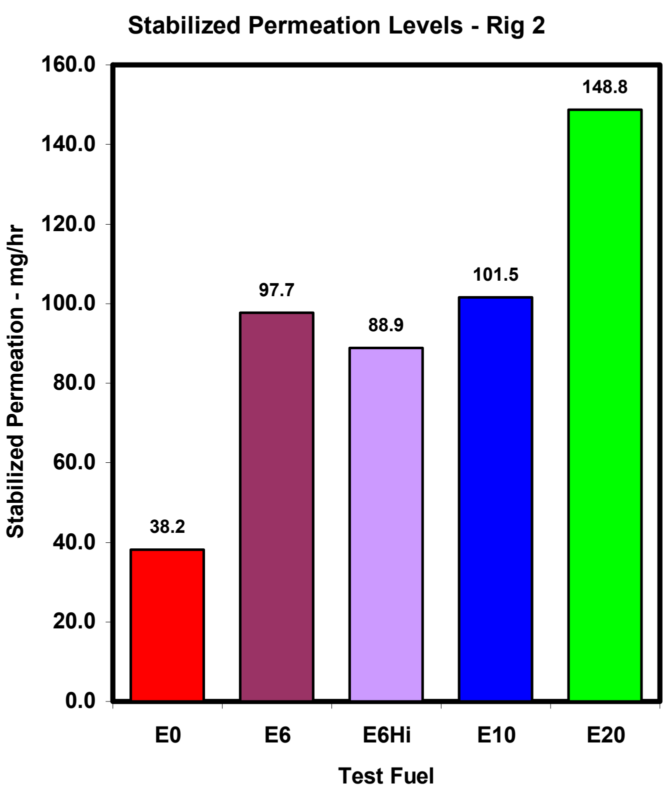


Figure 27

Rig 11 steady-state test results, shown in Figure 28, are distorted by the highly variable results experienced during the tests on the E6 fuel (see the earlier steady-state discussion on Rig 11). The E20 permeation was lower than the results measured with the E10 fuel, a different result than was seen on Rigs 1, 2 and 12.

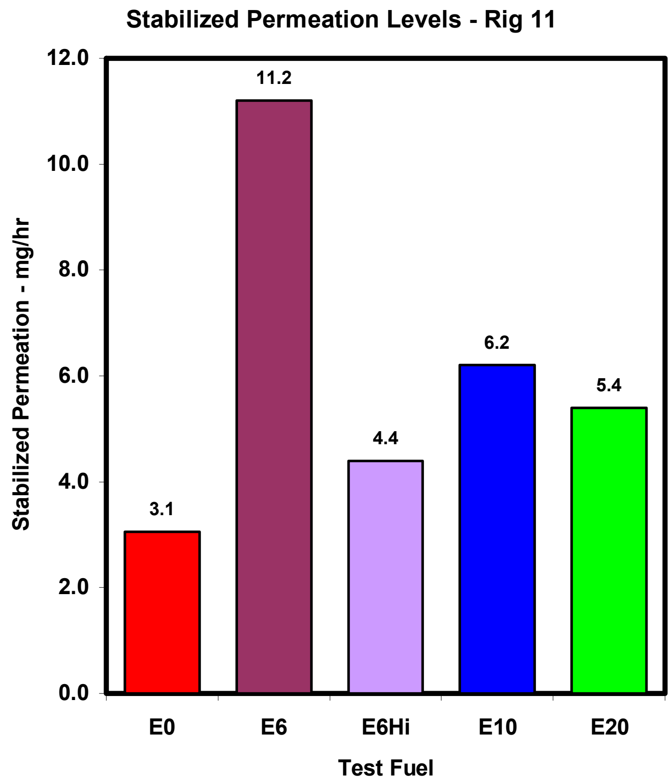


Figure 28

Rig 12 steady-state permeation results, shown in Figure 29 are more like the relationship seen with Rigs 1 and 2.

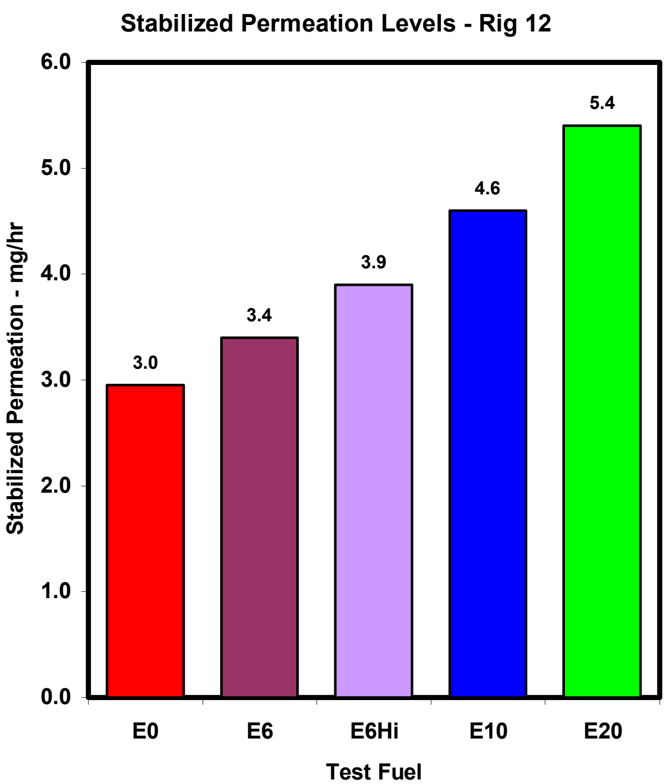


Figure 29

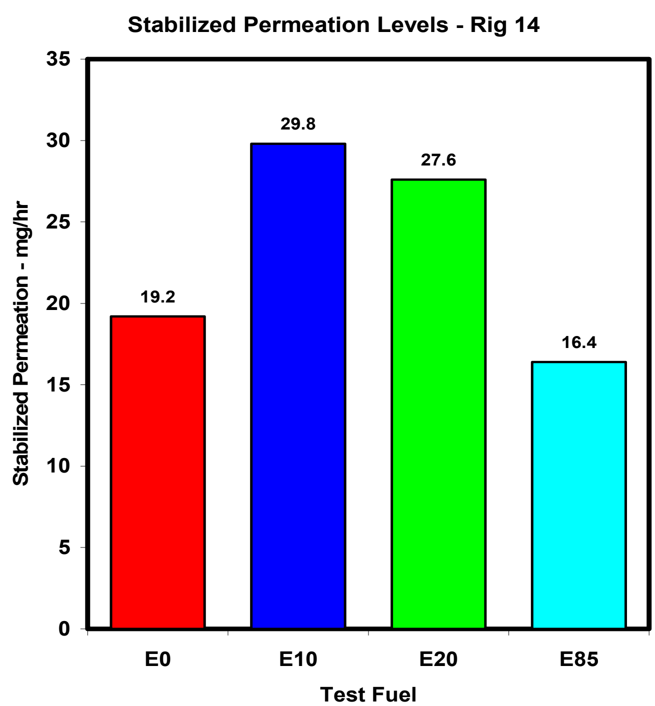


Figure 30

Rig 14 steady-state results, shown in Figure 30, indicate lower emission on the E20 fuel than was measured on E10, similar to the behavior of Rig 11. The steady-state 105°F permeation result on the E85 fuel was lower (-2.8 mg/hour) than the E0 base fuel, but not at half the value, as the diurnal results indicated.

In summary, the steady-state results may offer a slightly different picture of the permeation behavior of the different fuels on the different rigs, relative to the diurnal results. The small sample size, and the limited testing conducted, suggest some caution in evaluating these observed differences.

Speciation and Reactivity

Diurnal Speciation Results – A sample of the ambient HC concentration in the VT-SHED was collected in a Tedlar™ bag at the start and the end of the 24-hour diurnal period and later analyzed for HC species using a Varian™ chromatograph. The results of this "speciation" allowed the calculation of the average reactivity of the permeate for each of the rigs and fuels.

An example of the speciation results and the reactivity calculations for Rig 1 – Fuel E0, Test 6389, is shown in Table 9. Table 9 is one file in a Microsoft EXCEL® workbook titled "SHED Speciation and Reactivity Calculations for the Final Report.xls," available on the CRC web-site in the files for the E-65-3 report. This workbook contains all of the SHED speciations for the test fuels evaluated in this program.

Each file has been reordered into three vertical groups. The top group is those molecules with identified mass that have an assigned Carter Maximum Incremental Reactivity (MIR) value. The second vertical group is those measured mass components that do not have an assigned MIR value, and the last group is the molecules that had zero measured mass, but would have been identified if they were present, using the "Auto-Oil" chromatographic test technique. The first and second vertical groups were sorted in descending order of mass in each group. The lengthy listing of the third group, of those molecules with no detected mass, is offered to indicate to the reader what would have been measured, if present, using the chromatographic techniques available at the laboratory.

This table, and the others in the workbook, are organized from left to right as follows. The first column is the elution order number, or the order that the molecules would appear at the end of the chromatographic column. The second column is the specific molecule's name. The third column is the CAS number[8] for the molecule. The fourth column is the MIR value for the molecule, or the specific grams of ozone formed for each gram of HC identified under certain conditions. The fifth column is the net mass of each species identified in the SHED sample by the chromatograph. The sixth column is the percentage of the total mass identified as this species. The final column is the prediction of the mass of ozone that would be produced by that mass of that molecule using the Carter methodology.

[8] The CAS number is the Chemical Abstract Service registry number assigned to each specific molecule. CAS registry numbers are copyrighted by the American Chemical Society. Redistribution rights for CAS registry numbers are reserved by the American Chemical Society. "CAS registry" is a registered trademark of the American Chemical Society. The CAS REGISTRY mostly covers substances identified from the scientific literature from 1957 to the present with some classes (fluorine- and silicon-containing compounds) going back to the early 1900s. Each substance in REGISTRY is identified by a unique numeric identifier called a CAS Registry Number.

Table 9

Rig:	01E0					
Test#:	**6389**					
Detailed Hydrocarbon Speciation Results				24-Hour		
Elution No.	Species Name	CAS #	MIR g O_3/g HC	Net mass (mg)	% total mass	Predicted Ozone mg
81	Toluene	00108-88-3	3.97	14.321	17%	56.85
18	2-Methylbutane (Isopentane)	00078-78-4	1.67	10.787	13%	18.01
111.1	m-Xylene	00108-38-3	10.61	8.835	10%	93.74
21	n-Pentane	00109-66-0	1.53	3.666	4%	5.61
117	ortho-Xylene	00095-47-6	7.48	2.951	3%	22.08
111.2	p-Xylene	00106-42-3	4.24	2.591	3%	10.99
36.1	2-MePentane	00107-83-5	1.78	2.289	3%	4.08
135.1	1,2,4-TriMeBenz	00095-63-6	7.18	2.131	2%	15.30
109	Ethylbenzene	00100-41-4	2.79	2.066	2%	5.77
53	Benzene	00071-43-2	0.81	1.952	2%	1.58
34	2,3-Dimethylbutane	00079-29-8	1.13	1.514	2%	1.71
128	1-Methyl-3-Ethylbenzene	00620-14-4	9.37	1.501	2%	14.06
40	n-Hexane	00110-54-3	1.43	1.475	2%	2.11
63	2,2,4-TriMePentane (IsoOctane)	00540-84-1	1.43	1.437	2%	2.05
26	2-Methyl-2-butene	00513-35-9	14.44	1.298	2%	18.75
	Ethanol	00064-17-5	1.69	1.260	1%	2.13
49	Methylcyclopentane	00096-37-7	2.40	1.244	1%	2.99
56	Cyclohexane	00110-82-7	1.44	1.130	1%	1.63
79	2,3,4-Trimethylpentane	00565-75-3	1.22	0.986	1%	1.20
74	Methylcyclohexane	00108-87-2	1.97	0.955	1%	1.88
130	1,3,5-Trimethylbenzene	00108-67-8	11.22	0.953	1%	10.69
23	t-2-Pentene	00646-04-8	10.23	0.910	1%	9.31
38	3-Methylpentane	00096-14-0	2.06	0.905	1%	1.87
9	2-Methylpropane	00075-28-5	1.34	0.892	1%	1.20
12	n-Butane	00106-97-8	1.32	0.874	1%	1.15
86	3-Methylheptane	00589-81-1	1.33	0.832	1%	1.11
57	2-Methylhexane	00591-76-4	1.36	0.809	1%	1.10
42	t-2-Hexene	04050-45-7	8.35	0.754	1%	6.30
59.2	3-Methylhexane	00589-34-4	1.84	0.722	1%	1.33
129	1-Methyl-4-Ethylbenzene	00622-96-8	3.75	0.705	1%	2.64
127	n-Propylbenzene	00103-65-1	2.20	0.661	1%	1.45
136	n-Decane	00124-18-5	0.81	0.608	1%	0.49
90	2,2,5-Trimethylhexane	03522-94-9	1.31	0.541	1%	0.71
96	n-Octane	00111-65-9	1.09	0.532	1%	0.58
45.1	c-2-Hexene	07688-21-3	8.35	0.520	1%	4.34
83	2-Methylheptane	00592-27-8	1.18	0.500	1%	0.59
66	n-Heptane	00142-82-5	1.26	0.495	1%	0.62
77	2,4-Dimethylhexane	00589-43-5	1.79	0.476	1%	0.85
29	2,2-Dimethylbutane	00075-83-2	1.33	0.465	1%	0.62
50	2,4-Dimethylpentane	00108-08-7	1.63	0.447	1%	0.73
58	2,3-Dimethylpentane	00565-59-3	1.53	0.376	0%	0.58

Table 9 (continued)

Detailed Hydrocarbon Speciation Results			24-Hour			
Elution No.	Species Name	CAS #	MIR g O_3/g HC	Net mass (mg)	% total mass	Predicted Ozone mg
133	1-Ethyl-2-Methylbenzene	00611-14-3	6.61	0.365	0%	2.41
25	c-2-Pentene	00627-20-3	10.23	0.361	0%	3.69
115	Styrene	00100-42-5	1.94	0.346	0%	0.67
14	t-2-Butene	00624-64-6	13.90	0.331	0%	4.60
84.2	4-MeHeptane	00589-53-7	1.46	0.321	0%	0.47
113	3-Methyloctane	02216-33-3	1.42	0.257	0%	0.36
140	1,2,3-Trimethylbenzene	00526-73-8	11.25	0.239	0%	2.69
39.1	2-Methyl-1-pentene	00763-29-1	5.15	0.235	0%	1.21
48	2,2-Dimethylpentane	00590-35-2	1.21	0.199	0%	0.24
16	c-2-Butene	00590-18-1	13.22	0.184	0%	2.44
20	2-Methyl-1-butene	00563-46-2	6.47	0.179	0%	1.16
1	Methane	00074-82-8	0.01	0.124	0%	0.00
76.1	2,5-DiMeHexane	00592-13-2	1.66	0.121	0%	0.20
30	Cyclopentene	00142-29-0	7.32	0.099	0%	0.72
19.1	1-Pentene	00109-67-1	7.73	0.096	0%	0.74
76.2	EtCyPentane	01640-89-7	2.25	0.062	0%	0.14
39.2	1-Hexene	00592-41-6	6.12	0.033	0%	0.20
			Mass w/MIR Values	81.9	95.7%	352.7
				Specific Reactivity		4.31
43	3-Methyl-t-2-pentene	00616-12-6		1.196	1%	
47	Unknown #16			0.686	1%	
61	3-Methyl-c-2-pentene	00922-62-3		0.534	1%	
82.2	c-1,3-Dimethylcyclopentane	02532-58-3		0.330	0%	
88	2-Me-3-Et-pentane	00609-26-7		0.316	0%	
36.2	c-1,3-Dimethylcyclohexane	00638-04-0		0.288	0%	
62	4-Me-c-2-Pentene	00691-38-3		0.140	0%	
45.2	t-1,2-Dimethylcyclopentane	00822-50-4		0.130	0%	
123	3-MeCyclopentene	01120-62-3		0.069	0%	
			Mass w/o MIR Values	3.69	4.3%	
4	Ethane	00074-84-0		0.000	0%	
2	Ethylene	00074-85-1		0.000	0%	
3	Acetylene (Ethyne)	00074-86-2		0.000	0%	

Table 9 (continued)

Detailed Hydrocarbon Speciation Results			24-Hour			
Elution No.	Species Name	CAS #	MIR g O_3/g HC	Net mass (mg)	% total mass	Predicted Ozone mg
6	Propane	00074-98-6		0.000	0%	
8	Propyne	00074-99-7		0.000	0%	
22	2-Methyl-1,3-butadiene	00078-79-5		0.000	0%	
168	Naphthalene	00091-20-3		0.000	0%	
135.2	1,2,4,5-Tetramethylbenzene	00095-93-2		0.000	0%	
122	t-Butylbenzene	00098-06-6		0.000	0%	
162	Isopropylbenzene (Cumene)	00098-82-8		0.000	0%	
141	1,3-Diisopropylbenzene	00099-62-7		0.000	0%	
166	4-Isopropyltoluene (p-Cymene)	00099-87-6		0.000	0%	
70.1	1,4-Diisopropylbenzene	00100-18-5		0.000	0%	
147	n-Butylbenzene	00104-51-8		0.000	0%	
145	1,4-Diethylbenzene	00105-05-5		0.000	0%	
10.2	1-Butene	00106-98-9		0.000	0%	
11	1,3-Butadiene	00106-99-0		0.000	0%	
15	1-Butyne	00107-00-6		0.000	0%	
125.2	244Trimethyl1pentene	00107-39-1		0.000	0%	
75	2,4,4-Trimethyl-2-Pentene	00107-40-4		0.000	0%	
59.1	Cyclohexene	00110-83-8		0.000	0%	
91	1-Octene	00111-66-0		0.000	0%	
120	n-Nonane	00111-84-2		0.000	0%	
172	n-Dodecane	00112-40-3		0.000	0%	
169	1-Dodecene	00112-41-4		0.000	0%	
5	Propene	00115-07-1		0.000	0%	
10.1	2-Methylpropene	00115-11-7		0.000	0%	
118	1-Nonene	00124-11-8		0.000	0%	
146	1,2-Diethylbenzene	00135-01-3		0.000	0%	
138	sec-Butylbenzene	00135-98-8		0.000	0%	
143	1,3-Diethylbenzene	00141-93-5		0.000	0%	
32	Cyclopentane	00287-92-3		0.000	0%	
7	AlBenz	00300-57-2		0.000	0%	
163.1	Allene (Propadiene)	00463-49-0		0.000	0%	
13	2,2-Dimethylpropane	00463-82-1		0.000	0%	
51	2,2,3-Trimethylbutane	00464-06-2		0.000	0%	
163.2	1,2,3,4-TetMeBenzene	00488-23-3		0.000	0%	
142	Indan	00496-11-7		0.000	0%	
19.2	2-Butyne	00503-17-3		0.000	0%	
158	1,2,3,5-Tetramethylbenzene	00527-53-7		0.000	0%	
137	Amylbenz	00538-68-1		0.000	0%	
80	Isobutylbenzene	00538-93-2		0.000	0%	
28	Cyclopentadiene	00542-92-7		0.000	0%	
24	3,3-Dimethyl-1-butene	00558-37-2		0.000	0%	
78	2,3,3-Trimethylpentane	00560-21-4		0.000	0%	

Table 9 (continued)

Detailed Hydrocarbon Speciation Results				24-Hour		
Elution No.	Species Name	CAS #	MIR g O_3/g HC	Net mass (mg)	% total mass	Predicted Ozone mg
54	3,3-Dimethylpentane	00562-49-2		0.000	0%	
92	3,3-Dimethylhexane	00563-16-6		0.000	0%	
17	3-Methyl-1-butene	00563-45-1		0.000	0%	
82.1	2,3-dimethylhexane	00584-94-1		0.000	0%	
98.2	1,1-Dimethylcyclohexane	00590-66-9		0.000	0%	
73	2,2-DiMeHexane	00590-73-8		0.000	0%	
84.1	1-MeCyHexene	00591-49-1		0.000	0%	
64	1-Heptene	00592-76-7		0.000	0%	
37	c-1,4-DiMeCyHexane	00624-29-3		0.000	0%	
44	2-Methyl-2-pentene	00625-27-4		0.000	0%	
46	ETBE	00637-92-3		0.000	0%	
69	4-Methyl-t-2-pentene	00674-76-0		0.000	0%	
31.1	4-methyl-1-pentene	00691-37-2		0.000	0%	
52	1-Methylcyclopentene	00693-89-0		0.000	0%	
31.2	3-methyl-1-pentene	00760-20-3		0.000	0%	
150	3-Ethyl-c-2-Pentene	00816-79-5		0.000	0%	
153	1-Undecene	00821-95-4		0.000	0%	
151	1,3-Dimethyl-4-Ethylbenzene	00874-41-9		0.000	0%	
105	3,5-Dimethylheptane	00926-82-9		0.000	0%	
148	1,2-Dimethyl-4-Ethylbenzene	00934-80-5		0.000	0%	
100	2,3,5-Trimethylhexane	01069-53-0		0.000	0%	
144	1-Methyl-2-Propylbenzene	01074-17-5		0.000	0%	
149	1-Methyl-3-Propylbenzene	01074-43-7		0.000	0%	
154	n-Undecane	01120-21-4		0.000	0%	
33	MTBE	01634-04-4		0.000	0%	
104	Ethylcyclohexane	01678-91-7		0.000	0%	
125.3	PrCyHexane	01678-92-8		0.000	0%	
119	1,4-Dimethyl-2-Ethylbenzene	01758-88-9		0.000	0%	
103	c- & t-4-Nonene	02198-23-4		0.000	0%	
98.1	c-1,2-Dimethylcyclohexane	02207-01-4		0.000	0%	
89	t-1,3	02207-03-6		0.000	0%	
67.1	t-1,4-Dimethylcyclohexane	02207-04-7		0.000	0%	
101	2,4-Dimethylheptane	02213-23-2		0.000	0%	
112	4-Methyloctane	02216-34-4		0.000	0%	
152	2-Methyl-2-Hexene	02738-19-4		0.000	0%	
110.1	1,3-Dimethyl-2-Ethylbenzene	02870-04-4		0.000	0%	
55	2,3-DiMeHeptane	03074-71-3		0.000	0%	
110.2	2-MeOctane	03221-61-2		0.000	0%	
68.1	3-Me-1-Hexene	03404-61-3		0.000	0%	
139	3-Me-t-3-Hexene	03899-36-3		0.000	0%	
125.1	2,4-DiMeOctane	04032-94-4		0.000	0%	
121	1-Methyl-4-Isobutylbenzene	05161-04-6		0.000	0%	

Table 9 (continued)

Detailed Hydrocarbon Speciation Results				24-Hour		
Elution No.	Species Name	CAS #	MIR g O_3/g HC	Net mass (mg)	% total mass	Predicted Ozone mg
71	t-2-Nonene	06434-78-2		0.000	0%	
97.2	c-2-Heptene	06443-92-1		0.000	0%	
99	t-1,2-DiMeCyHexane	06876-23-9		0.000	0%	
70.2	c-2-Octene	07642-04-8		0.000	0%	
41.2	c-3-Hexene	07642-09-3		0.000	0%	
67.2	c-3-Heptene	07642-10-6		0.000	0%	
97.1	23-diMe-2-pentene	10574-37-5		0.000	0%	
41.1	t-3-Hexene	13269-52-8		0.000	0%	
27	t-2-Octene	13389-42-9		0.000	0%	
68.2	t-2-Heptene	14686-13-6		0.000	0%	
65	t-3-Heptene	14686-14-7		0.000	0%	
94	t-4-Octene	14850-23-8		0.000	0%	
87	2,2-Dimethyloctane	15869-87-1		0.000	0%	
161	1c-2t-3-TriMeCyPentane	15890-40-1		0.000	0%	
157	Methylindan	27133-93-3		0.000	0%	
35	Unknown #1			0.000	0%	
60	Unknown #2			0.000	0%	
72	Unknown #3			0.000	0%	
85	Unknown #4			0.000	0%	
95	Unknown #5			0.000	0%	
102	Unknown #7			0.000	0%	
106	Unknown #8			0.000	0%	
107	Unknown #9			0.000	0%	
108	Unknown #10			0.000	0%	
114	Unknown #11			0.000	0%	
116	Unknown #12			0.000	0%	
124	Unknown #13			0.000	0%	
126	Unknown #14			0.000	0%	
131	Unknown #15			0.000	0%	
132	Unknown #17			0.000	0%	
134	3-Methylnonane			0.000	0%	
155	Unknown #18			0.000	0%	
156	Unknown #19			0.000	0%	
159	Unknown #20			0.000	0%	
160	Unknown #21			0.000	0%	
165	Unknown #23			0.000	0%	
167	Unknown #24			0.000	0%	
170	Unknown #25			0.000	0%	
	Total			85.6	100.0 %	
				83.9	SHED FID (mg)	
				102.0	% GC of SHED FID	

Specific Reactivity Calculations - The Carter Maximum Incremental Reactivity (MIR) scale for the various VOC molecules was adopted by the CARB. It estimates that for each gram of the various VOC molecules, X grams of ozone would be produced under ideal conditions for ozone formation. The reference (approved by the CARB Staff for this purpose) to the values and the documentation is "THE SAPRC-99 CHEMICAL MECHANISM AND UPDATED VOC REACTIVITY SCALES" which can be found at

http://helium.ucr.edu/~carter/reactdat.htm

The link to the actual data is found down two thirds of the page, under the heading VOC Reactivity Data (Excel format) as of February 5, 2003 (r02tab.xls). It contains CAS number, MIR value and species name for 543 different species.

The average specific reactivity of the permeate was calculated for each of the 25 diurnal tests conducted on the five rigs and five fuels.

VOC reactivity varies with atmospheric conditions, in particular the VOC/NOx ratio. The MIR scale is based on low VOC/NOx ratios. The reactivity measure reported in this study, average VOC specific reactivity, has units of potential grams of ozone per gram of VOC and is a function of the composition of the VOC permeate. Specific reactivity provides an estimate of the ozone-forming potential per unit mass of the VOC permeate under conditions favorable for ozone formation, but it is not meant to predict actual levels of ozone and should be interpreted on a relative basis. Further, there are uncertainties in these reactivity estimates, e.g., the MIR scale represents a limited range of atmospheric conditions, does not include carryover of emissions from one day to the next, and does not include three-dimensional spatial variation in emissions.

The mass emissions times the MIR gives the theoretical potential ozone that would be formed by that mass under ideal conditions. This calculation was performed on all the identified molecules that had MIR factors. Not all the molecules measured had MIR factors. The unidentified compounds were assumed to have the same reactivity as the average of the identified compounds with MIR factors. The mass of the compounds for which no MIR factors existed was determined to be insignificant.

The specific reactivity for a speciated SHED diurnal sample was calculated by summing the mass of the individual species, and the predicted potential ozone using the MIR factor. The specific reactivity is the mass of ozone predicted divided by the mass of the hydrocarbons measured, in our example, 352.7 mg/81.9 mg, or 4.31 g of potential O_3/g VOC permeate emissions.

The next part of this report discusses the specific reactivities calculated for the six fuels tested in this project. When the permeate specific reactivities of the five rigs were compared across test fuels, it was observed that Rig 11 consistently produced the lowest result.

Thirteen diurnal tests on the E0 fuel were speciated (Table10). The average specific reactivity of the permeate of all the E0 diurnals was 3.99 (grams of ozone per gram of HC mixture), with two "eyeball" outliers, (test 6370 – Rig 11 = 2.91), and (test 6372 – Rig 12 = 5.48). The other six tests ranged from 3.80 to 4.26. The third and fourth columns in Table 9 allow a comparison of the SHED calculation of mass and the gas chromatograph's value. In general, reasonable agreement was found between the two estimates. The fifth and sixth columns report the identified mass (in mg and % of total) that had MIR factors for the individual species. Usually 90% or more had MIR values

Table 10

Fuel E0 Diurnal Permeate Reactivity Results

			Total GC	**Mass w/MIR Values**			
Rig (test #)	Test ID	Reported SHED mg	Mass - mg	mg	%	Specific Reactivity	Rig Wtd. Average
1	6389	83.9	85.6	81.9	95.7%	4.31	
1b	6900	97.2	101.6	96.1	94.7%	4.15	
2	6390	463.3	391.4	369.8	94.5%	4.26	
2b	6913	451.6	435.6	412.6	94.7%	4.16	
11	6370	48.0	36.6	32.5	88.8%	2.91	
11b	6889	29.7	32.4	30.9	95.4%	3.51	
12(1)	6372	38.7	29.3	26.0	88.8%	5.48	3.99
12(2)	6383	31.0	34.1	33.4	97.9%	4.10	
12b	6874	38.3	41.0	39.8	97.3%	3.73	
14(1)	6360	250.5	250.4	239.2	95.5%	3.80	
14(2)	6388	248.1	241.3	236.9	98.2%	3.85	
14b	6645	282.7	274.7	259.7	94.6%	3.89	
14c	6892	262.8	265.8	247.9	93.3%	3.91	

The average specific reactivity of the permeates for the five diurnal tests on the E6 fuel was 3.00 (Table 11), but this included one relatively low result (test 6507 – Rig 11 = 2.09). The average specific reactivity with that test omitted was 3.24. The 3.24 number compares well with the Fuel B permeate average of 3.27 from the original E-65 test program.

Table 11
Fuel E6 Diurnal Permeate Reactivity Results

Rig (test #)	Test ID	Reported SHED mg	Total GC Mass - mg	Mass w/MIR Values mg	%	Specific Reactivity	Rig Wtd. Average
1(1)	6471	417.1	264.1	264.1	100.0%	3.05	
1(2)	6479	533.3	461.3	447.3	97.0%	3.08	
2	6481	1426.0	1357.6	1326.8	97.7%	3.54	3.00
11	6507	144.1	127.7	127.7	100.0%	2.09	
12	6492	49.6	36.8	36.0	97.8%	3.30	

Four tests on the E6Hi fuel were speciated, with an average permeate specific reactivity of 3.17 (Table 12). Rig 11 had the lowest reactivity value for the four tests.

Table 12
Fuel E6Hi Diurnal Permeate Reactivity Results

Rig (test #)	Test ID	Reported SHED mg	Total GC Mass - mg	Mass w/MIR Values mg	%	Specific Reactivity	Rig Wtd. Average
1	6571	360.9	270.9	270.9	100.0%	3.30	
2	6570	1227.0	1400.7	1290.1	92.1%	3.66	3.17
11	6598	88.7	82.0	82.0	100.0%	2.58	
12	6569	45.0	39.2	38.7	98.6%	3.14	

The six diurnal tests on the E10 fuel had an average permeate specific reactivity of 2.94 (Table 13), with Rig 11 again yielding the lowest values. There is no current explanation why the fuel system components used in Rig 11 might produce a lower, or less reactive permeate.

Table 13
Fuel E10 Diurnal Permeate Reactivity Results

Rig (test #)	Test ID	Reported SHED mg	**Total GC** Mass - mg	**Mass w/MIR Values** mg	%	Specific Reactivity	Rig Wtd. Average
1	6665	467.8	443.2	438.2	98.9%	3.03	
2	6673	1300.6	1289.2	1262.3	97.9%	3.45	
11(1)	6675	149.3	163.2	160.8	98.6%	2.23	2.94
11(2)	6676	97.3	118.5	116.3	98.2%	2.43	
12	6642	64.3	54.9	53.8	98.0%	2.85	
14	6454	466.3	436.6	426.4	97.7%	3.05	

The five diurnal tests on the E20 fuel had an average specific reactivity of 3.04 (Table 14), with a range of values from 2.40 to 3.36. Again, the lowest specific reactivity of the rigs evaluated was Rig 11.

Table 14
Fuel E20 Diurnal Permeate Reactivity Results

Rig (test #)	Test ID	Reported SHED mg	Total GC Mass - mg	Mass w/MIR Values mg	%	Specific Reactivity	Rig Wtd. Average
1	6806	508.1	568.4	558.3	98.2%	3.20	
2	6816	1765.1	1687.5	1650.8	97.8%	3.32	
11	6805	102.0	94.5	93.1	98.6%	2.40	
12	6678	74.7	63.6	63.5	100.0%	2.92	3.04
14	6779	359.5	399.0	388.7	97.4%	3.36	

Two speciated diurnals were conducted on Rig 14 with the E85 fuel, and the results are shown in Table 15. The two permeate specific reactivities measured were 2.63 and 2.82 with an arithmetic average value of 2.73. The specific reactivity of the E85 permeate is expected to be low compared to other fuels since the ethanol fraction of the diurnal permeate was approximately two-thirds of the total mass (59 to 65 mass %).

Table 15
Fuel E85 Diurnal Permeate Reactivity Results

Rig (test #)	ID	Reported SHED mg	Total GC Mass -mg	Mass w/MIR Values mg	%	Specific Reactivity	Rig Wtd. Average
14(1)	6555	142.3	137.6	137.4	99.9%	2.63	
14(2)	6566	112.8	105.6	102.5	97.0%	2.82	2.73

Statistical Analysis

Statistical analyses were performed on the diurnal and steady-state emissions results, as well as on the specific reactivity results. Analysis of the residuals from preliminary regressions indicated that the variability in the diurnal data tended to be proportional to the magnitude of the measurement; therefore, a natural log transformation was used on the diurnal data, which yielded a constant standard deviation over the range of the data. However, the steady-state and reactivity data exhibited constant standard deviations without the log transformation, so no transformation was used for those variables.

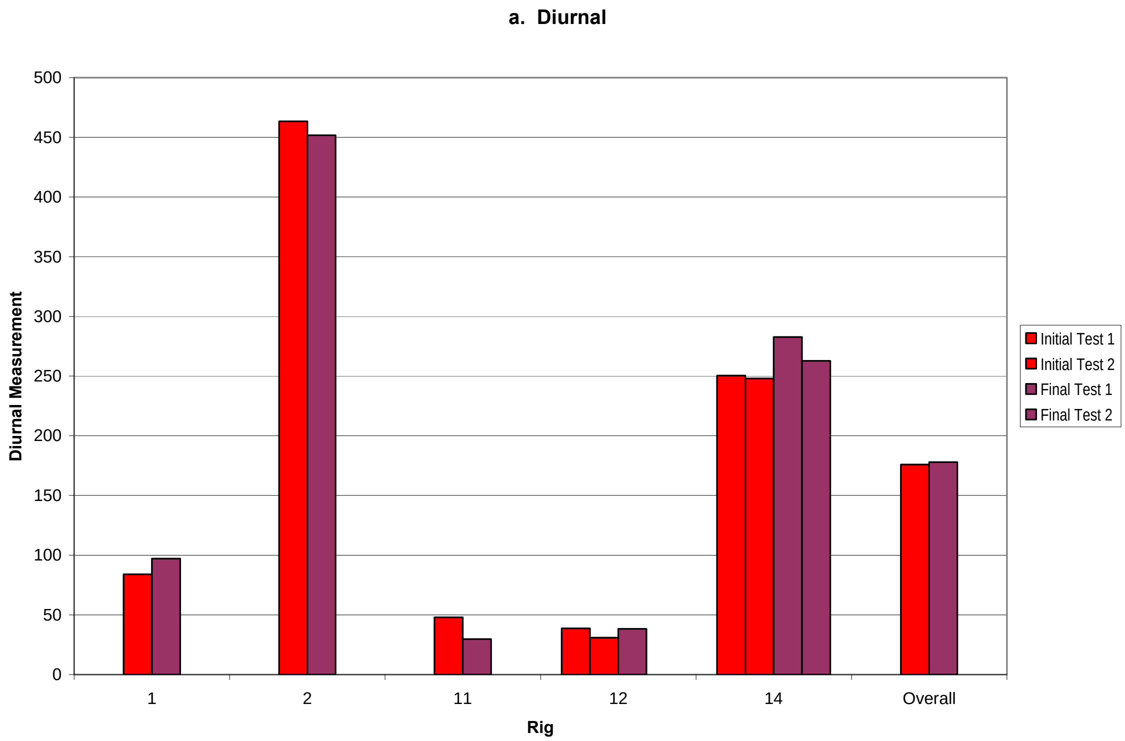
For each of the three dependent variables evaluated, tests were performed to determine the significance of three possible independent variables: 1) test timing; 2) fuel aromatics level; and 3) fuel ethanol content. Because E85 was only tested in one of the five vehicles (rigs), data for that fuel were not included in any of the analyses. All five vehicles (rigs) were included in the analyses for test timing and fuel ethanol content, but Rig 14 was not included in the analysis of the effect of fuel aromatics content because it was not tested on fuels E6 and E6Hi.

In recent years, CRC has employed mixed models that include both fixed and random effects in the analysis of emissions data. In these analyses, the random effects are the vehicle intercepts and vehicle-by-fixed effect interactions. The advantage of these mixed models is that the random effects are treated as being samples drawn from a normal population, and the resulting statistical tests include the observed variation in the random sample of vehicles. As a result, the tests of significance are applicable to the population of vehicles from which the sample was drawn. On the other hand, statistical tests using fixed-effect models are applicable only to the specific vehicles tested.

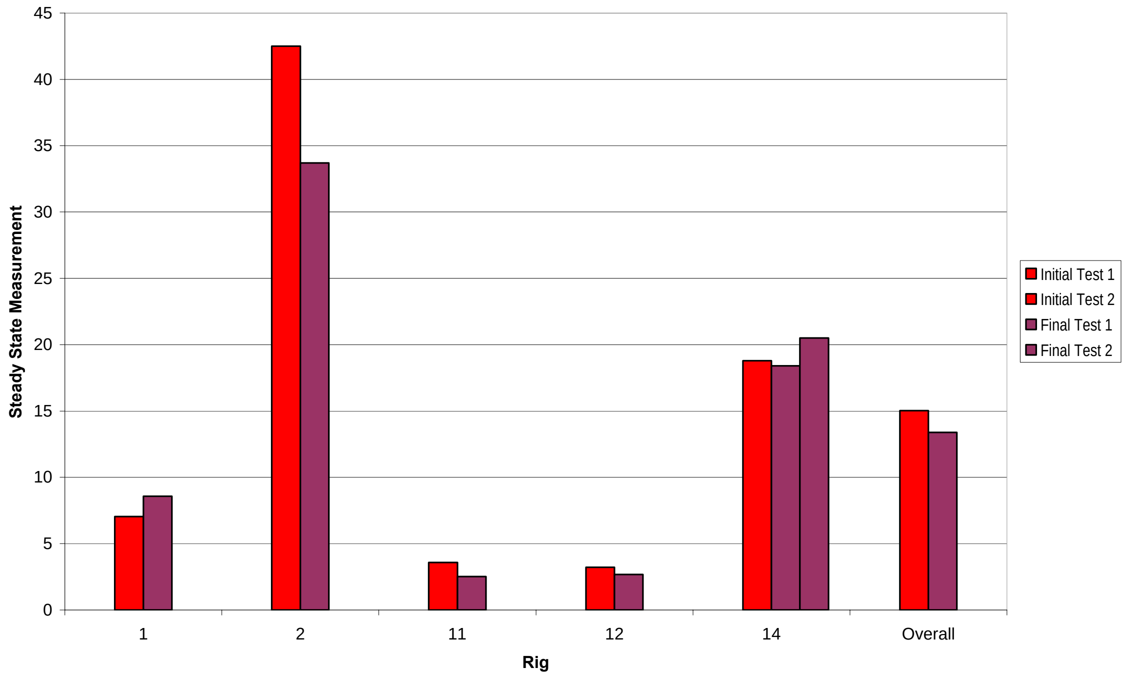
While mixed models permit more powerful conclusions to be drawn, they also depend on having a large enough random vehicle sample to be able to draw conclusions on fuel effects in the face of vehicle-to-vehicle variation. In this study, the small sample size (five vehicles) was not judged to be large enough to permit the use of mixed models, so fixed effects models were used. As a result, the statistical significance determinations made in this report apply only to the specific vehicles tested.

Test Timing

The E0 fuel was evaluated first and last on all the rigs. In addition, Rig 14 tested E0 after E85 and before E20. Examination of these tests on E0 allows determination of whether there was any change in rig performance over the course of the testing. These E0 results are shown graphically in Figure 31. The multiple initial E0 tests on Rigs 12 and 14 are the result of repeat diurnal tests and were thus very close together in time. The multiple final E0 results for Rig 14 are due to the testing of E0 before and after E20 and are thus further apart in time, but not as far apart as they are from the initial E0 tests.



b. Steady State



c. Specific Reactivity

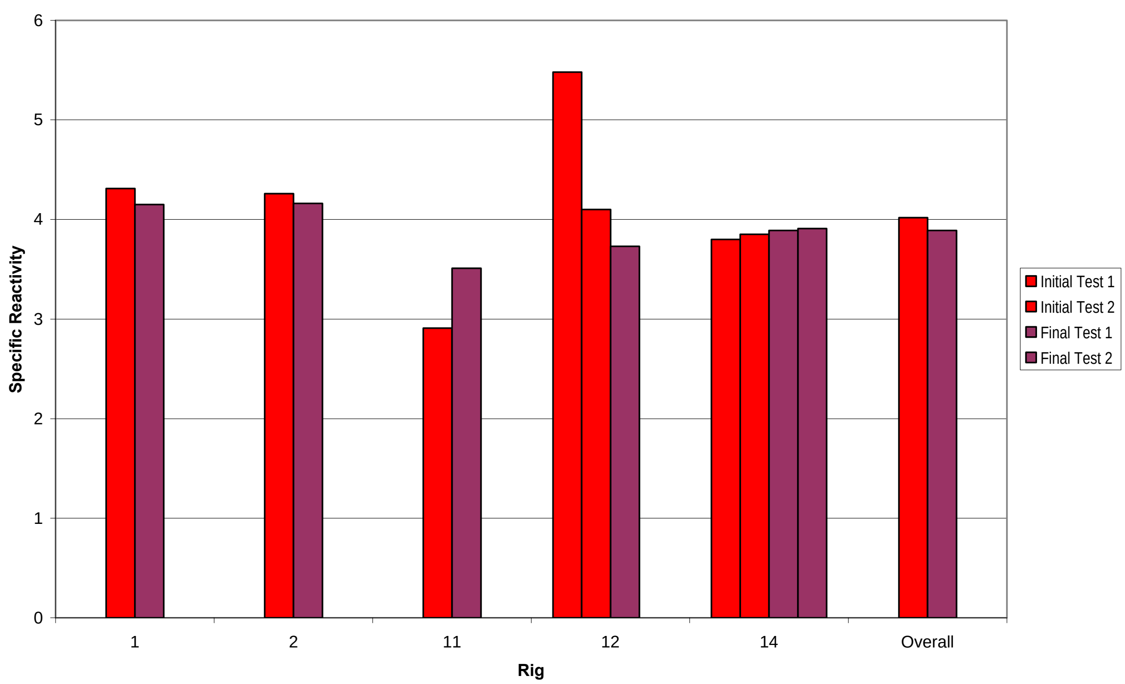


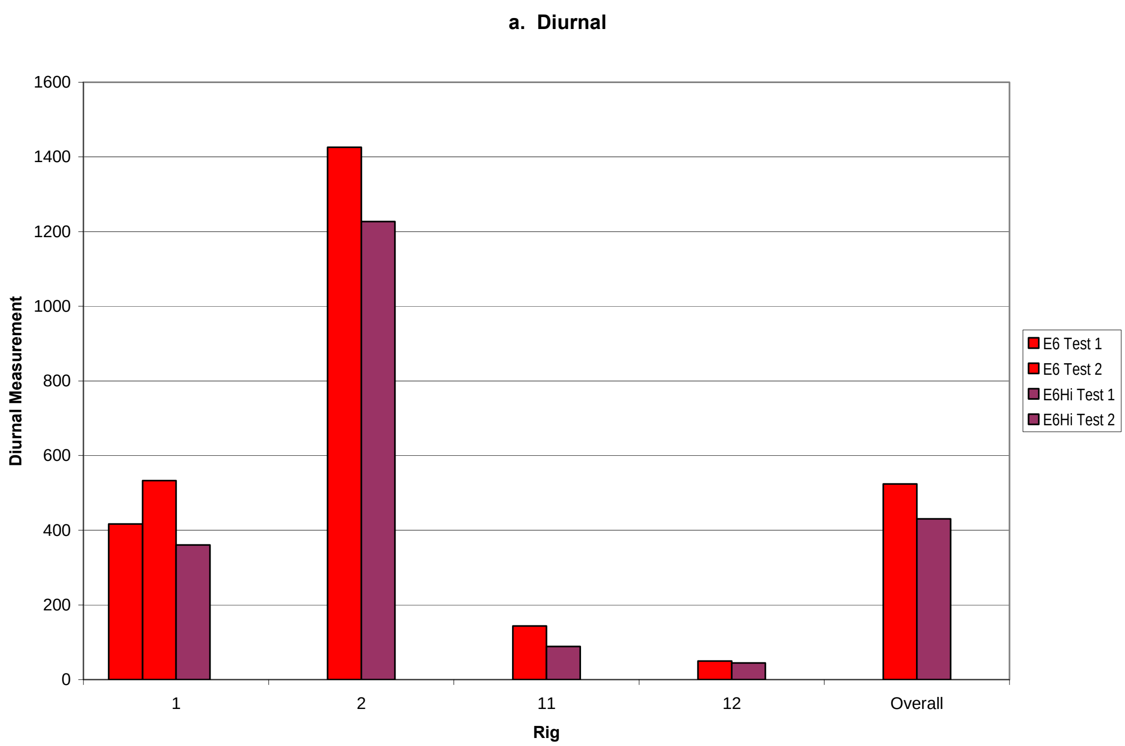
Figure 31

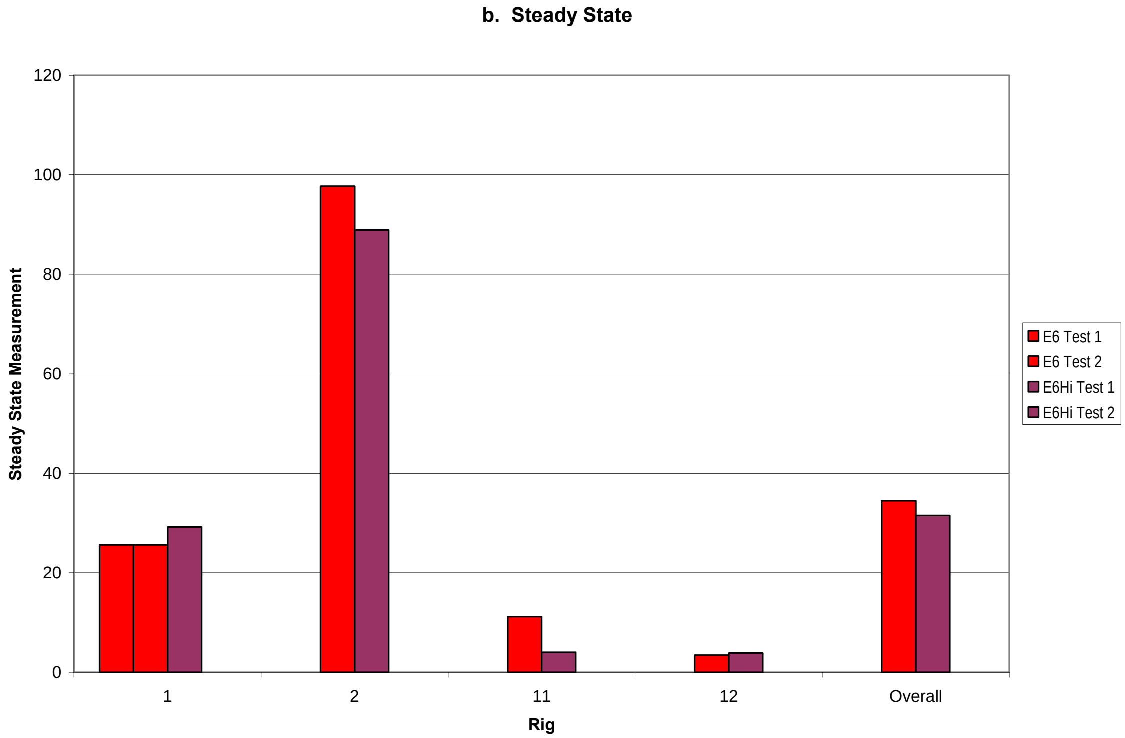
An ANOVA that treated the individual fuels without regard to fuel characteristics was run for each of the dependent variables. The model included fixed effects for fuel, rig and fuel by rig interaction. Within the

ANOVA, a contrast was set up to test the hypothesis that there were no significant differences between the E0 results at the beginning of the testing and the E0 results at the end of the testing (the extra E0 test on Rig 14 was treated as if it were made at the end of the test). No significant effect of test timing was observed for any of the three dependent variables ($p \geq 0.32$). Given that no significant effect was observed, all E0 measurements were treated the same, regardless of when they were obtained, in subsequent analyses.

Aromatics

Fuels E6 and E6Hi differed from one another primarily in their aromatics level. Comparison of these two fuels can thus determine the significance of any effect of aromatics content that was observed. These results are shown graphically in Figure 32.





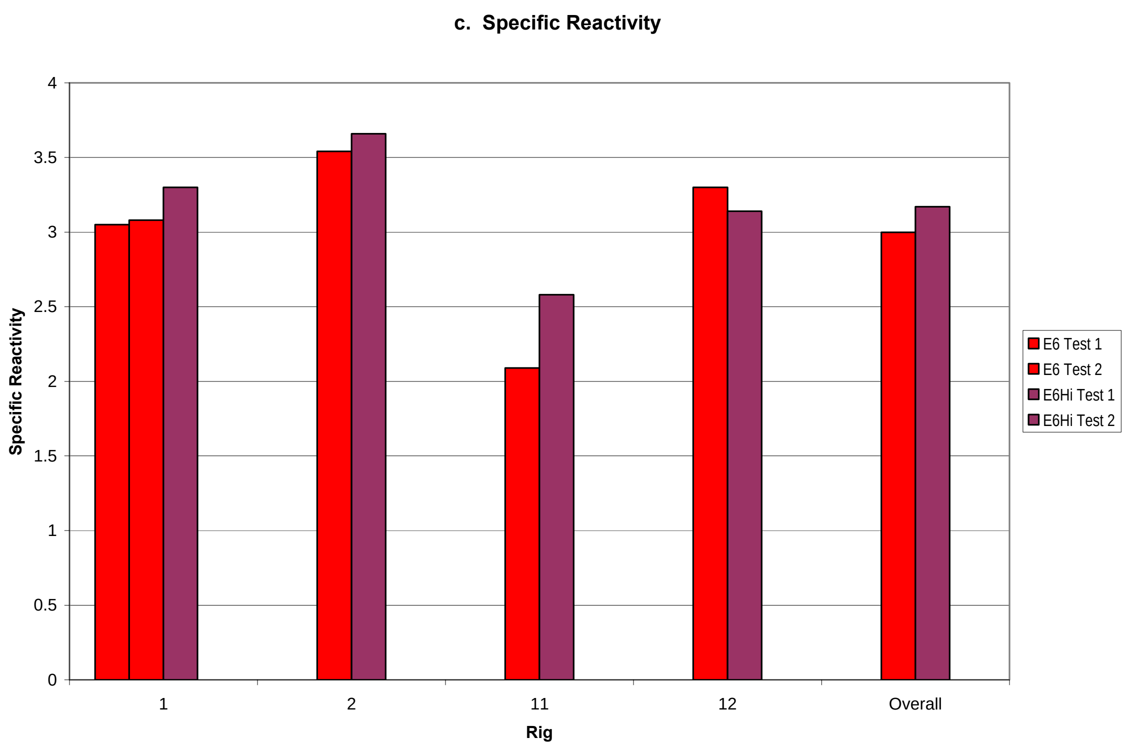


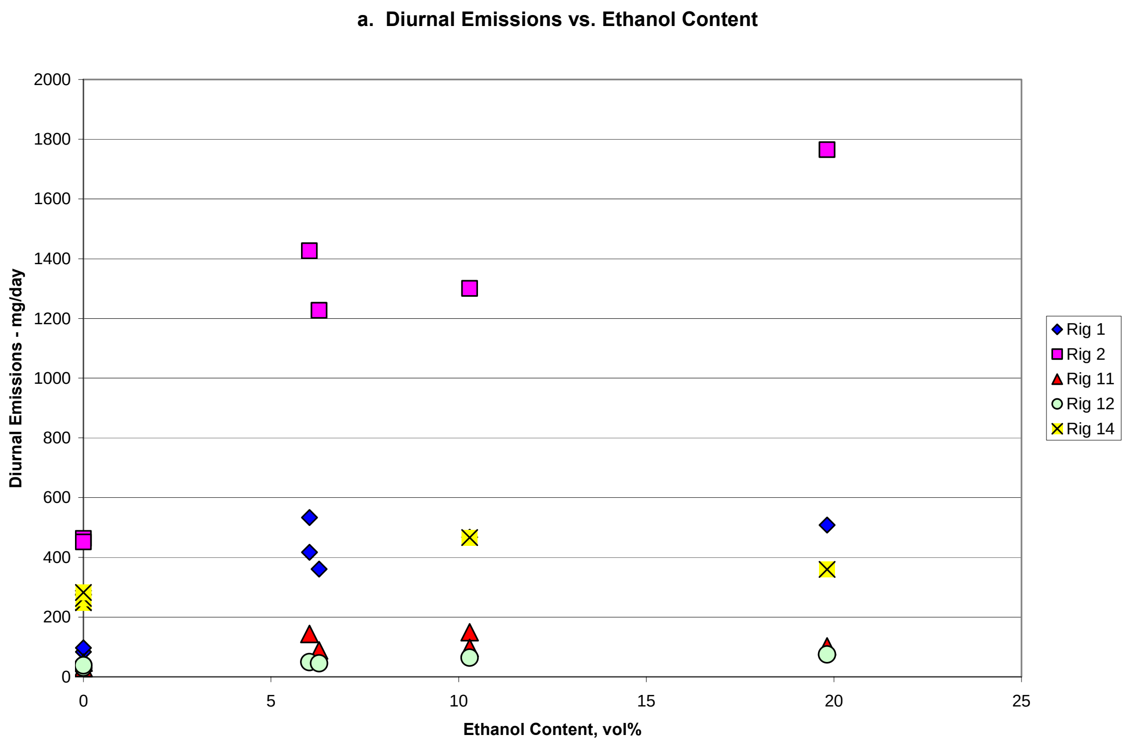
Figure 32

An ANOVA that treated the individual fuels without regard to fuel characteristics was run for each of the dependent variables. The model included fixed effects for fuel, rig and fuel by rig interaction. Within the

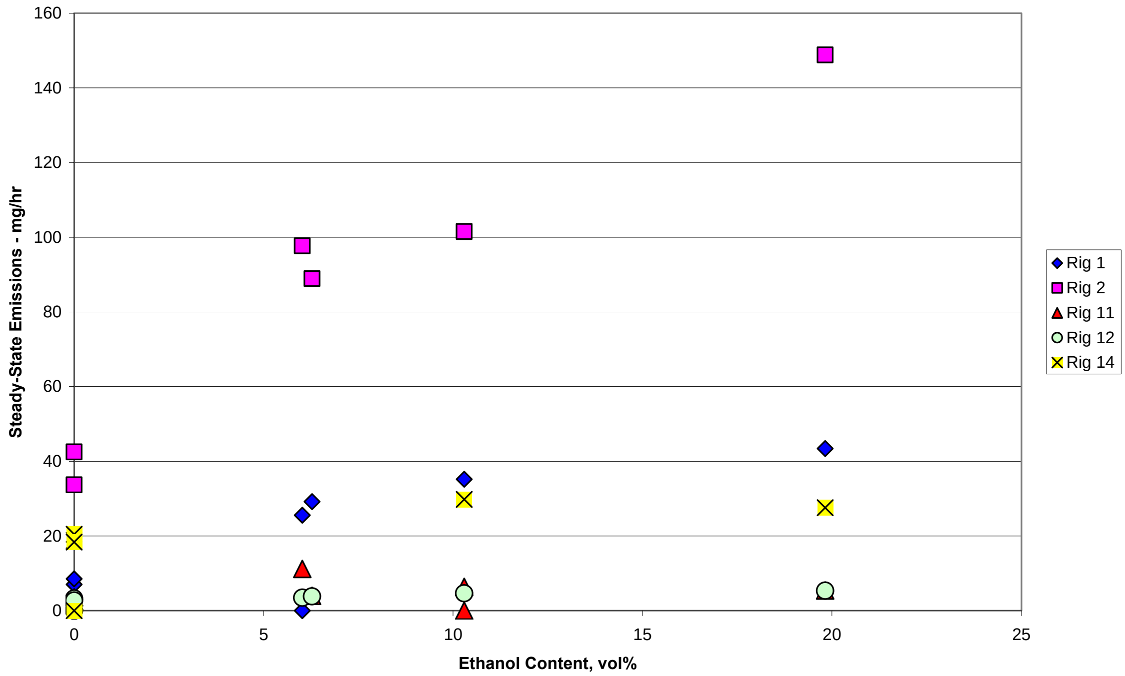
ANOVA, a contrast was set up to test the hypothesis that there were no significant differences between the E6 results and the E6Hi results. No significant effect of aromatics level was observed for any of the three dependent variables ($p \geq 0.11$). Given that no significant effect was observed, aromatics level was not considered in subsequent analyses.

Ethanol Content

In contrast to the other evaluations, the design of this experiment allows the evaluation of ethanol content as a continuous variable. Figure 33 shows the results for the three dependent variables vs. ethanol content for each rig.



b. Steady-State Emissions vs. Ethanol Content



c. Specific Reactivity vs. Ethanol Content

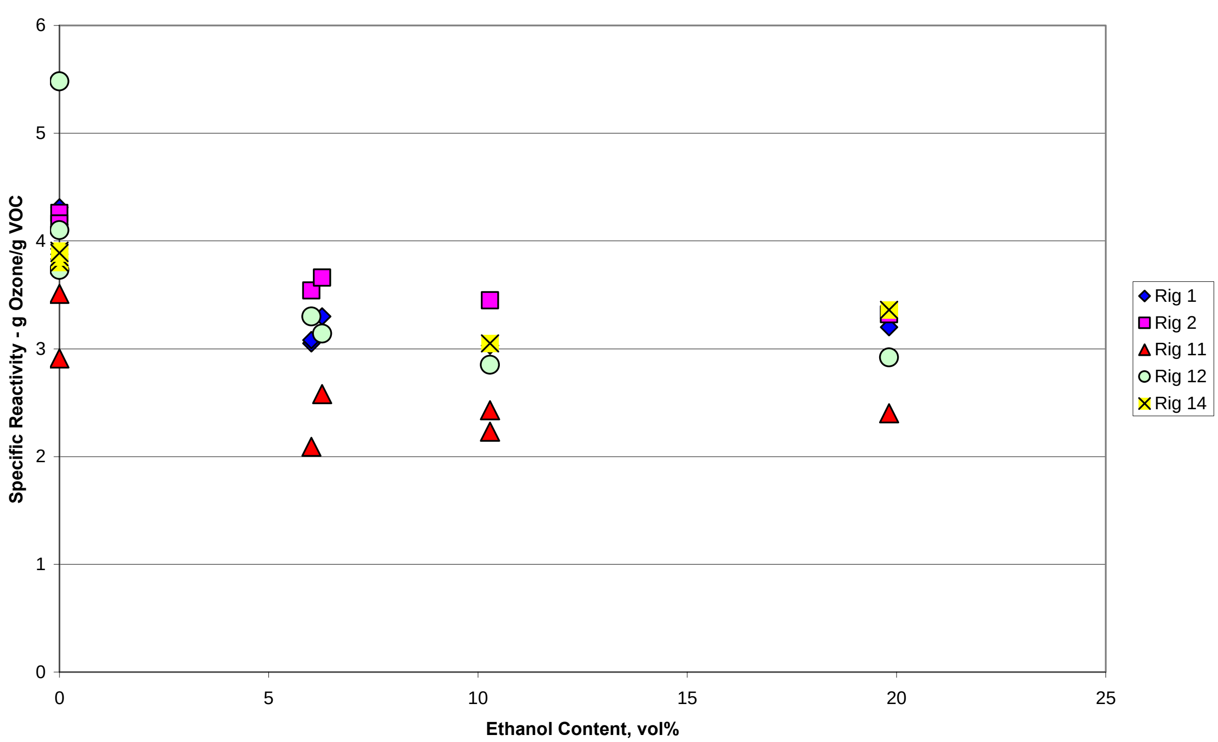


Figure 33

The plots indicate a general nonlinear relationship between the dependent variables and ethanol content. Closer inspection of the data reveals that, while the overall relationship is nonlinear, the data at nonzero ethanol contents is actually fairly linear: the nonlinearity exists between the E0 and ethanol-containing fuels. An example of this is shown in Figure 34 for Rig 1 diurnal emission results.

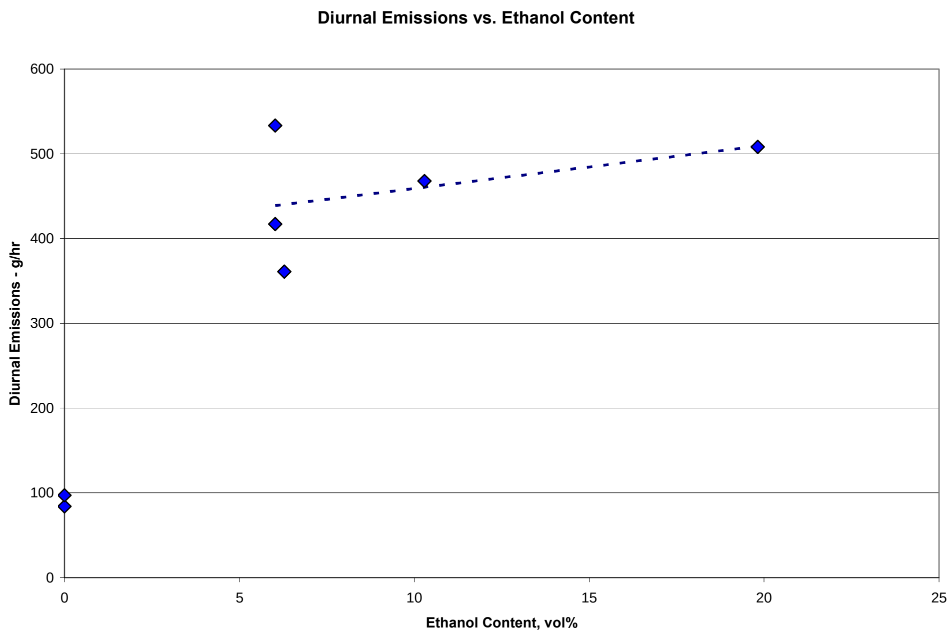


Figure 34

The dashed line is a linear fit vs. ethanol content for the five observations at nonzero ethanol contents. The reasonably good fit for these points contrasts with the E0 data. As a result of patterns like this in the data, a model was fit to the data that provides for a discontinuous function that includes a single point (intercept) based on the E0 data and a linear fit based on the fuels with nonzero ethanol content. This allows two tests to be performed to determine the effect of ethanol: one test that evaluates the effect of the presence or absence of ethanol, and another that evaluates the effect of changes in ethanol content for ethanol-containing fuels.

The regression model is thus:

$$y = a * Rig + b * \Pr esent + c * Ethanol + Rig * \Pr esent + Rig * Ethanol + \varepsilon$$

Where:

Rig	=	Test rig identifier
Present	=	Presence or absence of ethanol
Ethanol	=	Ethanol content, vol%
ε	=	Error term

The presence or absence of ethanol was statistically significant ($p \leq 0.05$) for all three independent variables. Both ln(diurnal) and steady-state emissions increased when ethanol was present, while Specific Reactivity decreased. Varying the ethanol content was significant for the steady-state data (emissions increased as ethanol content increased), but was not significant ($p \geq 0.44$) for the ln(diurnal) and reactivity data.

D. The CRC E-65-3 Steering Committee Members

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Loren Beard........................... DaimlerChrysler
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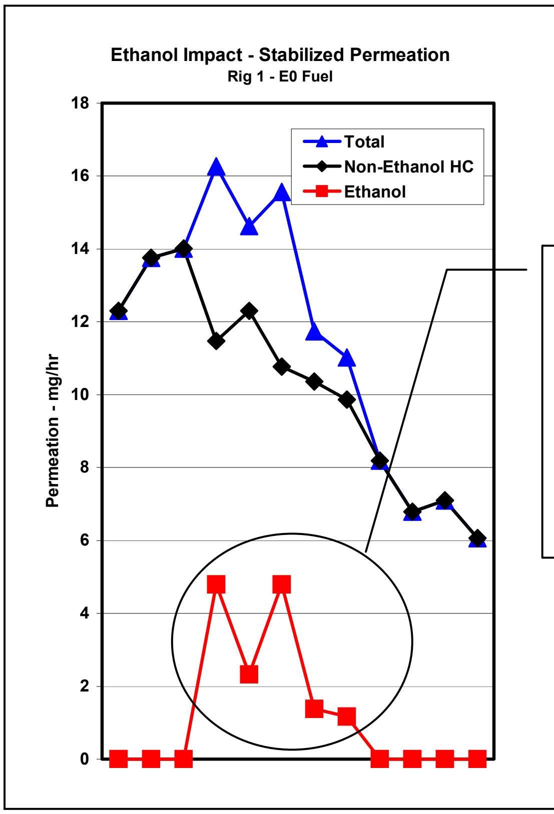
E. Appendix

The Ethanol Hang-up

During our initial stabilization with the E0 fuel, Rigs 1 and 2 unexpectedly exhibited ethanol content in the permeate, which created considerable concern and discussion. It was surprising when Rigs 1 and 2 indicated an ethanol component in the permeate long after the use of any ethanol-containing fuel. This led to the hypothesis that ethanol can lie dormant in the vehicle's fuel system, or be stored and reappear at a much later time.



The first three tests on Rig 1 detected no ethanol in the permeate, but the fourth test on 2-02-05, resulted in an ethanol rate estimate of 4.8 mg/hour. Rig 2 had a similar result during the same time period, as indicated later. The tests after 3-9-05 did not indicate ethanol in the permeate sample.

Figure 35

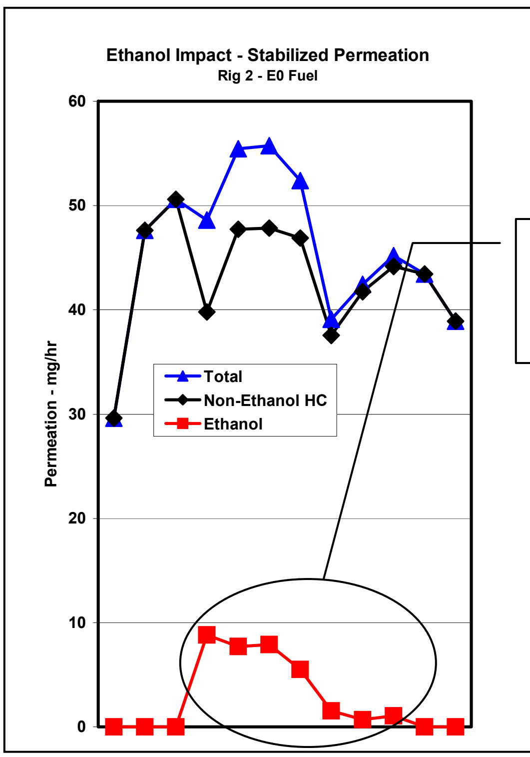
Table 16 - 2001 Toyota Tacoma Stabilization – Fuel E0

Rig	Fuel	Week	Date	Test#	NonEtOH mg/hour	EtOH mg/hour	NonEtOH + EtOH mg/hour	Running Average mg/hour
01	E0		01/11/05	Drain and 100% fill Fuel E0				
		0	01/12/05	6286	12.3	BDL	12.3	
		1	01/19/05	6293	13.8	BDL	13.8	
		2	01/26/05	6301	14.0	BDL	14.0	
		3	02/02/05	6306	11.5	4.8	16.3	14.1
		4	02/09/05	6313	12.3	2.3	14.6	14.7
		5	02/16/05	6324	10.8	4.8	15.6	15.1
			02/18/05	Drain and 100% fill Fuel E0				

NonEtOH Running

Rig	Fuel	Week	Date	Test#	NonEtOH mg/hour	EtOH Mg/hour	+ EtOH mg/hour	Average mg/hour
		6	02/23/05	6331	10.4	1.4	11.7	14.6
		7	03/02/05	6341	9.9	1.2	11.0	13.2
		8	03/09/05	6352	8.2	BDL	8.2	11.6
		9	03/16/05	6364	6.8	BDL	6.8	9.4
		10	03/23/05	6373	7.1	BDL	7.1	8.3
		11	03/29/05	6381	6.1	BDL	6.1	7.0

The stabilization data for Rig 1 on fuel E0 are listed in Table 15 and shown in Figure 35, and a similar presentation for Rig 2 follows in Table 16 and Figure 36. These rigs had been tested in the previous program with an E6 fuel (Fuel B), but had finished the program on the non-ethanol "Fuel C", and were stored for the down time (roughly six months) with the non-ethanol fuel in their tanks. Rigs 11, 12 and 14 did not show any ethanol in their measurements during the same time period. The measured levels were low, 5 mg/hour or less, but the source of the ethanol was not identified.



Rig 2, like Rig 1, also had a sudden appearance of ethanol in the results in the time period of 2-4-05 to 3-16-05.

Figure 36

Table 17 - 2000 Honda Odyssey Stabilization – Fuel E0

Rig	Fuel	Week	Date	Test#	NonEtOH	EtOH	NonEtOH + EtOH	Running Average
2	E0		01/11/05	Drain and 100% fill Fuel E0				
		0	01/12/05	6284	29.6	BDL	29.6	
		1	01/19/05	6294	47.6	BDL	47.6	
		1	01/20/05	6296	50.6	BDL	50.6	
		3	02/04/05	6309	39.8	8.8	48.6	44.1
		4	02/09/05	6314	47.7	7.7	55.5	45.3
		5	02/16/05	6326	47.8	7.9	55.7	51.9
			02/18/05	Drain and 100% fill Fuel E0				
		6	02/22/05	6330	46.9	5.5	52.4	53.1
		7	03/02/05	6343	37.6	1.5	39.1	50.7
		8	03/09/05	6354	41.7	0.7	42.4	47.4
		9	03/16/05	6365	44.2	1.0	45.2	44.8
		10	03/24/05	6375	43.4	BDL	43.4	42.5
		11	03/30/05	6385	38.9	BDL	38.9	42.5

That Rigs 1 and 2 had ethanol in their measured results at the same time, that later disappeared, can not be explained at this time.

Ethanol can persist as an element of the permeation emissions of a fuel system long after use of the ethanol fuel has been discontinued. The results from the previous E-65 test program indicated the presence of ethanol in the permeate at a measurable level for a period of up to 7 weeks after the fuel had been changed to the non-ethanol fuel (Fuel C). It is thought that this "hang-up" is due to the time it takes for the permeation components to make their way through the various elastomers in the vehicle's fuel system. Figure 37, representing the 10 rigs tested in the E-65 test program, is used to illustrate this effect. There appears to be a lingering presence of ethanol at levels of up to 5 mg/hour for a considerable period of time.

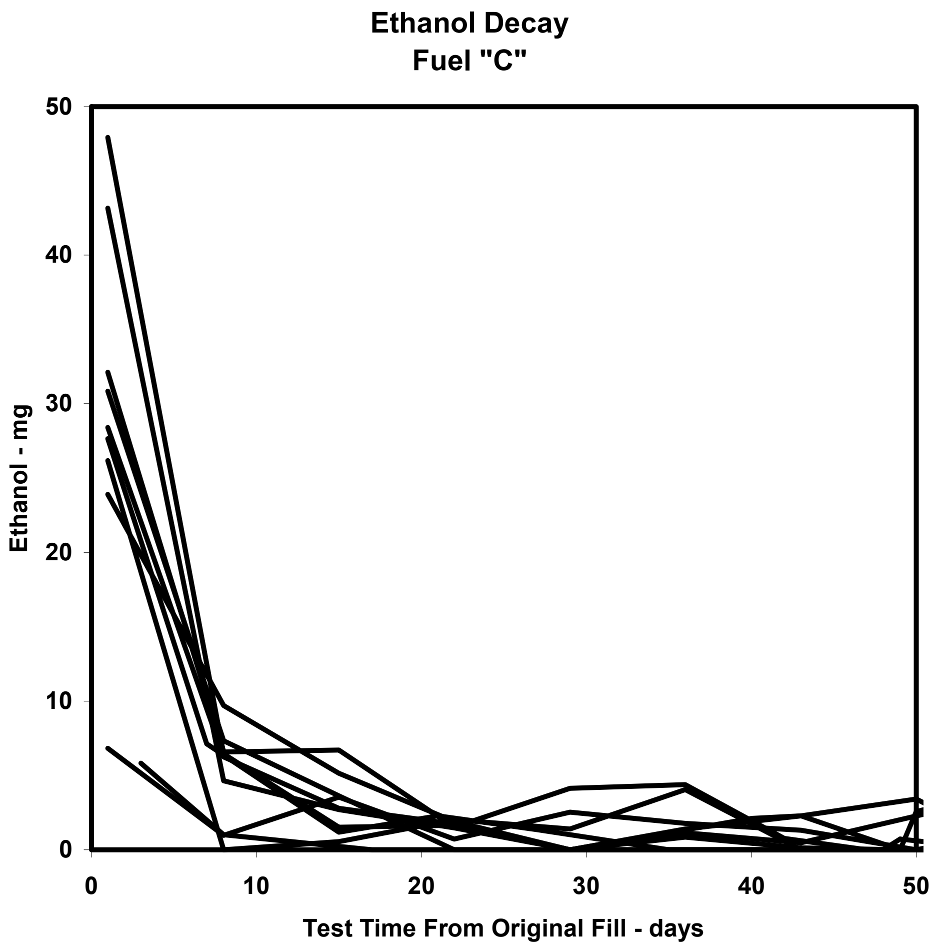


Figure 37

The data used for this plot came from the original E-65 permeation test program, and represents the ethanol permeation measured after the switch from the 5.7% ethanol fuel evaluation (Fuel B) to the non-ethanol fuel (Fuel C). The ten systems included in this analysis came from vehicle systems ranging from model year 1978 to 2001. All of the rigs exhibited "hang-up", or carry-over of the ethanol component from the previous fuel, during the new stabilization period with the non-ethanol fuel.